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—2020 Monitoring Report

Open-File Report 2022–1099

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

Cover. Young-of-year endangered sucker from Upper Klamath Lake, Oregon, 2020. Photograph by Ryan Bart, U.S. Geological Survey.

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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	
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 × °C) + 32.

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 Reservoir
CPUE	catch per unit effort
KLS	Klamath largescale sucker
KLS and SNS_LR	Klamath largescale suckers and shortnose suckers from the Lost River Basin
LRS	Lost River sucker
PIT	passive integrated transponder
SARP	Sucker Assisted Rearing Program
SNS	shortnose sucker
SD	standard deviation
SL	standard length
UKL	Upper Klamath Lake
USFWS	U.S. Fish and Wildlife Service
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 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 (USGS) monitoring program, begun 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 suggest that the 2020 age-0 cohort is one of the lowest since standardized monitoring began. Despite apparently low overwinter survival, the relatively large 2019 cohort persisted in our 2020 samples and continues to contribute to the populations. Although the 2019 cohort age-0 suckers were composed mainly of Lost River suckers, the age-1 suckers from the 2019 cohort were mainly shortnose suckers. Lost River suckers comprised the largest proportion of the 2020 year-class and were only captured in July and August. Shortnose suckers were mainly captured in August and September and comprised a smaller proportion of the 2020 year-class.

Age distribution of suckers captured in Clear Lake indicates greater juvenile survival than in Upper Klamath Lake. Most juvenile suckers captured were age-3 and age-4 suckers classified as the combination of Klamath largescale suckers (*Catostomus snyderi*) and shortnose suckers from the Lost River Basin, from the 2016 and 2017 cohorts. A lack of age-0 suckers captured in Clear Lake during years with the low inflow or lake levels initially lead us to believe that low water prevented spawning and year class formation. However, recent data indicate that some cohorts that were not captured as age-0 suckers were detected in later years at age-1 or age-2. This finding indicates that juvenile suckers in Clear Lake may spend one or more years in the tributaries or that sampling efficacy for age-0 suckers varies among years because of water depth.

The first 5 years of this monitoring program indicated different patterns in recruitment and survival of juvenile suckers between Upper Klamath and Clear Lakes. Since the monitoring program began in 2015, age-0 sucker catch rates, interpreted as indices of year-class strength, were greatest in Upper Klamath Lake in 2016 and 2019. In those years Lost River suckers made up the majority of age-0 sucker catches; however, in 2017 and 2020 the age-1 sucker catches from these cohorts were mainly composed of shortnose suckers or suckers with genetic markers of both Klamath largescale and shortnose suckers, indicating a low overwinter survival for Lost River suckers even when the age-0 catches were high. Age-0 suckers do not fully recruit to our sampling gear in Upper Klamath Lake until August, experience high mortality by September, and are almost undetectable by the following July or August in most years. In Clear Lake, suckers frequently are not captured until age-1 or age-2 and annual survival appears much greater.

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 sucker and shortnose sucker exist in Upper Klamath Lake (Klamath County, Oregon) and 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). 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 appear 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 results from 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 and others, 2015b).

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 appear 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 (USFWS) 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 2 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 and 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 unideal for monitoring long-term trends (Burdick and Martin, 2017). Nevertheless, USGS analyzed the 2001 through 2015 USGS dataset to identify patterns in recruitment, survival, and growth of age-0 suckers in Upper Klamath Lake (Burdick and Martin, 2017). Data collected by Simon and others (2013) indicated that the strongest year classes for both species within the 16 years of their record probably occurred prior to 2001 and in 2011. Relatively strong cohorts for both species also were produced in 2006 (Simon and others, 2013; Burdick and Martin, 2017). Overwinter and summer to autumn survival could not be assessed with data collected in either sampling program because sampling occurred primarily in the summer. The USGS cautioned that inconsistencies among years in the types of gear used, sample locations, and timing of sample collection could limit inferences made from these historic data.

The USGS juvenile sucker monitoring program was initiated in 2015 with the objective 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 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 and 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.

An additional benefit of the juvenile sucker cohort tracking program is the ability to monitor the success of the USFWS Sucker Assisted Rearing Program (SARP) for juvenile suckers (Day and others, 2021). Using passive integrated transponders (PIT), the USFWS PIT-tagged and released approximately 2,400 SARP suckers in the spring of 2018, 3,000 in the spring of 2019, 1,000 in the fall of 2019, and 4,200 in the spring of 2020 (Joshua Gondek, USFWS, written commun., September 23, 2022). The existing juvenile sucker monitoring program provides an opportunity to recapture and thus track these fish. Sufficient recaptures of tagged fish over time would potentially allow for survival estimates to be generated.

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 enters through two sources: (1) it upwells through the volcanic soils along the lakeshore and (2) it 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 feet [ft]) to 1,262.8 m (4,143 ft; USGS, 2019). Surface and groundwater inputs exceed down-river flows from about October to about June each year, causing the lake volume to increase. Agricultural water deliveries, down-river 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.

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) influence summer water-quality dynamics in Upper Klamath Lake (Eldridge and others, 2012a, b). 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 greater than or equal to (≥) 10, and microcystin toxin concentrations 40–60 parts per billion (ppb; Eldridge and others, 2012a, b).

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 enlarges 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 historic 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 (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 (Hewitt and others, 2021). Water can be delivered down river 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).

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 within the U.S. Forest Service's Modoc and Fremont-Winema National Forests. The area around the lake is rocky with sagebrush (*Artemisia* 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 Reservoir 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 water temperatures up to 26 °C, dissolved-oxygen ≥5 mg/L, pH around 8.5, and no detectable microcystin toxin (Burdick and others, 2015a).

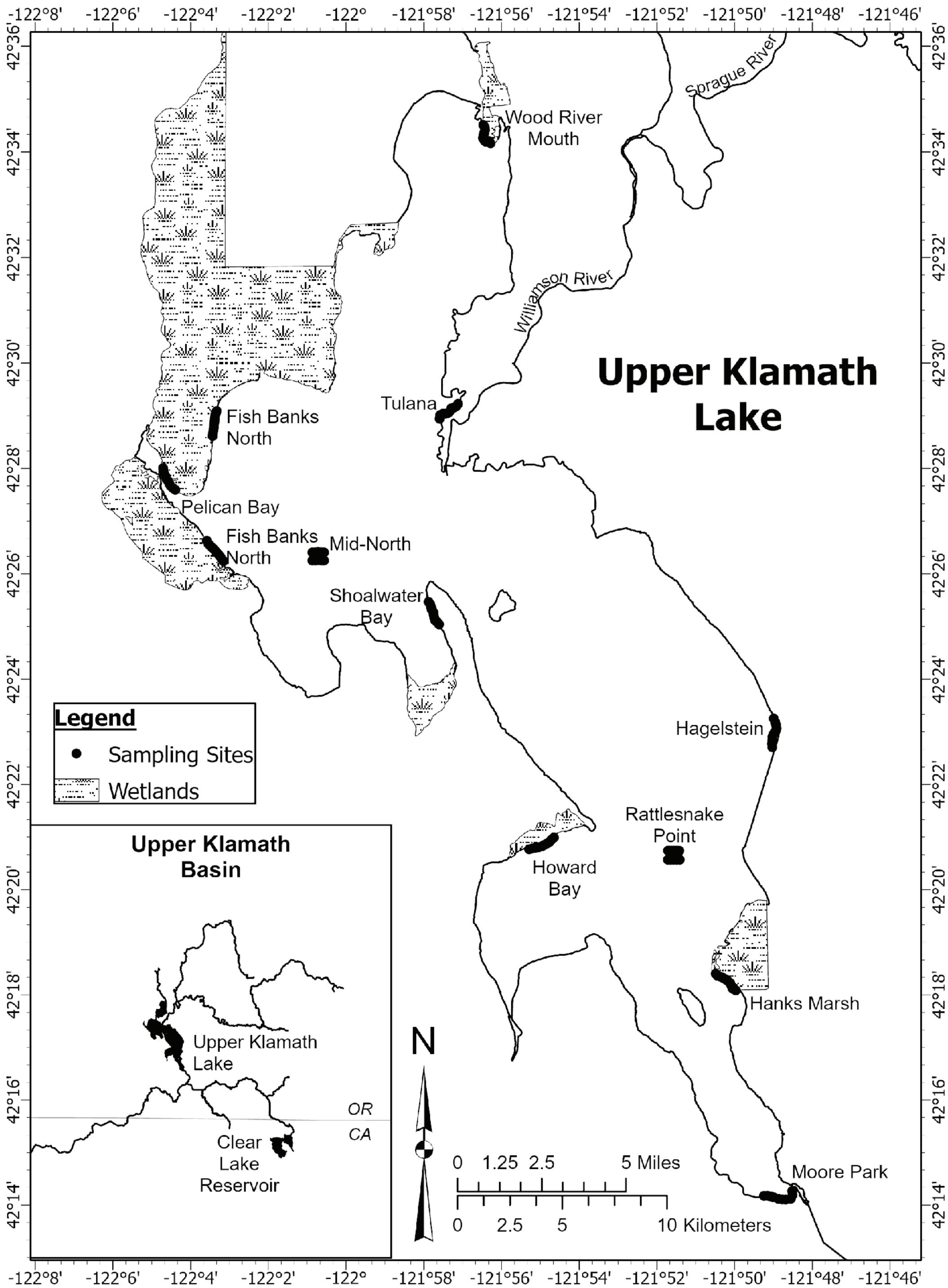

Figure 1. Locations of sample sites used to capture juvenile suckers in Upper Klamath Lake, Klamath County, Oregon, 2020.

