Prepared in cooperation with the Bureau of Reclamation

# Growth, Survival, and Cohort Formation of Juvenile Lost River (*Deltistes luxatus*) and Shortnose Suckers (*Chasmistes brevirostris*) in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California—2019 Monitoring Report

Open-File Report 2021–1119

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

**Cover.** Young-of-year endangered sucker from Upper Klamath Lake, Oregon, 2019. Photograph by Ryan Bart, U.S. Geological Survey.

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# Conversion Factors

U.S. Customary Units to International System of 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 | |
| hectare (ha) | 2.471 | acre |
| square kilometer ($km^2$) | 247.1 | acre |
| square meter ($m^2$) | 10.76 | square foot ($ft^2$) |
| millimeter square ($mm^2$) | 0.00155 | inches square ($in^2$) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as:

$°F = (1.8 \times °C) + 32$.

# Supplemental Information

Concentrations of chemical constituents are given in milligrams per liter (mg/L); 1 milligram per liter is equivalent to 1,000 parts per billion (ppb).

# Datums

Vertical coordinate information is referenced to the Bureau of Reclamation Vertical Datum.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

# Abbreviations

| | |
|---|---|
| CL | Clear Lake |
| CPUE | catch per unit effort |
| KLS | Klamath largescale sucker |
| PIT | passive integrated transponder |
| prob[LRS] | probability of being a Lost River sucker |
| SARP | Sucker Assisted Rearing Program |
| SD | standard deviation |
| SL | standard length |
| UKL | Upper Klamath Lake |
| USGS | U.S. Geological Survey |

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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 due to 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, that 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.

Upper Klamath Lake indices of year-class strength indicated that the 2019 year-class was the strongest in the past 5 years of monitoring. Low detections of age-1 and older suckers indicate that the 2018 cohort experienced poor survival within the first year of life. Shortnose suckers constituted the smallest proportion and suckers with uncertain species identification constituted the largest proportion of the 2019 year-class. Small numbers of Lost River sucker were captured consistently throughout the sampling season.

The relative abundance of age-0 suckers is not a good indicator of year-class strength in Clear Lake. There were no age-0 suckers captured in Clear Lake during the 2015 and 2019 sampling seasons. Most suckers captured were age-1 Klamath largescale/shortnose suckers, which indicated a relatively strong 2018 cohort. Four-year old juveniles from the 2015 cohort were present in 2019 in Clear Lake. Cohorts that do not recruit to our sampling gear until a year or more of age seem to indicate that (1) a stream resident life history is contributing to the lake population and (2) juvenile suckers occupy the Willow Creek drainage for a full year or more. Although these suckers could be either the non-endangered Klamath largescale or the endangered shortnose suckers, a stream resident life history 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 in most years.

## 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 Lost River suckers and shortnose suckers 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. Uncertainty exists regarding the role of recruitment limitation to Clear Lake populations, because year-classes seems 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 relative 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 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). 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 the Simon and others (2013) and USGS sampling 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 Upper Klamath Lake and Clear Lake. This monitoring program aims to track cohorts 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 will 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 meters (m) and a surface area of 305 square kilometers ($km^2$) 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 and 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 to 1,262.8 m (Bureau of Reclamation [2019] 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.

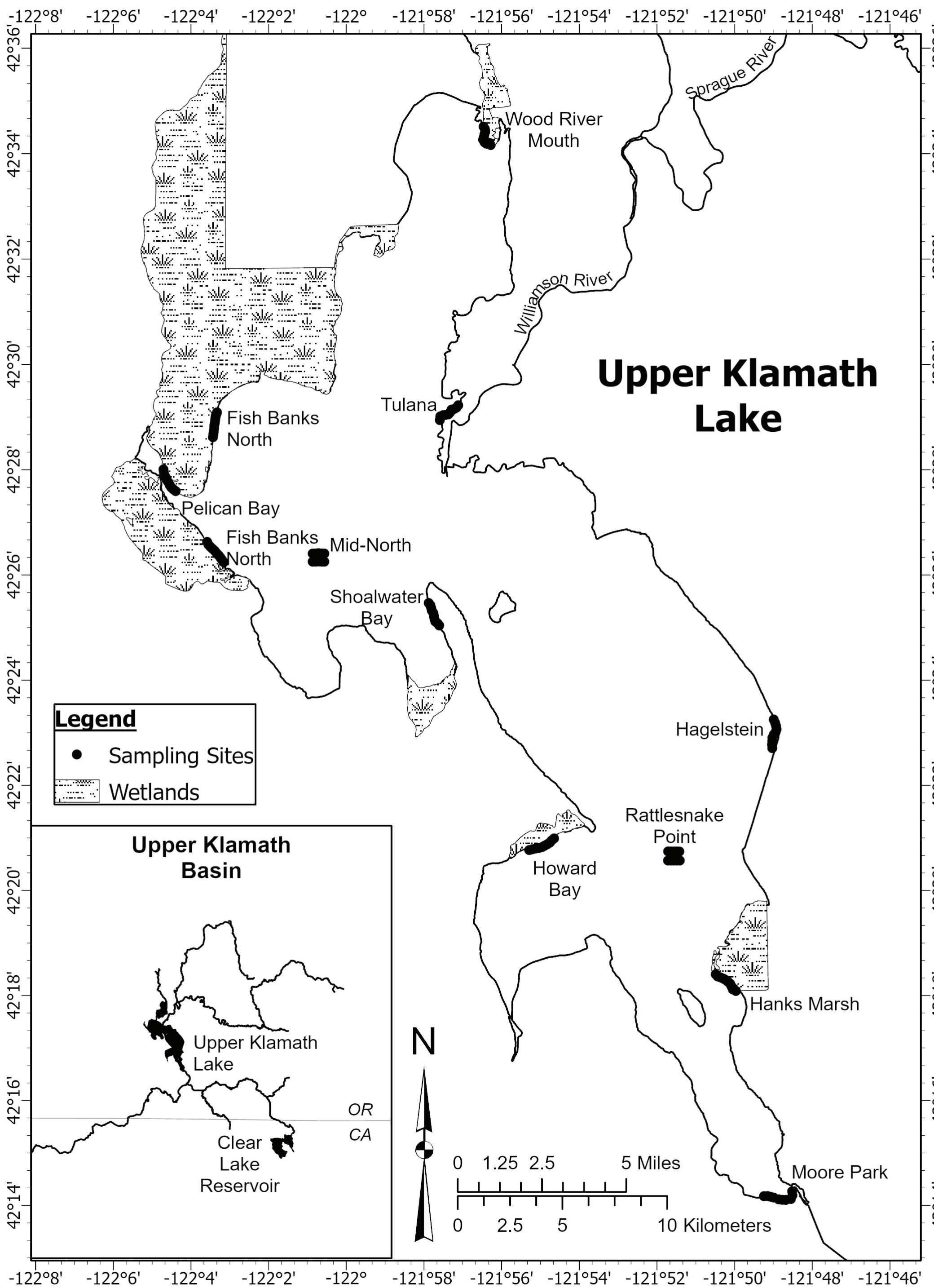


**Figure 1.** Locations of sample sites used to capture juvenile suckers in Upper Klamath Lake, Klamath County, Oregon, 2019.

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* sp.). 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 include: water temperatures greater than 24 degrees Celsius (°C), dissolved-oxygen less than 2 milligrams per liter (mg/L), pH at least 10, and microcystin toxin concentrations 40–60 parts per billion (ppb) (Eldridge, Caldwell Eldridge, and others, 2012; Eldridge, Wood, and others, 2012).

Clear Lake, located in the upper Lost River watershed, was historically a natural lake covering approximately 6,500 hectares (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 the eastern lobe of the reservoir near the dam. Inflows primarily occur in the winter or spring and the tributaries become intermittent by mid-summer. 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, the two parts of the lake become disconnected. At lake-surface elevations around 1,378.9 m, 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. The eastern lobe almost completely dries out when the lake-surface elevation decreases to about 1,377.7 m, 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).

Clear Lake is in the U.S. Fish and Wildlife Service's Clear Lake National Wildlife Refuge, and the upper watershed is almost entirely located in the U.S. Forest Service's 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 is likely the result of wind coupled with shallow water and fine sediments. Summer water temperatures have greater diel fluctuations and water quality is generally better than in Upper Klamath Lake, with Clear Lake water temperatures as high as 26 °C, dissolved oxygen at least 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 shore 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 are also present in Upper Klamath Lake and Clear Lake (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 (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).

Historically both species 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 others, 2010). The fishery was eventually closed in 1987 (Markle and Cooperman, 2002; Janney and others, 2008), but poor survival of juvenile suckers persisted in Upper Klamath Lake populations after closure of the fishery. Although adult survival is typically 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).

