Species Status Assessment for the Endangered Lost River Sucker and Shortnose Sucker

Final Report, version 1
March 2019

Klamath Falls Fish and Wildlife Office
Pacific Southwest Region
U.S. Fish and Wildlife Service

Contributing authors: Evan Childress, Josh Rasmussen, Daniel Blake, Serena Doose, Bjorn Erickson, Ryan Fogerty, Damian Higgins, Margie Shaffer, Michael Schwemm, and Elizabeth Willy

ACKNOWLEDGEMENTS

We express our gratitude to the numerous support staff in the Klamath Falls Fish and Wildlife Office and the Pacific Southwest Regional Office. We also acknowledge the countless researchers whose data and analyses make this project possible. This assessment was greatly improved from the expert input and review by M. Belk, M. Buettner, S. Burdick, and S. Swerdloff.

EXECUTIVE SUMMARY

The Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) are two closely related fish species, which occur in the lakes and rivers of the upper Klamath Basin in central southern Oregon and northern California. Even though the species were never widely distributed, they were extremely abundant until populations began to decline sometime in the late 1960's. Continued declines resulted in closure of the recreational fishery for the suckers and ultimately listing in 1988 as endangered under the Endangered Species Act of 1973, as amended.

This Species Status Assessment does not replace the previous review documents nor their subsequent revisions. The objective is for the Species Status Assessment document to be easily updatable as new information becomes available, to act as a "state-of-the-science" repository. All functions of the Endangered Species Program from listing to Section 7 consultation to recovery planning will rely on the document as a basis for synthesizing the status of the species in a rigorous, scientific manner. As such, the Species Status Assessment will provide a foundation for many other documents such as listing rules, recovery plans, and 5-year reviews.

The Species Status Assessment structure includes an integrated approach of assessing the needs of the species (Chapter 2), the current condition of the species (given past and present ecosystem dynamics – Chapters 3 and 4, respectively), and identifying the likely future condition of the species given probable future ecosystem conditions (Chapter 5). Species' needs are described for individuals, populations, and the species. Demographic rates (such as annual survival rates) provide insight into the status of the species. The Species Status Assessment couches these dynamics in three fundamental principles of conservation biology: Resiliency, Redundancy, and Representation. Resiliency is the ability of a population or a species to endure disturbance, such as rebounding in numbers after a disturbance-related decline. This characteristic is typically associated with population size, growth rate, or habitat quality, all of which may affect resiliency. The capacity of a population or species to endure especially catastrophic or widespread disturbance due to the existence of numerous sub-populations or populations is called redundancy. Having numerous more or less distinct groups can increase the probability of a species or population surviving a catastrophic event. Lastly, representation is the term used to describe the fact that diversity can promote the viability of a species because higher diversity increases the likelihood that a species or population can adapt to prevailing environmental conditions. Typically, representation refers to the distribution of genetic diversity within and among populations, but ecological diversity (such as life history traits) is also an important component.

Overall resiliency for Lost River sucker is generally low, primarily because redundancy is critically low. There are only three distinct spawning populations: Upper Klamath Lake-springs, Upper Klamath Lake-river, and Clear Lake Reservoir. Two of the remaining populations (Clear Lake Reservoir and Upper Klamath Lake-springs) have very low numbers and are at a high risk of localized catastrophic events. The Clear Lake Reservoir population is completely separate from the others. As a species, Lost River sucker appear to be relatively genetically distinct from the other sucker species in the basin.

Shortnose sucker also suffer from low resiliency as a species, despite having relatively high apparent redundancy compared to Lost River sucker. The low resiliency is due to the extremely low numbers in most populations, lack of access to suitable spawning habitat for several populations, and mixed genetics for others. There are currently only three known spawning populations (Upper Klamath Lake, Clear Lake Reservoir, and Gerber Reservoir). The number of representative populations diminishes when we consider the high levels of genetic introgression with Klamath largescale sucker (*Catostomus snyderi*). Furthermore, all populations possess low abundance.

Based on the future scenarios we analyzed here, it is likely that the Lost River sucker will continue to decline precipitously if conditions in Upper Klamath Lake remain unchanged. The species may remain in 50 years, but it is likely that it will be critically few in numbers. Given that the only other spawning population of this species, Clear Lake Reservoir, is extremely small, a substantial reduction in Upper Klamath Lake will put the species perilously close to extinction. These conclusions rely on the assumption that survival rates continue in the future similar to the recent past; however, if survival should decrease due to ageing populations, then we expect the declines to accelerate. This could significantly truncate our frame of reference.

If current conditions continue, we also expect the shortnose sucker population in Upper Klamath Lake to become extirpated within the next 30-40 years. Projections suggest that this population will decline 78% over the next 10 years to a level below 5,000 individuals. This would result in only two populations remaining for the species, both of which are highly genetically introgressed with the Klamath largescale sucker and geographically isolated behind dams without fish passage.

Both species are likely to realize reduced risk of extinction from implementation of the rearing program, but landscape-scale improvements to nutrient loads in Upper Klamath Lake will be necessary to achieve full recovery. The dire conditions of Lost River sucker in Clear Lake Reservoir suggest that recovery of the species will likely be unattainable without additional recovery efforts in this waterbody. Recovery of the species is likely to require substantially more drastic actions than the few considered here. Recovery of shortnose sucker appears more achievable in the Lost River sub-basin under the scenarios assessed, but uncertainties about the overall impacts of genetic introgression remain.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

LIST OF ABBREVIATIONS

μg	micrograms
AFA	*Aphanizomenon flos-aquae*
cm	centimeters
Co.	county
DO	dissolved oxygen
e.g.	exempli gratia – for example
et al.	and others
ft	feet
g	grams
i.e.	id est – in other words
in	inches
kg	kilograms
km	kilometers
L	liter
lbs	pounds
LC_{50}	lethal concentration – 50
LR	Lost River sucker
m	meters
mg	milligrams
mi	miles
mm	millimeters
NH_3	unionized ammonia
NW	not weighed
^oC	degrees Celsius
^oF	degrees Fahrenheit
p.	page
PIT	passive integrated transponder
pp.	pages
sec	second
SN	Shortnose sucker
TEMP	temperature
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service

CHAPTER 1 – INTRODUCTION

The Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) are two closely related fish species, which occur in the lakes of the upper Klamath Basin in central southern Oregon and northern California. Even though the species were never widely distributed (being wholly restricted to the lakes of the upper Klamath Basin), they were extremely abundant (Cope 1879 p. 785, Bendire 1889 p. 444) until populations began to decline sometime in the late 1960's. Continued declines resulted in closure of the recreational fishery for the suckers and ultimately listing in 1988 as endangered under the Endangered Species Act of 1973, as amended (USFWS 1988 p. 27130).

Since listing, extensive research has been conducted on the ecology of the species and the dynamics of their ecosystem. Numerous reviews of this research have occurred, including a recovery plan (USFWS 1993, entire) which was revised in 2013 (USFWS 2013a, entire), reviews of the status of each species (USFWS 2007a, 2007b, 2013b, 2013c), and Section 7 consultations under the Endangered Species Act. This Species Status Assessment provides a single, comprehensive review of the species' ecology and environmental conditions, past and present, to evaluate its general conservation trajectory and status, so that it can provide a framework to support the many other reviews and documents (Smith et al. 2018, entire).

This Species Status Assessment does not replace these previous documents nor their subsequent revisions. The objective is for the Species Status Assessment document to be easily updatable as new information becomes available, to act as a "state-of-the-science" repository. All functions of the Endangered Species Program from listing to Section 7 consultation to recovery planning will rely on the document as a basis for synthesizing the status of the species in a rigorous, scientific manner. As such, the Species Status Assessment provides a foundation to many other documents such as listing rules, recovery plans, and 5-year reviews.

The Species Status Assessment structure includes an integrated approach of assessing the needs of the species (Chapter 2), the current condition of the species (given past and present ecosystem dynamics – Chapters 3 and 4, respectively), and identifying the likely future condition of the species given probable future ecosystem conditions (Chapter 5). Species' needs are described for individuals, populations, and the species. The condition of the species is inherently reflected in the demographic rates (such as annual survival rates) of the species, but the Species Status Assessment couches these dynamics in three fundamental principles of conservation biology: Resiliency, Redundancy, and Representation (Evans et al. 2016b p. 6). Resiliency is the ability of a population or a species to endure disturbance, such as rebounding in numbers after a disturbance-related decline. This characteristic is typically associated with population size, growth rate, or habitat quality, all of which may affect resiliency. The capacity of a population or species to endure especially catastrophic or widespread disturbance due to the existence of numerous sub-populations or populations is called redundancy. Having numerous more or less distinct groups can increase the probability of a species or population surviving a catastrophic event. Lastly, representation is the term used to describe the fact that diversity can promote the viability of a species because higher diversity increases the likelihood that a species or population can adapt to prevailing environmental conditions. Typically, representation describes the distribution of genetic diversity within and among populations, but ecological diversity (such as life history traits) is also an important component.

To evaluate the ecological status of these two sucker species, we present here the breadth of current and future conditions of the species and their habitat, and we use these to gauge the species' overall resiliency, redundancy, and representation to understand the probability of these species persisting into the near future. This report provides a thorough assessment of biology and ecology of the suckers and assesses demographic risks, threats, and limiting factors in the context of near-term viability. It is often a challenge to determine the relevant period for these analyses. We have selected a window of up to 50 years because this spans multiple generations and is relevant in the context of some of the longer-term environmental dynamics. In many instances, the ecology of the species is very similar or data may be lacking for one of the species. We generally address the species together in these cases, unless there is specific information that warrants a specific distinction.

CHAPTER 2 – SPECIES ECOLOGY

This chapter outlines the ecological needs or requirements of the species. We interpret needs as the suite of conditions necessary to promote survival, stability, and viability at whatever level considered (i.e., individual, population, or species). Our assessment focuses on the fundamental ecology of the species. We begin by identifying the taxonomy, genetics, and historical range of the species. We then describe the life history of the species, and lastly, we present the ecological needs of the individuals, populations, and species each in turn, under the presumption that each is built on the needs of the former.

Taxonomy and Species Description

Both species are members of the Catostomidae family, commonly called suckers. This family of fish is comprised of 76 species and 14 **genera**[1], 97 percent of which occur only in North or Central America (Cooke et al. 2005 p. 319). These species have been classified into a subfamily, Catostominae, that accounts for the majority of species in the family, and within this subfamily both species belong to a tribe (Catostomini) that includes the genera *Chasmistes*, *Deltistes*, *Xyrauchen* (i.e. the razorback sucker[*Xyrauchen texanus*]), and *Catostomus* (Smith 1992 p. 795), but the taxonomic relationship of the species and genera within the tribe are somewhat unresolved (Harris and Mayden 2001 p. 232).

Lost River Sucker

The Lost River sucker (*Deltistes luxatus*) was first described by Cope (1879 p. 784) from Upper Klamath Lake specimens as *Chasmistes luxatus*. Because of unique triangular gill rakers that are not found in any other closely related sucker species, the species was elevated as the **monotypic** genus *Deltistes* in 1896 (Seale 1896 p. 269). The morphological distinctiveness of *Deltistes* was subsequently corroborated by analysis of fossil material of extinct species with similar diagnostic characteristics (Miller and Smith 1967 pp. 5–11). The Lost River sucker is currently recognized as the only surviving member of the genus (Nelson et al. 2004 p. 79).

Lost River sucker are large, long-lived cypriniform fishes, achieving sizes up to 0.8 m (2.6 ft) and 4.5 kg (9.9 lbs.; Figure 1). They are distinguished by an elongated body and sub-terminal mouth with a deeply notched, sparsely **papillose** and narrow lower lip (Figure 2; Scoppettone and Vinyard 1991 p. 359). Their coloration is dark on the back and sides fading to yellow or white on the belly. Small white nodules, known as tubercles, also extensively cover the body, particularly on spawning adults.

[1] **For a glossary of technical terms used in this report reference Appendix I. Words that appear in the glossary are bolded at the first appearance in the text.**

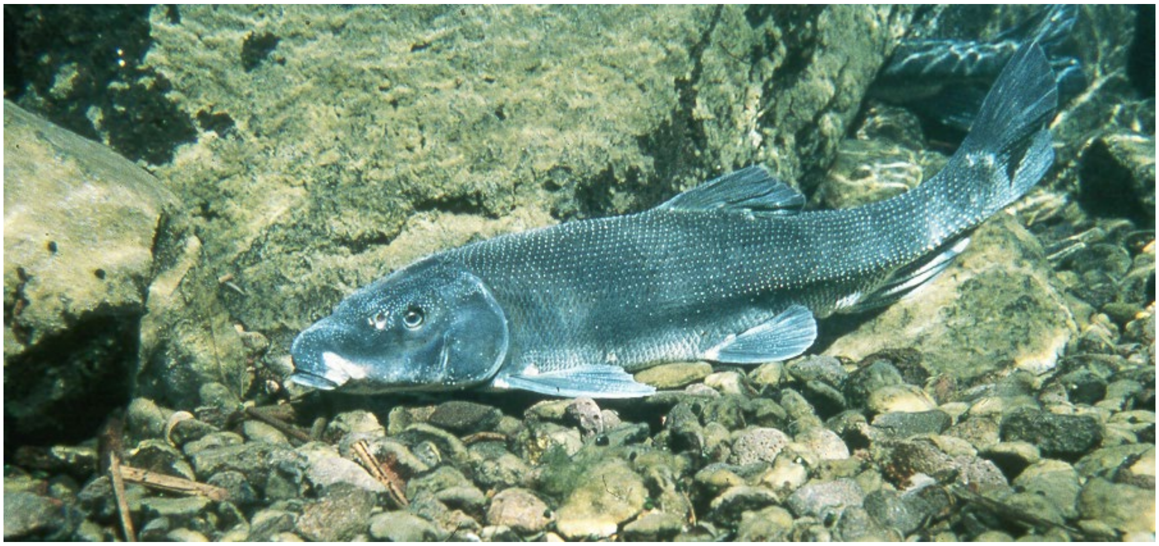


Photo by Tupper Blake, used with permission.

Figure 1 an adult Lost River sucker resting during the spawning season at the eastern shoreline springs of Upper Klamath Lake. The white speckles on the body are tubercles.

Shortnose Sucker

The *Chasmistes* genus includes three **extant** species: shortnose sucker (*Chasmistes brevirostris*), June sucker (*Chasmistes liorus*), and cui-ui (*Chasmistes cujus*), all of which are narrowly **endemic** within the remnant lakes of the western United States and all of which are listed as endangered under the Endangered Species Act. Extinct species from this genus have also been identified from the fossil record (Miller and Smith 1981 p. 4).

The shortnose sucker was also first described by Cope (1879 p. 785). A smaller head relative to the overall body size than Lost River sucker and oblique, terminal mouth, and thin, fleshy lips distinguish this species (Figure 2 and Figure 3). The lower lip is deeply notched, giving the appearance of two separate lobes, which are also narrow and nearly absent of papilla for the most part. Shortnose sucker reach approximately 0.65 m (2.1 ft) and 3.5 kg (7.7 lbs.). They have similar coloration to Lost River suckers with a dark back and sides and a white or silvery belly (Moyle 2002 p. 202), but they tend to have fewer tubercles, which are found mostly on the **caudal peduncle** of males during the spawning season.

Photos by J. Rasmussen, USFWS.

Figure 2 the three sucker species of the upper Klamath Basin: shortnose sucker (top), Lost River sucker (middle), and Klamath largescale sucker (bottom). The head and mouth shots are of the same individual. The shape of the head and lower lips are often diagnostic among the species. Images are not at the same scale.

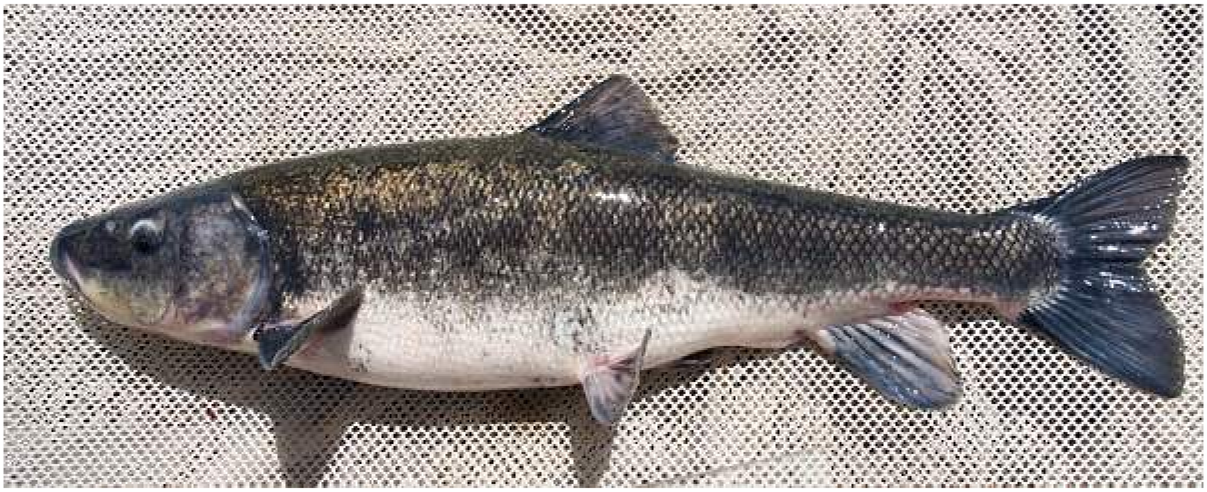


Figure 3 A Shortnose sucker adult captured in the Williamson River during the spawning run.

Genetics

As is common for the Catostomid family, Lost River and shortnose sucker possess **tetraploid genomes**. The Klamath Basin sucker community (including the two listed species as well as the non-listed Klamath largescale sucker [*Catostomus snyderi*] and Klamath smallscale sucker [*Catostomus rimiculus*]) appear to have all diverged from a common ancestor despite being classified as three distinct genera (Dowling et al. 2016 p. 20). **Mitochondrial DNA** and **microsatellite markers** indicate that **introgressive hybridization** has occurred to varying levels among the four Klamath Basin sucker species. Most notably, high levels of introgressive hybridization between shortnose sucker and Klamath largescale sucker make it impossible to distinguish between the two species using current molecular data (Tranah and May 2006 p. 312, Dowling et al. 2016 p. 19). Despite this, morphological and ecological distinctions are maintained to some degree, but individuals displaying physical characters intermediate to shortnose sucker and Klamath largescale sucker are also common, particularly in the Gerber and Clear Lake Reservoir populations (Markle et al. 2005 p. 480). The main ecological difference between these species are the Klamath largescale and Klamath smallscale suckers typically inhabit rivers and streams, as opposed to lakes for the two listed species. Lost River suckers are relatively genetically distinct from the other species, although some evidence of very limited hybridization with the other species does exist (Dowling et al. 2016 p. 21).

Introgressive hybridization is common among Catostomidae species (Dowling and Secor 1997 p. 604). Nevertheless, in the Klamath Basin, it is clear that suitable conditions have existed in the past for distinct species to evolve. Evolution into distinct species is usually due to some sort of process or barrier that prevents groups from interbreeding over a long period. Barriers can take many forms. They can be physical, such as segregation of two formerly connected populations, or ecological in nature, such as adaptation to different habitats. As species **diverge**, several process may affect the way genes are shared or exchanged. Introgressive hybridization can occur when barriers to gene exchange are weak or incomplete, allowing limited gene exchange between the separating groups. Relatively new barriers may not have been in place enough time for complete separation. Similarly, barriers may become comprised, such as by human-caused changes in the system, permitting gene exchange to resume between the previously diverging species. It is unclear whether the apparent introgressive hybridization between shortnose sucker and Klamath largescale sucker is due to recent development of barriers, weak barriers, or degradation of previously existing isolating barriers (Dowling et al. 2016 p. 19). There is some evidence, however, that the shortnose sucker and Klamath largescale sucker in particular are in the process of **converging** given the apparent reduction of morphological distinction between the two species compared to older specimens (Dowling et al. 2016 p. 20).

Historical Range and Distribution

Lost River sucker and shortnose sucker are endemic to the upper Klamath Basin, including the Lost River sub-basin (Figure 4). Historical documented occurrences of one or both species include Upper Klamath Lake (Cope 1879 pp. 784–785) and Tule Lake (Bendire 1889 p. 444), but the species likely occupied all of the major lakes within the upper Klamath Basin, including Lower Klamath Lake, Lake Ewauna, and Clear Lake. In addition to inhabiting the lakes.

Throughout the upper basin, the species historically utilized all major tributaries to the lakes for spawning and rearing, including the Williamson, Sprague, Wood and Lost Rivers and Willow, Boles, Ben Hall, and Barnes Valley Creeks. For example, the species ascended the Williamson River in the thousands and were “taken and dried in great numbers by the Klamath and Modoc Indians” (Cope 1879 p. 785). Historically, large sucker spawning migrations also occurred from Tule Lake up the Lost River to near Olene and Big Springs near Bonanza (Bendire 1889, entire). Suckers were also known to spawn in great numbers at several springs and seeps along the eastern shoreline of Upper Klamath Lake, including Barkley (Bendire 1889 p. 444) and at other spring-dominated areas in the northwestern corner of the lake, including Harriman, Crystal, Buck Island, and Malone Springs.

At the time of listing (1988), Lost River sucker and shortnose sucker were known to occupy Upper Klamath Lake and its tributaries and outlet (Klamath Co., Oregon). This included a “substantial population” of shortnose sucker in Copco Reservoir (Siskiyou Co., California), as well as collections of both species from Iron Gate Reservoir (Siskiyou Co., California) and J.C. Boyle Reservoir (Klamath Co., Oregon). Remnants and/or highly hybridized populations were also documented to occur in the Lost River system (Klamath Co., Oregon, and Modoc and Siskiyou Co., California) including both species in Clear Lake Reservoir (Modoc Co., California), but it was apparently presumed that Lost River sucker populations in Sheepy Lake, Lower Klamath Lake, and Tule Lake (Siskiyou Co. California) had been “lost” (USFWS 1988 p. 27130). Although not stated explicitly, shortnose sucker within Gerber Reservoir (Klamath Co., Oregon) were likely part of the “highly hybridized populations” in the Lost River Basin referenced in the listing.

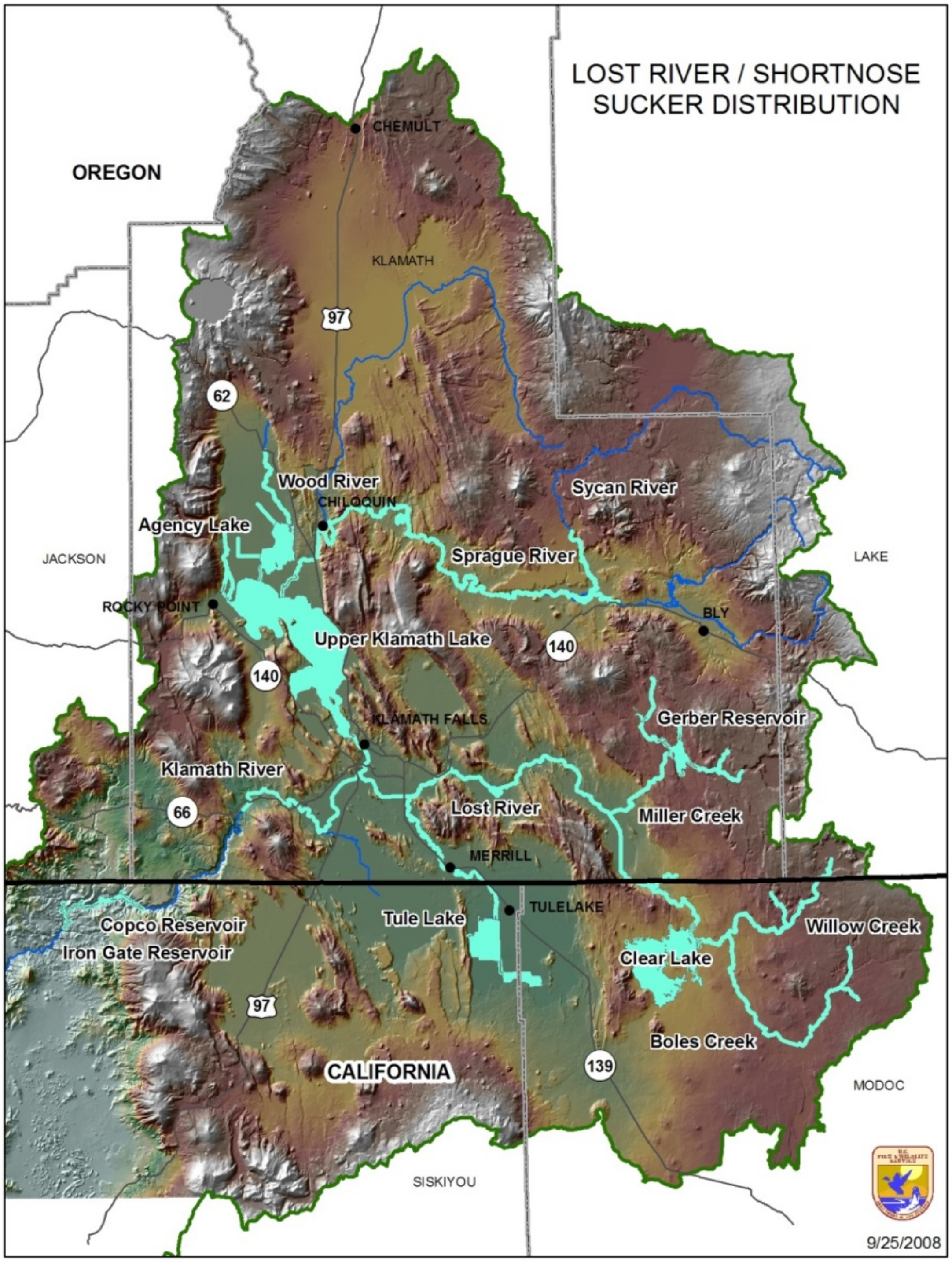


Figure 4 The Lost River and shortnose sucker are endemic to the lakes and rivers of the Upper Klamath Basin in south, central Oregon and north, central California. Lower Klamath Lake and Sheepy Lake are not depicted on the map because populations no longer occur there.