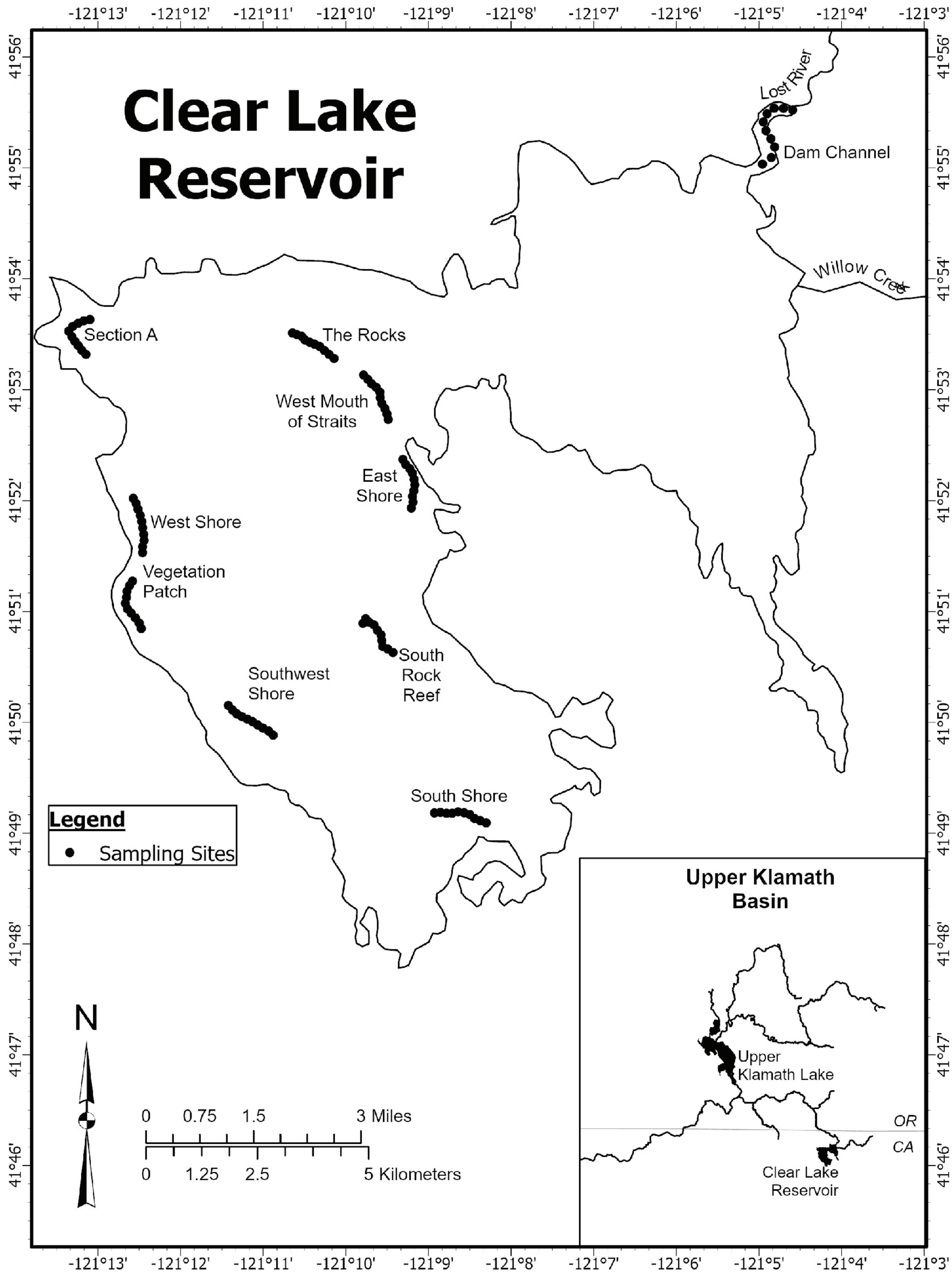

Figure 2. Locations of sample sites used to capture juvenile suckers in Clear Lake Reservoir, Modoc County, California, 2020.

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 and others, 2015b). Additionally, Klamath largescale suckers (*Catostomus snyderi*), which are the least lake dependent of the Upper Klamath Basin suckers are also 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, 2009b; 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); but the average expected life span is 20 years for Lost River suckers and 12 years for shortnose suckers (U.S. Fish and Wildlife Service, 2013).

Historically both species were abundant enough to support a subsistence fishery. 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 closed in 1987 (Markle and Cooperman, 2002; Janney and others, 2008), but poor survival of juvenile suckers persisted in Upper Klamath Lake populations post-closure of the fishery. Whereas 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).

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 and Clear Lakes. 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 ramp up 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). 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. Starting in 2016, for each sampling month, we sampled for a week in one lake and then the next week we sampled in the other lake. A July sampling period was added in 2018 to ensure that we did not miss early age-0 suckers. Sampling occurred in the same calendar weeks each year within each lake, with the exception of July 2018 in Upper Klamath Lake when poor air quality resulting from wildfires limited access to Upper Klamath Lake and delayed the sampling effort by one week compared to timing in other years.

Given the limitations of our selected 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 (<45 mm SL), have a low catchability in trap nets (Burdick and Martin, 2017). Because adult suckers (>300 mm SL) are captured at high rates in spring and fall trammel net sampling and infrequently in summer trap net sampling we presume 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 PIT-tagged and released suckers 71–236 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, 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 (<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). 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 2020, as in past years, 8 sites at each area in Upper Klamath Lake and 7 sites in each area in Clear Lake Reservoir were sampled during each sampling period (tables 1, 2). To address the concern of inadvertent bias in our fixed-site selection, randomly determined site locations were sampled during all sample years, and it was determined that there was no significant difference between fixed and random sites (Burdick and others, 2016). In order to compare catches between years, only fixed sites are reported in this publication.

Sample sites that were shallow and near shore in low water years of 2015 and 2016 were often in more than 3 m of water and far from shore from 2017 to 2020. Because juvenile sucker catch rates with trap nets decrease at depths greater than 3 m (Burdick and Hewitt, 2012), we captured few juvenile suckers at this depth. Therefore, we adjusted sample locations slightly each year to adjust for water depth. We started 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 small suckers (35–60 mm SL) from Upper Klamath Lake since 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

Table 1. Number of nets set for juvenile suckers by area and sampling period in Upper Klamath Lake, Oregon, 2020.

Area	Latitude	Longitude	Number of nets set in 2020			
			June 15–19	July 20–23	August 3–7	September 21–25
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	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	8
Total nets set			96	96	96	96

Table 2. Number of nets set for juvenile suckers by area and sampling period in Clear Lake Reservoir, California, 2020.

Area	Latitude	Longitude	Number of nets set in 2020			
			June 8–12	July 13–17	August 10–14	September 14–18
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

2 mm^2) piece of tissue from the caudal fin was collected for genetic identification to taxa. All suckers collected (129 from Clear Lake and 55 from Upper Klamath Lake) were measured, aged either by fin ray or presumed age-0, and identified to species via genetic analysis. 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 (Burdick, 2011). Suckers were released at their site of capture.

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 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 both lakes were either aged or systematically assumed to be age-0 by being 60 mm or less in standard length.