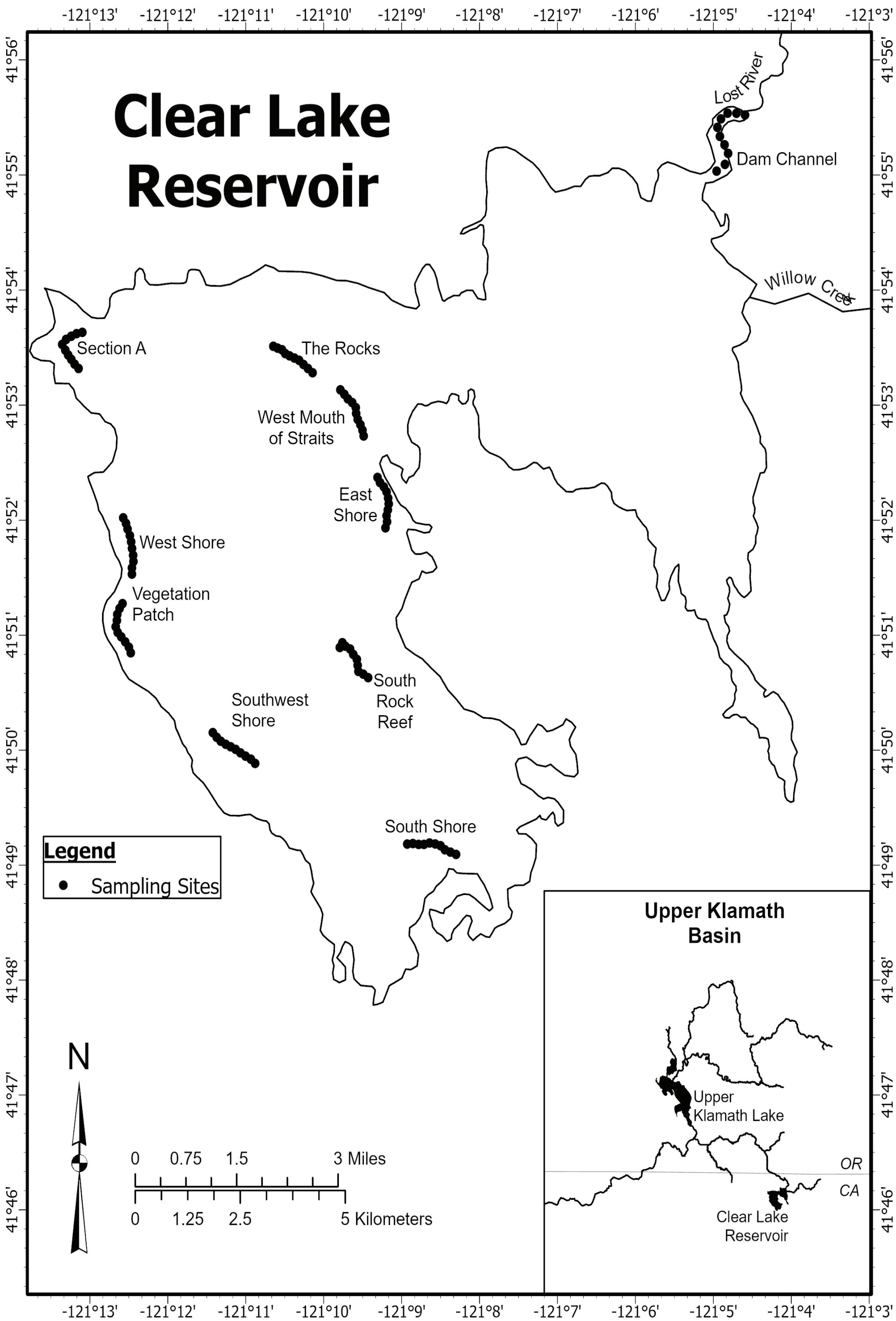


**Figure 2.** Locations of sample sites used to capture juvenile suckers in Clear Lake, Modoc County, California, 2019.

# Methods

## Sample Design

We sampled for suckers with trap nets to assess species-specific annual variability in production and growth, as well as annual and seasonal variability in survival of juvenile suckers in Upper Klamath Lake and Clear Lake. The timing of the sampling periods was selected based on previous catch data in Upper Klamath Lake. Specifically, we targeted age-1 suckers in early June, the beginning of recruitment of age-0 suckers to the gear 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). In 2015, sampling was conducted over three 3-week periods simultaneously in Upper Klamath Lake and Clear Lake. 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 2016, sampling events were within 1-week intervals in each lake and lakes were sampled in sequential weeks within each month. A July sampling period was added in 2018 to ensure that we did not miss early age-0 suckers. Sampling was in the same calendar weeks each year in each lake, except for July 2018 in Upper Klamath Lake. Air quality because of wildfires limited access to Upper Klamath Lake in July 2018 and delayed the sampling effort 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 from about 45 to 300 millimeters (mm, standard length [SL]). Fish small enough to pass through the mesh of our nets, such as small age-0 suckers (less than 45 mm 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 71 to 236 mm SL that were recaptured, indicating there was not strong size selectivity within this size range.

To reduce potential sample bias caused by apparently minor spatial heterogeneity in the densities, species, ages, sizes, 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 in 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) near-shore 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). Sampling areas were either 1-km long sections of shoreline or 300 square meters off-shore areas. Within each area, 10 fixed sites were identified as potentially accessible given a variety of water levels. In 2019, eight sites at 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 the difference between fixed and random sites was not significant (Burdick and others, 2016). Therefore, randomly determined sites were excluded from all analyses in this report.

Because of high lake-surface elevations in 2019 in Clear Lake, sample sites that were shallow and near shore in 2015 and 2016 were often in more than 3 m of water and far from shore in 2019. Because juvenile sucker catch rates with trap nets decrease at depths greater than 3 m (Burdick and Hewitt, 2012), we captured very few juvenile suckers. Therefore, we decided to change sampling sites slightly in 2019 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.

## 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 (less than 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 square millimeters) piece of tissue from the caudal fin was collected for genetic identification to taxa. The numbers of suckers that were aged, measured, and genetic samples collected and analyzed are shown in table 3. Due to budgetary constraints, 79 Upper Klamath Lake suckers and 9 Clear Lake suckers were not genetically identified. Emaciation, deformities, macro parasites, and petechial skin hemorrhaging were systematically recorded. Other abnormalities and afflictions were noted when they were observed. Individuals were scanned for the presence of a PIT tag to document recaptures from prior juvenile sampling efforts and hatchery program releases. If no tag was detected, the individual was larger than 60 mm SL, and lake conditions did not compromise sucker health, a PIT tag was inserted into the ventral abdominal musculature anterior to the pelvic girdle. Suckers were released at their site of capture.

**Table 1.** Number of nets fished for juvenile suckers by area and sampling period in Upper Klamath Lake, Oregon, 2019.

| Area | Latitude | Longitude | Number of nets set in 2019 | | | |
|---|---|---|---|---|---|---|
| | | | June 10–14 | July 22–26 | August 5–9 | September 9–13 |
| 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 | 7 | 8 | 8 | 8 |
| Tulana | 42° 29' 5.56" N | 121° 57' 19.40" W | 8 | 8 | 8 | 8 |
| 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 | 8 | 8 | 8 |
| Rattlesnake Point | 42° 20' 34.57" N | 121° 51' 3.79" W | 8 | 8 | 8 | 7 |
| Total nets set | | | 95 | 96 | 96 | 95 |

**Table 2.** Number of nets fished for juvenile suckers by area and sampling period in Clear Lake Reservoir, California, 2019.

| Area | Latitude | Longitude | Number of nets set in 2019 | | | |
|---|---|---|---|---|---|---|
| | | | June 3–7 | July 15–19 | August 12–16 | September 16–20 |
| 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 |

**Table 3.** Number of total suckers captured, aged using fin rays, and identified to species using genetics from Clear Lake, California, and Upper Klamath Lake, Oregon, 2019.

| Number of suckers | Clear Lake | Upper Klamath Lake |
|---|---|---|
| Aged or Presumed Age-0 | 200 | 489 |
| Measured (SL) | 200 | 489 |
| Genetic identification | 191 | 411 |
| Total captured | 200 | 490 |

## 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 by two readers, with each reader having no knowledge of the other's annuli count. When both readers agreed on the 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 suckers from both lakes were either aged or systematically assumed to be age-0 by being 60 mm or less in SL.

## 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 juvenile suckers from each lake, however, 79 genetic samples were not analyzed due to subsampling large catches of age-0 in single nets. 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 sucker using the mean posterior probability over the 10 repetitions. For species assignments for Upper Klamath Lake, we categorized suckers having a Prob[LRS] at least 0.95 Lost River suckers, those with a Prob[LRS] at most 0.05 non-Lost River suckers, and fish with a Prob[LRS] intermediate of the two values "Intermediate Prob[LRS]." We call 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 call the non-Lost River suckers in Clear Lake shortnose/Klamath largescale suckers, based on evidence that indicates Klamath largescale suckers constitute most of suckers in Clear Lake (Smith and others, 2020).

## Indices of Juvenile Sucker Year-Class Strength and Apparent Survival

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 assessed age-0 summer survival by comparing CPUE by year-class between the August and September sampling periods. To provide an index to compare between years, September age-0 CPUE was divided by August age-0 CPUE. If the CPUE was greater in September, not applicable (NA) was reported in the results.

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 almost completely homogeneous 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.

## 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 (2020a) to include data collected in 2019. Due to 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 to roughly compare the apparent health of suckers between years and lakes and potentially identify causes of sucker mortality. We pay 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). Afflictions were then quantified and compared to observed afflictions relative to previous years.

# Results

## Upper Klamath Lake Year-Class Strength and Apparent Survival

During the 2019 juvenile monitoring sampling, 490 suckers were captured in Upper Klamath Lake and most (99 percent) were age-0 (table 4, fig. 3). During this same sampling period, 484 age-0 suckers were captured in Upper Klamath Lake, and 143 were Lost River sucker, 63 were shortnose sucker, 199 were an intermediate prob[LRS], and 79 had no species identification (table 4, fig. 4). Most suckers captured in Upper Klamath Lake were less than 100 mm except for one individual captured near Hagelstein at 223 mm (fig. 5). Age-0 suckers from Upper Klamath Lake ranged from 35 to 93 mm SL (fig. 6). There was one sucker whose length was not recorded. We did not capture any of the approximately 3,000 PIT-tagged juvenile suckers released by the U.S. Fish and Wildlife Service Sucker Assisted Rearing Program (SARP) in 2019 or of the 2,400 released in 2018.