Life History

Lost River sucker and shortnose sucker are large-bodied, long-lived species. The oldest individual for which age has been estimated is 57 years for Lost River sucker and 33 years for shortnose sucker (Buettner and Scoppettone 1991 p. 21, Terwilliger et al. 2010 p. 244). Juveniles grow rapidly until reaching sexual maturity sometime between age four and nine years of age for Lost River sucker and between four and six years of age for shortnose sucker (Perkins et al. 2000b pp. 20 & 21). On average, approximately 90 percent of adults of both species survive from year to year, which enables populations to persist through periods with unfavorable spawning or recruitment conditions (Hewitt et al. 2017 pp. 15 & 21). Once achieving sexual maturation, Lost River sucker are expected to live on average 12.5 years based on annual survival rates (Hoenig 1983, entire, USFWS 2013a p. 12). Similarly, shortnose sucker adults live on average 7.4 years after having joined the adult population. Thus, for those individuals surviving to adulthood, we expect an average total life span of 20 years for Lost River sucker and 12 years for shortnose sucker, based on the average time to maturity and average adult life spans. Females produce a large number of eggs per year: 44,000 to 236,000 for Lost River sucker and 18,000 to 72,000 for shortnose sucker, of which only a small percentage survive to become juveniles. No direct measurements of larval survival have been made for these species, but a generally accepted value of larval mortality for stable populations of freshwater fish to reach the juvenile stage is approximately 96.4 percent (Houde 1989 p. 479, Houde and Bartsch 2009 p. 31). Larger, older females often produce more eggs (Perkins et al. 2000b p. 40), and therefore, can contribute more to production than recently matured females. The effects of **senescence** on the survival and reproduction of these two species are unknown at present, but the phenomenon of senescence appears to be widespread among vertebrates and the populations in Upper Klamath lake are clearly ageing (Hewitt et al. 2017 pp. 19, 23, 29).

Both species are **obligate** lake dwellers, typically only leaving lakes during spawning migrations. Spawning occurs from late-February through mid-June. Most populations spawn in tributary rivers or streams, but a subset of the Upper Klamath Lake population of Lost River sucker spawns at groundwater upwelling areas along the eastern lakeshore. Spawning at the lakeshore springs occurs primarily in April and early May (Hewitt et al. 2014 p. 9). Individuals of both species appear to spawn every year in Upper Klamath Lake (E. Janney, U.S. Geological Survey, personal comment). The number of individuals participating in spawning runs from Clear Lake varies dramatically across years as a function of access to the spawning stream, which depends on stream flow and lake levels (D. Hewitt, U.S. Geological Survey, personal communication). Spawning consists of females broadcasting their eggs into the water, which are fertilized most commonly by two accompanying males, though the number may be as high as seven males jockeying for close position to the female (Figure 5; Buettner and Scoppettone 1990 pp. 17 & 44). There is no parental care of the eggs. Fertilized eggs quickly settle within the top few inches of the gravel substrate and hatch around one week later. Larvae emerge from the gravel approximately 10 days after hatching at about 7 to 10 mm (0.2 to 0.6 in) **total length** and are mostly transparent with a small yolk sac (Coleman et al. 1988 p. 27).

Photo by G. Scoppettone, USGS

Figure 5 Suckers spawning in the manner of group broadcast spawning used by the suckers of the upper Klamath Basin.

Photo by R. Larson, USFWS

Figure 6 A sucker larvae from the upper Klamath Basin. This sucker is approximately 3 -4 weeks old and is transitioning into the juvenile stage because no yolk sac remains and the rays of the fins are nearly completely developed.

Generally, Lost River and shortnose sucker larvae spend little time in rivers after **swim-up**, drifting downstream to the lakes at about 14 mm (0.55 in) in length around 20 days after hatching (Figure 6; Cooperman and Markle 2003 pp. 1146 & 1147). In the Williamson and Sprague Rivers (Upper Klamath Lake population) and Willow Creek (Clear Lake Reservoir population), larval drift downstream from the spawning grounds begins in April and is typically completed by July with the peak in mid-May (Scoppettone et al. 1995 p. 19). Little is known about the drift dynamics of the larvae that hatch at the eastern shoreline springs in Upper Klamath Lake. Most downstream movement occurs at night near the water surface (Ellsworth et al. 2010 pp. 51–53).

Once in the lake, larvae inhabit near-shore areas (Cooperman and Markle 2004, entire). Larval density is generally higher within and adjacent to emergent vegetation than in areas devoid of vegetation (Cooperman and Markle 2004 p. 370). However, the two species appear to have slightly different habitat usage as larvae; shortnose sucker larvae predominantly use nearshore areas adjacent to and within emergent vegetation, but Lost River sucker larvae tend to occur more often in open water habitat than near vegetated areas (Burdick and Brown 2010 p. 19).

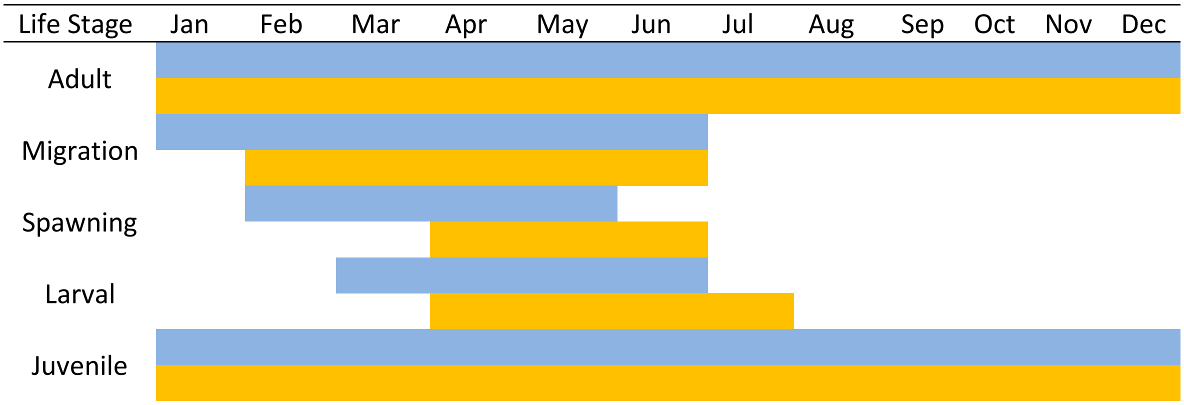
Larvae of both species transform into juveniles in mid-July between 20 and 30 mm (0.8-1.2 in) total length, and they then transition from predominantly feeding at the surface to feeding near the lake bottom (Markle and Clauson 2006 p. 496). One-year-old juveniles appear to predominantly occupy shallow near-shore habitats (Bottcher and Burdick 2010 p. 12, Burdick and Vanderkooi 2010 pp. 9 & 10). In general, juveniles have relatively high mortality rates compared to adults. Juvenile cohorts in Clear Lake Reservoir were estimated to survive at 33 to 44 percent annually (Burdick et al. 2016 pp. 18–19). Under normal conditions, mortality rates decrease as juveniles grow and survival improves. Because we have very little information about juveniles older than one year, primarily because are not common in the system, we assume these older juveniles are ecologically similar to adults (see below). This includes the assumption that they utilize habitats similar to adults. Once a juvenile becomes reproductively mature they are adults.

Adult Lost River sucker and shortnose sucker are widely distributed in Upper Klamath Lake during the fall and winter, but in the spring, congregations form in the northeast quadrant of the lake prior to moving into tributaries or shoreline areas for spawning. Less is known about populations in Gerber and Clear Lake Reservoirs (Leeseberg et al. 2007, entire). However, in Clear Lake adults appear to inhabit the western lobe of the reservoir more so than the eastern lobe (Barry et al. 2009 p. 3), which is probably due to its greater depth.

Individual Needs

Lost River and shortnose suckers occur as five generic life stages: migration, spawning, larval, juvenile, and adult (Table 1). The timing of occurrence of each life stage is similar between the two species, with the main difference occurring during spawning and incubation.

Table 1 Life Stage Diagram (adapted from Reiser et al. 2001 p. 4-3). Lost River sucker and shortnose sucker occur as five generic life stages: migration, spawning, larval, juvenile, and adult. Each of these may have specific ecological requirements. The table below presents the general time of year when each life stage is present within the system for each species. Lost River sucker are represented by blue and shortnose sucker are represented by yellow.



<u>Migration</u>

Adults in Upper Klamath Lake strongly cue on water temperature to initiate spawning migrations up the Williamson River. Migrations begin only after appropriate water temperatures have been achieved: 10°C (50°F) for Lost River sucker and 12°C (54°F) for shortnose sucker (Hewitt et al. 2017 pp. 11 & 24). Individuals running upstream to spawn will continue until the end of the spawning season so long as the water temperature is trending warmer (Hewitt et al. 2014 pp. 36 & 37). A cold snap will cause spawners to pause migration until temperatures warm again. Migration in Willow Creek (Clear Lake population) appears triggered by a general rising trend in stream temperatures rather than exceedance of a specific temperature threshold (D. Hewitt, U.S. Geological Survey, personal communication). Often, individuals in this population will begin running well before temperatures have reached the thresholds that are necessary for Upper Klamath Lake populations.

Spawners require safe access to quality spawning habitat and adequate mates. Attributes of high quality spawning habitat are outlined below in the section describing the needs for spawning. Shallow water near river outlets or low flows within rivers may limit access for river-spawning individuals (D. Hewitt, U.S. Geological Survey, personal communication). This condition is typically only an issue for populations in Clear Lake and Gerber Reservoirs. For lakeshore spring spawning habitat, access and availability can be reduced by shallow depths or dewatering at springs due to low lake levels (Burdick et al. 2015b, entire). Lost River and shortnose suckers may be more vulnerable to avian predation during spawning than at other times of the year because they must move through shallow habitat to spawn at some sites (D. Hewitt, U.S. Geological Survey, personal communication). We do not know specific hydrologic conditions required by these species for transit through stream system, but we believe that they are generally capable of navigating past most natural features within their range under average hydrologic conditions. As an example, a shortnose sucker individual in 2016 traversed approximately 35 km (21.7 mi) up Willow Creek during the spawning migration. To do so, the individual climbed two extremely steep sections of between 4.8 and 6.2 percent gradient for nearly 0.7 km (0.43 mi) and 0.37 (0.23 mi), respectively (J. Rasmussen, U.S. Fish and Wildlife Service, unpublished data).

Spawning

Spawning occurs from late-February through mid-June in rivers and shoreline springs. Spawning typically occurs over mixed gravel and cobble substrate in water depths less than 0.46 m (1.5 ft). Utilized depths range from 0.12 to 0.70 m (0.4 to 2.3 ft). Gravel is small rock ranging in size from 2 – 64 mm (0.8 – 2.5 in) in diameter, and cobble ranges in size from 65 – 256 mm (2.5 – 10 in) in diameter. Lost River suckers were observed to spawn at water velocities of 15 – 82 cm/sec (0.49 - 2.69 ft/sec; Coleman et al. 1988 p. iv). Eggs require flowing water and relatively open substrate that permits sufficient aeration. The flowing water keeps the area clean from silt and clay, which smother eggs by preventing oxygen exchange. These conditions also facilitate removal of waste materials from the egg during incubation. The small spaces between gravel pieces in the substrate may help restrict access by predators, and may limit the number of eggs that can randomly clump together as they settle. This may restrict the spread of diseases such as certain fungi that can grow on developing eggs.

Larvae

Generally, larval needs prior to swim-up are similar to those of eggs. Larvae need gravel for roughly the first two weeks after hatching and water that is well aerated and clean. Prior to swim-up, larvae also need gravel to provide some protection from predation and disease. Similar to eggs, gravel restricts access by predators and causes developing larvae to be somewhat dispersed, which reduces the transmission of disease. Approximately 10 days after hatching, when larvae reach about 7 to 10 mm (0.2 in to 0.6 in) total length and are still mostly transparent with a small yolk sac, they emerge out of the gravel (Coleman et al. 1988 p. 27, Buettner and Scoppettone 1990 pp. 24 & 46).

Generally, larvae spend little time in rivers after swim-up, but quickly drift downstream to the lakes. However, Hayes and Rasmussen (2017 pp. 131 & 132) found evidence of LRS rearing in the Sprague River as juveniles, presumably because these individuals did not outmigrate as larvae. This is likely a very small component of the population overall. In the Williamson and Sprague Rivers, larval movement away from the spawning grounds begins in April and concludes by early July. Downstream movement mostly occurs at night near the water surface (Ellsworth et al. 2010 p. 51). Once in the lake, larvae typically inhabit near-shore areas (Cooperman 2004 p. 84). Larval density is generally higher within and adjacent to **emergent vegetation** than in areas devoid of vegetation (Cooperman and Markle 2004 p. 373).The role of submergent vegetation is unclear because it is generally not present during most of the larval period due to the larval period occurring before the growing season, and in high water years in Clear Lake Reservoir it is nearly absent. Outmigrating larvae require sufficient flows through the river or creek, ultimately out-letting into a lake habitat. This **corridor** presumably also needs either fringe (e.g., emergent vegetation) or benthic (e.g., gravel) structure to provide areas for the larvae to rest and hide during daylight hours.

Once in the lake environment, larvae require habitat with appropriate water quality (Table 2), sufficient food, and structure that provides refuge from predators and turbulence. One study found that larvae need a pH below approximately 10.35, un-ionized ammonia (NH_3) below 0.48 mg/L (Lost River sucker) and 1.06 mg/L (shortnose sucker), temperatures below 31°C (88°F), and dissolved oxygen (DO) above 2.1 mg/L (Saiki et al. 1999 p. 40). These values reflect conditions that were lethal to 50 percent of individuals after 96 hours of exposure.

As larvae are in the process of transitioning to juveniles, they finish the remains of their yolk sac and begin eating external food. This includes midge (Chironomidae) larvae and adults as well as small crustaceans (Markle and Clauson 2006 pp. 494 & 495). Emergent vegetation provides cover from non-native predators (such as non-indigenous fathead minnows; *Pimephales promelas*) and habitat for prey items (Cooperman and Markle 2004 p. 375). Such areas may also provide refuge from wind-blown currents and turbulence, as well as areas of warmer water temperature which may promote accelerated growth (Cooperman et al. 2010 p. 36). These areas of emergent vegetation tend to occur along the fringes of the lakes in shallow areas.

Juveniles

It appears that individual juvenile needs are relatively similar to late-stage larvae, with some distinctions. Larvae transform into juveniles by mid-July at about 25 mm (1 in) total length. In addition to the midge and crustacean prey items, juveniles may take other macroinvertebrates (such as caddis flies) or an indistinguishable material comprised of sand, filamentous algae, and other digested materials (Buettner and Scoppettone 1990 pp. 40 & 54, Markle and Clauson 2006 p. 495). However, no diet data exist beyond early summer of their first year. Juvenile suckers primarily use relatively shallow (less than approximately 1.2 m [3.9 ft]) vegetated areas, but may also begin to move into deeper, un-vegetated off-shore habitats (Buettner and Scoppettone 1990 pp. 32, 33, 51, Hendrixson et al. 2007 pp. 15 & 16, Bottcher and Burdick 2010 pp. 12–14, Burdick and Brown 2010 pp. 42, 45, 50). One-year-old juveniles occupy shallow habitats during April and May, but may afterwards move into deeper areas along the western shore of Upper Klamath Lake until DO levels become reduced (Bottcher and Burdick 2010 p. 17, Burdick and Vanderkooi 2010 pp. 10, 11, 13). Once DO levels in this deeper area become suboptimal, juveniles appear to move into shallower areas throughout the rest of the lake.

Minimum water quality needs for juveniles are also similar to larval needs but juveniles appear to be slightly more tolerant of poor water quality (Table 2). Lastly, several predator groups may prey on juvenile suckers, including fish and birds. Klamath suckers are also subject to impacts from numerous diseases and parasites, which may have increased in density due to the high abundance of non-native species. Individuals need habitat structure or depth to avoid predation, and individuals also require water quality conditions within appropriate ranges to reduce stress and thereby minimize the vulnerability to predators and pathogens.

<u>Adults</u>

Adult Lost River sucker and shortnose sucker require distinct growth and spawning habitats. The growth habitat, found in lakes, is simply the habitat adults utilize for feeding and growing. Spawning habitat predominantly occurs in the tributaries to these lakes. However, a subset of Lost River sucker use lakeshore springs as their spawning habitat in Upper Klamath Lake. Few shortnose sucker spawn at these lakeshore sites; the low numbers suggest they are likely vagrant individuals not attempting to spawn. In their growth habitat, adult suckers require adequate food, water quality, and refuge from predation. Although adult sucker are hardier than juveniles and larvae, they are still susceptible to poor water quality, which can be associated with **die-offs**. Thus, adult suckers require adequate water quality within their growth habitat or at least refugia from poor water quality conditions in their primary habitat. The specifics of water quality dynamics and conditions is discussed further in Chapter 3.

Specific information on the diet of Lost River sucker or shortnose sucker adults is lacking; however, their morphology and the diets of closely related species yield some insight. *Chasmistes* species, including shortnose sucker, have **terminal** or **subterminal** mouths and **branched gill rakers** (Miller and Smith 1981 p. 7) which are presumed to be adaptations for straining zooplankton from the water column (Miller and Smith 1981 p. 1, Scoppettone and Vinyard 1991 p. 359). Ninety-two percent of gut contents of adult shortnose sucker in Clear Lake Reservoir consisted of a group of small crustaceans known as cladocerans (Parker et al. 2000 p. 17). Cladocera, commonly called water fleas (such the genus *Daphnia*), are typically are found distributed throughout the water column. *Deltistes* species have triangular gill rakers and mouths oriented more ventrally (toward the bottom), which suggests that they are dependent more on benthic organisms, such as macroinvertebrates. Parker et al. (2000 p. 17) found that midge larvae (family Chironomidae) comprised 96 percent of the abundance of adult Lost River sucker gut contents in Clear Lake Reservoir. Midge larvae inhabit the benthos until they swim up to emerge from the water as flying adults. Lost River sucker adults also tended to have more detritus in their gut than shortnose sucker (Parker et al. 2000 p. 7).

Based on radio-telemetry studies of suckers in Upper Klamath Lake, adults of both species tend to occupy areas with water depths of greater than 2 m (6.6 ft). Selection of these deeper than average habitats may reflect the distribution of their prey or it may confer protection from avian predators, which can consume suckers as large as 730 mm (28.7 in; Evans et al. 2016a p. 1262). Sucker adults are known to utilize shallower habitat when seeking more favorable water quality conditions in spring-fed areas, such as Pelican Bay (Banish et al. 2009 pp. 159 & 160). These spring-dominated sites likely provide better water quality conditions because the water is typically cooler (cooler water can hold more oxygen than warmer water) and clearer because of water flow in the area.

Table 2 Upper median lethal concentrations (LC50s) for pH, un-ionized ammonia (NH3), and water temperature (TEMP), and lower LC50s for dissolved oxygen (DO) to larval (35 days) and juvenile (3-7 months) Lost River (LR) and shortnose (SN) suckers at 24-h exposure intervals during 96-h-long tests. From Saiki et al. (1999 p. 40).

Variable	Species	Life Stage	Weight (g)	24 h		48 h		72 h		96 h	
pH	LR	Larva	NW[a]	10.42	(10.38±10.47)	10.39	(10.32±10.46)	10.36	(10.27±10.46)	10.35	(10.26±10.45)
	LR	Juvenile	0.28±0.49	10.66	(10.59±10.74)	10.62	(10.54±10.71)	10.39	(10.12±10.67)	10.3	(9.94±10.67)
	SN	Larva	NW[a]	10.38	(10.31±10.46)	10.38	(10.31±10.46)	10.38	(10.31±10.46)	10.38	(10.31±10.46)
	SN	Juvenile	1.01±1.11	10.69	(10.61±10.77)	10.66	(10.61±10.72)	10.58	(10.56±10.61)	10.39	(10.22±10.56)
NH3	LR	Larva	NW[a]	0.56	(0.52±0.61)[c]	0.51	(0.47±0.55)[c]	0.49	(0.45±0.54)[c]	0.48	(0.44±0.52)c
(mg/L)	LR	Juvenile	0.49±0.80	1.02	(1.01±1.04)	0.92	(0.82±1.04)	0.89	(0.77±1.04)	0.78	(0.70±0.86)
	SN	Larva	NW[a]	1.29	(0.83±2.00)	1.24	(0.82±1.88)	1.19	(0.79±1.78)	1.06	(0.73±1.53)
	SN	Juvenile	0.53±2.00	0.51	(0.30±0.87)	0.48	(0.28±0.82)	0.54	(0.35±0.82)	0.53	(0.34±0.82)
TEMP	LR	Larva	NW[a]	31.93	(31.82±32.04)[c]	31.85	(31.69±32.01)[c]	31.77	(31.58±31.96)[c]	31.69	(31.47±31.91)[c]
(°C)	LR	Juvenile	0.48±0.86	30.76	(30.04±31.50)	30.76	(30.04±31.50)	30.65	(30.04±31.27)	30.51	(29.99±31.04)
	SN	Larva	NW[a]	31.85	(31.75±31.96)	31.85	(31.75±31.96)	31.85	(31.75±31.96)	31.82	(31.75±31.90)
	SN	Juvenile	0.54±0.64	31.07	(29.44±32.80)	30.35	(29.44±31.28)	30.35	(29.44±31.28)	30.35	(29.44±31.28)
DO	LR	Larva	NW[a]	2.01	(1.90±2.13)	2.1	(2.07±2.13)	2.1	(2.07±2.13)	2.1	(2.07±2.13)
(mg/L)	LR	Juvenile	0.39±0.86	1.58	(1.35±1.86)	1.58	(1.35±1.86)	1.62	(1.41±1.86)	1.62	(1.41±1.86)
	SN	Larva	NW[a]	1.92	(1.89±1.96)	2.04	(1.90±2.18)	2.09	(1.90±2.29)	2.09	(1.90±2.29)
	SN	Juvenile	0.39±1.15	1.14	(0.84±1.55)	1.34	(1.15±1.55)	1.34	(1.15±1.55)	1.34	(1.15±1.55)

[a] NW, test animals were not weighed. This test was not repeated; the 95 percent confidence interval was calculated from statistical procedures used to estimate the LC_{50} value

Population Needs

Just as individuals need specific conditions to survive and prosper, populations also have requirements for maintaining stability and resiliency. These requirements consist of the resources and conditions necessary to sustain a genetically diverse population over tens to hundreds of years. Long-term persistence requires that a population maintain a stable abundance, or even increase when possible. All populations will experience some natural variation in abundance and growth rate over time, but overall a stable resilient population will average a growth rate of one. An average growth rate of one means that population abundance in any given year is more or less similar to the preceding year's abundance. The needs of a stable population are those conditions necessary to produce this average growth value consistently. The needs of an already reduced population include conditions that promote an average growth value of > 1 until the population reaches the environment's carrying capacity.

For most fish species, it is often only possible to generate estimates of the number of adults because of challenges in capturing smaller life stages. In the long-term, the growth rate patterns in the adults will reflect the dynamics of all life stages. Furthermore, adults typically comprise the most stable, long-term component of the population, and therefore, here we generally consider population needs as they affect adults. Annual changes in adult population size reflect two primary demographic forces: survival and recruitment. For long-term demographic stability, recruitment must be sufficiently large to offset losses from mortality. Under pre-disturbance conditions, the long lifespan and high adult survival of Lost River and shortnose sucker life history would offset their low annual recruitment. Therefore, in very general terms, populations of these species need conditions that permit high adult survival and successful spawning and rearing of enough individuals to offset average adult mortality.

Adequate recruitment rates depend on successful spawning and sufficiently high early-life survival rates. Successful spawning depends upon access to high quality spawning habitat. As discussed above, spawning typically occurs in tributary rivers, but Lost River sucker also spawn at springs emerging along lakeshores. Access to these habitats can depend on water levels both in the lake and in some cases the tributary rivers. Spawning at Upper Klamath Lake shoreline springs require access, which is depends on the water levels of Upper Klamath Lake. Sufficiently high survival rates at early life-stages depend on meeting the individual needs of eggs, larvae, and juveniles as discussed above.

Adult survival rates must be high enough to sustain the adult populations through periods of low recruitment. There is limited information on the historical frequency and magnitude of recruitment for Lost River and shortnose sucker, so delimiting specific requirements for adult survival is challenging. Adult survival within populations depends on the degree of attainment of the individual needs described above.

Beyond typical recruitment and survival rates, **catastrophic events** can dramatically reduce the abundance within populations and even lead to extirpation. An example would be an extreme degradation of water quality (e.g., dissolved oxygen). For populations that are low in numbers, a widespread catastrophic event has the potential to eliminate a significant proportion of individuals that could result in a loss of stability or even viability. To be resilient to such events and minimize the probability of extirpation, sucker populations must be large enough to both avoid immediate demographic concerns as well as maintain genetic diversity. In addition to a large population size, resiliency further depends on subsequent recruitment for populations to rebound to preexisting levels.

Sucker populations must also be large enough to withstand the deleterious effects of low genetic diversity. One way to characterize this diversity is termed representation, as described above. Representation refers to the breadth of genetic and ecological diversity within and among populations. Larger populations tend to have higher **effective population size**, which is a measure of genetic diversity of the breeding population. Populations with low effective population size are more vulnerable to inbreeding depression and genetic drift and may be less able to adapt to changing environmental conditions. Small populations are also vulnerable to **demographic effects**, such as random swings in sex ratio that may reduce population growth rates and effective population size. In other words, small populations may experience random variations in mortality or spawning that generate fewer individuals in one of the sexes than is necessary to maintain stability or viability. The effective population size required for maintaining Lost River and shortnose suckers is difficult to determine. No population of either species has been evaluated for inbreeding depression, effective number of breeders, or limiting demographic ratios.