Species Identification

To identify juvenile suckers to taxa, we applied genetic identification methods described by Smith and others (2020 and 2022). Caudal fin tissue was collected from juvenile suckers from each lake, dried, and analyzed at the USFWS Abernathy Fish Health Center in Abernathy, Washington. Individuals were assigned to their reporting/species group described in Smith and others (2022) using genetic stock identification (GSI) implemented in the R package rubias (Moran and Anderson, 2019). The rubias package is a Bayesian approach to the conditional GSI model which includes a leave-one-out cross validation and simulation method to enhance GSI accuracy (Anderson and others, 2008). We selected a mean posterior probability threshold of 0.9 for accepting individual assignments. Only individuals assigning to a reporting/species group above this threshold were categorized to species for subsequent analysis. Fish that could not be assigned to species based on the above criteria were considered to be indeterminate. The current genetic technique to separate Klamath largescale from shortnose suckers was built upon known species from the Upper Klamath Basin (Smith and others, 2020), and there is always the possibility that the selected markers do not translate into proper assignment of species in the Lost River Basin; consequently, although a few shortnose suckers were genetically identified in the Lost River system, most were not separated from Klamath largescale suckers and therefore were classified as the combination of Klamath largescale suckers and shortnose suckers from the Lost River Basin. Previous genetic techniques could only separate Lost River suckers from a mix of shortnose and Klamath largescale suckers (Hoy and Ostberg, 2015). In order to compare genetics across years we included a category of combined shortnose and Klamath largescale suckers in both Upper Klamath and Clear Lakes.

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 apparent 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 September CPUE was greater than the August CPUE, >1.00 was reported indicating that suckers were recruiting to the gear at a greater rate in September than in August. We also calculated an index of overwinter apparent survival for each year-class as the ratio of age-1 CPUE in June divided by age-0 CPUE from September from the previous year. If age-0 CPUE was zero and age-1 CPUE was greater than zero, then results were reported as >1.00.

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 relatively 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.

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 to 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 and others, 2015a). 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 2020 juvenile monitoring sampling, 55 suckers were captured in Upper Klamath Lake, and most (60 percent) were age-0 (table 3; fig. 3). Of the 33 age-0 suckers captured in Upper Klamath Lake, 20 were Lost River sucker, 11 were shortnose sucker, 1 was a Klamath largescale sucker, and 1 was indeterminant (table 3). Of the 22 suckers age-1 or greater captured in Upper Klamath Lake, 3 were Lost River sucker, 15 were shortnose sucker, and 4 were Klamath largescale sucker (table 3). Age-0 suckers from Upper Klamath Lake ranged from 42 mm to 99 mm SL (fig. 4). Most suckers captured in Upper Klamath Lake were less than 150 mm SL, with the exception of one individual caught near Mid-North at 159 mm and another individual caught at Rattlesnake Point at 236 mm (fig. 5). The 236 mm individual was a recently released shortnose sucker from the USFWS SARP.

The 2020 August CPUE for all sucker species combined in Upper Klamath Lake was lower than in most other sampling years and most similar to 2017 and 2018. Most of the 2020 year-class was composed of Lost River suckers (table 4). Age-0 Lost River Sucker CPUE in 2020 was slightly larger than in 2017 and 2018, somewhat smaller than in 2015 and 2019, and only about 10 percent of CPUE in 2016 (table 4). The 2020 shortnose sucker CPUE was between the 2017 and 2018 year-classes CPUE, and about a quarter of the 2015, 2016, and 2019 year-classes CPUE (table 4).

Cohort tracking among years indicated that within year and overwinter apparent survival of suckers was low in Upper Klamath Lake (tables 5, 6, 7, 8). Shortnose suckers had greater apparent survival than Lost River suckers within most years and all years for overwinter apparent survival (tables 7 and 8). A total of 18 age-1 suckers from the 2019 cohort, two age-2 suckers from the 2018 cohort, and two age-3 suckers from the 2017 cohort were captured throughout the sampling season in 2020 (fig. 3). CPUE of the 2019 cohort decreased to near zero starting in July 2020 (table 5). The 2020 cohort was caught during the July sampling period but did not fully recruit to the gear until August (table 6). Catch rates for the 2020 cohort declined between August and September (table 6). August to September survival indices for the 2020 cohort were moderate, with apparent survival greater than the 2015, 2016, 2017, and 2019 cohorts but lower than the 2018 cohort (table 7). August to September survival indices for the 2020 cohort were greater for shortnose suckers than for previous cohorts except 2018 (table 7).

Table 3. Catch per net and percentage of age-0 suckers for each taxa captured in Upper Klamath Lake, Oregon, 2020.

[Number of total and age-0 suckers captured by each taxa, the catch per net (catch per unit effort), and percentage of each taxa that were age-0 are given. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. **Abbreviations:** <, less than; CPUE, catch per unit effort]

Taxa	Upper Klamath Lake			
	Number of suckers	Number of age-0	Age-0 CPUE	Age-0 (percent)
Lost River suckers	23	20	0.05	87
Shortnose suckers	26	11	0.03	42
Klamath largescale suckers	5	1	<0.01	20
Indeterminant	1	1	<0.01	100
All taxa suckers	55	33	0.09	60

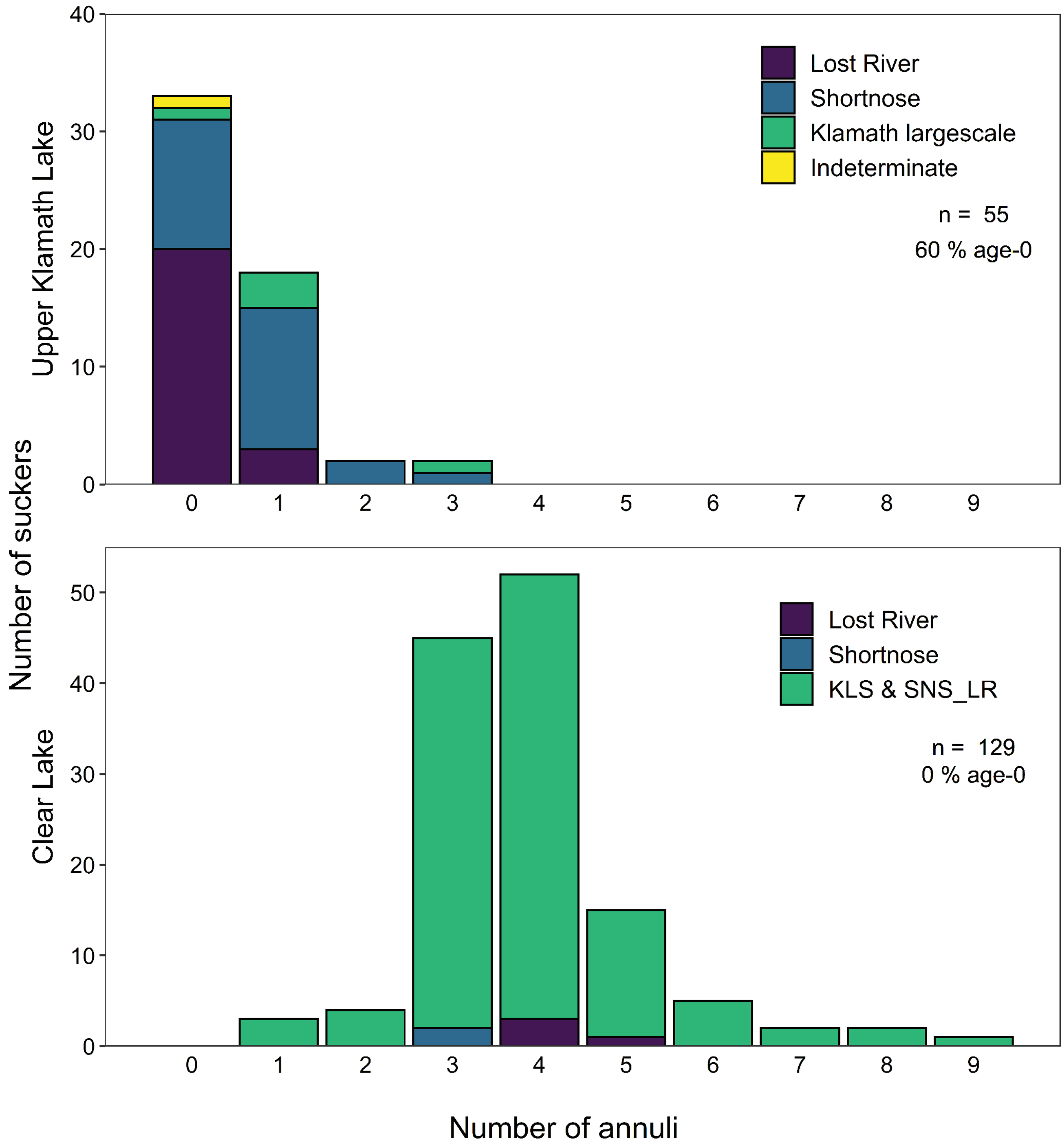

Figure 3. Number of annuli on suckers collected from Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2020. Number of fish in each panel (*n*) and percentage of the total number of suckers in each graph that had no annuli on fin rays (age-0) are given. KLS and SNS_LR refers to suckers classified as Klamath largescale suckers (*Catastomus snyderi*) or shortnose suckers (*Chasmistes brevirostris*) from the Lost River Basin.