The August CPUE for all sucker species combined in Upper Klamath Lake was higher in 2019 than in 2015, 2017, and 2018, and similar to 2016. Most of the 2019 year-class was composed of intermediate prob[LRS] (table 5). The size of the 2019 year-class of Lost River suckers appeared to be larger than the 2015, 2017, and 2018 year-classes but only about one-half the size of the 2016 year-class. The 2019 shortnose cohort was similar to the 2016 year-class, and larger than the 2015, 2017, and 2018 year-classes (table 5).

Cohort tracking among years indicated that within year and among year apparent survival of suckers was very low in Upper Klamath Lake. Only four age-1 suckers from the 2018 cohort (table 6) and one age-3 sucker from the 2016 cohort were captured. Catch rates were highest for the 2019 Upper Klamath Lake cohort during the August sampling period and decreased during the September sampling period (table 7). The 2019 cohort was captured during the July sampling period but did not seem to fully recruit to the sampling gear until August (table 7). August to September survival indices for the 2019 cohort were higher for all suckers combined and Lost River suckers than for previous cohorts. The survival index for shortnose suckers in 2019 was similar to 2016 and lower than in 2015 (table 8).

**Table 4.** Catch per net and percentage of age-0 suckers for each taxa captured in Upper Klamath Lake, Oregon, 2019.

[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. 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 | | | |
|---|---|---|---|---|
| | Number of suckers | Number of age-0 | Age-0 CPUE | Age-0 (percent) |
| Lost River suckers | 143 | 143 | 0.37 | 100 |
| Intermediate prob[LRS] | 201 | 199 | 0.52 | 99 |
| Shortnose suckers | 67 | 63 | 0.16 | 94 |
| No taxa data | 79 | 79 | 0.21 | 100 |
| All taxa suckers | 490 | 484 | 1.27 | 99 |

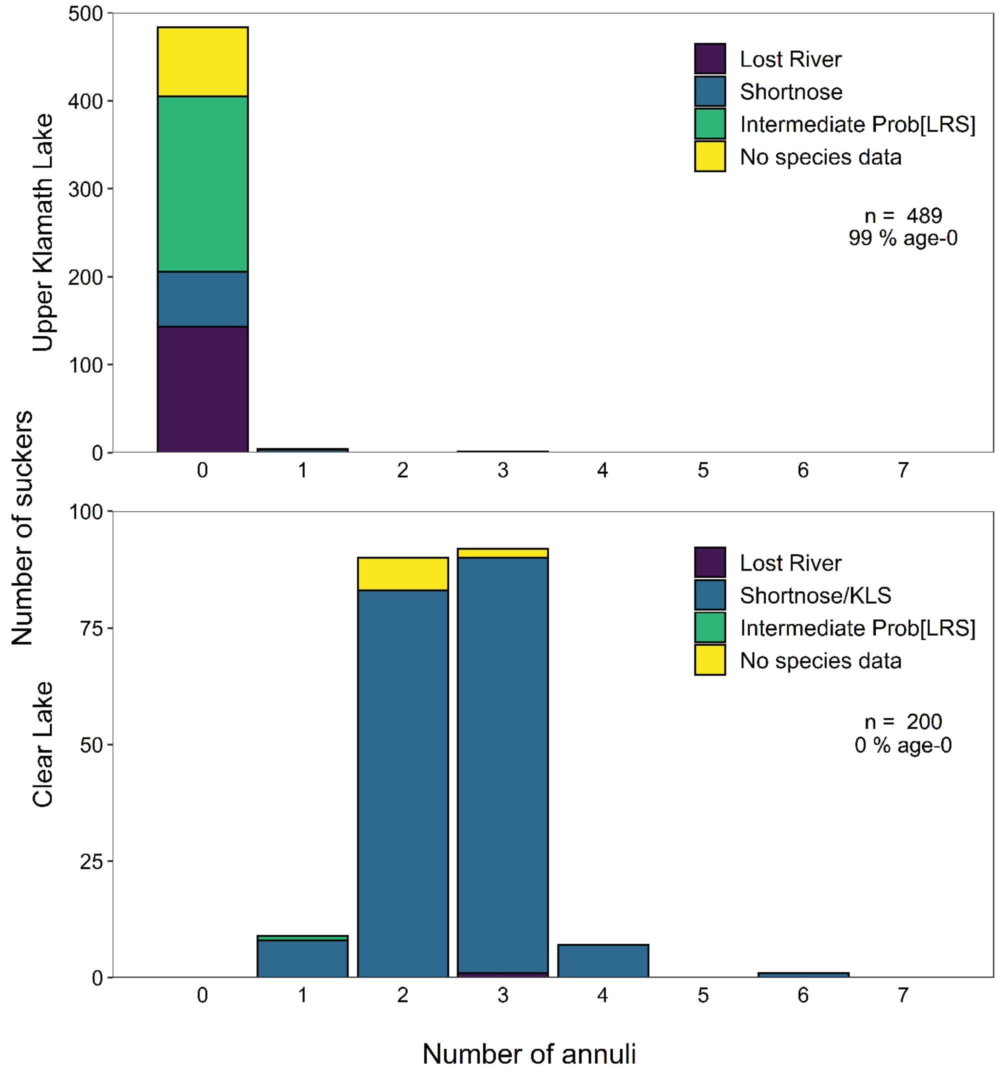


**Figure 3.** Number of annuli on suckers collected from Upper Klamath Lake, Oregon, and Clear Lake, California, 2019. Taxa were identified as the probability of STRUCTURE assignment Lost River sucker (prob[LRS]). Fish with prob[LRS] ≤ 0.05 are called shortnose suckers, fish with prob[LRS] ≥ 0.95 are called Lost River sucker, and fish with 0.05 < prob[LRS] < 0.95 are called Intermediate prob[LRS]. Clear Lake shortnose suckers labeled in the graph are shortnose/Klamath largescale suckers (KLS). Percentage of the total number (*n*) of suckers in each graph that had no annuli on fin rays (age-0) are given.

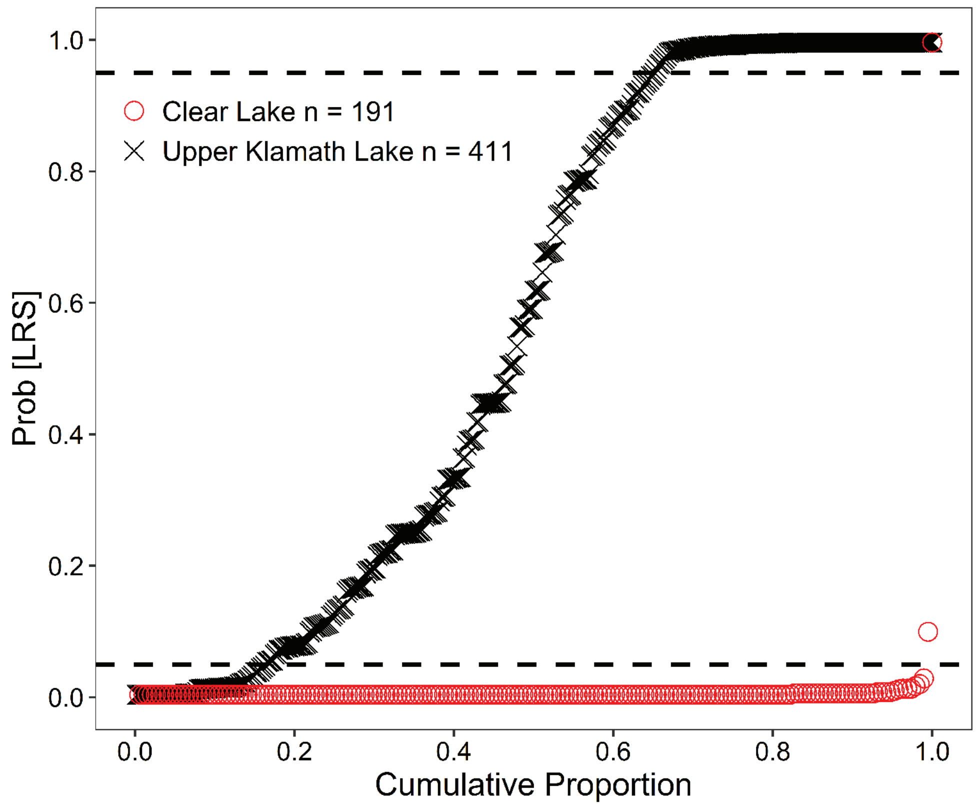


**Figure 4.** Probability of taxa assignment as Lost River sucker based on STRUCTURE (prob[LRS]) for all fish captured at fixed sites in Upper Klamath Lake, Oregon, and Clear Lake, California, 2019. Taxa were identified as the probability of STRUCTURE assignment Lost River sucker (prob[LRS]). Fish with prob[LRS] ≤ 0.05 are called shortnose suckers, fish with prob[LRS] ≥ 0.95 are called Lost River sucker, and fish with 0.05 < prob[LRS] < 0.95 are called Intermediate prob[LRS]. Clear Lake shortnose suckers labeled in the graph are shortnose/Klamath largescale suckers. Numbers of age-0 fish with genetics data from each lake (*n*) are given.