Lastly, maintaining genetically intact and diverse populations of suckers requires minimization of the effects of hybridization. Hybridization affects the species at both the population and species levels in similar ways, detailed below. In summary, population needs include the environmental conditions that support survival at all life stages (see Individual Needs Section) and sufficiently high numbers of individuals within each population to ensure population resiliency and genetic representation.

Species Needs

As with the idea that population needs are met the extent to which individual needs are met, the same holds true for species needs. In other words, for a species to persist, it requires a sufficient number of resilient and representative populations, known as redundancy (Evans et al. 2016b p. 6). Redundancy exists with replicate populations throughout the range of the species, so that if one or more populations experience catastrophic loss or extirpation, the species as a whole persists. It is difficult to quantify how much redundancy a species requires to ensure long-term persistence, but species with fewer populations are at greater risk of extinction. We believe that pre-settlement distribution is a reasonable starting point because this is the distributional extent of the species under historic natural conditions.

Given this, we presume that Lost River and shortnose sucker need two or more resilient and representative populations for each species, which possess the characteristics described in the preceding section. Upper Klamath and Clear Lake populations of both species are required at a minimum for the long-term persistence of the species. These two water bodies are the largest and most stable within the range of the species. We cannot conceive a scenario where recovery and stability occur without viable populations in each of these water bodies. Having these two populations provides some redundancy, but additional populations will certainly increase protection against extinction. Additional populations could include Gerber Reservoir, Tule Lake, and Lake Ewauna, among others. Small populations of both species occur in all but Gerber Reservoir (which is only currently occupied by shortnose sucker), but the lack of access to spawning habitat, appropriate environmental conditions, and/or genetic purity reduce overall resiliency in these areas and limit their utility in providing redundancy.

Geographic extent of the range of a species is generally an important component of redundancy. The farther apart populations are, the less likely they will be affected to the same degree by the same catastrophic event. Even prior to European settlement, these species were very narrowly distributed. The species inhabited five lakes, all within about 80 km (50 mi) of each other.

The second condition required for species persistence, representation, relates to the level and extent of diversity among the populations of a species. This typically refers to genetic diversity, but also applies to ecological diversity. Species require a range of genetic and ecological diversity throughout their populations to ensure adaptability as environmental conditions change. Not every population will possess the complete range of variation, but variation within and among populations is important for the long-term viability of species. Diversity increases the likelihood that a species will be able to persist through environmental changes because chances are greater there is a variant among individuals that can resist or exploit new conditions (Hallerman 2003 p. 405, Evans et al. 2016b p. 6).

It is difficult to quantify representation, much less what a species needs to ensure its persistence. Genetic diversity is often measured within populations by the number of **genetic loci** with greater than one **allele**, or the number of alleles at a specific locus, or even simple **heterozygosity** at a single locus (Billington 2003 pp. 75–83). Differences in allele frequencies and **genotypes** suggests genetic diversity among populations. Ecological diversity includes **richness** (the number of types of ecological variants, including behavioral or life history variants, or **phenotypical variants** within a species or population) or **evenness** (the relative proportion of the variants) within and among populations. Nevertheless, assigning specific required or minimum diversity values is not straightforward (Hallerman 2003 p. 407).

Several important landscape-level dynamics can affect species diversity. Connectivity among populations to allow for dispersal of migrants can promote genetic diversity by enabling genetic variants to spread among populations. Restriction of connectivity among populations can result in the loss of genetic diversity due to processes such as a **genetic bottleneck** or the **founder effect**. Connectivity to diverse habitats throughout the landscape at the species and population level can also promote ecological diversity by providing unique and diverse niches that individuals and populations can take advantage of, which may result in local adaption and increased genetic diversity. **Metapopulation dynamics** incorporate the issues of population connectivity and diversity within a species. The processes often function on a relatively long time scale.

Genetic introgression is relatively common among many species of sucker (Dowling et al. 2016 p. 3). This process can have significant impacts on species diversity and representation. Species require some sort of barrier to reproduction for evolution to occur and for new species to develop. When reproductive barriers between species are incomplete, those species can exchange genes as individuals interbreed. Low levels of interbreeding between species may actually increase genetic diversity (Dowling and Secor 1997, entire). However, it is more likely that introgression will be detrimental to a rare species' diversity as the genes of the more common species overwhelm and replace those of the rare species (Rhymer and Simberloff 1996 p. 83). This can result in complete replacement of substantial portions of a species' genome or even genetic extinction.

We are currently unable to identify anything for these two species beyond the qualitative, generic genetic needs. In general, the Lost River and shortnose sucker require genetic diversity (representation) at the population and species scale to ensure species viability and adaptability. This requires access to diverse habitats throughout the landscape, appropriate levels of introgression and **reproductive isolation**, and connectivity among populations that will promote genetic and ecological diversity through adaptation.

CHAPTER 3 – CAUSES AND EFFECTS OF CURRENT ENVIRONMENTAL CONDITIONS

The purpose of this chapter is to identify and explain the most relevant factors that relate to the current biological and environmental condition of Lost River and shortnose suckers. The current condition of the species is addressed in Chapter 4. Here we discuss those anthropogenic and environmental factors that affect the habitat and demographics of the species.

Habitat Loss and Alteration

Loss and alteration of habitats (including spawning and rearing habitats) were major factors leading to the listing of both species (USFWS 1988 pp. 27131 & 27132) and continue to be significant impediments to recovery. Both species utilize a spectrum of aquatic habitats during some stage of the life cycle, including river or stream habitats, open-water lake habitats, and the wetlands areas along banks and shores. However, widespread alterations and complete loss of habitat has occurred throughout the species' range. The most dramatic examples of wholesale habitat loss include Tule Lake (roughly 36,000 hectares [89,000 acres] lost) and Lower Klamath Lake (roughly 40,700 hectares [100,500 acres] lost) (National Research Council 2004 p. 53). These two lakes were both terminal bodies with a single major tributary, which were dammed in 1910 or diked in 1917 (respectively) to completely block inflows (National Research Council 2004 pp. 55 & 56). This resulted in a loss of approximately 392 km^2 (151 mi^2) or 88 percent of Tule Lake and 362 km^2 (140 mi^2) or 95 percent of Lower Klamath Lake (National Research Council 2004 p. 96). As the lake levels receded, the exposed lake bottoms were converted to agricultural uses. Prior to damming, Tule Lake hosted what was probably the largest population of Lost River sucker (Bendire 1889 p. 444). Anecdotal reports suggest that populations of Lost River sucker also occurred in Lower Klamath Lake (Cope 1879 p. 72), although we are not aware of any pre-1917 reports on scientific fish surveys of the Lower Klamath Lake prior to modification. Notable habitat loss also occurred in Upper Klamath Lake. Approximately 70 percent of the original 20,400 hectares (50,400 acres) of wetlands surrounding the lake, including the Wood River Valley (Figure 7), was diked, drained, or significantly altered between 1889 and 1971 (Gearhart et al. 1995 p. 7). In some cases, the creation of reservoir behind Gerber Dam and enlargement behind Clear Lake Dam produced additional habitat that is suitable for suckers in some degree.

Habitat was effectively lost to the populations as passage to those areas was blocked. Barriers that limit or prevent access to spawning habitat were threats when the species were listed. Chiloquin Dam was cited as the most influential barrier because it restricted access to potentially 95 percent of historic river spawning habitat in the Sprague River for the populations in Upper Klamath Lake (USFWS 1988 p. 27131). However, this dam was removed in 2008, improving access to approximately 120 km (75 mi) of river for spawning. Both species have been detected upstream of the dam site during the spawning season, albeit in very small numbers (Martin et al. 2013 p. 8). Additionally, several dams or water control structures hinder or completely impede movements of the species throughout their historic range. These include Gerber Dam (Figure 8), Clear Lake Dam (Figure 9), Anderson Rose Dam (Figure 10), Harpold Dam, Lost River Diversion Dam, Malone Dam, as well as numerous smaller check dams and the like (USBR 2000, entire).

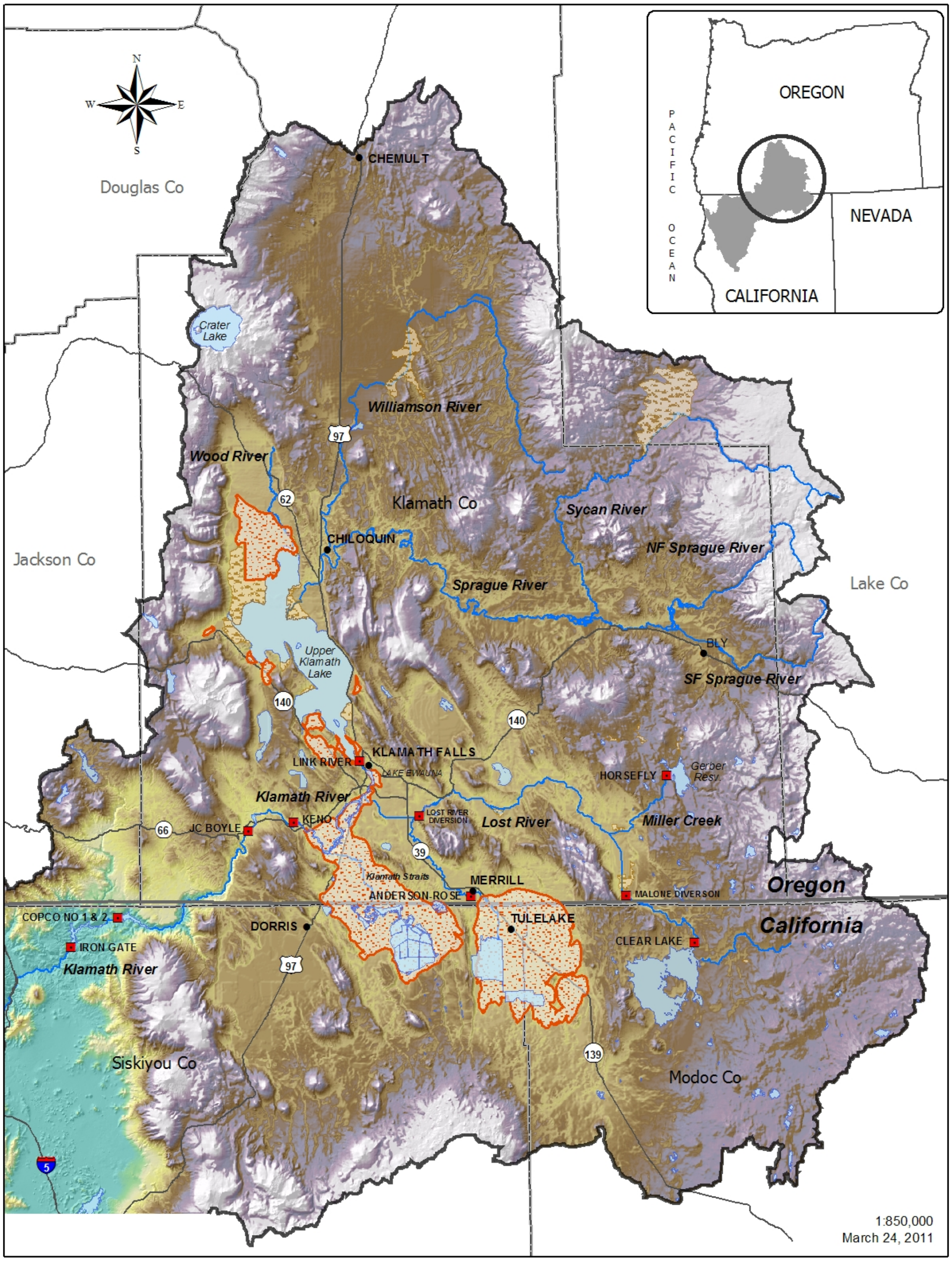


Figure 7 Upper Klamath Basin indicating areas of aquatic and wetland habitat that have been lost since overlain current conditions. Lost areas are outlined in orange.

All of these more substantial dams (i.e., the named ones above) were installed approximately 100 hundred years ago, and none possesses structures that permits volitional fish passage. For example, suckers attempting to run up the Lost River from Tule Lake are only able to travel 12 km (7.5 mi) before the Anderson-Rose Dam blocks access. The connection between Upper Klamath Lake and downstream environments was questionable for many decades because of a dilapidated fish passage ladder on the Link River Dam. This condition improved with the completion of a "sucker-friendly" fish ladder completed in 2005.

Photo by Bureau of Reclamation.

Figure 8 The Gerber Dam spilling under a high water year (2017) into Miller Creek. The dam rarely spills. Water typically passes downstream through gates near the bottom of the dam. The dam is approximately 26 m (85 ft) high.

Photo by Bureau of Reclamation.

Figure 9 the newly reconstructed Clear Lake Dam (2004), looking downstream towards the headwaters of the Lost River. The remains of the earthen footprint of the original Clear Lake Dam (constructed in 1910) is the flat "peninsula" just upstream of the dam. The new dam is 12.8 m (42 ft) tall.

Photo by USFWS.

Figure 10 Anderson-Rose Diversion Dam looking upstream. The dam is 7 m (23 ft) high. The Lost River channel, in the bottom left of the picture, only receives flow as spill over the dam. This is a complete barrier to fish passage within the river. The head of the J Canal (and associated diversion structures) are the main cement structures in the center-right of the picture.

Another equally important type of barrier is limited hydrologic connection to spawning or rearing habitat. This can be due to natural climatic patterns or result from human actions, such as water management for agricultural irrigation. For example, low lake levels adversely affect Clear Lake Reservoir sucker populations by limiting access to Willow Creek, the only known spawning tributary (Buettner and Scoppettone 1991 p. 8). Likewise, the amount of suitable shoreline spawning habitat in Upper Klamath Lake is significantly affected by even minor changes in lake elevation (Burdick et al. 2015b p. 483). Several spring-spawning populations, including Tecumseh Springs, Big Springs, and Barkley Springs, are extinct, in part due to disrupted connectivity.

Historically, wetlands comprised hundreds of thousands of hectares throughout the range of the species (Akins 1970 pp. 42–50, Bottorff 1989 p. ii, Gearhart et al. 1995 p. 16), some of which likely functioned as crucial habitat for larvae and juveniles. Other wetlands may have played vital roles in the quality and quantity of water. Loss of ecosystem functions such as these, due to alteration or separation of the habitat, is as detrimental as physical loss of the habitat. For example, increases of sediment input to the lake and prevalence of the blue-green cyanobacterium *Aphanizomenon flos-aquae* (AFA) coincide with destruction of riparian and marsh wetland areas associated with agricultural development above Upper Klamath Lake (Bradbury et al. 2004 p. 164). Volumes of fringe wetland habitats (including depths and area) greater than 15,000 m^3 have been associated with higher larval survival in Upper Klamath Lake (Cooperman et al. 2010 p. 34). Of the approximately 102 km^2 (39.3 mi^2) of wetlands still connected to Upper Klamath Lake, relatively little functions as rearing habitat for larvae and juveniles, partly due to lack of connectivity with current spawning areas and habitat alterations.

Climatic trends, resulting from both **anthropogenic** causes and natural variation, also play an important role. Since 1981, six of the ten lowest inflows into Upper Klamath Lake occurred after 2001[2]. Upper Klamath Lake, Clear Lake Reservoir and Gerber Reservoir are reservoirs that supply irrigation water for agricultural purposes. Lake levels respond strongly to drought, because each lake is relatively shallow, and because during droughts irrigation water usage is typically increased to offset lower than normal soil moisture in agricultural fields. Lake levels in Clear Lake Reservoir are even more sensitive to droughts given the limited local precipitation and broad, shallow **bathymetry** of the lake itself. The lake is a shallow water body with a large surface area, which generates high evaporation rates. Drought exacerbates conditions because the volume to surface area relationship skews even more. Severe or prolonged droughts likely negatively affect all sucker life stages throughout their range.

This myriad of habitat modifications can alter numerous ecological processes, although it is often challenging to infer direct causal pathways between individual modifications and tangible biological outcomes. Populations that historically operated as a metapopulation with periodic connection are now wholly isolated. This can restrict genetic and ecological representation within and among populations. Even if the movement of individuals among the various populations historically was rare, this could still provide the opportunity for beneficial genetics or adaptations to spread throughout the range of the

---

[2] See daily data for Williamson River discharge: https://waterdata.usgs.gov/or/nwis/inventory/?site_no=11493500&agency_cd=USGS. Accessed March 19, 2019.

species. Both of these processes increase the resiliency to the species, as the populations are better able to respond to the environmental conditions. Extirpation of numerous large populations and subpopulations will reduce the population redundancy of the species, and likely diversity as well. Lastly, with less rearing habitat (perhaps as little as 25 percent of historic amounts), the overall numbers of individuals that habitats can support is also greatly reduced.

Water Quality

The characteristics of the water in lakes and streams result from complex interactions among the geology, land use (historic and present), and climate of the region. The upper basin is comprised of several uplifted basins with numerous volcanic centers scattered throughout (O'Connor et al. 2014 pp. 4–6). Because of the volcanic inputs, the soils of the basin tend to be naturally high in phosphorus, which drives much of the primary productivity and subsequent water quality associations. Land use that shapes the flux of nutrients within the system can also affect water quality by increasing (grazing and logging) or decreasing (wetlands) nutrient loads, among other impacts. The climate of the basin is classified by the Köppen-Geiger as temperate with dry, warm summers (Peel et al. 2007 p. 1639) with most of the precipitation falling in the form of snow. Each water quality parameter that likely has significant impacts on the sucker species is summarized below. The vast majority of specific information on patterns and dynamics applies to Upper Klamath Lake, and as such, most of the following information deals specifically with that lake. Information for other water bodies in the range of the species is noted when available.

Dissolved Oxygen

The amount of oxygen (O_2) dissolved in water is controlled by water temperature, pressure and salinity (Graham 1990 p. 138). Important inputs of oxygen to lakes include diffusion from the atmosphere, inflow from streams and rivers, and photosynthesis from plants and **cyanobacteria**. Respiration due to decomposition of decaying organic matter is the major source of oxygen uptake in lakes, but photosynthetic plants during dark periods will also respire and uptake oxygen (Diaz and Breitburg 2009 pp. 2–4). Given that oxygen diffuses through water relatively slowly (Graham 1990 p. 137), the dynamics of inputs and uptake can create zones of extremely low oxygen concentrations.

Dissolved oxygen concentrations in spawning streams during the spawning migrations are generally not harmful to suckers because of the cold temperatures and churning of water in riffle areas, which increases oxygen concentrations. Concentrations in Upper Klamath Lake range annually from near 0 mg/L to greater than 10 mg/L (Morace 2007 p. 33), with notable spatial and temporal variation (Morace 2007 pp. 32–39). In Upper Klamath Lake, high nutrient loading (particularly phosphorus) causes massive, widespread blooms of *Aphanizomenon flos-aquae* (discussed in the Nutrients section below). As the bloom crashes, bacterial decomposition of the large quantities of organic matter consumes dissolved oxygen which often produces hypoxic and rarely completely anoxic (0 mg/L of dissolved oxygen) conditions in at least some locations in Upper Klamath Lake (Helser et al. 2004, entire, Lindenberg et al. 2008 p. 38). The severity of the dissolved oxygen depletion in Upper Klamath Lake varies depending on the size and timing of the bloom, wind action to mix the water column, and temperature (Laenen and LeTourneau 1995, entire, Helser et al. 2004, entire, Kann and Welch 2005, entire). At times dissolved oxygen levels in Upper Klamath Lake are continuously below the Oregon Department of Environmental Quality criterion of 5.5 mg/L for support of warm water aquatic life for weeks at a time during the summer (Kann 2017 p. 35). Hypoxic dissolved oxygen concentrations (generally < 4 mg/L) occur most frequently in late July and August (Morace 2007 p. 12). Decomposition of blue-green algae from Upper Klamath Lake through the Link River is the primary driver of low oxygen in the Keno Impoundment, including Lake Ewauna (Sullivan et al. 2010 p. 19). Dissolved oxygen within the Lost River has been listed as an impairment for the system (U.S. Environmental Protection Agency 2008 p. 40).

Lethal levels of dissolved oxygen were determined in laboratory settings for larval and juvenile Lost River and shortnose suckers by Saiki et al. (1999, entire) over a 4-day period (96 hours). Sublethal levels of DO were also determined for Lost River sucker juveniles by Meyer and Hansen (2002, entire) over a 14-day period. In both of those experiments, the range of DO concentrations that was lethal to at least 50 percent of the individuals exposed (LC_{50}) was from 1.34 to 2.10 mg/L. Dissolved oxygen levels in Upper Klamath Lake and downstream of the Keno impoundment during the summer period are sometimes at or below these levels. However, the duration and extent of when these conditions occurs varies, in both depth and location, and is influenced by other factors including water stratification, bloom decline, and wind-driven circulation (Wood et al. 2006 p. 29).

Nutrients (nitrogen/ammonia & phosphorus)

The Upper Klamath Basin has naturally high levels of nutrients in the soils, particularly phosphorus (Bradbury et al. 2004 p. 159) due to the numerous surrounding volcanoes that have been active in the recent geologic past. Runoff and erosion deliver phosphorus downstream to lakes, elevating them from the naturally eutrophic state to hypereutrophic. In Upper Klamath Lake, phosphorus concentrations vary seasonally and spatially (e.g., annual median values of total phosphorus > 250 µg/L; Kann 2017 p. 16). Irrigated pasture is a substantial nutrient source to Upper Klamath Lake (Ciotti et al. 2010, entire). Other external sources of phosphorous further add to eutrophication of Upper Klamath Lake (Bortelson and Fretwell, Marvin 1993 p. 9). The elevated levels of phosphorus in Upper Klamath Lake contribute to shifts in the algal community, now dominated by the non-toxic cyanobacteria AFA (Eilers et al. 2004 p. 13). Details of algal dynamics are further discussed in the "Chlorophyll-*a* and Algal Toxins" section below.

The dynamics of nutrient cycling in Upper Klamath Lake were highly affected by the loss and modification of fringe wetlands converted to other land uses. Wetlands influence nutrient dynamics through 1) trapping and immobilization of nutrients and sediments, and 2) production of dissolved organic matter. By slowing down water currents and decreasing wave action, wetlands act as sediment traps and temporary storage for water where wetland plants can help to immobilize nutrients through uptake and subsequent burial in the soil (Bradbury et al. 2004 p. 156). Marsh peats and organic soils typically act as sinks for nutrients and organic matter under natural conditions because decomposition is slower in anoxic soils than deposition of new material (Snyder and Morace 1997 p. 44). When wetlands are drained, the exposure of peat soils to air and oxygenated water leads to the release of sequestered nutrients and organic matter through accelerated decomposition (Snyder and Morace 1997 p. 42).

The nutrient and sediment dynamics in the remaining wetlands around Upper Klamath Lake also may have changed due to changes in the dynamics of lake elevations. A natural rock reef that marked the terminus of Upper Klamath Lake and the beginning of its outflow, the Link River, acted as a sill and kept the minimum lake level at 1262 m (4140 ft). Lowering of the reef and subsequent construction of Link River Dam (1921) allowed water to be stored and managed for agriculture purposes, which meant higher than historical levels during storage periods and lower levels during usage periods (Figure 11). Lake level fluctuations went from a potential range of approximately 1 m (3ft) historically to 2 m (6 ft) (National Research Council 2004 p. 99). Remaining wetlands can become dewatered at low lake levels. Virtually all of the fringe marsh areas of the lake are dewatered at a lake level of 4138 ft, and approximately half is dewatered at a lake elevation of 4140 ft (Reiser et al. 2001 p. 5.6-5.7). Similar to the effects of draining wetlands, temporarily exposing intact wetlands to air and oxygenated water during periods of low lake elevation likely increases decomposition of organic matter and leads to nutrient release (Snyder and Morace 1997 pp. 41–42).

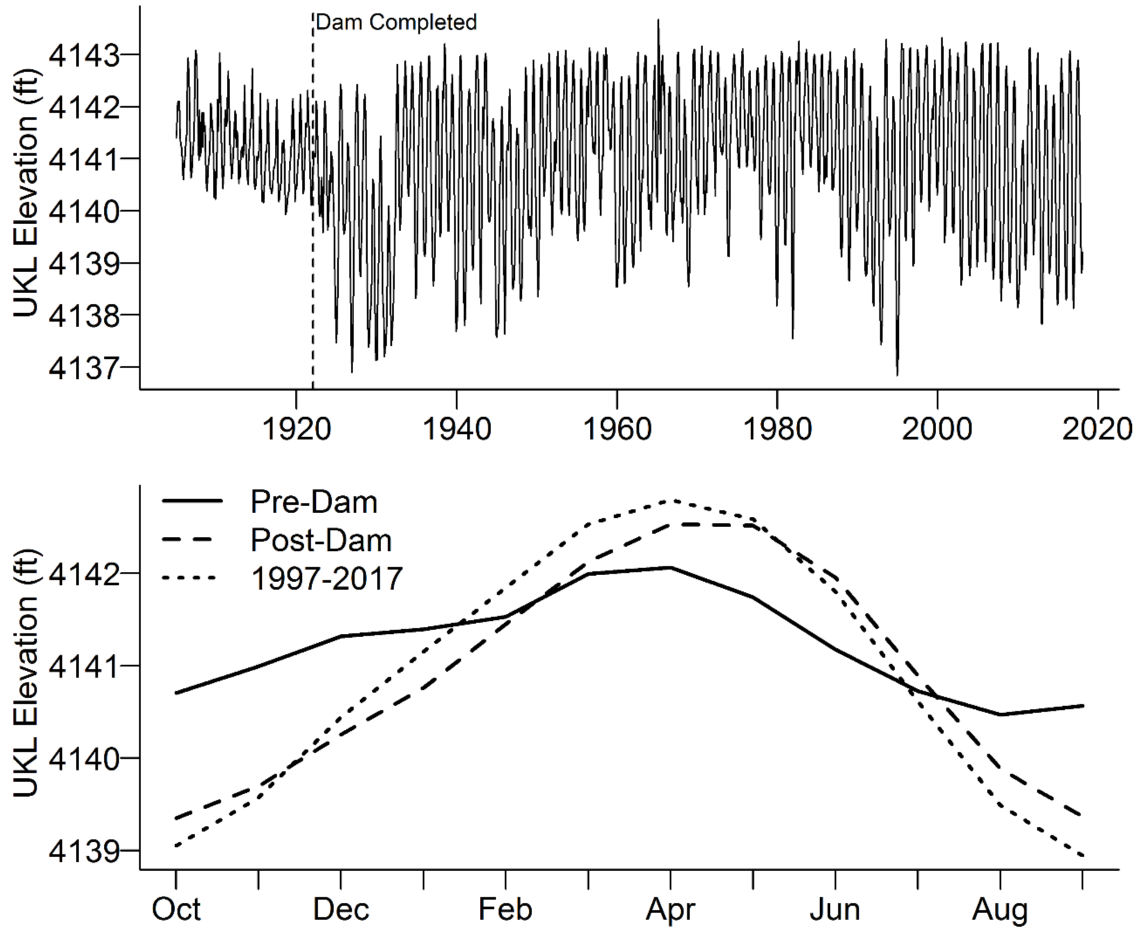


Figure 11 Historical Upper Klamath Lake end of month elevations. The lower panel shows averages across the pre-dam (1905-1921), post-dam (1922-2017), and 1997-2017 periods.