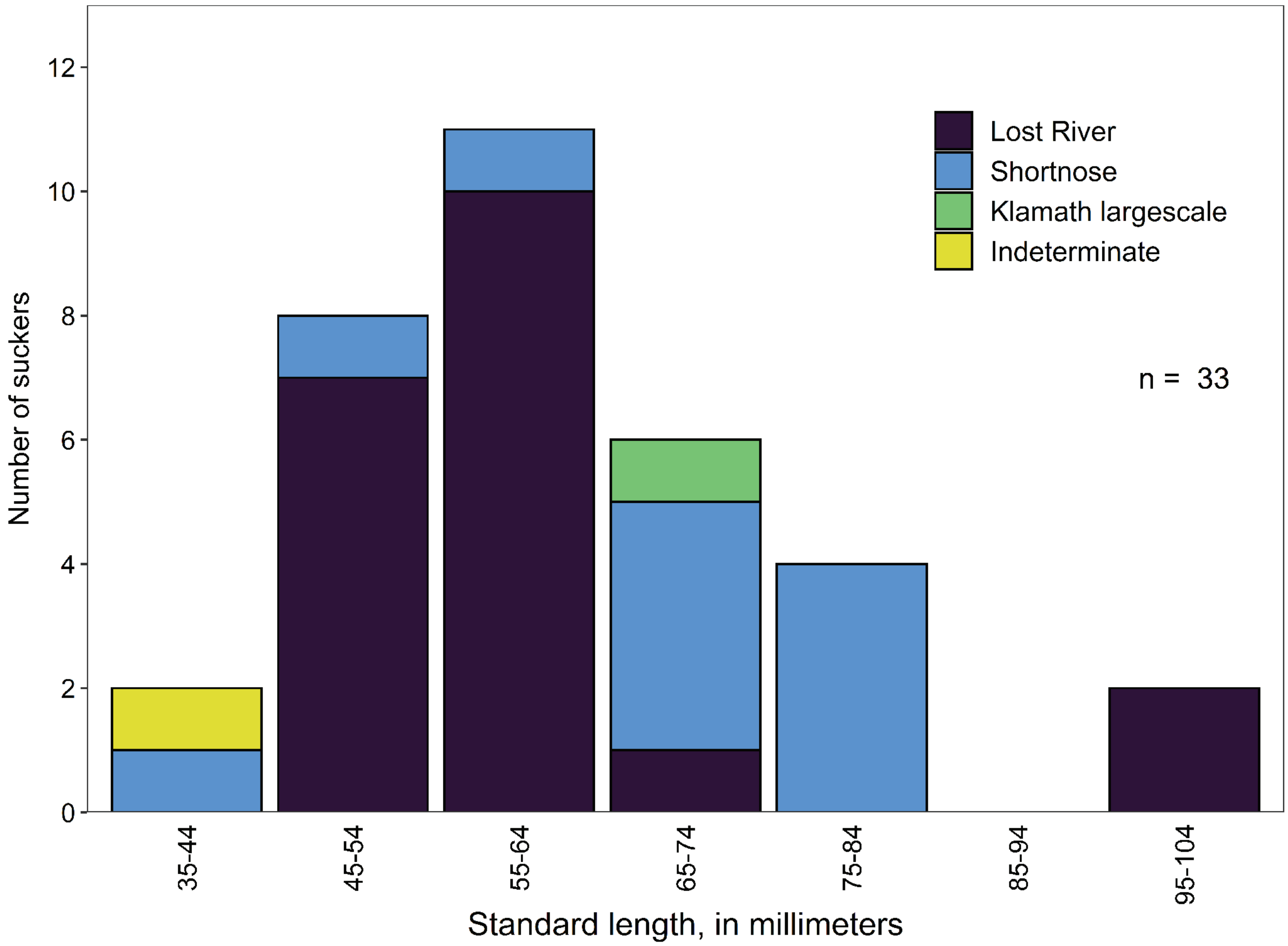

Figure 4. Standard lengths of age-0 suckers collected at fixed locations in Upper Klamath Lake, Oregon, 2020. Number of fish are given (*n*).

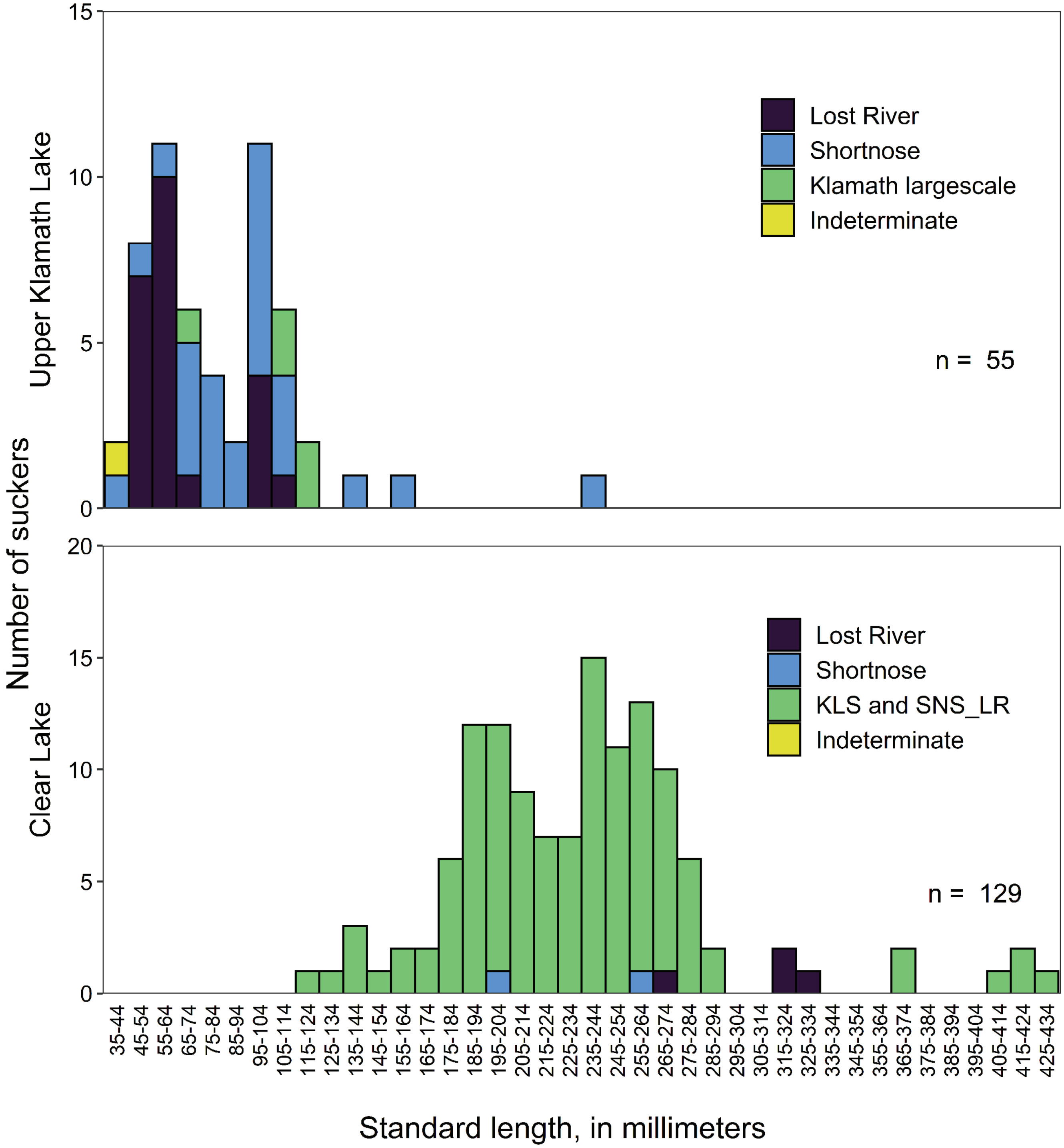

Figure 5. Standard lengths of all suckers collected at fixed locations in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2020. Number of fish in each panel are given (*n*). KLS and SNS_LR refers to suckers classified as Klamath largescale suckers (*Catastomus snyderi*) or shortnose suckers (*Chasmistes brevirostris*) from the Lost River Basin.