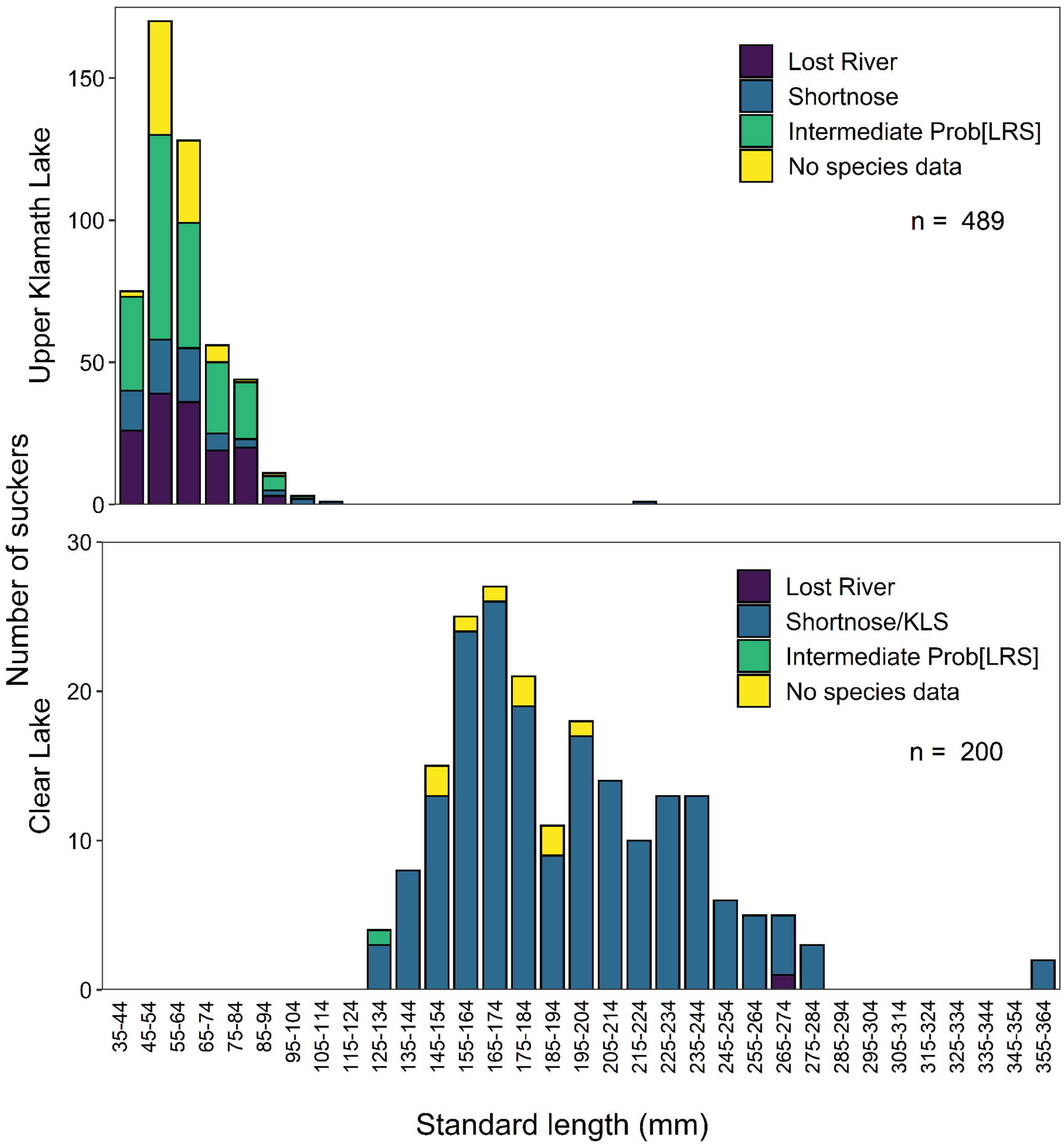


**Figure 5.** Standard lengths of all suckers collected at fixed locations in Upper Klamath Lake, Oregon, and Clear Lake, California, 2019. Taxa were identified as the probability of STRUCTURE assignment Lost River sucker (prob[LRS]). Fish with prob[LRS] ≤ 0.05 are called shortnose suckers, fish with prob[LRS] ≥ 0.95 are called Lost River sucker, and fish with 0.05 < prob[LRS] < 0.95 are called Intermediate prob[LRS]. Clear Lake shortnose suckers labeled in the graph are shortnose/Klamath largescale suckers (KLS). Number of fish in each panel are given (*n*).

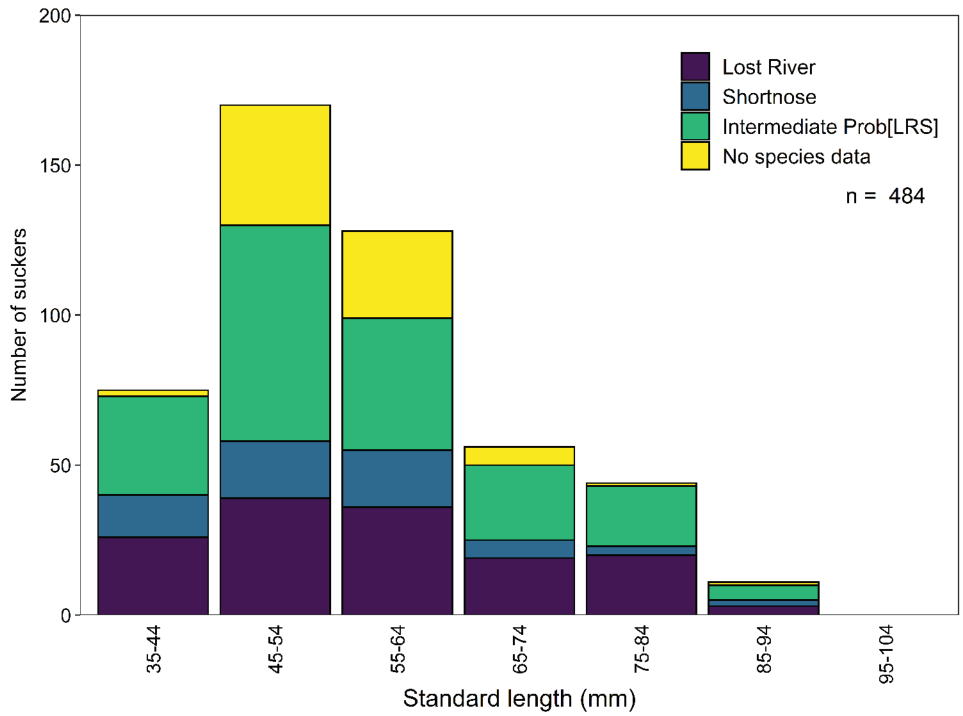


**Figure 6.** Standard lengths of age-0 suckers collected at fixed locations in Upper Klamath Lake, Oregon, 2019. Taxa were identified as the probability of STRUCTURE assignment Lost River sucker (prob[LRS]). Fish with prob[LRS] ≤ 0.05 are called shortnose suckers, fish with prob[LRS] ≥ 0.95 are called Lost River sucker, and fish with 0.05 < prob[LRS] < 0.95 are called Intermediate prob[LRS]. Clear Lake shortnose suckers labeled in the graph are shortnose/Klamath largescale suckers. Number of fish are given (*n*).

**Table 5.** Catch statistics for August age-0 suckers from Upper Klamath Lake, Oregon, 2015–19.

[*n* is the number of suckers. Total capture per unit effort (CPUE) was calculated as the number of fish captured per net set and includes suckers from which we did not collect genetic samples. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

| Parameter | Aug. 2015 (98 nets) | Aug. 2016 (96 nets) | Aug. 2017 (96 nets) | Aug. 2018 (88 nets) | Aug. 2019 (96 nets) |
|---|---|---|---|---|---|
| | | | Lost River suckers | | |
| *n* | 38 | 120 | 7 | 8 | 60 |
| Total CPUE | 0.39 | 1.25 | 0.07 | 0.09 | 0.62 |
| | | | Intermediate prob[LRS] | | |
| *n* | 32 | 59 | 12 | 4 | 112 |
| Total CPUE | 0.33 | 0.61 | 0.12 | 0.05 | 1.17 |
| | | | Shortnose suckers | | |
| *n* | 46 | 35 | 14 | 2 | 36 |
| Total CPUE | 0.47 | 0.36 | 0.15 | 0.02 | 0.38 |
| | | | Total suckers | | |
| *n* | 118 | 223 | 33 | 14 | 279 |
| Total CPUE | 1.20 | 2.32 | 0.34 | 0.16 | 2.91 |