In the Lost River portion of the basin, crop cultivation is the dominant land use and utilizes water from Clear Lake and Gerber Reservoirs as well as from Upper Klamath Lake (via private and Bureau of Reclamation Klamath Project canal systems). Ammonia concentrations in the Lost River are slightly lower in the upper reaches of the system (U.S. Environmental Protection Agency 2008 p. 41), which ultimately increases nutrient loading in Tule Lake sumps at the terminus of the Lost River. Nutrient concentrations are nearly tripled as the water moves from the bottom of the Lost River system through the refuges and the Klamath Straits Drain (U.S. Environmental Protection Agency 2008 p. 38).

During the 20th century, removal of trees and disturbance of the landscape during harvest led to erosion and increased sediment and nutrient delivery (Eilers et al. 2004 pp. 8 & 15). However, best management practices are in place to minimize the effects, at least from Federal activities.

There are two forms of ammonia in solution: ionized and un-ionized. The latter is more toxic to fish, and the proportion of each depends on temperature and pH of the water. Shortnose sucker larvae require un-ionized ammonia to be below 0.48 milligrams/Liter (mg/L; Lost River sucker) and 1.06 mg/L (Saiki et al. 1999 p. 40). The lowest significant partial-mortality concentration of un-ionized ammonia determined for larval Lost River suckers is 0.69 mg/L at a pH of 9.5 (Lease et al. 2003 p. 496). Un-ionized ammonia concentrations occasionally exceed these concentrations at deeper areas in Upper Klamath Lake during late July, coincident with blue-green algae bloom decline and low dissolved oxygen levels. However, it is unknown how long these periods last. It is also unknown what the geographic extent of these conditions due to the limited locations of sampling conducted historically.

Primary Productivity & Algal Toxins

Cyanobacteria (commonly known as blue-green algae) are common within many water bodies throughout the world. Cyanobacteria are unique bacteria in that they photosynthesize similar to plants, with oxygen as a by-product (Graham et al. 2016 p. 3). The influence of blue-green algae throughout an ecosystem can be substantial (Karjalainen et al. 2007, entire). These organisms strongly affect physical (temperature and turbidity, for example) and chemical (dissolved oxygen and pH, among others) properties of water, as well as inputs of toxins.

Populations or communities of cyanobacteria are often able to exploit the favorable conditions of Upper Klamath Lake to produce rapid and widespread blooms during the summer (Hoilman et al. 2008 pp. 15–21). Shading of the water column can result, which may affect light availability for the cyanobacteria (Kann 2017 p. 26). Additionally, in studies (Kahru 1993, entire) and modelling (Hense 2007, entire) marine cyanobacterial blooms where found to increase water temperature through increased solar energy absorption. . The associated organic matter with a massive bloom may also affect turbidity and potential disrupt the ability of juveniles to feed, perhaps by disrupting their vision (Engström-Öst et al. 2006 p. 112, Engström-Öst and Mattila 2008 p. 278). No specific data for Upper Klamath Lake suckers permit evaluation of this hypothesis.

Some species of blue-green algae may produce toxins, such as microcystin. Microcystin has been implicated in what is called netpen liver disease (Andersen et al. 1993, entire), which can result in high rates of mortality of fish, particularly salmonids (Kent 1990 p. 21). *Microcystis aeruginosa*, a species capable of producing microcystin, inhabits Upper Klamath Lake. The toxin has been detected in Upper Klamath Lake in potentially toxic concentrations (Caldwell Eldridge et al. 2012 p. 12). Much smaller abundance of *M. aeruginosa* occurs during the summer, compared to AFA, but *M. aeruginosa* is likely responsible for the production of microcystin in the lake, with concentrations in 2007–2008 peaking at 17 µg/L (VanderKooi et al. 2010 p. 1). Additional microcystin data collection in Upper Klamath Lake is ongoing, including studies of possible effects of algal toxins on native suckers. Juvenile suckers may incur exposure through ingestion of microcystin as they feed on chironomid larvae.

Upper Klamath Lake currently experiences enormous algal blooms annually from June to October (Kann 1997 p. 5). The complex timing and magnitude of the blooms vary among years and spatially; thus, it is difficult to link these dynamics to physical factors (Morace 2007, entire). Examination of lake sediment cores in Upper Klamath Lake has identified shifts in the relative abundance of the type of phytoplankton within the last two centuries. Starting in the second half of the 19th century, increases of diatom species indicated increased nutrient enrichment coincident with the arrival by settlers of European descent (Bradbury et al. 2004 p. 159). Similarly, the cyanobacterium AFA, which flourishes in phosphorus-rich environments, appeared in the late 19th century and became highly dominant in the system over the course of the 20th century (Bradbury et al. 2004 p. 162). The timing of shifts to an AFA dominated system suggests that the drainage of fringe wetlands around Upper Klamath Lake was a main cause of its current hypereutrophic condition (Bradbury et al. 2004 p. 164).

Historically, the presence of vast areas of fringe wetlands throughout Upper Klamath Lake likely suppressed AFA blooms through the decomposition of organic matter and filtering of nutrient inputs. Byproducts of decomposition of Upper Klamath Lake marsh vegetation (such as tannins) can inhibit growth of AFA (Haggard et al. 2013 pp. 17–19). Additionally, dissolved organic matter stains water a dark color, which reduces light penetration, and therefore, primary production (Solomon et al. 2015 p. 378). Dissolved organic matter can also directly bind nutrients making them inaccessible to primary producers (Jones 1992 p. 77). A historic description of Upper Klamath Lake having "a dark color and a disagreeable taste, occasioned apparently by decayed tule" (Williamson and Abbot 1855 p. 67) suggests the presence of high dissolved organic matter concentrations. Another early observer noted that the lake bottom was composed of large quantities of decomposing wetland vegetation (Evermann and Meek 1897 p. 62). The diking and draining of marshes around Upper Klamath Lake described above in the wetland habitat section likely reduced dissolved organic matter along with its inhibitory effect on AFA (Haggard et al. 2013 pp. 19–21).

pH

Levels of pH in the Klamath Basin vary daily, seasonally, and by location (Martin and Saiki 1999 p. 957, Morace 2007 p. 12). In eutrophic systems, pH levels tend to fluctuate widely during the summer months, often on a daily basis. During times of high algal productivity, water pH is usually between 9.0 and 10.0 during the daytime (Kann 2017 p. 8) because the cyanobacteria are photosynthesizing, which consumes dissolved carbon dioxide from the water. Dissolved carbon dioxide in the water is in equilibrium with carbonic acid (Wetzel 2001 p. 188). Therefore, when cyanobacteria or plants consume carbon dioxide during photosynthesis, some of the dissolved carbonic acid converts to carbon dioxide, thereby reducing the acid concentrations and increasing (making more basic) the pH of the water (Wetzel 2001 p. 201). The reverse happens at night when the blue-green algae respire and whenever bacteria decompose organic matter, such as dead blue-green algae cells. Because of these dynamics, blue-green algal photosynthesis and respiration cycles can cause pH to fluctuate by over an order of magnitude (i.e., > 1 pH units) over a 24-hour period[3].

Generally, pH in the reach from Link River Dam through the Keno Impoundment increases from spring to early summer and decreases in the fall; however, there are site-dependent variations in the observed

[3] See U.S. Geological Survey pH data (2004 – 2018) for mid-north site in UKL as an example: https://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=422622122004003. Accessed December 10, 2018.

trend. Peak values can exceed the Oregon Department of Environmental Quality allowable maximum of 9.0. Values in the Tule Lake Refuge consistently exceed a pH of 9, which is the maximum numeric objective, and values in the upstream Klamath Straits Drain often exceed the maximum numeric objective (U.S. Environmental Protection Agency 2008 p. 41).

Elevated pH values in excess of 10 for sustained periods can significantly reduce juvenile survival for suckers (Saiki et al. 1999 p. 40). Looking at pH exposure values in Lost River sucker fry held in net pens in Upper Klamath Lake, Stone et al. (Stone et al. 2017 p. 8) determined that pH values exceeding 10 decrease the probability of their survival by 38 percent. Saiki et al. (1999 p. 40) also determined that pH levels between 10.3 and 10.39 were lethal for 50 percent of larval and juvenile Lost River and shortnose suckers exposed (in a laboratory setting) over 96 hours.

Temperature

Temperature regimes in water bodies are controlled primarily by absorption of solar radiation (Wetzel 2001 pp. 72 & 73). The flux of heat in lakes is largely associated with the surface, and so alterations to the surface area or depth of a lake (such as impoundments) will likely affect the thermal regime. Based on USGS water quality **Sondes** deployed in Upper Klamath Lake that record temperatures hourly, temperatures exceeding 28°C (82.4°F), which has been identified as a high stress threshold for Lost River and shortnose suckers (Loftus 2001 pp. 2–11), did not occur at four of five sites in the years 2008 to 2017. Temperatures higher than 28°C (82.4°F) did occur in some years in the upper water column along Eagle Ridge, the deepest section of the lake, but the duration was less than 6 hours in all years except 2017. Temperatures exceeding 25°C (77°F), the low stress threshold for suckers (Loftus 2001 pp. 2–11), were more common and occurred in most years at most sites, with single events lasting for multiple days in some cases. These frequencies are similar to the findings from temperature measurements during the 1990s, which indicated frequent low stress events but only very rare high stress conditions (Loftus 2001 pp. 3 & 4).

The temperature range lethal to at least 50 percent of larval and juvenile Lost River and shortnose suckers over 96 hours is between 30.0 to 31.9°C (86.0 – 89.4°F; Saiki et al. 1999 p. 40). This indicates the two sucker species have tolerance limits for surviving in many lakes/reservoirs of the Upper Klamath Basin where suckers occur. Stone et al. (Stone et al. 2017 p. 9) determined that increased temperatures reduce Lost River sucker survival, and that each 2.5°C (4.5°F) increase in temperature decreased fry survival by 47 percent over the 7 days of exposure. This emphasizes the importance of thermal relief provided by springs in Upper Klamath Lake and the flows from the Williamson and Wood Rivers - particularly during the summer.

Indirect and Synergistic Effects on Suckers

The collapse of large algal blooms has been linked with fish die-offs in Upper Klamath Lake, which have been observed periodically since at least the 1960s (Perkins et al. 2000a, entire). The development of algal blooms raise pH and un-ionized ammonia concentrations to levels that may be stressful to suckers (Saiki et al. 1999 p. 40, Morace 2007 p. 13). Although the observed mortality appears to be linked most directly to low oxygen, chronic stress due to high pH, ammonia, and temperature earlier in the season may increase sucker susceptibility to low oxygen conditions (Perkins et al. 2000a p. 29). Hourly measurements of dissolved oxygen and pH, and weekly measurements of ammonia during the summers of 2013 and 2014 in Clear Lake indicated these parameters were less variable than in Upper Klamath Lake and did not cross stress thresholds for suckers (Burdick et al. 2015a pp. 19–21).

We do not have adequate data for Gerber Reservoir to understand its water quality dynamics in detail. However, data collected more or less regularly from 1992 – 1995 indicate maximum summer temperatures around 22° C (71°F; Piaskowski and Buettner 2003 p. 28). Dissolved oxygen minimums also appeared to remain above 4 mg/L during this same period (Piaskowski and Buettner 2003 p. 27). In the same study, pH varied between 6.5 and 10.3 (Piaskowski and Buettner 2003 p. 11).

Poor water quality conditions may also cause indirect impacts, such as increasing sucker susceptibility to disease, parasites, and predators through increased stress levels and altered behavior. Stressful conditions, such as low DO, increase the probability of infection with bacteria and parasites, as well as disease, which often does not manifest without stressful conditions that weaken fish immune systems (Herman 1990 pp. 46–50). Thus, suckers with compromised immune systems have a higher probability of dying due to infection. Similarly, altered behavior due to stressful water quality conditions is likely to lead to higher rates of predation. When larval and juvenile suckers were exposed to low DO, they had difficulty swimming and exhibited gasping behavior at the water surface (Saiki et al. 1999 p. 41). In the wild, this behavior would increase exposure to avian predation. Additionally, adult suckers seek refuge from poor water quality in spring-influenced areas that have clear water and are shallower than preferred depths (Banish et al. 2007, entire); increased visibility and reduced depth may increase exposure of adults to avian predation as well. Thus, exposure to poor water quality is likely to increase mortality from other stressors.

Harvest

Migrating suckers were a historically important food source for the Klamath Tribes and were harvested in large numbers during the spring months (Bendire 1889 p. 444, Evermann and Meek 1897 p. 60). Settlers of European descent also depended on sucker migrations as a source of food and oil. Some commercial harvest for food and fish oil occurred around the early 1900s. Historical accounts of sucker harvest from the late 19th century describe a large fishery on the Lost River for fish migrating upstream from Tule Lake (Bendire 1889 p. 444, Gilbert 1897 p. 6). Blockage of the population from its spawning habitat for agricultural purposes eventually eliminated the fishery. However, a large recreational fishery for suckers eventually developed in the Williamson and Sprague Rivers. In 1967, the Klamath Falls fisheries agent for the Oregon Fish and Game Commission was quoted in the newspaper as stating, "we've estimated that about 100,000 pounds—that's 50 tons—of mullet [suckers] were snagged out of the two rivers in a three-week period" (Cornacchia 1967). This snag fishery, which targeted primarily Lost River sucker but included shortnose sucker (Bienz and Ziller 1987 p. X), existed in the Williamson and Sprague Rivers up to 1987 when the Oregon Fish and Game Commission outlawed harvest of both species.

Up until 1987, fishing pressure during the spawning migration likely contributed to population declines in Lost River and shortnose sucker in the Williamson and Sprague Rivers, but the magnitude of the effect is difficult to discern due to a lack of data on population sizes and harvest quantities during most of the 20th century. At present, some Lost River and shortnose sucker are captured while anglers target other species in Upper Klamath Lake; however, the numbers are likely small, and anglers are required by law to immediately release the fish.

Climate Change

Models predict annual average temperatures in the Upper Klamath Basin will rise 2.1 to 3.6 °F from the 1960-1990 baseline by the decade of 2035-2045 due to climate change (Barr et al. 2010 p. 8, Risley et al. 2012 p. 4). At present, lethal temperatures for suckers are uncommon, but stressful temperatures for suckers occur with regularity (see the above section on Temperature). Climate change will increase the frequency and duration of these stressful temperature events and is likely to make high stress events more common.

Changes in precipitation are highly uncertain. Annual precipitation may increase or decrease overall under climate change (Barr et al. 2010 p. 8, Risley et al. 2012 p. 4). However, climate models consistently predict that a larger proportion of annual precipitation and run-off will occur as rain events in the winter (Barr et al. 2010 p. 9, Risley et al. 2012 p. 4). Warmer temperatures during the winter will also reduce the proportion of precipitation falling as snow. Precipitation in the form of snow acts somewhat as a buffer for the hydrologic system, providing more gradual and manageable input into the lakes than rain. It is more difficult to predict the effects of precipitation changes to suckers, but they will alter the dynamics of spring flows, reducing the size of snowmelt runoff during the spawning season. This may restrict access to spawning areas in smaller watersheds, such as those entering Clear Lake and Gerber Reservoir, and reduce reproductive success when spawning is possible.

Klamath Basin Sucker Assisted Rearing Program

The USFWS started an assisted rearing program for Lost River and shortnose sucker in 2015 to supplement populations in Upper Klamath Lake through augmentation. The primary target of the effort are shortnose sucker, but the lack of an efficient way to identify larvae and juveniles means that both species are collected and reared. The Bureau of Reclamation proposed funding such a program as a way to improve the environmental baseline of the species to minimize impacts to suckers that may result from Klamath Project operations with a 10-year target of releasing 8,000 to 10,000 suckers with lengths of at least 200 mm. The USFWS funded expansion of the program to an annual target level of 5,000 suckers through 2019 in an effort to meet goals outlined in the recovery plan.

The program was designed to maximize genetic diversity and maintain natural behaviors post-release as much as possible (Day et al. 2017 pp. 306 & 307). Larvae are collected as they drift downstream in the Williamson River, so no brood stock are maintained and the effects of artificial breeding are avoided. Collection efforts extend across the drift season to maximize the genetic variability. Juveniles are stocked into semi-natural ponds and growth depends on a combination of natural and artificial feed.

The first release of reared suckers into Upper Klamath Lake occurred in spring 2018, so the proportion of released individuals that will join the spawning population is unknown. Thus, the assisted rearing program is likely to be a source of recruitment for both shortnose and Lost River sucker in Upper Klamath Lake, but the impact on population trajectories will be uncertain until information on survival and recruitment probabilities of released individuals is available.

Environmental Contaminants

Contaminants from agricultural application of pesticides could be deleterious to suckers. However, an evaluation of pesticide use on Tule Lake National Wildlife Refuge concluded that the type and concentration of chemical applications were unlikely to harm suckers in Tule Lake (Haas 2007 p. 3). Mercury deposited from the atmosphere can be highly toxic to fish and wildlife when it is converted into methylmercury. Methylation is stimulated by repeated inundation and drying, which occurs in the wetlands around Upper Basin Lakes as well as on the lands of Tule Lake and Lower Klamath National Wildlife Refuges where lands are rotated between agricultural use and wetland habitat for waterfowl (Eagles-Smith and Johnson 2011 pp. 27 & 28). However, mercury concentrations measured in suckers and other fish from the Upper Klamath Basin in 1988-1989 were below the national average for all fish (Sorenson and Schwarzbach 1991 p. 41). Overall, there is not strong evidence that contaminants have contributed substantially to the decline of sucker populations in the Upper Klamath Basin.

Predation

Lost River and shortnose suckers evolved with predation pressure on larvae and juveniles from native fish species, including redband trout (*Oncorhynchus mykiss newberrii*), blue chub (*Gila coerulea*), and Tui chub (*Gila bicolor*). Non-native fishes are a potential threat through predation or as sources of exotic diseases/parasites. Approximately 20 fish species have been introduced accidentally or deliberately into the upper Klamath River basin. These comprised about 85 percent of fish biomass in Upper Klamath Lake when the suckers were listed (Scoppettone and Vinyard 1991 p. 375, National Research Council 2004 pp. 188 & 189). The introduced fish species most likely to affect Lost River sucker and shortnose sucker are the fathead minnow and yellow perch (*Perca flavescens*). Additional **exotic**, predatory fishes, although typically in relatively low numbers, include bullheads (*Ameiurus* species), largemouth bass (*Micropterus salmoides*), crappie (*Pomoxis* species), green sunfish (*Lepomis cyanellus*), pumpkinseed (*Lepomis gibbosus*), and Sacramento perch (*Archoplites interruptus*; Koch et al. 1975 p. 17, Logan and Markle 1993 pp. 27–29). These fish may prey on young suckers and compete with them for food or space (Markle and Dunsmoor 2007 pp. 573–577).

Fathead minnows were first documented in the Klamath Basin in the 1970s and are now the most numerous fish species in Upper Klamath Lake (Simon and Markle 1997 p. 146). Controlled experiments have demonstrated that adult fathead minnows prey on sucker larvae (Markle and Dunsmoor 2007 p. 573). In Upper Klamath Lake, higher fathead minnow abundances were associated with lower sucker catch rates (Markle and Dunsmoor 2007 p. 576). Likewise, as indirect evidence, higher larval sucker survival rates were also associated with greater water depth and shoreline vegetative cover, habitat that helps larvae avoid predation (Markle and Dunsmoor 2007 pp. 575–576). These data suggest that predation by overly abundant fathead minnows may be an important threat to larval sucker survival and that loss of emergent wetland habitat may exacerbate this. Other non-native fishes may also pose a threat to Lost River sucker and shortnose sucker; however, little **quantitative** information exists to indicate their influence on sucker abundance and distribution.

Several species of birds can prey on Lost River sucker and shortnose sucker. Bald eagles prey on spawning suckers at Ouxy Springs (one of five areas where Lost River sucker spawn along the eastern shoreline of Upper Klamath Lake) and spawning areas near the Chiloquin Dam site. In Clear Lake Reservoir, radio-tags and Passive Integrated Transponders (PIT tags) of individuals of both species have been located on islands associated with nesting colonies of American white pelican (*Pelecanus erythrorhynchus*), double-crested cormorant (*Phalacrocorax auritus*), and great blue heron (*Ardea herodias*). Pelicans and double-crested cormorants can target juveniles and adults. There are also numerous other species of piscivorous birds, including terns, grebes, and mergansers, that may prey on juvenile and larval suckers throughout their range. Avian predation can be responsible for mortality of up to 8.4 percent of available juveniles and 4.2 percent of available adults annually in Clear Lake (Evans et al. 2016a pp. 1261 & 1262). Low dissolved oxygen leads to gasping behavior in juvenile suckers (Martin and Saiki 1999 p. 41), which increases exposure to avian predators near the lake surface. Initial study indicates that a minimum of 6-8 percent but more likely approximately 12-16 percent of juvenile suckers in Upper Klamath Lake are consumed by nesting pelicans and cormorants; juvenile suckers are likely susceptible to predation by other species such as Caspian terns, western grebes, and common mergansers (Evans et al. 2016a p. 1265). It is difficult to determine whether avian predation has increased or decreased relative to historic levels, but bird populations in general in the Klamath Basin have certainly declined from historic numbers. Consequently, it is more likely that the absolute amount of predation has also diminished.

The primary effect of predation to the species is a reduction of numbers (i.e., resiliency), particularly of the smaller life stages. Predation on spawning adults also increases mortality rates of this crucial, sensitive life stage. Additionally, predation may alter behavior of targeted life stages. For example, predation on adults at spawning sites may limit the amount of time spent on the spawning ground. Alternatively, juveniles may select less optimal habitat if predation pressure is higher, which could be reflected in individual condition and eventually survival rates. These types of impacts could potentially have effects on diversity (i.e., representation) if differential predation occurs among various genetic groups due to differences in life history strategies or geographic locations. However, data are still relatively sparse on how predation specifically affects survival rates of these species.

Disease and Parasites

Numerous classes of parasites infect LRS and SNS, some of which are associated with morbidity and mortality. Infections can cause physiological stress, blood loss, decreased growth rates, reduced swimming performance, lower overwinter fitness, and mortality, especially in small fish (Marcogliese 2004, entire, Kirse 2010, entire). Additionally, parasites may provide a route for other infectious pathogens by creating a wound in the skin, or they can make fish more susceptible to predation by modifying their behavior (Robinson et al. 1998 pp. 605 & 606, Marcogliese 2004, entire).

The LRS and the SNS are hosts to various species of bacteria, protozoa, myxozoa, trematodes, nematodes, leeches, and copepods (Foott 2004 pp. 3 & 4, Janik 2017 pp. 6 & 7). These can infect the eye, gills, kidney, blood, heart, muscle, skin, and gut. Many of these are pathogenic and can be associated at times with morbidity in suckers (Foott 2004 pp. 3–5, Foott and Stone 2005 pp. 7–9, Foott et al. 2010 pp. 5–13, Burdick et al. 2015a pp. 36–39, Hereford et al. 2016 pp. 35–38).

It is likely that most of the parasites currently able to infect Klamath suckers share an evolutionary history with suckers, suggesting that it is unlikely that native parasites cause the annual loss of juvenile cohorts. It is possible that the advent of a hyper-abundant introduced species has also increased the number of parasite hosts in the system. This could then theoretically increase the total number of parasites in the system, which could increase the infection rates of suckers. This phenomenon is known as parasite spillback (Kelly et al. 2009, entire). Furthermore, *Lernaea cyprinacea* (commonly known as anchor worms) are introduced (Plaul et al. 2010 p. 65) and frequently parasitize sucker juveniles (Janik 2017 pp. 48 & 49). While it is clear that parasites and disease affect individual survival, we currently do not have enough information to assess accurately the degree to which these negatively affect sucker population survival and viability.

Parasites were not identified as a threat at the time of listing, but recent information suggests they could be a threat to the suckers (Kent et al. 2017, entire). Kent et al. (2017) found substantial heartworms that indicate significant impacts to juvenile suckers, but the data set is not large enough to determine conclusively. Anchor worm parasitism on **age-0** suckers appears to be highly variable from year to year in Upper Klamath Lake (Bottcher and Burdick 2010 p. 15), ranging from 0 to 40 percent annual infection rates between 1995 and 2008 (Simon and Markle 2007 pp. 15 & 19). In a study of juvenile Lost River sucker survival in *in situ* cages in Upper Klamath Lake, most moribund fish were infested with *Ichthyobodo*, a protozoan parasite typically found in skin and gills (Hereford et al. 2016 p. 35). Parasites have both been identified as an ultimate source of mortality for some juvenile suckers that likely increases under chronic stress (Hereford et al. 2016 p. 35). Poor water quality is also likely to increase susceptibility of juvenile suckers to diseases and parasites (Snieszko 1974, entire, Walters and Plumb 1980, entire).