Table 4. Catch statistics for August age-0 suckers from Upper Klamath Lake, Oregon, 2015–20.

[*n* is the number of suckers. Total capture per unit effort was calculated as the number of fish captured per net set and includes suckers from which we did not collect genetic samples. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. Prior to 2020 shortnose (*Chasmistes brevirostris*) and Klamath largescale suckers (*Catastomus snyderi*) could not be separated; therefore, to compare among years these taxa are combined. **Abbreviations:** Aug., August; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers; CPUE, capture per unit effort]

Parameter	Aug. 2015 (98 nets)	Aug. 2016 (96 nets)	Aug. 2017 (96 nets)	Aug. 2018 (88 nets)	Aug. 2019 (96 nets)	Aug. 2020 (96 nets)
Lost River suckers						
n	38	120	7	8	60	15
Total CPUE	0.39	1.25	0.07	0.09	0.62	0.16
Shortnose suckers, Klamath largescale suckers, and SNS/KLS						
n	46	35	14	2	36	8
Total CPUE	0.47	0.36	0.15	0.02	0.38	0.08
Indeterminant						
n	32	59	12	4	112	1
Total CPUE	0.33	0.61	0.12	0.05	1.17	0.01
Total suckers						
n	118	223	33	14	279	24
Total CPUE	1.20	2.32	0.34	0.16	2.91	0.25

Table 5. Catch statistics for the 2019 cohort of suckers from Upper Klamath Lake, Oregon.

[Percentage of nets to successfully capture one or more suckers by each taxa, mean and standard deviation 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. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. Prior to 2020 shortnose (*Chasmistes brevirostris*) and Klamath largescale suckers (*Catastomus snyderi*) could not be separated; therefore, to compare among years these taxa are combined. **Abbreviations:** Jul., July; Aug., August; Sep., September; Jun., June; SNS/KLS; suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers; SD standard deviation; NA, used instead of standard deviations that are not applicable because of low sample sizes]

Parameter	Jul. 22–26, 2019 (96 nets)	Aug. 5–9, 2019 (96 nets)	Sep. 9–13, 2019 (95 nets)	Jun. 15–19, 2020 (96 nets)	Jul. 20–23, 2020 (96 nets)	Aug. 3–6, 2020 (96 nets)	Sep. 21–25, 2020 (96 nets)
Lost River suckers							
Percentage	8	22	19	2	0	0	1
Mean (SD)	4.75 (4.46)	2.86 (5.67)	2.50 (1.50)	1.00 (NA)	0.00 (NA)	0.00 (NA)	1.00 (NA)
Total CPUE	0.40	0.62	0.47	0.02	0.00	0.00	0.01
Shortnose suckers, Klamath largescale suckers, and SNS/KLS							
Percentage	8	17	9	10	0	3	0
Mean (SD)	1.75 (0.89)	2.25 (3.15)	1.44 (0.73)	1.20 (0.42)	0.00 (NA)	1.00 (0.00)	0.00 (NA)
Total CPUE	0.15	0.38	0.14	0.13	0.00	0.03	0.00
Indeterminant							
Percentage	7	24	26	0	0	0	0
Mean (SD)	5.57 (7.91)	4.87 (8.61)	192 (1.21)	0.00 (NA)	0.00 (NA)	0.00 (NA)	0.00 (NA)
Total CPUE	0.41	1.17	0.51	0.00	0.00	0.00	0.00
Total suckers							
Percentage	15	36	38	10	0	3	1
Mean (SD)	6.50 (10.75)	7.97 (22.64)	3.17 (2.97)	1.40 (0.70)	0.00 (NA)	1.00 (0.00)	1.00 (NA)
Total CPUE	0.95	2.91	1.20	0.15	0.00	0.03	0.01

Table 6. Catch statistics for the 2020 cohort of suckers from Upper Klamath Lake, Oregon.

[Percentage of nets to successfully capture one or more sucker by each taxa, mean and standard deviation 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. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. **Abbreviations:** Jul., July; Aug., August; Sep., September; SD, standard deviation; NA, used instead of standard deviations that are not applicable because of low sample sizes]

Parameter	Jul. 20–23, 2020 (96 nets)	Aug. 3–6, 2020 (96 nets)	Sep. 21–25, 2020 (96 nets)
Lost River suckers			
Percentage	3	10	2
Mean (SD)	1.00 (0.00)	1.50 (0.71)	1.00 (0.00)
Total CPUE	0.03	0.16	0.02
Shortnose suckers			
Percentage	0	3	6
Mean (SD)	0.00 (NA)	1.00 (0.00)	1.33 (0.52)
Total CPUE	0.00	0.03	0.08
Klamath largescale suckers			
Percentage	0	0	1
Mean (SD)	0.00 (NA)	0.00 (NA)	1.00 (NA)
Total CPUE	0.00	0.00	0.01
Indeterminant			
Percentage	0	1	0
Mean (SD)	0.00 (NA)	1.00 (NA)	0.00 (NA)
Total CPUE	0.00	0.01	0.00
Total suckers			
Percentage	3	15	8
Mean (SD)	1.00 (0.00)	1.36 (0.63)	1.38 (0.52)
Total CPUE	0.03	0.20	0.11

Table 7. August to September survival indices for age-0 suckers in each taxa captured in Upper Klamath Lake, Oregon, 2015–20.

[Taxa were identified based on their genetic information from genetic stock identification results. Prior to 2020 shortnose (*Chasmistes brevirostris*) and Klamath largescale suckers (*Catastomus snyderi*) could not be separated; therefore, to compare among years these taxa are combined. **Abbreviations and symbols:** >, greater than; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers]

Taxa	2015	2016	2017	2018	2019	2020
Lost River suckers	0.15	0.16	0.13	0.00	0.76	0.13
Shortnose suckers, Klamath largescale suckers, and SNS/KLS	0.51	0.34	0.00	>1.00	0.36	>1.00
Total suckers	0.35	0.19	0.03	>1.00	0.41	0.58

Table 8. September age-0 to June age-1 survival indices of suckers in each taxa captured in Upper Klamath Lake, Oregon, for cohorts from 2015 to 2019.

[Taxa were identified based on their genetic information from genetic stock identification results. Prior to 2020 shortnose (*Chasmistes brevirostris*) and Klamath largescale suckers (*Catastomus snyderi*) could not be separated; therefore, to compare among years these taxa are combined. **Abbreviations and symbols:** >, greater than; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers]

Taxa	2015	2016	2017	2018	2019
Lost River suckers	0.25	0.05	0.00	0.00	0.04
Shortnose suckers, Klamath largescale suckers, and SNS/KLS	0.35	0.23	>1.00	0.25	0.92
Total suckers	0.26	0.23	>1.00	0.19	0.12

Clear Lake Reservoir Year-Class Strength and Apparent Survival

The majority of suckers captured in Clear Lake Reservoir in 2020 were classified as the combination of Klamath largescale suckers and shortnose suckers from the Lost River Basin from 3 to 5 years old, and ranged from 136 to 325 mm SL (figs. 3 and 4). Of the suckers captured during the 2020 Clear Lake Reservoir sampling, seven were under age-3 and ten were older than age-5. None of the 129 suckers captured in Clear Lake Reservoir during the 2020 juvenile monitoring sampling were age-0 (fig. 3; table 9). Only 6 of the 129 suckers were not classified as the combination of Klamath largescale and shortnose suckers from the Lost River Basin: 4 were Lost River suckers, and 2 were shortnose suckers based on Klamath Basin genetics (figs. 3 and 5).