**Table 6.** Catch statistics for the 2018 cohort of suckers from Upper Klamath Lake, Oregon.

[Percentage of nets to successfully capture one or more suckers 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]

| Parameter | Jul. 25–Aug. 3, 2018 (95 nets) | Aug. 6–24, 2018 (88 nets) | Sep. 9–14, 2018 (87 nets) | Jun. 3–7, 2019 (95 nets) | Jul. 22–26, 2019 (96 nets) | Aug. 5–9, 2019 (96 nets) | Sep. 9–13, 2019 (95 nets) |
|---|---|---|---|---|---|---|---|
| **Lost River suckers** | | | | | | | |
| Percentage | 3 | 6 | 0 | 0 | 0 | 0 | 0 |
| Mean (SD) | 1.33 (0.58) | 1.60 (0.89) | 0.00 (NA) | 0.00 (NA) | 0.00 (NA) | 0.00 (NA) | 0.00 (NA) |
| Total CPUE | 0.04 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Intermediate prob[LRS]** | | | | | | | |
| Percentage | 3 | 3 | 5 | 1 | 0 | 0 | 0 |
| Mean (SD) | 1.00 (0.00) | 1.33 (0.58) | 1.25 (0.50) | 1.00 (NA) | 0.00 (NA) | 0.00 (NA) | 0.00 (NA) |
| Total CPUE | 0.03 | 0.05 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 |
| **Shortnose suckers** | | | | | | | |
| Percentage | 1 | 2 | 8 | 2 | 1 | 0 | 0 |
| Mean (SD) | 1.00 (NA) | 1.00 (0.00) | 1.00 (0.00) | 1.00 (0.00) | 1.00 (NA) | 0.00 (NA) | 0.00 (NA) |
| Total CPUE | 0.01 | 0.02 | 0.08 | 0.02 | 0.01 | 0.00 | 0.00 |
| **Total suckers** | | | | | | | |
| Percentage | 6 | 10 | 10 | 3 | 1 | 0 | 0 |
| Mean (SD) | 1.33 (0.82) | 1.56 (1.33) | 1.56 (0.73) | 1.00 (0.00) | 1.00 (NA) | 0.00 (NA) | 0.00 (NA) |
| Total CPUE | 0.08 | 0.16 | 0.16 | 0.03 | 0.01 | 0.00 | 0.00 |

**Table 7.** Catch statistics for the 2019 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. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.05]

| Parameter | Jul. 22–26, 2019 (96 nets) | Aug. 5–9, 2019 (96 nets) | Sep. 9–13, 2019 (95 nets) |
|---|---|---|---|
| Lost River suckers | | | |
| Percentage | 8 | 22 | 19 |
| Mean (SD) | 4.75 (4.46) | 2.86 (5.67) | 2.50 (1.50) |
| Total CPUE | 0.40 | 0.62 | 0.47 |
| Intermediate prob[LRS] | | | |
| Percentage | 7 | 24 | 26 |
| Mean (SD) | 5.57 (7.91) | 4.87 (8.61) | 1.92 (1.29) |
| Total CPUE | 0.41 | 1.17 | 0.51 |
| Shortnose suckers | | | |
| Percentage | 8 | 17 | 9 |
| Mean (SD) | 1.75 (0.89) | 2.25 (3.15) | 1.44 (0.73) |
| Total CPUE | 0.15 | 0.38 | 0.14 |
| Total suckers | | | |
| Percentage | 15 | 36 | 38 |
| Mean (SD) | 6.50 (10.75) | 7.79 (22.64) | 3.17 (2.97) |
| Total CPUE | 0.95 | 2.91 | 1.20 |

**Table 8.** August to September survival indices for age-0 suckers in each taxa captured in Upper Klamath Lake, Oregon, 2015–19.

[NA is used instead of standard deviations that are not applicable due to low sample sizes]

| Taxa | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Lost River suckers | 0.15 | 0.16 | 0.13 | NA | 0.76 |
| Shortnose suckers | 0.51 | 0.34 | NA | >1.00 | 0.36 |
| Total suckers | 0.35 | 0.19 | 0.03 | >1.00 | 0.41 |

## Clear Lake Year-Class Strength and Apparent Survival

Most suckers captured in Clear Lake were shortnose/Klamath largescale suckers from 1 to 3 years old, ranging from 131 to 282 mm SL (figs. 3 and 5). During the 2019 Clear Lake sampling, nine of the suckers captured were older than age-3. None of the 200 suckers captured in Clear Lake during the 2019 juvenile monitoring sampling were age-0 (fig. 3). One sucker was a Lost River sucker, 189 were shortnose/Klamath largescale sucker, 1 was an intermediate prob[LRS], and 9 had no species identification (fig. 4). The most abundant cohorts among our catches from all years of the study were from 2016, followed by the 2017 and 2018 cohorts (table 9).

The age distribution of suckers indicate better annual survival of suckers in Clear Lake than in Upper Klamath Lake. In Upper Klamath Lake, almost all suckers were age-0 indicating very little survival to age-1. The oldest sucker we captured in Clear Lake was an age-10 sucker from the 2009 cohort. We captured seven age-4 shortnose/Klamath largescale suckers from the 2015 cohort. Age-1 and age-2 suckers from the 2017 and 2018 cohorts were also in our catches but in low numbers.

In some years, suckers did not seem to fully recruit to our catches until 3 years of age. The peak of the 2015 cohort catches was during the September 2017 sampling effort, or when the cohort was age-2 (table 10). The 2016 cohort catches peaked during September 2016 when the cohort was age-0. The 2017 cohort catch peaked during the July 2019 sampling effort or when the cohort was age-2. Although the 2018 cohort was detected in low numbers during the 2018 sampling, it also followed the same trend as other cohort being captured at higher rates once it reached age-1 (table 10).

## 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. 7). Apparent growth seemed less rapid from August 2017 to September 2019, than during the previous time period. The presence of a few smaller individuals in the 2016 cohort, captured from July to September 2018, may have resulted in smaller average lengths. Difference in mean lengths from August 2016 to August 2017 was 82.96, and 28.66 mm from August 2017 to August 2018, and 41.27 mm from August 2018 to August 2019. Inferences may be limited when suckers from the 2016 cohort reached a length at which they approached the maximum gear selectivity.

## Afflictions

Suckers in Upper Klamath Lake generally had more macro parasites, deformities, and skin afflictions than suckers in Clear Lake. The two primary afflictions observed during the 2019 monitoring season in both lakes were attached *Lernaea* sp. and petechial hemorrhaging. Other afflictions observed were lamprey wounds on eleven Clear Lake suckers and three Upper Klamath Lake suckers. Five suckers from Clear Lake had missing or blind eyes whereas no suckers from Upper Klamath Lake were observed with this affliction. We did not observe any fish with black spot (metacercariae of *Bolbophorus* spp.) from either lake in 2019.

**Table 9.** Catch statistics for August age-0 suckers from Clear Lake, California, 2015–19.

[*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]

| Parameter | Aug. 2015 (70 nets) | Aug. 2016 (70 nets) | Aug. 2017 (70 nets) | Aug. 2018 (69 nets) | Aug. 2019 (70 nets) |
|---|---|---|---|---|---|
| Lost River suckers | | | | | |
| *n* | 0 | 2 | 4 | 0 | 0 |
| Total CPUE | 0.00 | 0.03 | 0.06 | 0.00 | 0.00 |
| Intermediate prob[LRS] | | | | | |
| *n* | 0 | 1 | 0 | 0 | 0 |
| Total CPUE | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| Shortnose/Klamath largescale suckers | | | | | |
| *n* | 0 | 15 | 3 | 3 | 0 |
| Total CPUE | 0.00 | 0.21 | 0.04 | 0.04 | 0.00 |
| Total suckers | | | | | |
| *n* | 0 | 18 | 7 | 3 | 0 |
| Total CPUE | 0.00 | 0.26 | 0.10 | 0.04 | 0.00 |

**Table 10.** Catch statistics for the 2015–19 cohorts of shortnose/Klamath largescale suckers from Clear Lake, 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]

| Parameter | Jun. 2015 (70 nets) | Aug. 2015 (70 nets) | Sep. 2015 (70 nets) | Jun. 2016 (70 nets) | Aug. 2016 (70 nets) | Sep. 2016 (70 nets) | Jun. 2017 (69 nets) | Aug. 2017 (70 nets) | Sep. 2017 (70 nets) | June. 2018 (70 nets) | Jul. 2018 (70 nets) | Aug. 2018 (69 nets) | Sep. 2018 (70 nets) | Jun. 2019 (70 nets) | Jul. 2019 (70 nets) | Aug. 2019 (70 nets) | Sep. 2019 (70 nets) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 Cohort | | | | | | | | | | | | | | | | | |
| Percentage | 0 | 0 | 0 | 0 | 0 | 7 | 1 | 7 | 9 | 7 | 4 | 6 | 1 | 1 | 1 | 3 | 4 |
| Mean | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.20 | 1.17 | 1.00 | 1.33 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SD | NA | NA | NA | NA | NA | 0.00 | NA | 0.45 | 0.41 | 0.00 | 0.58 | 0.00 | NA | NA | NA | 0.00 | 0.00 |
| Total CPUE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.01 | 0.09 | 0.10 | 0.07 | 0.06 | 0.06 | 0.01 | 0.01 | 0.01 | 0.03 | 0.04 |
| 2016 Cohort | | | | | | | | | | | | | | | | | |
| Percentage | | | | | 14 | 53 | 4 | 36 | 16 | 19 | 31 | 20 | 13 | 26 | 27 | 33 | 9 |
| Mean | | | | | 1.50 | 2.95 | 1.00 | 1.80 | 1.27 | 1.31 | 1.23 | 1.50 | 1.22 | 1.61 | 1.11 | 1.39 | 1.17 |
| SD | | | | | 0.53 | 4.65 | 0.00 | 1.22 | 0.47 | 0.75 | 0.43 | 0.76 | 0.44 | 0.78 | 0.46 | 0.72 | 0.41 |
| Total CPUE | | | | | 0.21 | 1.56 | 0.04 | 0.64 | 0.20 | 0.24 | 0.39 | 0.30 | 0.16 | 0.41 | 0.30 | 0.46 | 0.10 |
| 2017 Cohort | | | | | | | | | | | | | | | | | |
| Percentage | | | | | | | | 4 | 6 | 13 | 33 | 28 | 16 | 20 | 30 | 23 | 4 |
| Mean | | | | | | | | 1.00 | 1.00 | 1.33 | 1.22 | 1.05 | 1.36 | 2.00 | 1.62 | 1.12 | 1.00 |
| SD | | | | | | | | 0.00 | 0.00 | 0.50 | 0.52 | 0.23 | 0.67 | 1.04 | 0.92 | 0.34 | 0.00 |
| Total CPUE | | | | | | | | 0.04 | 0.06 | 0.17 | 0.40 | 0.29 | 0.21 | 0.40 | 0.49 | 0.26 | 0.04 |
| 2018 Cohort | | | | | | | | | | | | | | | | | |
| Percentage | | | | | | | | | | 6 | 3 | 4 | 0 | 4 | 1 | 3 | 0 |
| Mean | | | | | | | | | | 1.00 | 1.50 | 1.00 | 0.00 | 1.67 | 1.00 | 1.00 | 0.00 |
| SD | | | | | | | | | | 0.00 | 0.71 | 0.00 | NA | 0.58 | NA | 0.00 | NA |
| Total CPUE | | | | | | | | | | 0.06 | 0.04 | 0.04 | 0.00 | 0.07 | 0.01 | 0.03 | 0.00 |
| 2019 Cohort | | | | | | | | | | | | | | | | | |
| Percentage | | | | | | | | | | | | | | 0 | 0 | 0 | 0 |
| Mean | | | | | | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| SD | | | | | | | | | | | | | | NA | NA | NA | NA |
| Total CPUE | | | | | | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 |