The effects of parasitism and disease are effectively identical to the effects of predation presented above, namely a reduction of numbers or alteration of behavior that can ultimately be expressed as a reduction in average survival rates of a given life stage. We currently do not have enough information to assess the degree to which parasites negatively impact sucker survival and productivity.

Hybridization and Introgression

Hybridization is a single interbreeding event between individuals of two species. Introgression is the subsequent incorporation of genetic materials into the genome of the species resulting from numerous hybridization events (i.e., back crossing). Introgression is common among suckers in general and well documented among the Klamath Catostomids, particularly between shortnose sucker and Klamath Largescale sucker (Dowling et al. 2016 p. 3). In theory, selective pressure that favors particular alternative strategies in life history, morphology, or other factors causes divergence among individuals. As the groups become more dissimilar, reinforcement of the distinction can occur as barriers to reproduction arise. Less complete barriers can allow gene flow (introgression) between the groups. The most typical result is dilution of the adaptations that characterize each individual species, generating intermediate forms and loss of specific characters that promoted distinction between the species. Ongoing introgressive hybridization is generally viewed as a negative effect because it potentially reduces diversity (representation) as the genes of the more numerically dominant species replace those of the rarer species. Additionally, this process may also reduce fitness if individuals are less adapted phenotypically to exploit specific niches within an environment. Depending on the degree of this reduction, it could result in lower survival rates and reduced population resiliency. It is also possible that introgression increases diversity by introducing new and beneficial mutations into species genomes. This would possibly increase diversity both within and among populations (Dowling et al. 2016 p. 2), but for rare species it is more likely that introgression will result in a reduction of the integrity of the genome as genes from more common species overwhelm the rare species (Rhymer and Simberloff 1996 p. 83).

Water Management

The Bureau of Reclamation manages several reservoirs in the upper Klamath Basin to provide water for the 250,000-acre Klamath Project, established in 1905. The largest reservoirs include Upper Klamath Lake, Clear Lake Reservoir (both are modified natural lakes) and Gerber Reservoir. Numerous other public and private control structures are scattered throughout the range of the species. Water management creates the possibility of **entrainment** through water control structures into canals, ditches, and other modified habitats. Here we use the term entrainment to mean the transport (typically involuntary) of suckers at any life stage through any water control structure, regardless of whether it is into a canal or the **tailwaters** below a dam on an otherwise natural river.

We classify structures associated with water management into two types: those intended to impound water (such as dams) and structures intended to divert water at diversion points into canals. Much of the information associated with impoundment structures, particularly dams, is addressed above in the section on Habitat Loss. These structures alter the nature of the habitat both upstream and downstream, most often in ways detrimental to the viability of the species. For example, habitat below Clear Lake Dam no longer functions as a migration corridor for spawning individuals because of impassable barriers, and does not provide optimal habitat for **outmigrating** larvae given the unnatural flow patterns through the system. Conversely, the habitat above the dam has changed from a system with a large vegetated wetland associated with open water prior to the dam to a nearly homogenous open-water system with few emergent plants in most years. The impacts of lake levels on the species are addressed in the Habitat Loss and Water Quality sections of Chapter 3 above.

At the time of listing, flows into the A canal entrained thousands of suckers, including some adults, each year into the canal, the largest diversion canal in the upper basin. Construction of screening facilities over the A Canal reduced entrainment of suckers into this major diversion point of the Klamath Project, although larvae are still at risk. Under the present design, fish screened from entering the A Canal return to Upper Klamath Lake via pipeline at a point that is near the river gates of the Link River Dam (Marine and Gorman 2005 p. 1). The most significant diversion is the A Canal near the outlet of Upper Klamath Lake. This canal diverts between 500 cubic feet per second (cfs) to 1,000 cfs between April and October (USBR 2000 p. 23). To reduce the impact to adult and juvenile sucker, the canal was fitted with a fish screen in 2003 (Bennetts et al. 2004 p. 4). Adults are blocked from entering the A Canal by a trash rack with vertical slits that allows water to pass, but blocks anything greater than 5 cm (2 in) wide. The screen itself is behind the trash rack, and effectively prevents fish larger than 20 mm (0.8 in) in length from proceeding into the canal. An estimated 10-40 percent of fish between 10 and 14 mm (0.4 and 0.6 in) pass through the screen (Simon and Markle 2013 pp. 31, 32, 72). The fish screen has reduced adult and juvenile entrainment by approximately 73-94 percent; still, 10,000s to 100,000s of larvae of each species are entrained annually into the A Canal (Simon and Markle 2013 pp. 31 & 32). The screen prevents juveniles from moving into the A Canal by diverting them in a bypass channel that uses gravity to transport fish for release into the Link River just below the dam or pumps the fish through a track that eventually releases them back into Upper Klamath Lake about 0.5 km (0.31 mi) above the Link River dam. The pumps that divert fish back to Upper Klamath Lake operate mid-July through September. All larvae that reach this point either pass through to the A Canal or are diverted downstream into the Link River.

Substantial entrainment also occurs at the river gates of the Link River Dam (Figure 12; Marine and Lappe 2009 pp. 1–4). More water passes through the Link River Dam than through the A Canal, but no fish screen has been installed due to logistical constraints; thus, larger numbers of larvae are likely to be entrained at the Link River Dam than at the A Canal (Simon and Markle 2013 pp. 31 & 32), but ultimately both systems insert the larvae at the same point in the Link River. During the late summer of 2006 through 2009, over 3,500 age-0 juvenile suckers were collected in the Link River just below the dam with intermittent sampling of a fraction of the channel (Laeder and Wilkens 2010 pp. 3–6, Wilkens 2010 p. 2). The Committee on Endangered and Threatened Fishes in the Klamath River Basin of the National Research Council recommended screening to prevent downstream losses at Link River Dam (National Research Council 2004 p. 348). Gutermuth et al. (2000 pp. 15–17) also documented tens of thousands of young suckers entrained at the PacifiCorp hydropower canals and turbines associated with the Link River Dam. PacifiCorp operates the East Side and West Side hydroelectric diversion that draw near the Link River Dam and run roughly parallel to the Link River. These diversions are currently shut down between July 15 and November 15 to reduce entrainment when vulnerable life stages of listed suckers are present. PacifiCorp has also completed a Habitat Conservation Plan (PacifiCorp 2013, entire). The company plans to limit the operations of these canals for power production, and, if approved, to eventually shut them down (PacifiCorp 2013 p. 64). Flows are now exclusively for maintenance and to provide very small amounts of irrigation water.

Figure 12 The Link River Dam (constructed 1921) looking north towards Upper Klamath Lake. The cement extension on the left of the dam is the newly constructed (2004) fish ladder to permit passage for suckers and other species. The patch of white in the river immediately upstream of the dam is the original rock reef that maintained the elevations of Upper Klamath Lake. The channels carved into the reef to allow for lower lake levels appear along the shores on either side. The dam is 6.7 m (22 ft) tall.

Juvenile and larval suckers that are entrained through the Link River Dam or the bypass channel of the A Canal screen are most likely transported by flows in the Link River to Lake Ewauna where poor water quality conditions are common. Extremely low dissolved oxygen concentrations (< 1 mg/L) occur annually, often for multiple months (Kirk et al. 2010 p. 2.36). Thus, larval and juvenile suckers are unlikely to survive in Lake Ewauna after entrainment at Link River Dam. Historically some larvae and juveniles likely immigrated to Lower Klamath Lake, which may have provided additional rearing habitat and suckers could subsequently return to Upper Klamath Lake. Lower Klamath Lake was drained for agricultural use, and the remaining wetlands are no longer hydrologically connected to Lake Ewauna for fish passage. Thus, age-0 suckers that leave Upper Klamath Lake through the Link River encounter poor water quality without the additional suitable habitat that was historically available. These suckers are likely lost from the Upper Klamath Lake population. Small numbers of suckers that passed through the fish screen as larvae are salvaged as juveniles from the canal system each year when it drains in late fall, but most larvae that pass through the screen likely die.

Until recently, most suckers that pass through the gates at Link River Dam or that survive passage through the hydroelectric facilities were probably lost from the breeding population. These individuals probably either died in poor water quality conditions in Keno Reservoir or passed further downstream into reservoirs along the Klamath River, from which upstream passage is blocked. However, recent surveys by the Bureau of Reclamation have detected a relatively small population residing in Lake Ewauna, indicating that some percentage of suckers persist following passage through the Link River Dam gates or the hydroelectric facilities. A new fish ladder was also constructed at Link River Dam in

2004 through which adult suckers have been documented using PIT tag readers moving upstream through Link River. Nevertheless, the number of detections of tagged fish traversing the fish ladder from Link River into Upper Klamath Lake each year typically numbers around 25 individuals.

There are also significant unscreened diversion structures that divert water from Lake Ewauna, including the Lost River Diversion Channel and Ady Canal, but very little data concerning the amounts of entrainment through these structures exists (Foster and Bennetts 2006, entire, Korson et al. 2010, entire). In addition to major diversion points, several hundred small, typically unscreened diversions in tributary streams and rivers and the lakes proper may also affect Lost River sucker and shortnose sucker. In 2001, the Bureau of Reclamation reported 193 diversions within the Klamath Project that were "directly connected to endangered sucker habitat below Upper Klamath Lake," with only three of these diversions equipped with fish screens (USBR 2001 p. 2). The Bureau also noted there are at least 24 large diversions outside of the Klamath Project service area but within the range of the species that have the potential of entraining suckers (USBR 2001 p. 3). The influence on sucker abundance and recovery of these diversions is unknown.

The Clear Lake Dam was rebuilt in 2004. The gates were screened at this time to prevent entrainment of any fish larger than 30 mm (1.18 in) through the dam into a system that generally lacks suitable sucker habitat. However, challenges with seating the screen well in the substrate at times does permit juveniles to pass through the dam in addition to larvae. Sutphin and Tyler (2016 p. 10) estimated that more than 260,000 larval suckers and 3,659 juvenile suckers were entrained through the dam from late April to late July 2013. The gates at Gerber Reservoir are unscreened and can permit all life stages of shortnose sucker to pass into Miller Creek (which becomes dewatered each year after the irrigation season), but we do not have any estimates of how many are actually entrained.

Research and Monitoring

Research and monitoring are additional factors that have the potential of directly and indirectly affecting the viability of both Lost River and shortnose sucker. Hundreds to thousands of adults and juveniles are captured each year to conduct various research and population monitoring activities. For the most part data are collected and the individuals are released back into the lake with minimal injury. However, the Service anticipates that in a single year mortality from these activities will be less than 35 adults and 30 juveniles, and that individuals harmed through injury will be less than 30 adults and 60 juveniles (USFWS 2018 p. 10). Nevertheless, these activities can potential promote the viability of the species through improved management due to more accurate information.

CHAPTER 4 – CURRENT CONDITION

In this chapter, we describe the status (in terms of resiliency, redundancy, and representation) of Lost River and shortnose sucker across their range. To avoid unnecessary repetition, we try to minimize the discussion of the habitat conditions and effects, detailed in Chapter 3. The purpose of this chapter is not so much to present the relative changes in resiliency, redundancy, and representation compared to historic levels, but to describe the current levels of these parameters.

It is clear that the abundance of suckers has greatly diminished compared to historic levels – a reduction in resiliency. In addition, the loss of a number of suitable lake habitats and their associated populations has reduced redundancy for both species. However, the specific causes of these conditions are often complex and at times unclear. We have created a simplistic conceptual model to present what we consider the most likely relevant causal factors (Figure 13).

Resiliency, redundancy, and representation are all inter-related. For example, the two spawning subpopulations of Lost River sucker in Upper Klamath Lake are redundant, which increases the resiliency of the population as a whole. In the sections below, we describe the conditions for each of the 3 R's of conservation while noting the areas of connection among the three.

Population Resiliency

Upper Klamath Lake contains the largest remaining populations of both Lost River and shortnose suckers with approximately 100,000 adult Lost River sucker river-spawners, 8,000 adult Lost River sucker shoreline-spring-spawners, and 19,000 adult shortnose suckers (Figure 14). Nevertheless, the resiliency of these populations has been dramatically reduced compared to historic levels. We consider the resiliency of both species in this population to be very low, although Lost River sucker are somewhat more resilient than shortnose sucker because they have greater numbers and two spawning subpopulations. The low resiliency is due to numerous inter-related factors. The primary cause for both species is a lack of recruitment of new individuals to the adult populations. This lack of recruitment has led to sharp declines in population sizes (Hewitt et al. 2017 p. 30). The primary limiting factor for the population appears to be juvenile survival because successful reproduction occurs annually and adult survival is relatively high.

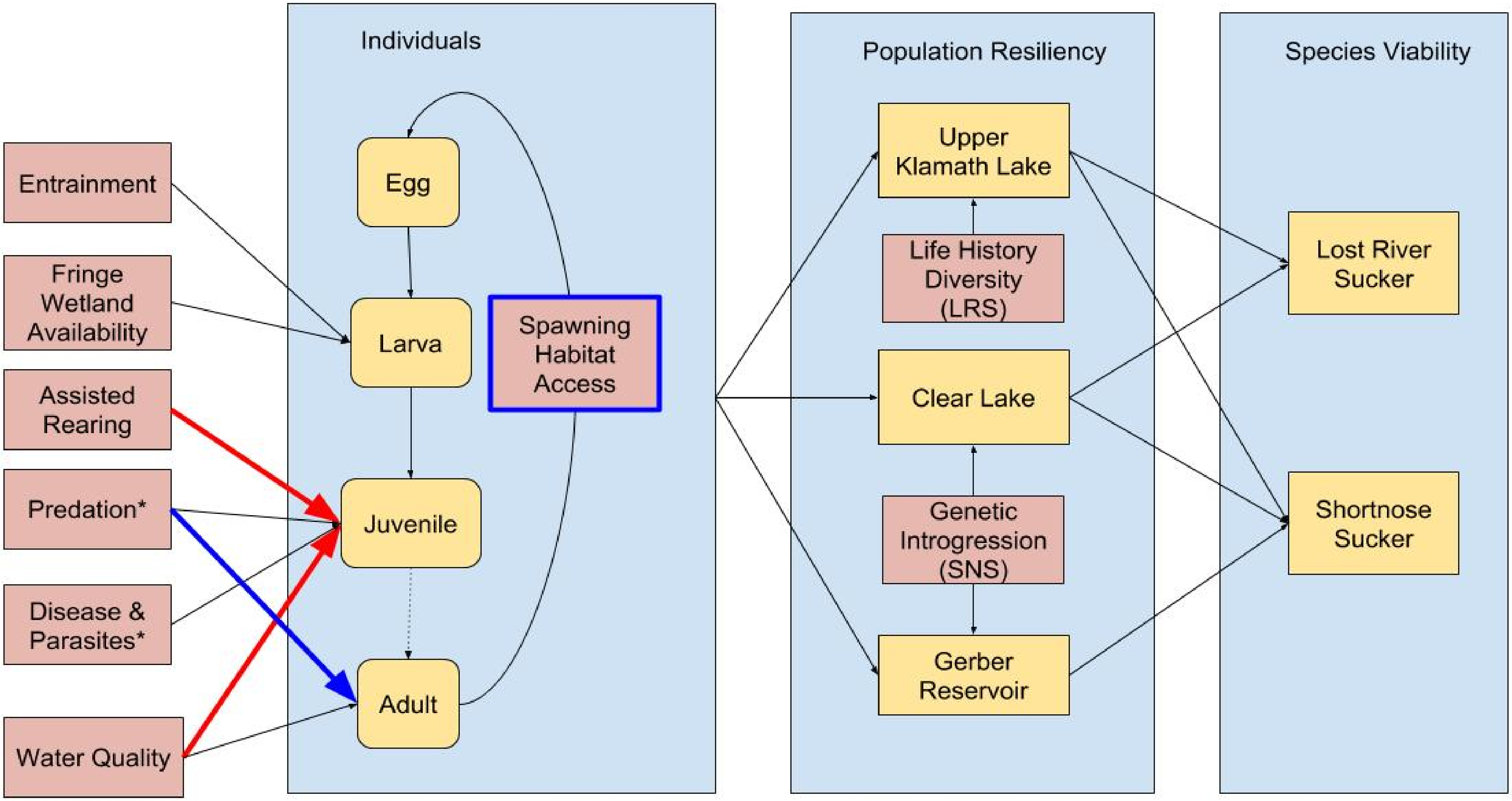


Figure 13 A simplistic conceptual model of the likely or most relevant causal factors affecting the status of the species. The pink boxes represent the causal factors, with arrows pointing to life stages or populations that we believe the factor affects. Bolded arrows represent factors believed to be strongest for that life stage, and the colored arrows (and box outline) indicate specific populations: red = Upper Klamath Lake, blue = Clear Lake Reservoir, and black = all populations. Individuals react to the specific causal factor and subsequently provide resiliency to the populations, as indicated by the middle blue box. Population-level causal factors are indicated here. Lastly, population contributes to the viability of the species. The attribute of redundancy is portrayed in the number of populations of each species.

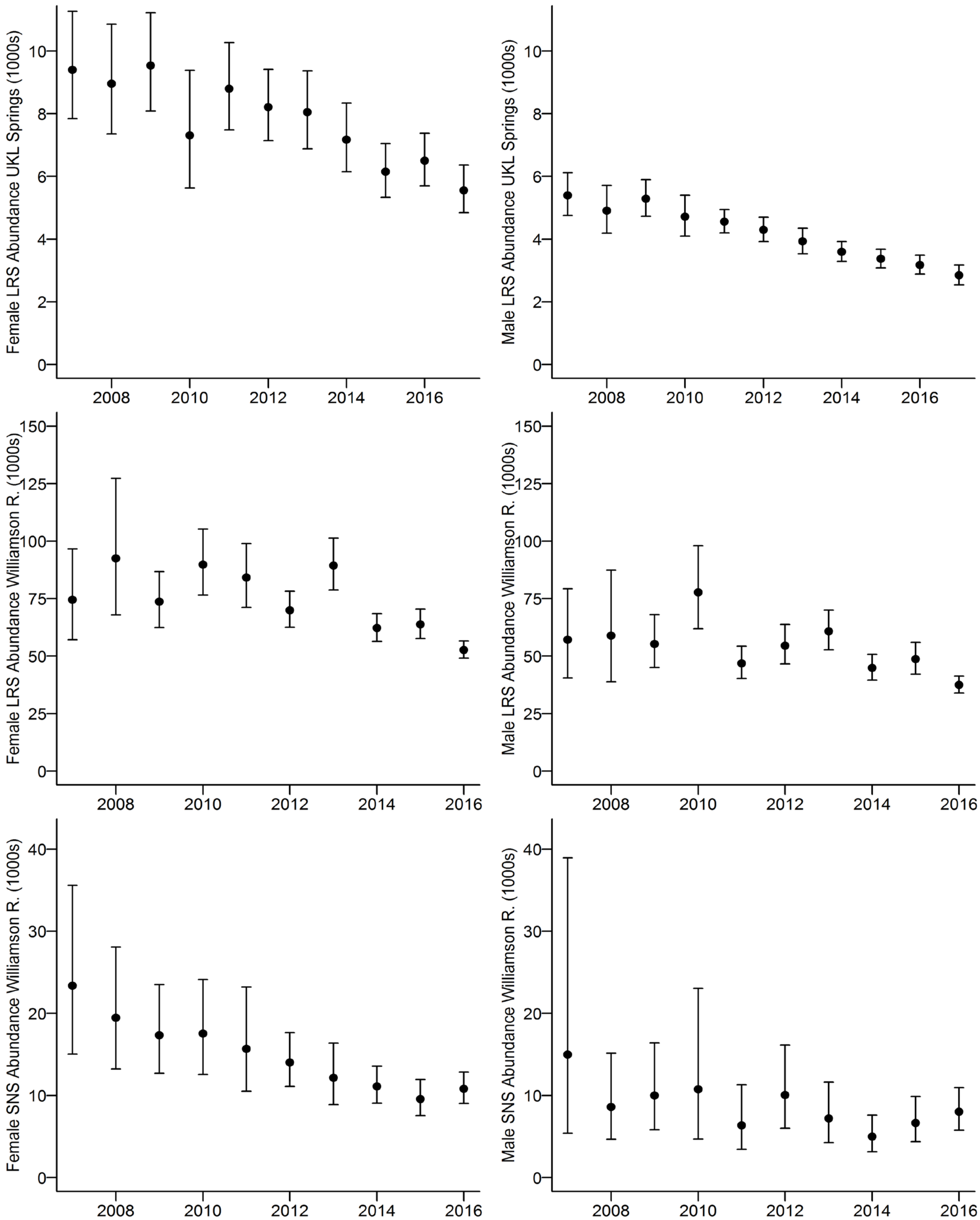


Figure 14 estimated abundance of spawning Lost River and shortnose sucker from Upper Klamath Lake. Points represent the mean estimate and error bars indicate the 95 percent credible interval.

The Lost River sucker population that spawns in the Williamson River drainage has declined by approximately 60 percent since 2002 (Hewitt et al. 2017 p. 22). In 2016, there were an estimated 49,074-56,546 (95 percent credible interval) female Lost River sucker and 33,920-41,251 (95 percent confidence interval) males spawning in the Williamson River (E. Childress, unpublished analysis). Lost River sucker that spawn at the lakeshore groundwater seeps is much smaller than the river-spawning population of Lost River sucker, with an estimated 4,847-6,360 (95 percent confidence interval) females and 2,538-3,170 (95 percent confidence interval) males spawning in 2017 (Figure 14, E. Childress, unpublished analysis). Similar to the Williamson River population, this lakeshore spawning population has declined an estimated 56 percent since 2002 (Hewitt et al. 2017 p. 16). The shortnose sucker population in Upper Klamath Lake has also declined substantially since 2001, losing approximately 75 percent between 2001 and 2014 (Hewitt et al. 2017 p. 25). Despite the steep declines in Upper Klamath Lake populations of Lost River and shortnose sucker, the size of the populations still provides some resilience to typical disturbances, but these levels are likely relatively miniscule when compared to historic levels.

Both species spawn successfully in the Sprague River, producing larvae that drift downstream to Upper Klamath Lake. Captures of 1,000s to 10,000s of larvae from the Sprague and Williamson Rivers (Cooperman and Markle 2003 pp. 1146 & 1147, Ellsworth and Martin 2012 p. 32) conservatively suggest that combined larval production of both species is on the order of 100,000s to 1,000,000s; note that these numbers are ballpark estimates and not a characterization of inter-annual variation, which is also substantial. Despite the removal of Chiloquin Dam on the Sprague River in 2008, the majority of spawning activity still occurs downstream of the former dam site with less than 10 percent of fish moving beyond the historic dam site (Martin et al. 2013 pp. 7–8). It is uncertain whether spawning further upstream would result in higher reproductive success or increased size or condition of larvae when they return to Upper Klamath Lake. Successful spawning in the Sprague River suggests that the needs of both species for spawning access and suitable egg incubation habitat are met to some degree. However, information on historical conditions is not available to compare with the limited data on recent years of larval production, so it is not possible to evaluate to what degree current conditions are suboptimal in the Williamson and Sprague Rivers.

Lost River sucker also spawn successfully at groundwater seeps along the Upper Klamath Lake margin. There is typically access to these areas between February and May; however, lake elevations lower than approximately 4141.40-4142.0 ft (1262.3-1262.5 m) reduce the number of spawning individuals and the amount of time spent on the spawning grounds (Burdick et al. 2015b pp. 487 & 488). Upper Klamath Lake elevations less than 4142.0 ft (1262.5 m) occurred by May 31 in six years between 1975 and 2017, which is equivalent to 14 percent of spawning seasons[4]. Thus, lake elevations have the potential to affect spawning for Lost River sucker, but this has rarely occurred over the last 43 years.

[4] See Daily Data for lake elevation: https://waterdata.usgs.gov/or/nwis/inventory/?site_no=11505800&agency_cd=USGS. Accessed March 19, 2019.

Production of sucker larvae in Upper Klamath Lake varies annually but occurs in all years (Ellsworth et al. 2010, entire). Sucker larvae are found in higher densities within and adjacent to emergent wetlands (Cooperman and Markle 2004 p. 370). The availability of these habitats varies with lake elevation (Dunsmoor et al. 2000 p. 19). Before the installation of Link River Dam, minimum annual lake elevations were typically greater than 4140.0 ft (1262.3 m; see Figure 11; Kann and Welch 2005 pp. 150 & 151), with most of the fringe wetland habitat inundated during much of the summer. Mean end-of-July lake elevations were similar between the pre-dam period and recent years 1997 and 2017 (Figure 11).However, end-of-month lake elevations in August and September are substantially lower under modern water management practices compared to pre-dam elevations and substantially reduce the amount of inundated wetland habitat. Although the population level implications of this management change are difficult to determine, reductions in available wetland habitat are likely to decrease larval and juvenile survival and thereby reduce the resiliency of the populations.

The number of juveniles captured in Upper Klamath Lake during sampling efforts typically decreases in late summer, and very few individuals are captured at age-1 or older (Burdick and Martin 2017 p. 30), suggesting complete **cohort** failure each year. These declines occur during the periods with the most degraded water quality conditions in Upper Klamath Lake, but a clear empirical link between water quality parameters and mortality rates is not conclusively established. One prominent hypothesis is that water quality is directly responsible for the unnaturally high levels of juvenile mortality. Another is that water quality interacts with other sources of mortality to lead to the persistent cohort failure by causing chronic stress that renders the individuals more susceptible to forms of predation or infection (as described in Chapter 3). The specific causes of repeated cohort failure at the juvenile stage are a critical uncertainty preventing recovery because juvenile mortality is the primary factor that contributes to the low resilience of both Lost River and shortnose sucker populations in Upper Klamath Lake.