The age distribution of suckers in Clear Lake indicates better annual survival of juvenile suckers than in Upper Klamath Lake, where very few age-1 or older suckers are captured. The oldest sucker we captured in Clear Lake was a 410 mm standard length age-9 sucker from the 2011 cohort (fig. 3). We captured two each age-7 and age-8 suckers from the 2012 and 2013 cohorts, five age-6 suckers from the 2014 cohort, and 15 age-5 suckers from the 2015 cohort. The most abundant cohorts captured were from 2016 (age-4) and 2017

Table 9. Catch statistics for August age-0 suckers from Clear Lake Reservoir, California, 2015–20.

[*n* is the number of suckers. Total catch per unit effort was calculated as number of suckers captured divided by the number of nets set. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. Prior to 2020 shortnose (*Chasmistes brevirostris*) and Klamath largescale suckers (*Catastomus snyderi*) could not be separated; therefore, to compare among years these taxa are combined. **Abbreviations:** Aug., August; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers; CPUE, catch per unit effort]

Parameter	Aug. 2015 (70 nets)	Aug. 2016 (70 nets)	Aug. 2017 (70 nets)	Aug. 2018 (69 nets)	Aug. 2019 (70 nets)	Aug. 2020 (70 nets)
Lost River suckers						
n	0	2	4	0	0	0
Total CPUE	0.00	0.03	0.06	0.00	0.00	0.00
Shortnose suckers, Klamath largescale suckers, and SNS/KLS						
n	0	15	3	3	0	0
Total CPUE	0.00	0.21	0.04	0.04	0.00	0.00
Indeterminant						
n	0	1	0	0	0	0
Total CPUE	0.00	0.01	0.00	0.00	0.00	0.00
Total suckers						
n	0	18	7	3	0	0
Total CPUE	0.00	0.26	0.10	0.04	0.00	0.00

(age-3). Age-1 and age-2 suckers from the 2018 and 2019 cohorts were also represented in our catches but in low numbers. No age-0 suckers were captured in Clear Lake in 2020.

There were several year-classes of suckers that were not captured as age-0 suckers; however, these year-classes were captured for the first time as age-1 to age-3 (table 10). 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. The 2018 cohort catch peaked during June 2019 sampling effort when the cohort was age-1. Although the 2019 cohort was not detected during the 2019 sampling, it also followed the same trend as other cohorts being caught at greater rates once it reached age-1 (table 10).

Afflictions

Unlike other years, in 2020, suckers in Clear Lake generally had more macro parasites, deformities, and skin afflictions than suckers in Upper Klamath Lake. The primary affliction observed during the 2020 monitoring season in both lakes was attached *Lernaea* sp. Other afflictions observed were lamprey wounds on twelve Clear Lake Reservoir suckers and two Upper Klamath Lake suckers. Petechial hemorrhaging of the skin was observed on seven Clear Lake suckers and one Upper Klamath Lake sucker. Six 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* sp.) from either lake in 2020 (table 11).

Missing or deformed opercula were observed only in Clear Lake juvenile suckers in 2020, whereas in previous sampling years this affliction was only observed in age-0 Upper Klamath Lake suckers (table 12). Except for 2015, opercular deformities were more common in Lost River suckers than shortnose suckers. Opercular deformities occurred in Lost River suckers from 0 to 62 percent of the time within each year, whereas this deformity occurred less than 10 percent of the time in shortnose suckers within each year. Of the three suckers with opercula afflictions in 2020, two had one affected operculum, and one had both missing or deformed. All suckers with missing or deformed opercula in 2020 were age-4 suckers classified as the combination of Klamath largescale suckers and shortnose suckers from the Lost River Basin.

Lernaea sp. were the most common parasite seen on juvenile suckers in 2020. All *Lernaea* sp. observations in age-0 suckers occurred from Upper Klamath Lake, and there was only one *Lernaea* sp. per individual (table 13). Age-1 and older suckers in Upper Klamath Lake had a greater proportion of fish with *Lernaea* sp. attached than those in Clear Lake (table 14). The most *Lernaea* sp. attached to an individual juvenile sucker was six, but most often only one *Lernaea* sp. was attached. Although this parasite was a relatively common occurrence in Upper Klamath Lake and Clear Lake, we could not detect any obvious signs that *Lernaea* sp. caused mortality of juvenile suckers in 2020.

Petechial hemorrhaging of the skin on age-0 fish was only observed in one Upper Klamath Lake sucker (table 15). The proportion of age-0 suckers in Upper Klamath Lake with petechial hemorrhaging in 2020 was low relative to previous years (table 15). Petechial hemorrhaging was observed on a lower proportion of age-1 and older suckers relative to 2019 in both lakes (table 16). Although petechial hemorrhaging was observed on Clear Lake suckers age-1 and older in 2020, it was still a relatively rare affliction not commonly observed in Clear Lake.

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 scarcity of age-1 and older suckers in Upper Klamath Lake is likely attributable to juvenile mortality. Several observations support the presumption that mortality, rather than reduced selectivity or emigration from sampled areas, explains the reduction in catch by age. 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, 2009b).

Table 10. Catch statistics for the 2015–20 cohorts of shortnose/Klamath largescale suckers (*Chasmistes brevirostris/Catastomus snyderi*) from Clear Lake Reservoir, California.

[Percentage of nets to successfully capture one or more shortnose/Klamath largescale sucker (*Chasmistes brevirostris/Catastomus snyderi*) by each cohort, mean and standard deviation 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. **Abbreviations and symbols:** --, no data; Jun., June; Aug., August; Sep., September; Jul., July; NA, not applicable (put in place of standard deviations that are not applicable because of low sample sizes); SD, standard deviation]

Metric	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)	Jun. 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)	Jun. 2020 (70 nets)	Jul. 2020 (70 nets)	Aug. 2020 (70 nets)	Sep. 2020 (70 nets)
2015 cohort																					
Percent	0	0	0	0	0	7	1	7	9	7	4	6	1	1	1	3	4	6	4	4	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	1.25	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	0.50	0.00	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	0.07	0.04	0.04	0.04
2016 cohort																					
Percent	--	--	--	0	14	53	4	36	16	19	31	20	13	26	27	33	9	20	11	14	1
Mean	--	--	--	0.00	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	1.29	1.63	1.7	1.00
SD	--	--	--	NA	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	0.61	0.92	1.16	NA
Total CPUE	--	--	--	0.00	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	0.26	0.19	0.24	0.01
2017 cohort																					
Percent	--	--	--	--	--	--	0	4	6	13	33	28	16	20	30	23	4	16	11	14	4
Mean	--	--	--	--	--	--	0.00	1.00	1.00	1.33	1.22	1.05	1.36	2.00	1.62	1.12	1.00	1.64	1.25	1.4	1.00
SD	--	--	--	--	--	--	NA	0.00	0.00	0.50	0.52	0.23	0.67	1.04	0.92	0.34	0.00	0.67	0.71	0.97	0.00
Total CPUE	--	--	--	--	--	--	0.00	0.04	0.06	0.17	0.40	0.29	0.21	0.40	0.49	0.26	0.04	0.26	0.14	0.20	0.04
2018 cohort																					
Percent	--	--	--	--	--	--	--	--	--	6	3	4	0	4	1	3	0	3	0	3	0
Mean	--	--	--	--	--	--	--	--	--	1.00	1.50	1.00	0.00	1.67	1.00	1.00	0.00	1.00	0.00	1.00	0.00
SD	--	--	--	--	--	--	--	--	--	0.00	0.71	0.00	NA	0.58	NA	0.00	NA	0.00	NA	0.00	NA
Total CPUE	--	--	--	--	--	--	--	--	--	0.06	0.04	0.04	0.00	0.07	0.01	0.03	0.00	0.03	0.00	0.03	0.00
2019 cohort																					
Percent	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	1	3	0
Mean	--	--	--	--	--	--	--	--	--	--	--	--	--	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00
SD	--	--	--	--	--	--	--	--	--	--	--	--	--	NA	NA	NA	NA	NA	NA	0.00	NA

Table 10. Catch statistics for the 2015–20 cohorts of shortnose/Klamath largescale suckers (*Chasmistes brevirostris/Catastomus snyderi*) from Clear Lake Reservoir, California.—Continued

[Percentage of nets to successfully capture one or more shortnose/Klamath largescale sucker (*Chasmistes brevirostris/Catastomus snyderi*) by each cohort, mean and standard deviation 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. **Abbreviations and symbols:** --, no data; Jun., June; Aug., August; Sep., September; Jul., July; NA, not applicable (put in place of standard deviations that are not applicable because of low sample sizes); SD, standard deviation]

Metric	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)	Jun. 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)	Jun. 2020 (70 nets)	Jul. 2020 (70 nets)	Aug. 2020 (70 nets)	Sep. 2020 (70 nets)
2019 cohort—Continued																					
Total CPUE	--	--	--	--	--	--	--	--	--	--	--	--	--	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00
2020 cohort																					
Percent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	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

Table 11. Proportions of age-0 suckers with black spot (metacercariae of *Bolbophorus* sp.), Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–20.