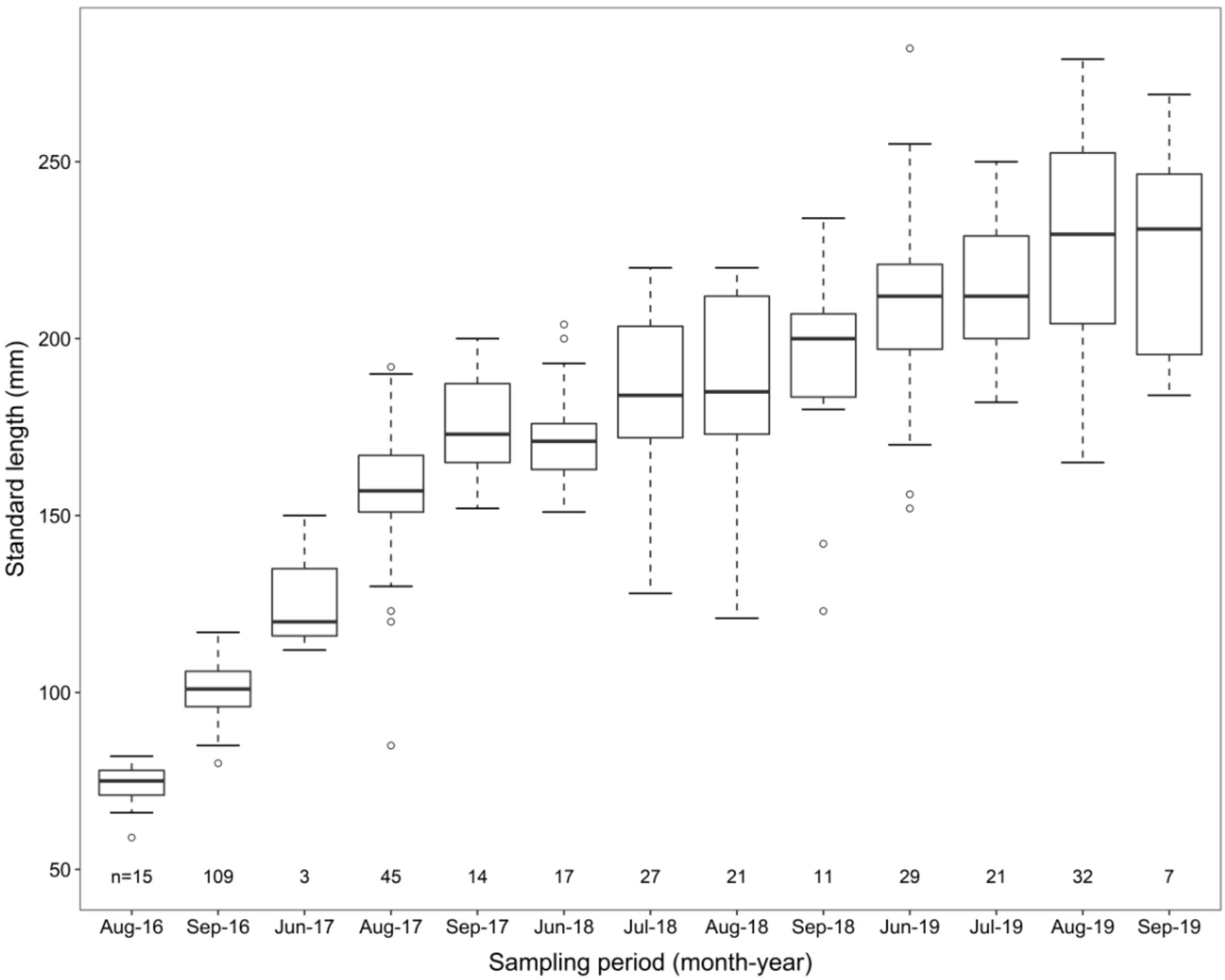


**Figure 7.** Standard length of 2016 cohort of shortnose/Klamath largescale suckers from Clear Lake, California. Sample sizes (n) are given at the bottom of the plot. Black lines within boxes represent the median of data, boxes represent the 1st and 3rd quartiles, and whiskers represent minimums and maximums (quartile – 1.5 × interquartile range). Open circles represent outliers calculated by points outside the whisker range. [mm, millimeter].

Missing or deformed opercula were observed only on Upper Klamath Lake age-0 suckers (table 11). Lost River sucker had the most observations of deformed or missing opercula whereas no observations were made for shortnose sucker. There were 22 suckers with opercula afflictions—13 had one affected operculum and 9 had missing or deformed opercula. Deformed opercula were not observed on suckers in 2018 but were observed during 2015–17 monitoring. Missing or deformed opercula have not been observed on Clear Lake suckers from monitoring efforts from 2015 to 2019.

*Lernaea* sp. were the most common parasite seen on age-0 suckers in 2019 with most observations from Upper Klamath Lake and few from Clear Lake (table 12). The most *Lernaea* sp. attached to an individual juvenile sucker were 15 but most often only one *Lernaea* sp. was attached. *Lernaea* sp. were observed on age-1 and older fish from Clear Lake (table 13); however, only five suckers in this age category were captured in Upper Klamath Lake. Although this parasite was relatively common in Upper Klamath Lake, there were no obvious signs that *Lernaea* sp. cause mortality of juvenile suckers.

Petechial hemorrhaging on age-0 fish was observed on Upper Klamath Lake suckers (table 14). The proportion of age-0 suckers with petechial hemorrhaging in 2019 was lower relative to previous years except for 2018 (table 14). Petechial hemorrhaging was observed on a slightly lower proportion of age-1 and older suckers relative to 2018 in Upper Klamath Lake but was more prevalent than in other years (table 15). Although petechial hemorrhaging was observed on Clear Lake suckers age-1 and older in 2019, it was still a relatively rare affliction not commonly observed in Clear Lake.

**Table 11.** Proportions of age-0 suckers with missing or deformed opercula, Upper Klamath Lake, Oregon, and Clear Lake, California, 2015–19.

[Sample size of age-0 suckers captured given in parentheses. Clear Lake shortnose suckers labeled in the plot are shortnose/Klamath largescale suckers. NA represents proportions that are not applicable due to no age-0 fish captured. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.0. **Abbreviations:** CL, Clear Lake; UKL, Upper Klamath Lake]

| Taxonomic group | UKL 2015 | CL 2015 | UKL 2016 | CL 2016 | UKL 2017 | CL 2017 | UKL 2018 | CL 2018 | UKL 2019 | CL 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Lost River sucker | 0.05 (41) | NA | 0.11 (136) | 0.00 (10) | 0.62 (8) | 0.00 (4) | 0.00 (12) | 0.00 (0) | 0.10 (143) | NA |
| Intermediate prob[LRS] | 0.08 (38) | NA | 0.12 (67) | 0.00 (2) | 0.08 (12) | 0.00 (1) | 0.00 (12) | 0.00 (0) | 0.03 (199) | NA |
| Shortnose sucker | 0.09 (58) | NA | 0.02 (45) | 0.00 (124) | 0.07 (14) | 0.00 (7) | 0.00 (10) | 0.00 (10) | 0.00 (63) | NA |
| Total | 0.07 (139) | NA | 0.10 (258) | 0.00 (149) | 0.21 (34) | 0.00 (12) | 0.00 (36) | 0.00 (10) | 0.05 (484) | NA |

**Table 12.** Proportions of age-0 suckers with attached *Lernaea sp.*, Upper Klamath Lake, Oregon, and Clear Lake, California, 2015–19.