Adult survival for Lost River and shortnose sucker is consistently high in Upper Klamath Lake, though annual survival rates vary somewhat between the species and spawning locations. Both spawning subpopulations of Lost River sucker in Upper Klamath Lake have experienced an average annual survival rate of 0.91 percent between 2002 and 2013 (range: 0.80 - 0.96 percent; Hewitt et al. 2017 pp. 15 & 21). Shortnose sucker experienced average annual survival rates of 0.84 percent during 2001 to 2013 (range: 0.69 - 0.95 percent; Hewitt et al. 2017 p. 28). Survival estimates of other populations are not possible due to a lack of data.

Clear Lake Reservoir currently supports the largest populations of both endangered suckers in the Lost River drainage. Data for the Clear Lake populations are very limited compared to those in Upper Klamath Lake, but we can generalize to a degree. Recent monitoring data suggest that the status of both species in Clear Lake Reservoir is tenuous given low resiliency.

Despite our inability to estimate accurately absolute abundance of the populations due to the lack of robust data, the low numbers of captures and recaptures suggests that these populations are smaller than those in Upper Klamath Lake are. This is particularly true for Lost River sucker. Between 2004 and 2010, only 1,360 individual Lost River sucker were captured in Clear Lake Reservoir (Hewitt and Hayes

2013 p. 5). In comparison, captures in Upper Klamath Lake of Lost River sucker averaged over 2,000 individuals annually with more than 12,000 individuals captured during this same time period (Hewitt et al. 2017 p. 12). Clear Lake sampling takes place in the fall whereas Upper Klamath Lake sampling occurs in spring when the fish congregate in preparation for spawning migrations, but the sheer magnitude of the difference suggests that the Lost River sucker population in Clear Lake Reservoir is much smaller than the Lost River sucker population in Upper Klamath Lake. The Clear Lake Lost River sucker population also appears to be much smaller than the Clear Lake Reservoir shortnose sucker population. Over the 2004 to 2010 period, 4.5 times as many individual shortnose sucker (6,240 individuals) were captured in Clear Lake Reservoir compared to Lost River sucker (Hewitt and Hayes 2013 p. 6). The average annual captures of individual shortnose sucker in Clear Lake Reservoir (1,040 per year) is comparable to Upper Klamath Lake rates (1,350 individuals) and may suggest that the population sizes are similar.

Several factors may contribute to the low population resiliency in Clear Lake Reservoir. One is access to spawning habitat. When conditions permit access, adults ascend Willow Creek, the single major tributary flowing into Clear Lake Reservoir, spawn successfully, and produce juvenile cohorts in Clear Lake Reservoir (Buettner and Scoppettone 1991 pp. 47 & 48, Sutphin and Tyler 2016 p. 10). However, adult access to Willow Creek is limited by lake levels and sufficiently high stream flows, and successful larval production also depends on stream flows high enough to permit subsequent downstream migration of drifting larvae (D. Hewitt, U.S. Geological Survey, personal communication).

One important source of larval mortality in Clear Lake Reservoir is predation by several native or non-native aquatic species, including blue chub, fathead minnow, Sacramento perch, or bullfrog (*Lithobates catesbeianus*). Additionally, entrainment by flows through the Clear Lake dam into the Lost River appears to be a significant impact to larvae and juveniles. Although a fish screen was installed when Clear Lake dam was replaced in 2002, it is estimated over 250,000 larval and 3,600 juveniles suckers were entrained through the dam in 2013 (Sutphin and Tyler 2016 p. 10). Nevertheless, when spawning conditions are suitable for producing strong annual cohorts (estimated to be slightly less than half of the years; D. Hewitt, U.S. Geological Survey, personal communication) juveniles, particularly shortnose sucker, can survive to recruit to the adult population. The multiple age classes of juveniles captured during sampling are evidence of this (Burdick and Rasmussen 2013 p. 14), as well as the diverse size class distributions of adults (D. Hewitt, U.S. Geological Survey, personal communication). Lost River sucker adults in Clear Lake Reservoir possess restricted size class distributions (see Burdick et al. 2018 p. 19). The cause of this distinction is not clear, nor are there generally accepted hypotheses.

Gerber Reservoir is only inhabited by shortnose sucker and the non-listed Klamath largescale sucker. This population of shortnose sucker likely has similar population dynamics to Clear Lake Reservoir populations, but data are much sparser. Surveys of the population in Gerber Reservoir last occurred in 2006. Based on mark-recapture data from 2004 (Leeseberg et al. 2007, entire), 2005, and 2006 (Barry et al. 2007, entire), the population of shortnose sucker may have been as high as 42,000 individuals. In 2015, drought conditions reduced water levels within the reservoir to approximately 1 percent of the maximum storage. This undoubtedly reduced shortnose sucker numbers because of the limited available habitat, but we do not have specific data to estimate accurately the extent of this reduction although BOR will initiate population monitoring in 2018.

The outlet of Gerber Reservoir does not have a fish screen, so suckers are vulnerable to entrainment downstream into Miller Creek, which historically flowed into the Lost River, but is now completely blocked and diverted for irrigation purposes. Small numbers of juvenile suckers (10s to 100s per year) have been caught in Miller Creek (Shively et al. 2000 p. 89, Hamilton et al. 2003 pp. 3–4), but the proportion of juveniles entrained and the population impacts of entrainment are unknown.

The other populations scattered throughout the range of the species have low resiliency, based on limited surveys (Desjardins and Markle 2000 pp. 14 & 15, Hodge and Buettner 2009 pp. 4–6, Kyger and Wilkens 2011 p. 3).

Redundancy

Redundancy of populations for these species has always been relatively low. Pre-settlement populations probably numbered no more than four for each species. Redundancy for both species has been greatly reduced due to the destruction of at least two major populations (Lower Klamath Lake and Tule Lake) as well as numerous subpopulations or spawning locations, namely at springs throughout Upper Klamath Lake and the Lost River. The draining of Tule Lake and Lower Klamath Lake for agricultural use essentially eliminated two of the major water bodies inhabited by both species. Lower Klamath Lake populations are completely extirpated and Tule Lake has a very small number of individuals that lack access to suitable spawning habitat. Because of this, Tule Lake does not provide substantial redundancy for the species. These water bodies represented two of the three major lake/marsh complexes in the Upper Klamath Basin; the remaining one is Upper Klamath Lake, which supports the largest extant populations of both species.

Although large swaths of habitat were destroyed throughout the range of the species, some of the developments for agricultural use increased available habitat for Lost River and shortnose suckers. In particular, Clear Lake was enlarged and lake elevations were stabilized by the creation of Clear Lake Reservoir. This increased the amount of accessible habitat available for this population, but it is unclear how this may have also affected the quality of habitat – for better or for worse. Clear Lake Reservoir supports populations of both Lost River and shortnose sucker at present. Additionally, the construction of a dam on Miller Creek to create Gerber Reservoir in the Lost River drainage created new **lacustrine** habitat in the reservoir that currently supports a population of shortnose sucker. Reservoirs constructed for hydropower production along the main stem of the Klamath River also support small numbers of suckers, but there is no evidence that these populations reproduce. Removal of these Klamath River dams under consideration so it is very unlikely that these populations will provide redundancy for the species in the future. Suckers were historically able to move among the various lake habitats, at least during periods of high water. There are important differences in the status and threats to the remaining populations, so the details for each location are discussed separately.

In terms of redundancy within a population, only the Lost River sucker in Upper Klamath Lake currently have more than one substantial spawning subpopulations. This provides some redundancy, albeit small, because of the low number of spring-spawners and the temporal and spatial overlap of spawners and adult habitat. For example, climate change will likely reduce snow pack and therefore reduce spring run-off in the river because of warmer temperatures and more precipitation falling as rain (Markstrom et al. 2012, entire, Risley et al. 2012, entire). These changes may reduce spawning success in the Williamson and Sprague Rivers, but are unlikely to impact the groundwater seeps in the same way.

There are four primary spawning areas along the eastern shoreline (Sucker, Silver Building, Ouxy, and Cinder springs), which are all within 6 km (3.7 mi) of each other. This proximity makes these spawning sites of reduced utility in resisting catastrophic disturbances. In addition to these extant spawning locations, there were additional historical spawning subpopulations at Barkley Springs, Harriman Springs and likely other springs throughout Upper Klamath Lake. These subpopulations have disappeared completely, greatly reducing the redundancy within the population. This loss increases the sensitivity of the population to widespread or catastrophic disturbances.

Both species in Clear Lake are entirely dependent on the Willow Creek watershed for spawning habitat. Lost River sucker utilize the lower portions of the creek as far as the confluence with Boles Creek, as well as Boles Creek (a tributary to Willow Creek) as far as Avanzino Reservoir (approximately 43 km [27 mi]). Shortnose sucker ascend both Willow Creek and Boles Creek much further than LRS (approximately 143 km [89 mi]). This provides a small amount of resilience for the SNS population in Clear Lake Reservoir, but the linkage between the two streams suggests that the redundancy benefit provided is minimal. It is not clear why LRS do not utilize the higher reaches of Willow Creek, especially because LRS are the species that travel the greater distance in the Sprague River.

There are at least two distinct spawning tributaries for shortnose sucker in the Gerber Reservoir system: Barnes Valley Creek and Ben Hall Creek. Approximately 88 percent of the adults leaving Gerber Reservoir to spawn ascend Barnes Valley Creek. The presence of two spawning streams creates some redundancy within the population that may help to increase the probability of successful spawning each year, as well as reduce the risk of localized catastrophic events, but the unbalanced utilization of the sites may reduce that benefit somewhat.

Listed Klamath suckers also occur in small numbers in a handful of other waterbodies. These populations consist almost exclusively of shortnose sucker, but also include a handful of Lost River sucker. The shortnose sucker are found in Lake Ewauna, Tule Lake, the main stem reservoirs, and the Lost River proper (Shively et al. 2000 pp. 82–86). Lake Ewauna probably functions as a subpopulation to Upper Klamath Lake to some degree. Hundreds of listed suckers (both species) have been captured, tagged, and translocated to Upper Klamath Lake from Lake Ewauna since 2010 (Kyger and Wilkens 2011 p. 3; N. Banet, U.S. Geological Survey, personal comment). Similarly, hundreds of individuals of both species were captured in Tule Lake during a three-year effort (Hodge and Buettner 2009 pp. 4–6). A two-year effort in the main stem reservoirs on the Klamath River (Desjardins and Markle 2000 pp. 14 & 15) produced slightly more than 200 captures, 99 percent of which were shortnose sucker. The number of catches given the effort suggests that these populations possess very few individuals. Lost River sucker only occur in Tule Lake in addition to the populations discussed above (Shively et al. 2000 pp. 87–89). All of these minor populations possess extremely low resiliency due to a combination of degraded habitat, low numbers, and restricted access to suitable spawning habitat.

Representation

Representation of diversity within and among populations of each species is difficult to quantify. **Hybridization** and **introgression** between shortnose sucker and Klamath largescale sucker is well documented, and evidenced by phenotypic intermediates in morphology (Markle et al. 2005 p. 476) and lack of discrimination among molecular markers (Dowling et al. 2016 p. 19). However, morphological distinctiveness of the species varies by location (Markle et al. 2005 p. 476). Spawning between these species is partially isolated temporally and spatially (Markle et al. 2005 p. 480). In Upper Klamath Lake morphological attributes of both species are more or less maintained, while other populations such as Gerber and Clear Lake reservoir show a spectrum of morphological intermediates (Dowling 2005 pp. 21 & 22). Despite genetic evidence of hybridization, the access to a diversity of habitats presumably maintains phenotypes of both species to some degree.

Genetic representation is lower for both species in Clear Lake Reservoir as compared to conspecifics in Upper Klamath Lake. In this reservoir, both species have lower heterozygosity and allelic richness compared to conspecifics in Upper Klamath Lake (Smith and VonBargen 2015 p. 24). Lower genetic diversity could be due to the population being derived from a limited number of individuals trapped when the dam was installed (i.e., founder effects) or simply due to genetic drift associated with small population size. Additionally, lack of connectivity with other populations also further depresses genetic diversity via reduced gene flow. Of more importance, the shortnose sucker population in Clear Lake Reservoir is highly introgressed with Klamath largescale sucker (Tranah and May 2006 p. 313, Dowling et al. 2016, entire). Shortnose sucker are more genetically similar to Klamath largescale within the same subbasin than they are to conspecifics from the other subbasin (Smith and VonBargen 2015 p. 14). Within the Lost River subbasin, shortnose sucker and Klamath largescale sucker can be difficult to distinguish morphologically. This can potentially erode species distinctiveness (genetic representation) within the population as well as reduce the abundance of phenotypic shortnose sucker (i.e., abundance of individuals that possess the morphology associated with shortnose sucker and thereby reduce the overall resiliency of the species within the reservoir). Genetic representation within the Gerber Reservoir population is very similar to that of Clear Lake Reservoir. The shortnose sucker are highly introgressed with Klamath largescale, and the population is isolated from other populations.

Unlike the shortnose sucker, hybridization and introgression involving the endangered Lost River sucker does not appear to be extensive (Dowling et al. 2016 p. 18). At present, both endangered suckers in Upper Klamath Lake possess population sizes large enough to maintain genetic diversity and prevent the negative effects of inbreeding. We cannot make similar conclusions about other populations because we lack accurate estimates of population sizes.

The draining of Tule Lake and Lower Klamath Lake and the construction of dams and irrigation structures has isolated the populations such that there is no exchange of individuals between the major remaining populations in Upper Klamath Lake, Gerber Reservoir, and Clear Lake, and the system no longer functions as a metapopulation. This reduction of redundancy and connectivity could also have negative impacts on representation of diversity within the species.

Maintenance of ecological and phenotypic distinction between shortnose sucker and Klamath largescale in Upper Klamath Lake suggest that introgression between these species does not threaten the resiliency of the endangered shortnose sucker population in Upper Klamath Lake. However, the resiliency of the shortnose sucker populations in Clear Lake Reservoir and Gerber Reservoir may be even less than it appears because few individuals possessing the distinct genetics and ecology of the species occur.

Species Level Conditions

Lost River Sucker

Overall resiliency for this species is generally low, primarily because redundancy is critically low (Table 3). There are only three distinct spawning populations: Upper Klamath Lake-springs, Upper Klamath Lake-river, and Clear Lake Reservoir. Two of the remaining populations (Clear Lake Reservoir and Upper Klamath Lake-springs) have very low numbers and are at a high risk of localized catastrophic events, such as fish kills due to poor water quality. The Clear Lake Reservoir population is isolated from the others. The Lost River sucker that spawn at the eastern shoreline springs of Upper Klamath Lake are unique. It is the only known spawning congregation outside of a river environment. This ecological redundancy could provide resilience to localized disturbances. However, juveniles produced from both spawning populations are subject to similar conditions in Upper Klamath Lake, and both experience recruitment failure due to high juvenile mortality.

As a species, Lost River sucker appear to be relatively genetically distinct. Mitochondrial DNA suggests only about 2.0 percent of Lost River sucker introgress with other species. This is the lowest of all the sucker species within the basin (Dowling et al. 2016 pp. 12 & 13). Nevertheless, the known genetic distinction from shortnose sucker is still relatively low (Hoy and Ostberg 2015 p. 675). Given these conditions the species was determined previously to have a high degree of the threat of extinction and a low recovery possibility (recovery priority number 4C; USFWS 2013b p. 3).

Shortnose sucker

Shortnose sucker also suffer from low resiliency as a species, despite having relatively high apparent redundancy compared to Lost River sucker. The low resiliency is due to the extremely low numbers in most populations, inadequate access to suitable spawning habitat for most populations, and genetic impurity in most populations (i.e., impaired representation). There are currently only three known spawning populations (Upper Klamath Lake, Clear Lake Reservoir, and Gerber Reservoir). There may be an additional two populations (Lake Ewauna and Topsy Reservoir – a Klamath main stem reservoir) where spawning could potentially occur, albeit in very small numbers. In Upper Klamath Lake there are fewer shortnose sucker than Lost River sucker, by nearly an order of magnitude, but shortnose sucker is more abundant than Lost River sucker in the Lost River subbasin overall. However, the number of populations is effectively reduced when we consider the high levels of genetic introgression with Klamath largescale sucker, and all of the populations are characterized by low abundance. Given these dynamics the species overall has been determined previously to have a high threat of extinction and a low recovery probability (recovery priority number 5C; USFWS 2013c p. 3).

Table 3 Population attributes for endangered suckers in the upper Klamath Basin. Locations are UKL – Upper Klamath Lake, CLR – Clear Lake Reservoir, GBR – Gerber Reservoir, and others (such as reservoirs on the Klamath River, Lake Ewauna, and Tule Lake sump 1A).

Species	Location	Population Size	Reproductive Success	Larval/Juvenile Entrainment	Larval/Juvenile Survival	Adult Survival	Resiliency	Representation	Redundancy (species)
SNS	UKL	Low	Presumed Adequate	Moderate	Low/Zero	High	Low	Moderate	
SNS	CLR	Low	Intermittent	Moderate	Moderate	Moderate	Low	Impaired	Moderate
SNS	GBR	Low	Intermittent	Moderate	Presumed Adequate	Presumed Adequate	Low	Impaired	
LRS	UKL	Moderate	Presumed Adequate	Moderate	Low/Zero	High	Moderate	Moderate	Low
LRS	CLR	Low	Intermittent	Moderate	Moderate	Moderate	Very Low	Unknown	
LRS/SNS	Other	Low	Low/Zero	Moderate	Low/Zero	Presumed Adequate	Very Low	Unknown	NA

CHAPTER 5 — FUTURE CONDITION

The purpose of this chapter is to identify plausible scenarios that may occur in the future, and provide assessments of how we believe specific populations of Lost River sucker and shortnose sucker will respond. Where data are sufficient we strive to be quantitative, but in many cases limited data compel us toward qualitative assessment. We assess the scenarios over a window of approximately 50 years, which was chosen to be long enough that biologically meaningful changes could occur in the ecosystem and/or the demography of the species, but short enough to provide some confidence in projections.

We address the two major populations (Upper Klamath Lake and Clear Lake Reservoir) of each species separately, including a status quo scenario as well other threat-specific scenarios. These populations are treated separately because the major threats, and therefore solutions to population declines, differ between the systems. The Gerber Reservoir shortnose sucker population is expected to behave similarly to the population in Clear Lake Reservoir. Similar scenarios were not completed for other smaller populations (e.g., Lake Ewauna, Tule Lake) due to a lack of data to support realistic scenarios and the minimal contribution of these populations to species viability. Any number of hypothetical scenarios could have been addressed, but our intent here is to only include scenarios that are both plausible and relevant. In some instances, we were unable to address specifically relevant threats because no plausible scenarios could be developed that would relate to changes in the dynamics of that threat. For example, creating feasible scenarios that involved alteration of the rates of genetic introgression between shortnose sucker and Klamath largescale sucker proved difficult. In other cases (parasite infection rates for example), scenarios were not considered because we did not believe that those factors currently play a major role in population dynamics, and probable outcomes would apparently differ very little from the status quo.

Several factors create difficulties in projecting Lost River sucker and shortnose sucker population responses into the future. Ecosystem function and species ecology are complex, and data are lacking on important demographic rates (such as egg viability, larval survival, etc.) as well as their responses to changes in the environment. Most importantly, the lack of adequate data on recruitment rates for any population—and the lack of recruitment in Upper Klamath Lake specifically—make it difficult to evaluate the response of this critical demographic rate to changes in environmental conditions with much certainty. The magnitude of direct and indirect ecological pathways, as well as interactive effects, also presents a noteworthy information gap. The sections below reflect our best understanding of the probable outcomes to these select possible future scenarios. Nevertheless, we believe this exercise is beneficial because it provides a framework to characterize expectations and illuminate potential management priorities to achieve recovery.

Upper Klamath Lake

Status Quo

Populations of Lost River sucker and shortnose sucker in Upper Klamath Lake do not appear to be successfully recruiting. New, small individuals are not found among spawning adults, which is expected if younger individuals were joining the spawning population, and juveniles disappear from the system within the first 1-2 years of life. If we assume that this pattern continues into the future, future population trajectories can be simulated simply using estimates of current population size and adult annual survival rates. This analysis was conducted combining abundance estimates (Figure 14; E.S. Childress, unpublished analysis) and annual survival estimates (Hewitt et al. 2017 pp. 15, 21, 28) to simulate population trajectories for 50 years (Rasmussen and Childress 2018, entire). Current population sizes are estimated to be approximately 90,000 Lost River sucker spawning in the Williamson and Sprague Rivers, 8,000 Lost River suckers spawning at the lakeshore groundwater seeps, and 19,000 shortnose suckers. Annual survival estimates were sex-specific and simulated as random draws from a distribution fit to the empirically derived survival estimates. In this approach, each simulation provides a unique trajectory, and together they represent the range of expected outcomes given the model assumptions.

Without additional recruitment, these simulations indicate point estimates for the probability of extirpation of SNS males from Upper Klamath Lake are 47 percent by year 2040 and greater than 99 percent by year 2046 (Figure 15 a,b). Females have a higher average annual survival rate and are projected to remain in the system longer with a probability of extirpation of 42 percent by year 2046 and greater than 99 percent by year 2054. Similarly, the LRS groundwater seep spawning population is projected to lose all males with a probability of 48 percent by year 2047 and 99 percent by year 2052 (Figure 15 c,d). Females from this population are projected to persist in small numbers at the end of 50 years (2067) with an average projection of 150 remaining individuals (range: 0-295). The larger numbers of LRS remaining in the Williamson River spawning population lead to projections of 0 percent probability of extirpation in spite of slightly lower annual survival rates than the groundwater seep population. However, the number of remaining individuals is projected to be quite small with an average estimate of 317 males (range: 80-904) and 1,341 females (range: 824-1,972).

These results portend a dire future for Upper Klamath Lake sucker populations if conditions do not change. Shortnose sucker would be completely lost, substantially reducing the redundancy of SNS overall through the loss of one of the three existing populations. Loss of SNS from Upper Klamath Lake would also substantially reduce representation because it is the least genetically introgressed with KLS and is the only remaining population with clear morphological distinction between the species. LRS may not be completely lost from the system after 50 years, but resiliency would be dramatically reduced. The small number of remaining individuals would be less resilient to disturbance events, and life history diversity would be lost through the elimination of one of two spawning populations. Further, reduced population resiliency would likely result in the loss of rare alleles, and as such, potentially limit adaptive ability to future environments. Representation would also be substantially reduced through a genetic bottleneck. At present, the LRS Upper Klamath Lake population represents one of two extant populations and by far the largest population; its loss or reduction to 1-2 percent of current abundance would put the species on the brink of extinction.

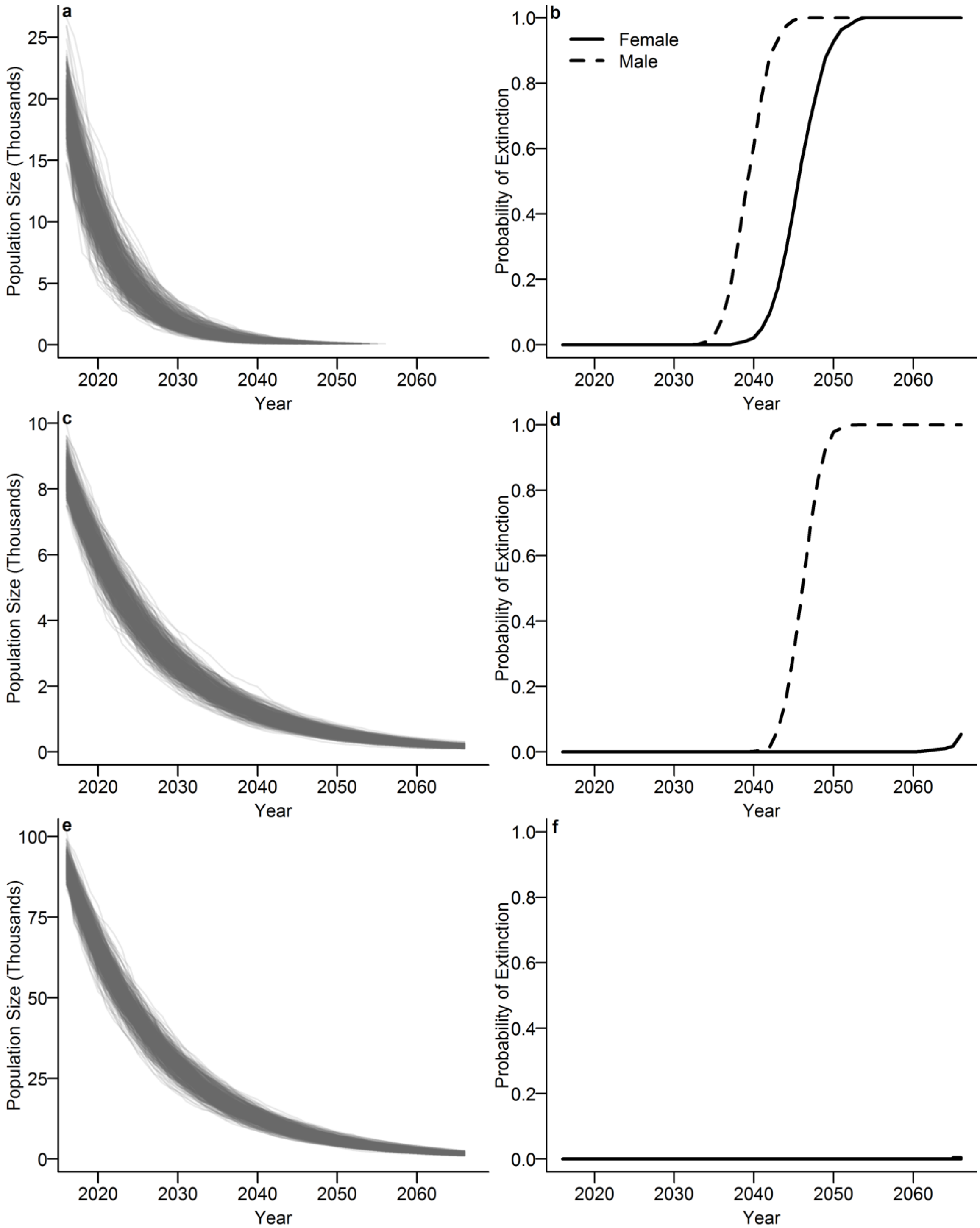


Figure 15 Simulated population trajectories (a,c,e) and probability of extinction (b,d,f) for Upper Klamath Lake sucker populations of shortnose sucker (a,b), Lost River sucker spawning at the lakeshore groundwater seeps (c,d), and Lost River sucker spawning in the Williamson River (e,f). These trajectories assume no new recruitment of individuals to the adult spawning population (Rasmussen and Childress 2018 p. 586).