[Sample size of age-0 suckers captured given in parentheses. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. Prior to 2020, shortnose (*Chasmistes brevirostris*) and Klamath largescale (*Catastomus snyderi*) suckers could not be separated; therefore for comparison purposes we combined 2020 shortnose suckers, and suckers classified as the combination of Klamath largescale suckers and shortnose suckers from the Lost River Basin. **Abbreviations:** CL, Clear Lake Reservoir; UKL, Upper Klamath Lake; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers; NA, proportions that are not applicable because no age-0 fish were captured]

Taxonomic group	UKL 2015	CL 2015	UKL 2016	CL 2016	UKL 2017	CL 2017	UKL 2018	CL 2018	UKL 2019	CL 2019	UKL 2020	CL 2020
Lost River sucker	0.00 (41)	NA	0.03 (136)	0.00 (10)	0.00 (8)	0.00 (4)	0.00 (12)	0.00 (0)	0.00 (143)	NA	0.00 (20)	NA
Shortnose and Klamath largescale suckers	0.04 (58)	NA	0.11 (45)	0.00 (124)	0.00 (14)	0.00 (7)	0.00 (10)	0.00 (10)	0.00 (63)	NA	0.00 (12)	NA
Indeterminant	0.00 (38)	NA	0.04 (67)	0.00 (2)	0.00 (12)	0.00 (1)	0.00 (12)	0.00 (0)	0.00 (199)	NA	0.00 (1)	NA
Total	0.03 (139)	NA	0.05 (258)	0.00 (149)	0.00 (34)	0.00 (12)	0.00 (36)	0.00 (10)	0.00 (484)	NA	0.00 (33)	NA

Table 12. Proportions of age-0 suckers with missing or deformed opercula, Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–20.

[Sample size of age-0 suckers captured given in parentheses. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. Prior to 2020, shortnose (*Chasmistes brevirostris)* and Klamath largescale (*Catastomus snyderi*) suckers could not be separated; therefore for comparison purposes we combined 2020 shortnose suckers, and suckers classified as the combination of Klamath largescale suckers and shortnose suckers from the Lost River Basin., **Abbreviations:** CL, Clear Lake Reservoir; UKL, Upper Klamath Lake; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers; NA, proportions that are not applicable because no age-0 fish were captured]

Taxonomic group	UKL 2015	CL 2015	UKL 2016	CL 2016	UKL 2017	CL 2017	UKL 2018	CL 2018	UKL 2019	CL 2019	UKL 2020	CL 2020
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	0.00 (20)	NA
Shortnose and Klamath largescale suckers	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	0.00 (12)	NA
Indeterminant	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	0.00 (1)	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	0.00 (33)	NA

Table 13. Proportions of age-0 suckers with attached *Lernaea sp.*, Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–20.

[Sample size of age-0 suckers captured given in parentheses. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. Prior to 2020, shortnose (*Chasmistes brevirostris)* and Klamath largescale (*Catastomus snyderi*) suckers could not be separated; therefore for comparison purposes we combined 2020 shortnose suckers, and suckers classified as the combination of Klamath largescale and shortnose suckers from the Lost River Basin, **Abbreviations:** CL, Clear Lake Reservoir; UKL, Upper Klamath Lake; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers; NA, proportions that are not applicable because no age-0 fish were captured]

Taxonomic group	UKL 2015	CL 2015	UKL 2016	CL 2016	UKL 2017	CL 2017	UKL 2018	CL 2018	UKL 2019	CL 2019	UKL 2020	CL 2020
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	0.00 (20)	NA
Shortnose and Klamath largescale suckers	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	0.25 (12)	NA
Indeterminant	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	0.00 (1)	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	0.09 (33)	NA

Table 14. Proportions of age-1 and older suckers with attached *Lernaea sp.*, Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015– 20.

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

Lake	2015	2016	2017	2018	2019	2020
Upper Klamath Lake	0.20 (15)	0.40 (15)	0.17 (12)	0.50 (4)	0.00 (5)	0.23 (22)
Clear Lake Reservoir	0.30 (20)	0.08 (50)	0.07 (88)	0.04 (196)	0.10 (200)	0.19 (129)

Table 15. 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, 2015–20.

[Sample size of age-0 suckers given in parentheses. Taxa were identified based on their genetic information from genetic stock identification results. Indeterminant refers to individuals that could not be assigned to a species since the mean posterior probability was less than 0.9. Prior to 2020, shortnose (*Chasmistes brevirostris)* and Klamath largescale (*Catastomus snyderi*) suckers could not be separated; therefore for comparison purposes we combined 2020 shortnose suckers, and suckers classified as the combination of Klamath largescale and shortnose suckers from the Lost River Basin, **Abbreviations:** CL, Clear Lake Reservoir; UKL, Upper Klamath Lake; SNS/KLS, suckers with a mixture of genetic markers from shortnose suckers and Klamath largescale suckers; NA, proportions that are not applicable because no age-0 fish were captured]

Taxonomic group	UKL 2015	CL 2015	UKL 2016	CL 2016	UKL 2017	CL 2017	UKL 2018	CL 2018	UKL 2019	CL 2019	UKL 2020	CL 2020
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	0.00 (20)	NA
Shortnose and Klamath largescale suckers	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	0.08 (12)	NA
Indeterminant	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	0.00 (1)	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	0.03 (33)	NA

Table 16. Proportions of age-1 and older suckers with petechial hemorrhages of the skin in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, 2015–20.

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

Lake	2015	2016	2017	2018	2019	2020
Upper Klamath Lake	0.07 (15)	0.07 (15)	0.08 (12)	0.50 (4)	0.20 (5)	0.00 (22)
Clear Lake Reservoir	0.05 (20)	0.00 (50)	0.00 (88)	0.04 (196)	0.07 (200)	0.03 (129)

Although mortality is substantial for Lost River and shortnose suckers, it appears to be greater for juvenile Lost River than shortnose suckers as seen by the overwinter survival indices. Although earlier years did not separate out shortnose suckers from Klamath largescale suckers, the 2020 age-1 catch was composed of a greater number of shortnose suckers than Lost River or Klamath largescale suckers. There is always the possibility that the index for past years reflects a greater portion of Klamath largescale suckers surviving to age-1; however, the lack of age-1 Klamath largescale suckers captured during 2020 and the identification of more shortnose suckers than Klamath largescale suckers using vertebrae counts in past studies (Burdick and others, 2008, 2009a; Burdick and Brown, 2010) suggest that the past 5 years may also have a lack of age-1 Klamath largescale suckers. Burdick and Martin (2017) reported the same survival trend; however, they were unable to determine why there were differences in species mortality rates. One hypothesis is that the Lost River suckers, which hatch earlier than shortnose suckers, may encounter unfavorable water quality at a critical juncture in their development.

There are several possible explanations for why we only detected one of the thousands of PIT-tagged suckers that were released into Upper Klamath Lake from the SARP program through 2020. 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, 19 SARP fish in 2019, and 13 SARP fish in 2020, indicating that directed emigration was an unlikely explanation for the disappearance of these fish. As of the writing of this report, USGS crews have detected 181 PIT tags from SARP-released suckers on bird colonies cumulatively from 2018, 2019, and 2020 scanning efforts, indicating bird predation may be a factor in the survival of some SARP fish (Evans and others, 2016). However, Evans and others (2021) estimated that predation rates on SARP fish were only 4.4–8.8 percent from 2018 through 2020, indicating that colonial bird predation accounts for a small percentage of the mortality of these suckers.

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 of concern. 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). Although age-0 survival was intermediate from August–September for the 2019 cohort compared to age-0 survival of other cohorts, the overwinter survival of the 2019 cohort was low, resulting in a substantial loss of this cohort. 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 substantial recruitment event soon for both species to recover naturally. As of the writing of this report, we have no indication that such an event is imminent.