[Sample size of age-0 suckers captured given in parentheses. Clear Lake shortnose suckers labeled in the plot are shortnose/Klamath largescale suckers. NA represents proportions that are not applicable due to no age-0 fish captured. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.0. **Abbreviations:** CL, Clear Lake; UKL, Upper Klamath Lake]

| Taxonomic group | UKL 2015 | CL 2015 | UKL 2016 | CL 2016 | UKL 2017 | CL 2017 | UKL 2018 | CL 2018 | UKL 2019 | CL 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Lost River sucker | 0.67 (41) | NA | 0.63 (136) | 0.20 (10) | 0.12 (8) | 0.25 (4) | 0.33 (12) | 0.00 (0) | 0.22 (143) | NA |
| Intermediate prob[LRS] | 0.71 (38) | NA | 0.57 (67) | 0.00 (2) | 0.33 (12) | 0.00 (1) | 0.08 (12) | 0.00 (0) | 0.16 (199) | NA |
| Shortnose sucker | 0.48 (58) | NA | 0.40 (45) | 0.08 (124) | 0.29 (14) | 0.14 (7) | 0.00 (10) | 0.00 (10) | 0.11 (63) | NA |
| Total | 0.67 (139) | NA | 0.57 (258) | 0.08 (149) | 0.26 (34) | 0.17 (12) | 0.14 (36) | 0.00 (10) | 0.16 (484) | NA |

**Table 13.** Proportions of age-1 and older suckers with attached *Lernaea sp.*, Upper Klamath Lake, Oregon, and Clear Lake, California, 2015– 19.

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

| Lake | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Upper Klamath Lake | 0.20 (15) | 0.40 (15) | 0.17 (12) | 0.50 (4) | 0.00 (5) |
| Clear Lake | 0.30 (20) | 0.08 (50) | 0.07 (88) | 0.04 (196) | 0.10 (200) |

**Table 14.** 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, California, 2015–19.

[Sample size of age-0 suckers given in parentheses. Clear Lake shortnose suckers labeled in the plot are shortnose/Klamath largescale suckers. NA represents proportions that are not applicable due to no age-0 fish captured. Intermediate prob[LRS] refers to suckers having a probability of being Lost River suckers intermediate between the values of 0.95 and 0.0. **Abbreviations:** CL, Clear Lake; UKL, Upper Klamath Lake]

| Taxonomic group | UKL 2015 | CL 2015 | UKL 2016 | CL 2016 | UKL 2017 | CL 2017 | UKL 2018 | CL 2018 | UKL 2019 | CL 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Lost River sucker | 0.56 (41) | NA | 0.23 (136) | 0.00 (10) | 0.00 (8) | 0.00 (4) | 0.17 (12) | 0.00 (0) | 0.08 (143) | NA |
| Intermediate prob[LRS] | 0.34 (38) | NA | 0.16 (67) | 0.00 (2) | 0.08 (12) | 0.00 (1) | 0.00 (12) | 0.00 (0) | 0.08 (199) | NA |
| Shortnose sucker | 0.26 (58) | NA | 0.13 (45) | 0.02 (124) | 0.14 (14) | 0.00 (7) | 0.00 (10) | 0.00 (10) | 0.06 (63) | NA |
| Total | 0.37 (139) | NA | 0.19 (258) | 0.01 (149) | 0.09 (34) | 0.00 (12) | 0.06 (36) | 0.00 (10) | 0.07 (484) | NA |

**Table 15.** Proportions of age-1 and older suckers with petechial hemorrhages of the skin in Upper Klamath Lake, Oregon, and Clear Lake, California, 2015–19.

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

| Lake | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Upper Klamath Lake | 0.07 (15) | 0.07 (15) | 0.08 (12) | 0.50 (4) | 0.20 (5) |
| Clear Lake | 0.05 (20) | 0.00 (50) | 0.00 (88) | 0.04 (196) | 0.07 (200) |

# Discussion

## Upper Klamath Lake

The lack of substantial recruitment to the spawning population continues to be the bottleneck 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 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 their downward trend until extirpated from Upper Klamath Lake.

The lack of age-1 and older suckers in Upper Klamath Lake is likely attributable to juvenile mortality. The presumption that mortality rather than reduced selectivity or emigration from sampled areas explains the reduction in catch by age is supported by several observations. Most of our catch in Clear Lake were age-1 and older suckers, indicating 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). A lack of directed movement toward the lake's outlet suggests that emigration is not the primary reason for a lack of older juvenile suckers in Upper Klamath Lake (Burdick and others, 2009).

There are several possible explanations for why we did not detect PIT-tagged suckers that were released into Upper Klamath Lake from the SARP program in 2018 and 2019. About 2,400 SARP suckers were released in the spring of 2018, and 3,000 in the spring of 2019 (Childress and others, 2019). Given the large size of Upper Klamath Lake, these are relatively small numbers of fish to detect, even when ignoring post-release mortality. PIT-tag antennas operating in the Link River at the outlet of Upper Klamath Lake and in the Williamson and Sprague Rivers detected 3 SARP fish in 2018 and 19 SARP fish in 2019, indicating that directed emigration was an unlikely explanation for the disappearance of these fish. As of the writing of this report, 102 PIT tags from SARP released suckers have been detected on bird colonies cumulatively from 2018 and 2019 scanning efforts, indicating bird predation may be a factor in the survival of some SARP fish.

Although it is typical for survival 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. Although survival was intermediate from August–September 2019 compared to survival in previous years, 2019 is far from being considered a successful cohort. High fecundity may be a life history strategy to overcome high mortality for juvenile suckers in the Klamath Basin, but near complete mortality is unsustainable (Rasmussen and Childress, 2018). Given that the adult populations of Lost River and shortnose suckers have decreased by more than 50 percent since the early 2000s (Hewitt and others, 2018), there would have to be a significant recruitment event soon for both species to recover naturally.

## Clear Lake

With higher juvenile sucker survival than in Upper Klamath Lake, intermittent recruitment of new spawners has been documented for Clear Lake populations (Hewitt and Hayes, 2013). The mechanisms behind intermittent cohort success are not completely understood. Hypotheses include (1) limited access to spawning habitat in dry years, (2) differential juvenile sucker mortality among years, and (3) differential rates of avian predation among years that are mediated by water levels and fish size, especially for small fish.

A lack of age-0 suckers captured in the low water years of 2014 and 2015 in Clear Lake led Burdick and others (2016) to conclude cohorts were not formed in those years. Lake-surface elevations less than 1,378.9 m prevented adult suckers from migrating up the spawning tributaries in the spring of both years (Hewitt and others, 2021). Therefore, Burdick and others (2016) concluded that without access from the lake to the river spawning did not occur. After high flows in the Willow Creek drainage increased lake-surface elevations in 2016, the 2014 and 2015 cohorts were detected in Clear Lake (fig. 8). The 2015 cohort continued to be detected in increasingly high numbers through 2018 and was detected again in 2019. The presence of the 2015 juvenile cohort in Clear Lake challenged Burdick and others (2016) presumption that high springtime lake elevations are required to form year-classes in Clear Lake (Bart and others, 2020a). The 2015 cohort may be offspring of stream resident suckers that only recruited to Clear Lake when high water flushed them from the tributaries.

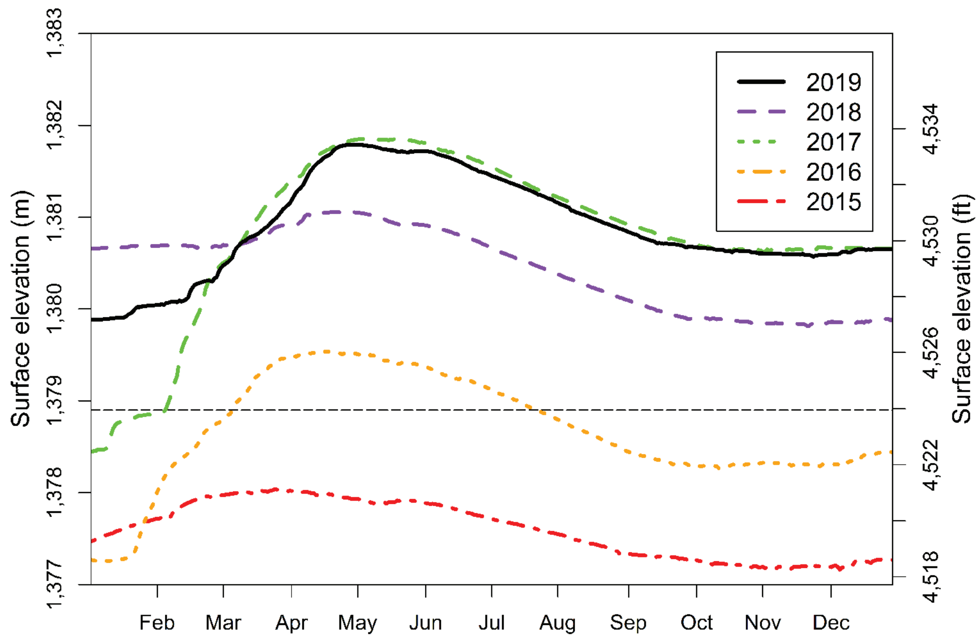


**Figure 8.** Lake-surface elevation, Clear Lake, California, 2015–19. The surface elevation indicating separation between Clear Lake and Willow Creek is the straight horizontal dashed line at 1,378.8 meters. Surface elevations are in meters (m) and feet (ft) above Bureau of Reclamation Vertical Datum.