Klamath Basin Sucker Assisted Rearing Program

One way to improve recruitment in the face of complete early life mortality is through an assisted rearing program. As discussed in Chapter 3, an assisted rearing program was initiated in 2015 with the dual goals of offsetting the harm and harassment of age 0 suckers during the operation of the Bureau of Reclamation's Klamath Irrigation Project and improving the status of SNS in Upper Klamath Lake population through successful recruitment. At present, this effort targets the release of 3,500 subadults (i.e., juveniles between 1 – 4 years old) per year that were collected as larvae from the Williamson River. The first release, which is likely to be substantially smaller than the target, occurred in spring 2018. The current program rears larvae of both endangered SNS and LRS, as identification during early life-stages is problematic. As identification methods become available, efforts will increasingly target SNS. The scale of the Klamath Basin Sucker Assisted Rearing Program is likely to be adjusted in the future to meet recovery goals for both species. Therefore, we present projections for Upper Klamath Lake sucker populations with the addition of varying numbers of individuals for varying durations.

The full details of the modeling and the statistical methods are detailed elsewhere (Rasmussen and Childress 2018, entire); however, two assumptions are important for interpretation of the results presented here. First, annual survival in the future was assumed to remain similar to what was been observed in the years 2002-2015. Second, stocked individuals were assumed to enter the population at age 4 and survive at the same rates as adults. This second assumption was necessary because no information on early life survival or the survival of reared individuals in Upper Klamath Lake was available. However, this assumption means that actual production of stocked individuals would need to be higher than the nominal rates presented here to achieve the same results. Higher production would be necessary to offset mortality prior to reaching age 4.

Projections indicate that even relatively low production of age-4 individuals can greatly reduce the probability of extinction in 50 years (Figure 16). However, they also indicate that short-duration stocking efforts, even at relatively high levels, will not be effective at sustaining abundance. Stocking at rates that would produce at least 2,500 age-4 shortnose sucker per year for the next 50 years would be required to sustain the population at or above its current level. Although a shorter duration effort could achieve the same result, it would still require 35 to 40 years of stocking 10,000 individuals annually. Lower levels of Lost River sucker stocking would be necessary to maintain the groundwater seep spawning population because of lower starting population size and higher survival rates. As few as 500 age-4 individuals per year for the next 50 years would be required to sustain current population abundance; alternatively, 10,000 individuals could be stocked for ~20 years, which would lead to strong initial population growth and a subsequent decline, but a similar population size would be expected after 50 years (Figure 16). Despite relatively high annual survival rates, a higher starting population size of the Lost River sucker population in the Williamson River means that at least 5,500 age-4 individuals would be necessary to maintain the population at its current abundance. A shorter duration program could achieve the same results, but it would still require 10,000 individuals for at least 40 years.

One significant uncertainty for rearing efforts to maintain the Lost River sucker population at the lakeshore groundwater seeps is whether Lost River suckers hatched at the lakeshore will return to spawn at the same location. Although there is strong site fidelity for spawning adults, who return to the same spawning location very consistently year after year (Burdick et al. 2015b pp. 484 & 485) it is not known whether they establish their spawning location based on early life imprinting, genetic predisposition, attraction to spawning congregations upon maturity, or some other mechanism. Depending on the mechanism, reared Lost River sucker collected at the lakeshore spawning grounds or in the Williamson River may recruit to either population.

The results of these projections suggest that assisted rearing has the potential to maintain Upper Klamath Lake sucker populations over the next 50 years even in the absence of natural recruitment if current adult survival rates continue into the future. However, production of reared individuals would need to be higher than current levels to achieve stable abundance for all of the populations. Likewise, it is expected that production would need to continue until consistent natural recruitment in the lake occurs. Significant uncertainties remain about survival and recruitment rates for reared individuals, which will influence the reliability of the estimates presented here. As reared individuals are repatriated to Upper Klamath Lake and monitored for survival and recruitment, it will be possible to refine projections to reduce uncertainty and improve the program's ability to meet particular population targets.

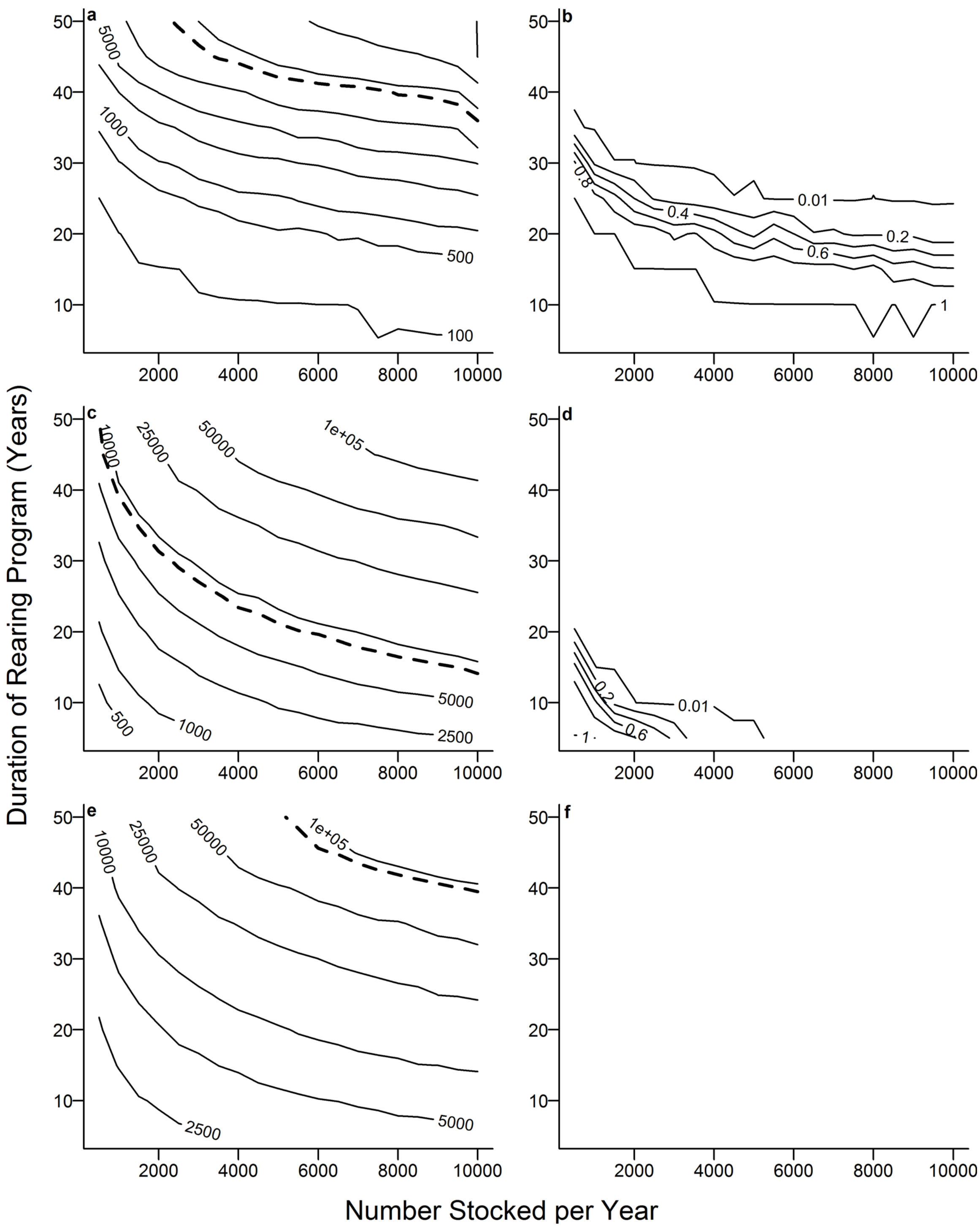


Figure 16. Median projected population size (a,c,e) and probability of extirpation (b,d,f) after 50 years for Upper Klamath Lake sucker populations of shortnose sucker (a,b), Lost River sucker spawning at the lakeshore groundwater seeps (c,d), and Lost River sucker spawning in the Williamson River (e,f) for assisted rearing scenarios at different scales and durations. Panel f is blank because the expected probability of extirpation is zero across all scenarios for Lost River sucker spawning in the Williamson River. In the underlying models, stocked individuals are assumed to be the only source of recruitment (reproduced from Rasmussen and Childress 2018 p. 587).

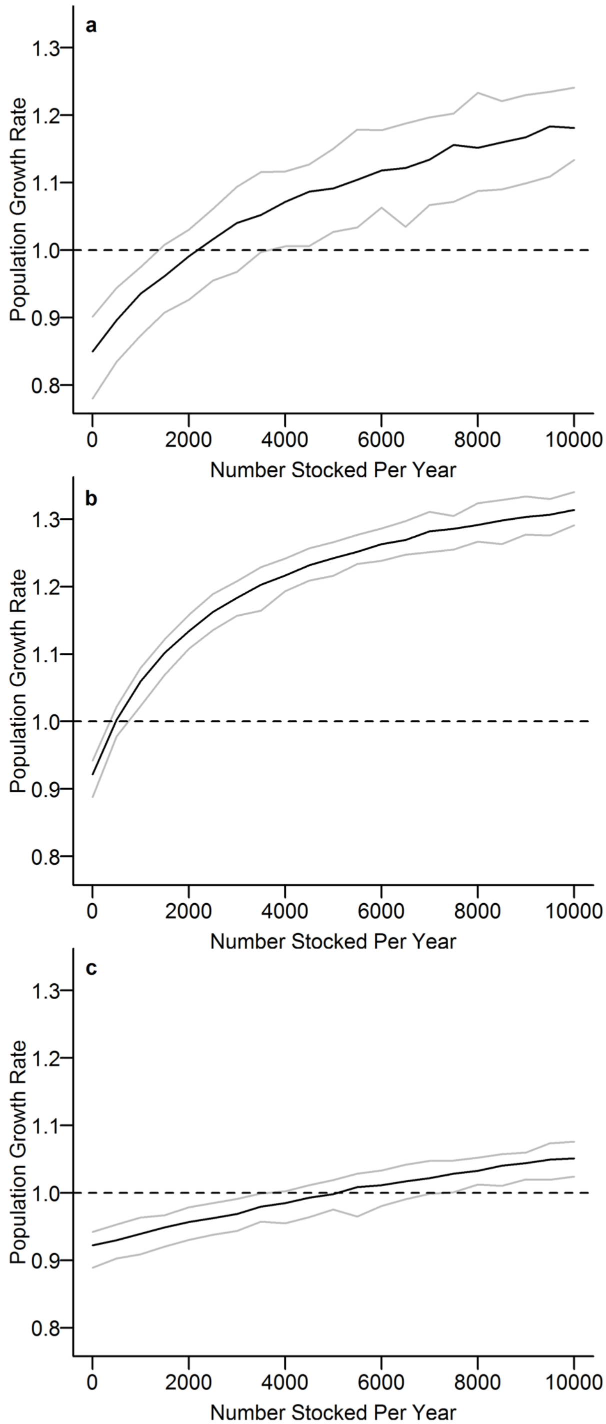


Figure 17 Short-term population growth rates (y-axis) in Upper Klamath Lake in response to stocking rates (x-axis) for shortnose suckers (a). Lost River suckers spawning at lakeshore groundwater seeps (b), and Lost River suckers spawning in the Williamson and Sprague Rivers (c). Black lines indicate the median result from simulations and 95 percent of the simulation results are contained within the gray lines (reproduced from Rasmussen and Childress 2018 p. 588)

Water Quality Improvements

Recent and ongoing restoration efforts aim to reduce phosphorus inputs to Upper Klamath Lake and are likely to benefit sucker populations via improvements to water quality. In this scenario, we evaluate the likely effects of reductions in phosphorus loading on sucker populations in Upper Klamath Lake. The Oregon Department of Environmental Quality has identified a target of 40 percent reduction in external phosphorus loading to Upper Klamath Lake from 1992-1998 levels as the state water quality standard (Boyd et al. 2002 p. 65). Over the past two decades, there has been substantial effort to reduce nutrient inputs to Upper Klamath Lake through projects such as restoration of lake fringe wetlands and reduction of water use and nutrient export from grazed lands (Walker et al. 2012 p. 4). There is some indication that restoration efforts may have already reduced annual phosphorus loads approximately 11 percent below 1992-1998 averages, though there is substantial uncertainty due to interannual variation from environmental conditions (Walker et al. 2012 pp. 31 & 32). The draining and agricultural use of historical wetlands around Upper Klamath Lake has been a major source of nutrients (Snyder and Morace 1997 pp. 29–33), and there are continued efforts to restore these lands to wetlands. One notable pending effort plans to inundate approximately 14,000 acres of drained wetland habitat around the former Agency Lake Ranch and Barnes Ranch on the western shore of Agency Lake. Other efforts include fencing to prevent cattle access to creek beds and treatment wetlands for agricultural run-off. Meeting the phosphorus targets identified by Oregon Department of Environmental Quality (Boyd et al. 2002 pp. 63–67) is likely a best case scenario for the impact of such restoration efforts on phosphorus loads, so we assumed a 40 percent reduction in phosphorus inputs as the basis for this scenario and the analysis presented below. Phosphorus is often the limiting nutrient in freshwater systems and is the driving nutrient in this system.

A mechanistic model of the influence of phosphorus inputs to phosphorus availability, storage, and algal biomass is available from a recent study (Wherry and Wood 2018, entire). The model relies on a combination of empirically derived and theoretically based parameters. Given concurrent data on dissolved oxygen dynamics, the model does a good job of recreating phosphorus and algal dynamics. For predictions without reliance on oxygen data, which is necessary for future projections, the model still captures phosphorus dynamics but is less reliable in predicting algal biomass. The model indicates there is a lag between reduction in phosphorus inputs and reduction in phosphorus availability in Upper Klamath Lake due to recycling of phosphorus contained in lake sediments. It is likely to take over three decades for the system to reach new, lower equilibrium phosphorus concentrations after a 40 percent reduction in phosphorus inputs, but most of the benefit would occur much earlier. Approximately half of the reduction in actively cycled sediment phosphorus is projected to happen within the first five years and over two-thirds is projected to occur within a decade (Wherry and Wood 2018 fig. 18).

Reducing phosphorus inputs to Upper Klamath Lake is likely to reduce the magnitude of algal blooms and their deleterious effects, such as high pH and ammonium, and low dissolved oxygen (Boyd et al. 2002 p. 63). The predictive mechanistic model does not capture the extreme peaks of algal biomass or the crashes very well, so interpretation of the impacts of reduced phosphorus availability is necessarily qualitative (Wherry et al. 2015, entire, Wherry and Wood 2018, entire). Still, there is strong evidence that phosphorus limits the growth and magnitude of algal blooms in Upper Klamath Lake, including a strong correlation between total phosphorus and algal biomass in Upper Klamath Lake, suppression of bioavailable phosphorus during bloom development and almost complete sequestration of phosphorus in algal biomass during blooms (Walker et al. 2012 pp. 2 & 3). Thus, reduction in phosphorus availability should reduce the magnitude of algal blooms. Elevated pH and un-ionized ammonium and low dissolved oxygen are all byproducts of the algal dynamics in Upper Klamath Lake. As the bloom develops, pH becomes elevated and as it crashes dissolved oxygen decreases during decomposition. Un-ionized ammonium concentrations tend to peak between these two phases because ammonium is released during decomposition. Concentrations of the un-ionized form increases as pH increases (Thurston et al. 1979 pp. 7–427). Reducing the magnitude of the algal bloom should reduce the frequency of extreme pH, un-ionized ammonium, and dissolved oxygen levels since these are all a direct result of the extreme algal dynamics. The mechanistic model described above predicts a reduction of 44 percent in algal biomass peaks with a 40 percent reduction in phosphorus inputs. Interestingly, proportional reductions in algal biomass were predicted to be smaller for 10 percent and 20 percent reductions in phosphorus inputs with only 4 percent and 13 percent reductions in algal biomass, respectively. Although the specific reductions are difficult to assess at present, the frequency of deleterious water quality conditions should be substantially reduced by a 40 percent reduction in phosphorus inputs within 5-10 years of initiation of declines with continued improvements for 30 years.

We expect that these improvements would increase juvenile survival rates such that natural recruitment could occur. Although there is some uncertainty about the cause of total juvenile mortality, reductions in juvenile capture tend to overlap or follow the period of the worst water quality in late summer (see Burdick and Martin 2017 pp. 36 & 37), suggesting that water quality is a major component of juvenile mortality, but it is currently impossible to estimate the magnitude of the effect size. Improved water quality could also increase adult survival because die-offs are associated with low dissolved oxygen events; however, adult survival is relatively high under current conditions (Hewitt et al. 2018 pp. 12, 17, 21). Reproductive success and larval survival are less likely to be influenced by improvements to water quality because they occur outside the period of poor water quality; however, if fringe wetland restoration is the method for reducing phosphorus, increased habitat availability for larvae may increase larval survival and growth rates. Due to the relatively high adult survival rates, even low annual recruitment could sustain or increase population abundances (Rasmussen and Childress 2018 pp. 588 & 589). Alternatively, relatively rare, highly successful recruitment years could also sustain the populations (Rasmussen and Childress 2018 pp. 588 & 589). Therefore, we expect that the reduction in phosphorus inputs to Upper Klamath Lake could stabilize or increase the Upper Klamath Lake populations primarily through reductions in juvenile mortality within 10-30 years. However, the lag in the effects of reduced phosphorus inputs means that recruitment is not likely to occur within the first 5-10 years after restoration, which would lead to sharp declines in abundance (Figure 15). Combining reductions in phosphorus inputs with a rearing program that could sustain population abundance until the benefits of restoration are realized would lead to much faster recovery and reduced probability of extinction.

Clear Lake Reservoir

Given the relatively limited data on populations in Clear Lake Reservoir it is not possible to simulate population scenarios with enough confidence that would justify using this approach. Instead, we rely on expert opinion and assessment of probable outcomes given certain broad scenarios and our understanding of the ecology of Lost River and shortnose sucker. We determined that two future scenarios were plausible for the Lost River and shortnose sucker in Clear Lake Reservoir: status quo and improved access to spawning habitat. As with the scenarios for Upper Klamath Lake, we considered the likely outcome to these scenarios within the next 50 years.

Status Quo

The status quo scenario assumes that biological rates and trends over the next 50 years will be similar to the recent history. We assume that environmental conditions and variation, such as water management, agricultural practices, or many other factors, will continue as they have been in last two decades or so. However, our status quo scenario does assume that climate variation will be as predicted by broad climatic models.

Since the 1950s, climatic patterns of western North America generally have trended towards less snowfall (the primary source of precipitation in the upper Klamath basin), earlier snowmelt, and subsequently earlier peak spring runoff (Hamlet et al. 2005 pp. 11 & 12, Stewart et al. 2005 pp. 1140 & 1141, Knowles et al. 2006 pp. 4547 & 4548). Current climate models indicate that these trends are likely to continue into the future (Barnett et al. 2008 p. 1082). A suite of climate models predict that over the next 100 years the mean flow of the Sprague River will increase during winter months but decrease during the spawning period (Markstrom et al. 2012 pp. 121–123, Risley et al. 2012 pp. 3–5). We expect similar patterns will occur in the Clear Lake Reservoir watershed.

Lost River Sucker

The population of Lost River sucker in Clear Lake Reservoir is characterized by very low population size, limited recruitment, and spawning within two streams, with limited distribution in Willow Creek. If current environmental conditions persist, we expect that similar population dynamics will also persist. Climatic conditions consistent with current trends are likely to impact negatively the population through changes to habitat and/or vulnerability to predation. Access to spawning habitat could become even more restricted due to reduced spring flows, further reducing resiliency by limiting annual larval production. Less precipitation overall will result in restricted habitat availability (in the reservoir or in persistent pools within the otherwise dry stream channel) that could result in degraded water quality or elevated predation from aquatic or avian sources. With the low population resiliency at present and likely further reductions in the future, the population is especially vulnerable to catastrophic events, such as extreme or extended droughts. Therefore, we believe there is a high probability that the population of Lost River sucker will be extirpated from Clear Lake Reservoir within the next 50 years.

Shortnose Sucker

The shortnose sucker population in Clear Lake Reservoir is somewhat more abundant than the Lost River sucker, suggesting greater resiliency. Although, the SNS population spawns in two streams compared to one, the streams are interdependent because one is a tributary to the other, which provides minimal if any redundancy to Clear Lake Reservoir populations. Nevertheless, data suggest that periodic reproduction and subsequent recruitment do occur within the population.

Considerations for the shortnose sucker population under the status quo scenario are only slightly more complex. Similar outcomes to those outlined above for the Lost River sucker are likely: reduced resiliency because of reduced larval production, increased predation, and/or habitat degradation. An additional outcome likely to affect the SNS population if current trends continue is dilution of the genome via persistent introgression with Klamath largescale sucker. This can result when individuals become crowded into less spawning habitat. A potentially analogous example occurred in Utah Lake when the June sucker and Utah sucker (*Catostomus ardens*) overlapped during spawning in severe drought conditions of the early 1930s. Miller and Smith (1981 p. 12) concluded that "pure" June sucker no longer existed because all remaining individuals appeared morphologically intermediate. They subsequently created the new taxon *Chasmistes liorus mictus* to describe June sucker (Miller and Smith 1981 pp. 15–17). A similar situation may arise in Clear Lake Reservoir with SNS and could lower resiliency by reducing the phenotypic integrity of SNS.

It is very likely that if current conditions continue the number of shortnose suckers in Clear Lake Reservoir will decline, thereby reducing resiliency. We cannot quantify the degree to which this will increase the risk of extirpation of the species, other than to note that it is possible that extirpation will occur within the next 50 years.

Improved Spawning Access

Access to spawning habitats for both species in Clear Lake Reservoir is a function of streamflow, reservoir water levels, and potentially the configuration of the stream channel just above the mouth of the creek. When water levels are high the reservoir connects directly to the spawning tributary at the mouth of Willow Canyon, but under lower water conditions there can be as much as an additional 3 km (1.9 mi) from the mouth of the canyon to the point where the creek connects to the reservoir. This connection is approximately 1.5 km (0.9 mi) above the dam, and may be as much as 8.6 km (5.3 mi) from the nearest suitable adult habitat – the area in between is often wetted but very shallow. These factors often interact, and in nearly half of the recent years, adults were not able to reach spawning grounds.

This scenario assumes that all potential impacts are unchanged from current conditions (status quo), with the exception that the frequency with which the adults are able to access the spawning habitat is increased. This could occur by several mechanisms: improvements to water management to produce higher water levels during the spawning period with greater frequency or physical reconfiguration of the channel within the reservoir to facilitate passage of migrating adults. A naturally wetter climatic cycle could also produce the similar outcomes. However, we do not specify the mechanism here, nor do we quantify the degree to which the increased access occurs. Our limited data restricts us from reliably analyzing such specific scenarios.

We believe that improved access to spawning grounds would benefit Lost River sucker and shortnose sucker in the similar ways. Both would produce annual cohorts more regularly that would eventually contribute numbers to the adult populations. This would increase the resiliency of the population to respond to periodic catastrophic events, but we are unable to postulate the degree to which this would impact the risk of extirpation of the populations.

Gerber Reservoir

In many respects, the ecology of the shortnose sucker population residing in Gerber Reservoir is very similar to the one in Clear Lake Reservoir. The population apparently consists of relatively few individuals, many of whom are introgressed with Klamath largescale suckers. The system possesses limited spawning areas and is subject to massive declines in reservoir habitat due to drought and water management. These conditions suggest that adverse weather and catastrophic events would be considerably challenge the population. We are unable to assess specific scenarios critically because we lack sufficient data to grant confidence in any specific conclusions. Nevertheless, we believe that it is probable that conditions and population responses are likely similar to the scenarios described above for shortnose sucker within Clear Lake Reservoir.

Species-level Effects

Based on the scenarios included here, it is likely that the Lost River sucker will continue to decline precipitously if conditions in Upper Klamath Lake remain unchanged. The species may remain in 50 years, but it is likely that it will be critically few in numbers. Given that the only other spawning population of this species, Clear Lake Reservoir, is extremely small, a substantial reduction in Upper Klamath Lake will put the species perilously close to extinction. These conclusions are contingent on the assumption that survival rates continue similar to the recent past; however, if survival should increase due to ageing populations, then we expect the declines to accelerate. This could significantly truncate our period of reference.

If current conditions continue, we expect the shortnose sucker population to go extinct within the next 30-40 years. Projections suggest that shortnose suckers populations will decline by 78% over the next 10 years to fewer than 5,000 individuals, if conditions persist. This would result in only two populations remaining for the species, both of which are highly genetically introgressed with the Klamath largescale sucker and geographically isolated behind dams without fish passage.

Both species are likely to realize greater stability from implementation of the rearing program, but landscape-scale improvements to nutrient loads in Upper Klamath Lake will be necessary to achieve full recovery. The dire conditions of Lost River sucker in Clear Lake Reservoir suggest that recovery of the species will likely be unattainable given the likely scenarios analyzed here and the requirement to have a viable population in the Lost River basin as well as the Upper Klamath Lake drainage. Recovery of the species is likely to require substantially more drastic actions than the few considered here. Recovery of shortnose sucker appears more achievable in the Lost River sub-basin under the scenarios assessed, but uncertainties about the overall impacts of genetic introgression remain.