Clear Lake Reservoir

With greater 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 and (2) differential juvenile sucker mortality among years. It has been shown that varying rates of juvenile sucker mortality is associated with differential rates of avian predation among years that are mediated by water levels and fish size, especially for small fish (Evans and others, 2021). Other hypothesis of why survival is better in Clear Lake than Upper Klamath Lake include the differences in water quality between the two lakes, and the suspicion that the Clear Lake population is composed mainly of Klamath largescale suckers, which rear in the river before entering the lake.

A lack of age-0 suckers captured in the low water years of 2014 and 2015 in Clear Lake Reservoir 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 spawning did not occur without access from the lake to the river. After high flows in the Willow Creek drainage increased lake-surface elevations in 2016 (fig. 6), the 2014 and 2015 cohorts were detected in Clear Lake Reservoir, and these cohorts continued to be collected through 2020. The 2015 cohort continued to be detected in high numbers through 2019 and was detected again in 2020. 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 Reservoir (Bart and others, 2020a). We suspect that the majority of the 2015 cohort is offspring of stream resident Klamath largescale suckers that only recruited to Clear Lake when high water flushed them from the tributaries. Although the current genetic techniques can separate Klamath largescale suckers from shortnose suckers in the Klamath Basin, there is still uncertainty in separating these species in the Lost River Basin (Smith and others, 2020). Most of the suckers from the 2015 cohort were genetically classified as the combination of Klamath largescale suckers and shortnose suckers from the Lost River Basin. However, a stream resident life history is consistent with these fish being Klamath largescale suckers.

There are several possible explanations for annual variation in age-0 sucker catches. 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). These fish appear to be stranded in these pools and unable to reenter the lake because of low water levels. Furthermore, several cohorts of suckers in Clear Lake were not captured during our sampling until age-1 (Bart and others, 2020a, b; Bart and others 2021). One possible explanation is that juvenile suckers rear for a year or more in tributaries before recruiting to Clear Lake. The lack of access between the tributaries and Clear Lake does not explain why age-0 sucker catches were low or absent in 2017–20. Lake levels were relatively high and adult suckers were detected on remote PIT-tag arrays migrating into Willow Creek during springs of 2017–20, indicating that spawning likely occurred (Hewitt and others, 2021). 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 2020, but this was not the case. In 2018 and 2020, creek flows were relatively low as indicated by a lack of rapid spring lake level increase (fig. 6). Therefore, in these years a long instream residency time, if it occurred, may not be entirely voluntary. Suckers may have made 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.

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 (*Nannopterum auritum*) 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 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,

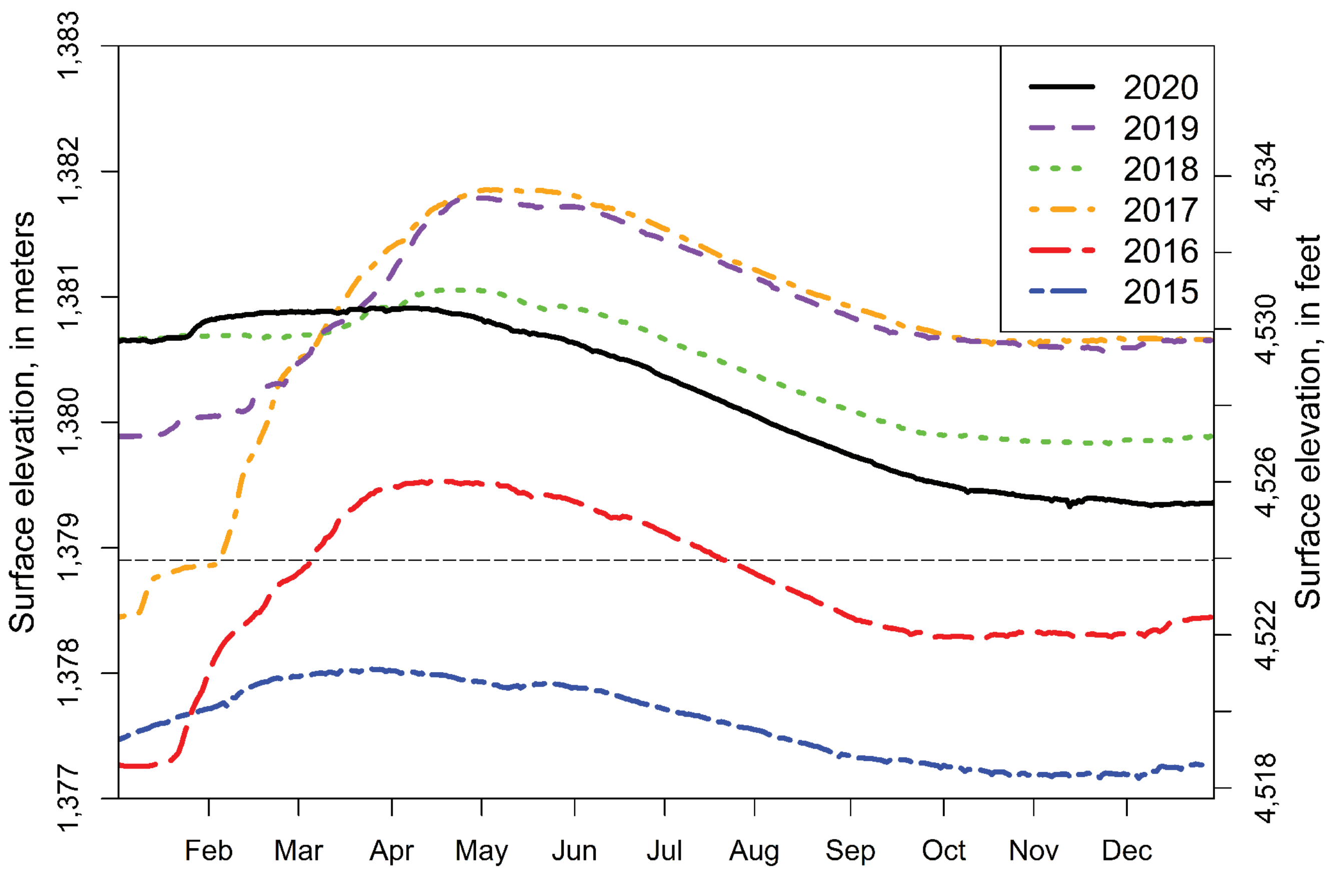

Figure 6. Lake-surface elevation, Clear Lake Reservoir, California, 2015–20. The surface elevation indicating separation between Clear Lake Reservoir and Willow Creek is the straight horizontal dashed line at 1,378.8 meters. Surface elevations are in meters (m) and feet (ft) above Bureau of Reclamation Vertical Datum.

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. 6). Although we attempted to adjust our sampling sites to account for yearly variation in depths, our sites were deeper in 2017–20 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 2020 if they were in shallower water than what we were sampling. Whatever the reason for the lack of age-0 sucker captures in 2020, 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 2021 is needed to confirm the existence of the 2020 cohort.

Afflictions

Opercular deformities that are more common for Lost River than shortnose suckers make the gills more vulnerable to parasites and poor water quality, ultimately increasing the chances of mortality. Because there were no age-1 or older suckers in Upper Klamath Lake with deformed opercula, there is the potential that it is serious enough of an affliction that it increases the probability of mortality before fish can reach older ages. However, we did see opercular deformities in several of the age-4 suckers classified as the combination of Klamath largescale suckers and shortnose suckers from the Lost River Basin in Clear Lake in 2020, indicating there may be additional confounding factors. Although this affliction has been observed on other sucker species (Barkstedt and others, 2018), the exact cause of deformed opercula 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 is one of the most common afflictions on juvenile suckers captured in both lakes, occurring to some degree in all sampling years. 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 and others, 2015a).

The causes of petechial hemorrhaging, which generally appears more frequently 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 and others, 2015a). Petechial hemorrhages of the skin have been found to be caused by irritants including abrasion, bacteria, or toxins (Ferguson and others, 2011). The low prevalence of observed hemorrhages in Clear Lake relative to Upper Klamath Lake indicates that abrasions caused by our method of capture is unlikely to be the primary reason for 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.

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 through 2020 monitoring seasons, there were no suckers with black spot (Bart and others 2020a, b; Bart and others, 2021). 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, 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 from our data that it is a substantial source of mortality for juvenile suckers.

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