There are several possible explanations for annual variation in age-0 sucker catches. Age-0 sucker catches were relatively high in Clear Lake in 2011–13 before our present sampling plan was implemented. They were also high in 2016, low in 2017 and 2018, and absent in 2014–15 and 2019. Most cohorts of suckers in Clear Lake do not seem to fully recruit to our samples until age-2 (Bart and others, 2020a; Bart and others, 2020b). Juvenile and adult suckers have been documented in disconnected pools and reservoirs throughout the Willow and Boles Creek drainages during summer 2018 (Martin and others, 2021). One possible explanation is that juvenile suckers rear for a year or more in tributaries before recruiting to Clear Lake. A longer instream residency time for suckers in the Clear Lake drainage than the Upper Klamath Lake drainage may not be entirely voluntary. Suckers may make spawning runs during high flows, but by the time larvae hatch water may be insufficient to allow for outmigration to the lake thus trapping suckers in disconnected pools.

The lack of access between the tributaries and Clear Lake does not explain why age-0 sucker catches were low or absent in 2017–19. With higher water levels and access to Willow Creek for spawning habitat, we expected to see large numbers of age-0 suckers in Clear Lake from 2017 to 2019, but this was not the case. Adult suckers were detected on remote PIT-tag arrays migrating into Willow Creek during springs of 2017–19, indicating that spawning likely occurred (Hewitt and others, 2021).

Clear Lake surface elevation and Willow Creek flows may affect the annual rate of bird predation on suckers (Hewitt and others, 2021). Double-crested cormorants (*Phalacrocorax auratus)* and American white pelicans (*Pelecanus erythrorhynchos)* prey upon vulnerable suckers as they enter Willow Creek to spawn. Hewitt and others (2021) hypothesized that adult sucker mortality is greatest when lake-surface elevation ranges from 1,378.9 m to 1,379.2 m above mean sea level during the spawning migration. Several cohorts that cease to be captured in trammel net catches at the age of first spawning may indicate that young or small adult suckers are especially vulnerable to bird predation. When the lake-surface elevation is less than 1,378.9 m or if instream flows are very low, suckers cannot access spawning habitat in Willow Creek and are therefore less susceptible to predation. The formation of nesting islands for American white pelican and double-crested cormorant at lake-surface elevations greater than 1,378.9 m provides protection for the birds' eggs from predators, resulting in greater numbers of birds to be present for a longer period (Evans and others, 2016). As lake-surface elevation increases above 1,378.9 m, bird islands shrink in size, thus reducing bird nesting habitat and the number of nesting birds available to prey on suckers. At lake-surface elevation above 1,379.2 m, deep water also provides cover for migrating suckers (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 2013). Poor survival of suckers that first attempt to spawn in low water years may explain the absence of some cohorts from adult sucker sampling.

Another possibility is that differences in water depth among years affects our ability to capture suckers in Clear Lake. In Upper Klamath Lake, age-0 Lost River and shortnose sucker habitat use is optimized at depths less than 1 m and decreases with deeper depths (Burdick and Hewitt, 2012). Water depth in Clear Lake changes substantially among years (fig. 8). Although we attempted to adjust our sampling sites toward the shoreline to account for yearly variation in depths, our sites were deeper in 2017–19 than in 2011–16. Although we aimed to sample depths of 3 m or less when Clear Lake water levels were high, we were still sampling deeper depths than depths sampled in 2011–16. Therefore, it is possible that our sampling did not coincide with high densities of age-0 suckers from 2017 to 2019 if they were in shallower water than what we were sampling. Whatever the reason for the lack of age-0 sucker captures in 2019, it is still possible that a cohort was formed and not detected. Given our continued pattern of catching cohorts once they are past age-0, sampling Clear Lake in 2020 is needed to confirm the existence of the 2019 cohort.

## Afflictions

Only age-0 suckers from Upper Klamath Lake were observed with missing or deformed opercula. There were no opercular deformities observed during the 2018 sampling season; however, we saw approximately 5 percent of all age-0 suckers from Upper Klamath Lake with this deformity in 2019. This affliction makes the gills more vulnerable to parasites, oxygen deficiencies, and poor water quality in general, ultimately increasing the chances of mortality. Because there were no age-1 or older suckers with deformed opercula, there is the potential that it is serious enough of an affliction that it causes mortality before fish can reach older ages. We did not see this affliction in Clear Lake suckers in 2019 or in previous years (Burdick and others, 2018; Bart and others, 2020a; Bart and others, 2020b). When looking at the prevalence of deformed opercula by species, shortnose suckers constituted most of the instances in 2015 and Lost River suckers constituted most instances in 2016 (Burdick and others, 2018). Although this affliction has been observed on other sucker species (Barkstedt and others, 2015), the exact cause of deformed opercula in Upper Klamath Lake is difficult to determine but potential explanations could be inbreeding, hybridization (Winemiller and Taylor, 1982; Tringali and others, 2001), nutrient deficiency (Chávez de Martínez, 1990; Lall, 2002), heavy metals, pesticides, high egg incubation temperature (Boglione and others, 2013) or a combination of these factors.

*Lernaea* sp. parasitism was the most common affliction on juvenile suckers captured in both lakes. 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 is most often limited to a focal area in the skin and skeletal muscle directly surrounding the attachment site, indicating this parasite is unlikely to cause systemic infections that result in mortality (Burdick, Elliott, and others, 2015).

The causes of petechial hemorrhaging, which was almost exclusively found on suckers from Upper Klamath Lake, are unknown. 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). Petechial hemorrhages of the skin have been found to be caused by irritants including abrasion, bacteria, or toxins (Ferguson and others, 2011). The very low prevalence of observed hemorrhages in Clear Lake relative to Upper Klamath Lake indicates that abrasions due to our method of capture is 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 indicated that the infection was likely confined to the skin.

Lamprey wounds were seen in both lakes but are likely not a large source of mortality. All lamprey species in the Upper Klamath Basin are native (Kostow, 2002), some of which are endemic. Given the low prevalence of lamprey wounds and that lamprey have coevolved with suckers in the Klamath Basin, it is unlikely that they are the primary cause of annual juvenile sucker year-class failure. Older suckers are potentially more vulnerable to lamprey because there is more surface area on larger suckers for them to attach themselves.

Incidence of black spot was hypothesized to be associated with high mortality of juvenile suckers (Markle and others, 2014). In previous years monitoring, black spot was only recorded on a small proportion of fish, and during the 2018 and 2019 monitoring seasons, there were no suckers with black spot (Bart and others 2020a; Bart and others 2020b). In years when black spot was observed, it was more prevalent in Upper Klamath Lake than in Clear Lake (Burdick and others, 2016; Burdick and others, 2018; Bart and others, 2020b). There is the potential that we are missing cases of black spot in suckers when it is not visible externally. Markle and others (2020) found that out of 55 fish observed without external black spot, 10 had internal muscle or gill infections of black spot. Although this would indicate that black spot is underrepresented in our data, there is no indication that it is a significant source of mortality for juvenile suckers from our data.

## Conclusions

Most adult Lost River and shortnose suckers in Upper Klamath Lake were hatched in the early 1990s and averaged approximately 28 years old in 2019 (Hewitt and others, 2018). Lost River sucker have a maximum estimated life span of 57 years and 33 years for shortnose sucker (Terwilliger and others, 2010). Upper Klamath Lake shortnose sucker are approaching the maximum known age for the species making them especially at risk of extirpation.

Monitoring juvenile suckers in 2019 did not indicate upcoming recruitment into adult sucker populations in Upper Klamath Lake. Although age-0 suckers were detected in larger numbers during the 2019 Upper Klamath Lake sampling, they were still captured in relatively low numbers relative to pre-2015 monitoring (Burdick and Martin, 2017). We did not detect significant survival or persistence of previous cohorts in Upper Klamath Lake with few fish captured older than age-0. We found apparent relative Upper Klamath Lake juvenile sucker August to September survival to be low in 2019 compared to previous years. Due to a lack of full recruitment to our trap nets and very low catch rates, we were not able to calculate age-0 mortality from June through August.

We did not capture juvenile PIT-tagged SARP suckers reared and released by the U.S. Fish and Wildlife Service to offset natural juvenile mortality and are unable to predict if this action will be effective. We do know a proportion of tagged SARP fish were detected on bird colonies; however, avian predation is unlikely to account for failure of entire cohorts. All afflictions observed were at low intensities and did not indicate large mortality events. Although Markle and others (2020) hypothesized black spot to be a high source of mortality, we did not observe any juveniles with this affliction. Similar to previous juvenile sucker monitoring reports, we were unable to identify a specific cause of cohort failure; however, from our findings we conclude there are several causes of death that may cumulatively cause mortality of juvenile suckers.

Clear Lake suckers continue to have better survival and recruitment than Upper Klamath Lake suckers. Most suckers captured in Clear Lake were classified as shortnose/Klamath largescale sucker. Of the detected cohorts, the 2016 cohort continues to persist at larger numbers relative to older Clear Lake cohorts. As we continue to monitor Clear Lake suckers, we may start to observe the 2016 cohort recruit to the adult monitoring efforts. Although there were no age-0 suckers captured during the 2019 monitoring, there is the potential that our sampling did not coincide with age-0 habitat use. To explore this possibility, juvenile sampling efforts in the future will be moved closer to shore to sample a shallower range of depths where age-0 suckers may not have been sampled in the past.

There is the continued potential that juveniles rear in Willow Creek longer than previously thought. Stream dwelling characteristics that are typically attributed to Klamath largescale suckers may explain this observation. Although the mechanisms behind juvenile sucker migration to Clear Lake are not fully understood, the connectivity between Willow Creek and Clear Lake is an important aspect to cohort success.

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