LITERATURE CITED

Akins, G. J. 1970. The effects of land use and land management on the wetlands of the upper Klamath Basin. Western Washington State College, Bellingham.

Andersen, R. J., H. A. Luu, D. Z. X. Chen, C. F. B. Holmes, M. L. Kent, M. Le Blanc, and D. E. Williams. 1993. Chemical and biological evidence links microcystins to salmon 'netpen liver disease.' Toxicon 31:1315–1323.

Banish, N. P., B. J. Adams, and R. S. Shively. 2007. Distribution and habitat associations of radio-tagged adult Lost River and shortnose suckers in Upper Klamath Lake, Oregon: 2005-2006 report. U.S. Geological Survey, Western Fisheries Research Center, Klamath Falls Field Station.

Banish, N. P., B. J. Adams, R. S. Shively, M. M. Mazur, D. A. Beauchamp, and T. M. Wood. 2009. Distribution and habitat associations of radio-tagged adult Lost River suckers and shortnose suckers in Upper Klamath Lake, Oregon. Transactions of the American Fisheries Society 138:153–168.

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. L. B.-2. P. L. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science 319:1080–1083.

Barr, B. R., M. E. Koopman, C. Deacon Williams, S. J. Vynne, R. Hamilton, and B. Doppelt. 2010. Preparing for Climate Change in the Klamath Basin:1–36.

Barry, P. M., B. S. Hayes, E. C. Janney, R. S. Shively, A. C. Scott, and C. D. Luton. 2007. Monitoring of Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers in Gerber and Clear Lakes, 2005-2006. Page (W. F. R. S. Klamath Falls Field Station U.S. Geological Survey, U.S. Department of Interior, Ed.). Klamath Falls, Oregon.

Barry, P. M., E. C. Janney, D. A. Hewitt, B. S. Hayes, and A. C. Scott. 2009. Population dynamics of adult Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers in Clear Lake, California, 2006-2008: Open File Report 2009-1109. U.S. Geological Survey, Reston, Virginia.

Bendire, C. E. 1889. The Lost River sucker. Forest and Stream 32:444–445.

Bennetts, D., C. Korson, and R. Piaskowski. 2004. A-canal fish screen monitoring and evaluation activities in 2003. United States Bureau of Reclamation, Klamath Falls, Oregon.

Bienz, C. S., and J. S. Ziller. 1987. Status of three lacustrine sucker species (catostomidae). The Klamath Tribes and Oregon Department of Fish and Wildife, Klamath Falls, Oregon.

Billington, N. 2003. Mitochondrial DNA. Pages 59–100 *in* E. M. Hallerman, editor. Population genetics: Principles and applications for fisheries scientists. American Fisheries Society, Bethesda.

Bortelson, G. C., and O. Fretwell, Marvin. 1993. A review of possible causes of nutrient enrichment and decline of endangered sucker populations in Upper Klamath Lake, Oregon. Water-resources Investigations Report 93-4087. Portland.

Bottcher, J. L., and S. M. Burdick. 2010. Temporal and spatial distribution of endangered juvenile Lost River and shortnose suckers in relation to environmental variables in Upper Klamath Lake, Oregon: 2009 annual data summary, Open File Report 2010-1261. U.S. Geological Survey, Reston, Virginia.

Bottorff, J. 1989. Concept plan for waterfowl habitat protection, Klamath Basin, Oregon and California: North American waterfowl management plan category 28. Portland, Oregon.

Boyd, M., S. Kirk, M. Wiltsey, and B. Kasper. 2002. Upper Klamath Lake drainage total maximum daily load (TMDL) and water quality managment plan (WQMP). Portland, Oregon.

Bradbury, J. P., S. M. Colman, and R. Reynolds. 2004. The history of recent limnological changes and human impact on Upper Klamath Lake, Oregon. Journal of Paleolimnology 31:151–165.

Buettner, M., and G. Scoppettone. 1990. Life history and status of Catostomids in Upper Klamath Lake, Oregon: Completion report. Reno Field Station, National Fisheries Research Center, U.S. Fish and

Wildlife Service, U.S. Department of Interior, Reno, Nevada.
Buettner, M., and G. Scoppettone. 1991. Distribution and information on the taxonomic status of shortnose sucker, *Chasmistes brevirostris*, and Lost River sucker, *Deltistes luxatus*, in the Klamath River Basin, California. Reno, Nevada.
Burdick, S. M., and D. T. Brown. 2010. Distribution and condition of larval and juvenile Lost River and shortnose suckers in the Williamson River Delta Restoration Project and Upper Klamath Lake, Oregon: 2009 Annual Data Summary: Open-file Report 2010-1216. Page (U. S. G. Survey, Ed.). Reston, Virginia.
Burdick, S. M., D. G. Elliott, C. O. Ostberg, C. M. Conway, A. Dolan-Caret, M. S. Hoy, K. P. Feltz, and K. R. Echols. 2015a. Health and condition of endangered juvenile Lost River and shortnose suckers relative to water quality and fish assemblages in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California. U.S. Geological Survey Open-File Report 2015-1217.
Burdick, S. M., D. A. Hewitt, J. E. Rasmussen, B. Hayes, E. Janney, and A. C. Harris. 2015b. Effects of lake surface elevation on shoreline-spawning Lost River Suckers. North American Journal of Fisheries Management 35:478–490.
Burdick, S. M., and B. A. Martin. 2017. Inter-annual variability in apparent relative production, survival, and growth of juvenile Lost River and shortnose suckers in Upper Klamath Lake, Oregon, 2001-2015. Open-File Report 2017-1069. U.S. Geological Survey, Reston, VA.
Burdick, S. M., C. O. Ostberg, M. E. Hereford, and M. S. Hoy. 2016. Juvenile sucker cohort tracking data summary and assessment of monitoring program, 2015. U.S. Geological Survey Open-File Report 2016-1164. Reston, Virginia.
Burdick, S. M., C. o Ostberg, and M. S. Hoy. 2018. Juvenile Lost River and shortnose sucker year class strength, survival, and growth in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California: 2016 monitoring report. Open-file report 2018-1066. Reston, Virginia.
Burdick, S. M., and J. E. Rasmussen. 2013. Age and condition of juvenile Catostomids in Clear Lake California, Open-File Report 2013-1188. U.S. Geological Survey, Reston.
Burdick, S. M., and S. P. Vanderkooi. 2010. Temporal and spatial distribution of endangered juvenile Lost River and shortnose suckers in relation to environmental variables in Upper Klamath Lake, Oregon, 2008 annual data summary, Open File Report 2010-1051. U.S. Geological Survey, Reston, Virginia.
Caldwell Eldridge, S. L., T. M. Wood, and K. R. Echols. 2012. Spatial and temporal dynamics of cyanotoxins and their relation to other water quality variables in Upper Klamath Lake, Oregon, 2007-2009. USGS Sceintific Investigations Report 2012-5069. U.S. Geological Survey, Reston, VA.
Ciotti, D., S. M. Griffith, J. Kahn, and J. Baham. 2010. Nutrien and sediment transport on flood-irrigated pasture in the Klamath Basin, Oregon. Rangeland Ecology & Management 63:308–316.
Coleman, M. E., J. Kahn, and G. Scoppettone. 1988. Life history and ecological investiagations of Catostomids from the Upper Klamath Lake Basin, Oregon. Seattle, Washington.
Cooke, S. J., C. M. Bunt, S. J. Hamilton, C. A. Jennings, M. P. Pearson, M. S. Cooperman, and D. F. Markle. 2005. Threats, conservation strategies, and prognosis for suckers (Catostomidae) in North America: insights from regional case studies of a diverse family of non-game fishes. Biological Conservation 121:317–331.
Cooperman, M. S. 2004. Natural history and ecology of larval Lost River suckers and larval shortnose suckers in the Williamson River-Upper Klamath Lake System. Oregon State University, Corvallis, Oregon.
Cooperman, M. S., and D. F. Markle. 2003. Rapid out-migration of Lost River and shortnose sucker larvae from in-river spawning beds to in-lake rearing grounds. Transactions of the American Fisheries Society 132:1138–1153.
Cooperman, M. S., and D. F. Markle. 2004. Abundance, size, and feeding success of larval shortnose

suckers and Lost River suckers from different habitats of the littoral zone of Upper Klamath Lake. Environmental Biology of Fishes 71:365–377.

Cooperman, M. S., D. F. Markle, M. Terwilliger, and D. C. Simon. 2010. A production estimate approach to analyze habitat and weather effects on recruitment of two endangered freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences 67:28–41.

Cope, E. D. 1879. Fishes of Klamath Lake, Oregon. American Naturalist 13:784–785.

Cornacchia, P. 1967. Mullet homely, but popular. Eugene, OR.

Day, J. L., J. L. Jacobs, and J. Rasmussen. 2017. Considerations for the propagation and conservation of endangered lake suckers of the western United States. Journal of Fish and Wildlife Management 8:301–312.

Desjardins, M., and D. F. Markle. 2000. Distribution and biology of suckers in lower Klamath Reservoirs. Department of Fisheries and Wildlife, Oregon State University, Portland, Oregon.

Diaz, R. J., and D. L. Breitburg. 2009. The hypoxic environment. Pages 1–23 *in* J. G. Richards, A. P. Farrell, and C. J. Brauner, editors. Hypoxia. Academic Press, Amsterdam.

Dowling, T. 2005. Conservation genetics of endangered Lost River and shortnose suckers.

Dowling, T. E., D. F. Markle, G. J. Tranah, E. W. Carson, D. W. Wagman, and B. P. May. 2016. Introgressive Hybridization and the Evolution of Lake-Adapted Catostomid Fishes. PLoS ONE 11.

Dowling, T. E., and C. L. Secor. 1997. The role of hybridization and introgression in the diversification of animals. Annual Review of Ecology and Systematics 28:593–619.

Dunsmoor, L., L. Basdekas, B. Wood, and B. Peck. 2000. Quality, composition, and distribution of emergent vegetation along the Lower River and Upper Klamath Lake shorelines of the Williamson River Delta, Oregon. Completion Report. Klamath Tribes and Bureau of Reclamation.

Eagles-Smith, C. A., and B. L. Johnson. 2011. Contaminants in the Klamath Basin: historical patterns, current distribution, and data gap identification. Draft Administrative Report, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, OR.

Eilers, J. M., J. Kann, J. Cornett, K. Moser, and A. St. Amand. 2004. Paleolimnological evidence of change in a shallow, hypereutrophic lake: Upper Klamath Lake, Oregon. Hydrobiologia 520:7–18.

Ellsworth, C. M., and B. A. Martin. 2012. Patterns of larval sucker emigration from the Sprague and lower Williamson Rivers of the Upper Klamath Basin, Oregon after the removal of Chiloquin Dam--2009-10 annual report. U.S. Geological Survey Open-File Report 2012-1037.

Ellsworth, C. M., T. J. Tyler, and S. P. Vanderkooi. 2010. Using spatial, seasonal, and diel drift patterns of larval Lost River suckers *Deltistes luxatus* (Cypriniformes:Catostomidae) and shortnose suckers *Chasmistes brevirostris* (Cypriniformes:Catostomidae) to help identify a site for a water withdrawl structure. Environmental Biology of Fishes 89:47–57.

Engström-Öst, J., M. Karjalainen, and M. Viitasalo. 2006. Feeding and refuge use by small fish in the presence of cyanobacteria blooms. Environmental Biology of Fishes 76:109–117.

Engström-Öst, J., and J. Mattila. 2008. Foraging, growth and habitat choice in turbid water: an experimental study with fish larvae in the Baltic Sea. Marine Ecology Progress Series 359:275–281.

Evans, A. F., D. A. Hewitt, Q. Payton, B. M. Cramer, K. Collis, and D. D. Roby. 2016a. Colonial waterbird predation on Lost River and Shortnose suckers in the Upper Klamath Basin. North American Journal of Fisheries Management 36:1254–1268.

Evans, D. M., J. P. Che-Castaldo, D. Crouse, F. W. Davis, R. Epanchin-Niell, C. H. Flather, R. K. Frohlich, D. D. Goble, Y.-W. Li, and T. D. Male. 2016b. Species recovery in the United States: Increasing the effectiveness of the Endangered Species Act. Issues in Ecology 20:1–28.

Evermann, B. W., and S. E. Meek. 1897. A report upon salmon investigations in the Columbia River Basin and elsewhere on the Pacific Coast in 1896. Bulletin of the United States Fish Commission 17:15–84.

Foott, J. S. 2004. Health monitoring of adult Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) in Upper Klamath Lake, Oregon, April – September 2003. U.S. Fish & Wildlife Service, Anderson, California.

Foott, J. S., and R. Stone. 2005. Bio-energetic and histological evaluation of juvenile (0+) sucker fry from Upper Klamath Lake collected in August and September 2004. Anderson, California.

Foott, J. S., R. Stone, and R. Fogerty. 2010. FY2009 Technical Report: Health and energy evaluation of juvenile fish from Link R. trap and haul project and J-canal salvage. United States Fish and Wildlife Service California-Nevada Fish Health Center, Anderson, California.

Foster, K., and D. Bennetts. 2006. Entrainment monitoring report for the Lost River Diversion Channel in 2005. Klamath Falls, Oregon.

Gearhart, R. A., J. K. Anderson, M. G. Forbes, M. Osburn, and D. Oros. 1995. Watershed strategies for improving water quality in Upper Klamath Lake, Oregon. Volume I: Use of wetlands for improving water quality in Upper Klamath Lake, Oregon. Humboldt State University, Arcata, California.

Gilbert, C. H. 1897. The fishes of the Klamath Basin. Bulletin of the United States Fish Commission 17:1–13.

Graham, J. B. 1990. Ecological, evolutionary, and physical factors influencing aquatic animal respiration. American Zoologist 30:137–146.

Graham, J. L., N. M. Dubrovsky, and S. M. Eberts. 2016. Cyanobacterial harmful algal blooms and U.S. Geological Survey science capabilities. Open-file report 2016-1174. U.S. Geological Survey, Department of Interior, Reston, Virginia.

Gutermuth, B., C. Watson, and J. Kelly. 2000. Link River hydroelectric project (east and westside powerhouses) final entrainment study report. Cell Tech and PacificCorp Environmental Services.

Haas, J. 2007. A toxicological unit analysis of risk to listed suckers in the Tule Lake sumps of pesticide use on the federal lease lands on Tule Lake National Wildlife Refuge. Division of Ecological Contaminants. U.S. Fish and Wildlife Service, Sacramento, CA.

Haggard, K. G., N. S. Geiger, P. M. Hayes, and A. J. Milligan. 2013. Suppression of cyanobacterial growth of *Aphanizomenon flos-aquae* by vascular plant decomposition productions in Upper Klamath Lake, Oregon. Lake and Reservoir Management 29:13–22.

Hallerman, E. M. 2003. Population viability analysis. Pages 403–418 *in* E. M. Hallerman, editor. Population genetics: Principles and applications for fisheries scientists. American Fisheries Society, Bethesda.

Hamilton, A., R. Piaskowski, and S. Snedaker. 2003. 2003 progress report: Evaluation of fish entrainment and fish habitat use along Miller Creek, Lost River Basin, Oregon. Bureau of Land Management, Klamath Falls Area Office.

Hamlet, A. F., P. W. Mote, M. P. Clark, and D. P. Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the western United States. Journal of Climate 18:4545–4561.

Harris, P. M., and R. L. Mayden. 2001. Phylogenetic relationships of major clades of Catostomidae (Teleostei: Cypriniformes) as inferred from mitochondrial SSU and LSU rDNA sequences. Molecular phylogenetics and evolution 20:225–237.

Hayes, M. F., and J. E. Rasmussen. 2017. Evaluation of endangered lakesucker rearing in tributaries to Upper Klamath Lake by use of X-ray imaging. Western North American Naturalist 77:130–135.

Helser, T. E., M. Loftus, D. W. Reiser, and N. Hendrix. 2004. A statistical model of Upper Klamath Lake adult sucker depth utilization. In: Page A compendium of technical memoranda related to water quality and population demographics of shortnose (*Chasmistes brevirostris*) and Lost River (*Deltistes luxatus*). R2 Consultants, Portland, Oregon.

Hendrixson, H. A., S. M. Burdick, B. L. Herring, and S. P. Vanderkooi. 2007. Nearshore and offshore habitat use by endangered, juvenile Lost River and shortnose suckers in Upper Klamath Lake, Oregon. Klamath Falls, Oregon.

Hense, I. 2007. Regulative feedback mechanisms in cyanobacteria-driven systems: a model study. Marine Ecology Progress Series 339:41–47.

Hereford, D. M., S. M. Burdick, D. G. Elliott, A. Dolan-Caret, C. M. Conway, and A. C. Harris. 2016. Survival, movement, and health of hatchery-raised juvenile Lost River suckers within a mesocosm in Upper Klamath Lake, Oregon. U.S. Geological Survey Open-File Report 2016-1012. Reston, Virginia.

Herman, R. L. 1990. The role of infectious agents in fish kills. Pages 45–56 *in* F. P. Meyer and L. A. Barclay, editors. Field manual for the investigation of fish kills. U.S. Fish & Wildlife Service, Resource Publication 177.

Hewitt, D. A., and B. S. Hayes. 2013. Monitoring of adult Lost River and shornose suckers in Clear Lake Reservoir, California, 2008-2010. U.S. Geological Survey Open-File Report 2013-1301. U.S. Geological Survey, Reston, VA.

Hewitt, D. A., E. C. Janney, B. S. Hayes, and A. C. Harris. 2014. Demographics and run timing of adult Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers in Upper Klamath Lake, Oregon, 2012. Klamath Falls Field Station, Western Fisheries Research Station, U.S. Geological Survey, U.S. Department of Interior, Reston, Virginia.

Hewitt, D. A., E. C. Janney, B. S. Hayes, and A. C. Harris. 2017. Status and trends of adult Lost River (*Delistes luxatus*) and shortnose (*Chasmistes brevirostris*) sucker populations in Upper Klamath Lake, Oregon, 2015: USGS Open-File Report 2017-1059. U.S. Geological Survey, Reston, Virginia.

Hewitt, D. A., E. C. Janney, B. S. Hayes, and A. C. Harris. 2018. Status and trends of adult Lost River (*Delistes luxatus*) and shortnose (*Chasmistes brevirostris*) sucker populations in Upper Klamath Lake, Oregon, 2017: USGS Open-File Report 2018-1064. U.S. Geological Survey, Reston, Virginia.

Hodge, J., and M. Buettner. 2009. Sucker population monitoring in Tule Lake and lower Lost River, 2006 - 2008. Completion Report. Klamath Falls, Oregon.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82:898–903.

Hoilman, G. R., M. K. Lindenberg, and T. M. Wood. 2008. Water quality conditions in Upper Klamath and Agency Lakes, Oregom 2005: Scientific Investigations Report 2008-5026. U.S. Geological Survey, Reston.

Houde, E. D. 1989. Comparative growth, mortality, and energetics of marine fish larvae: temperature and implied latitudinal effects. Fishery Bulletin 87:471–495.

Houde, E. D., and J. Bartsch. 2009. Mortality. Pages 27–42 *in* E. W. North, A. Gallego, and P. Petitgas, editors. Manual of recommnded practices for modelling physical-biological interactions during fish early life. ICES Cooperative Research Report No. 295, Copenhagen.

Hoy, M. S., and C. O. Ostberg. 2015. Development of 20 TaqMan assays differentiating the endangered shortnose and Lost River suckers. Conservation Genetics Resources 7:673–676.

Janik, A. J. 2017. Aspects of the parasite fauna and related diseases in juveniles fishes in Upper Klamath Lake, OR. Oregon State University.

Jones, R. I. 1992. The influence of humic substances on lacustrine planktonic food chains. Hydrobiologia 229:73–91.

Kahru, M. 1993. Cyanobacterial blooms cause heating of the sea surface. Marine Ecology Progress Series 101:1–7.

Kann, J. 1997. Ecology and water quality dynamics of a shallow hypereutrophic lake dominated by cyanobacteria. University of North Carolina, Chapel Hill.

Kann, J. 2017. Upper Klamath Lake 2016 data summary report. Ashland, Oregon.

Kann, J., and E. B. Welch. 2005. Wind control on water quality in shallow, hypereutrophic Upper Klamath Lake, Oregon. Lake and Reservoir Management 21:149–158.

Karjalainen, M., J. Engström-Öst, S. Korpinen, H. Peltonen, J.-P. Pääkkönen, S. Rönkkönen, S. Suikkanen, and M. Viitasalo. 2007. Ecosystem consequences of cyanobacteria in the northern Baltic Sea. AMBIO: A Journal of the Human Environment 36:195–202.

Kelly, D. W., R. A. Paterson, C. R. Townsend, R. Poulin, and D. M. Tompkins. 2009. Parasite spillback: a neglected concept in invasion ecology? Ecology 90:2047–2056.

Kent, M. L. 1990. Netpen liver disease (NLD) of salmonid fishes reared in sea water: Species susceptibility, recovery, and probable cause. Diseases of Aquatic Organisms 8:21–28.

Kent, M. L., A. Janik, V. V Tkach, A. Choudhury, and J. T. Peterson. 2017. Describing the potential predator field of young suckers in Upper Klamath Lake: Parasites - report prepared for the Klamath Basin Area Office, Bureau of Reclamation. Department of Fisheries and Wildlife, Oregon State University and Oregon Cooperative Research Unit, Corvallis, Oregon.

Kirk, S., D. Turner, and J. Crown. 2010. Upper Klamath and Lost River subbasins total maximum daily loads (TMDL) and water quality management plan. Portland, Oregon.

Kirse, S. C. 2010. Parasite ecology of fish with black spot disease.

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the western United States. Journal of Climate 19:4545–4559.

Koch, D. L., J. J. Cooper, G. P. Contreras, and V. King. 1975. Survey of the fishes of the Clear Lake Reservoir Drainage. Reno, Nevada.

Korson, C., A. Wilkens, and D. Taylor. 2010. Klamath Project: A canal endangered sucker monitoring, 2010. Klamath Falls, Oregon.

Kyger, C., and A. Wilkens. 2011. Endangered Lost River and shortnose sucker distribution and relative abundance in Lake Ewauna, and use of the Link River dam fish ladder, Oregon: Annual Report 2010. Klamath County, Oregon.

Laeder, J., and A. Wilkens. 2010. Klamath Project: A canal endangered sucker monitoring, 2006-2009. Klamath Falls, Oregon.

Laenen, A., and A. P. LeTourneau. 1995. Upper Klamath Basin nutrient-loading study: estimate of wind-induced resuspension of bed sedinent during periods of low lake elevation. Open-file report 95-414. Portland.

Lease, H. M., J. A. Hansen, H. L. Bergman, and J. S. Meyer. 2003. Structural changes in gills of Lost River suckers exposed to elevated pH and ammonia concentrations. Comparative Biochemistry and Physiology 134:491–500.

Leeseberg, C. A., P. A. Barry, G. Whisler, and E. C. Janney. 2007. Monitoring of Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers in Gerber and Clear Lake Reservoirs: Annual Report 2004. Klamath Falls, Oregon.

Lindenberg, M. K., G. Hoilman, and T. M. Wood. 2008. Water quality conditions in Upper Klamath and Agency Lakes, Oregon, 2006. Scientific Investigations report 2008-5201. Reston, Virginia.

Loftus, M. E. 2001. Assessment of potential water quality stress to fish: supplement to Effects of water quality and lake levle on the biology and habitat of selected fish species in Upper Klamath Lake. Portland, Oregon.

Logan, D. J., and D. F. Markle. 1993. Fish faunal survey of Agency Lake and northern Upper Klamath Lake, Oregon. Klamath Falls, Oregon.

Marcogliese, D. J. 2004. Parasites: Small Players with Crucial Roles in the Ecological Theater. EcoHealth 1:151–164.

Marine, K. R., and M. Gorman. 2005. Monitoring and evaluation of the A-canal fish screen and bypass facility. Klamath Falls, Oregon.

Marine, K. R., and P. Lappe. 2009. Link River Dam surface spill experiment: evaluation of differential juvenile sucker downstream passage rates. Klamath Falls, Oregon.

Markle, D. F., M. R. Cavalluzzi, and D. C. Simon. 2005. Morphology and taxonomy of Klamath Basin suckers (Catostomidae). Western North American Naturalist 65:473–489.

Markle, D. F., and K. Clauson. 2006. Ontogenetic and habitat-related changes in diet of late larval and juvenile suckers (Catostomidae) in Upper Klamath Lake, Oregon. Western North American Naturalist 66:492–501.

Markle, D. F., and L. K. Dunsmoor. 2007. Effects of Habitat Volume and Fathead Minnow Introduction on Larval Survival of Two Endangered Sucker Species in Upper Klamath Lake, Oregon. Transactions of the American Fisheries Society 136:567–579.

Markstrom, S. L., L. E. Hay, C. D. Ward-Garrison, J. C. Risley, W. A. Battaglin, D. M. Bjerklie, K. J. Chase, D. E. Christiansen, R. W. Dudley, R. J. Hunt, K. M. Koczot, M. C. Mastin, S. Regan, R. J. Vigr, K. C. Vining, and J. F. Walker. 2012. Integrated watershed-scale response to climate change for selected basins across the United States: Scientific Investigations Report 2011-5077. U.S. Geological Survey, Reston, Virginia.

Martin, B. A., D. A. Hewitt, and C. M. Ellsworth. 2013. Effects of Chiloquin Dam on spawning distribution and larval emigration of Lost River, shortnose, and Klamath largescale suckers in the Williamson and Sprague Rivers, Oregon. Klamath Falls Field Station, Western Fisheries Research Station, U.S. Geological Survey, U.S. Department of Interior.

Martin, B. A., and M. K. Saiki. 1999. Effects of ambient water quality on the endangered Lost River sucker in Upper Klamath Lake, Oregon. Transactions of the American Fisheries Society 128:953–961.

Meyer, J. S., and J. A. Hansen. 2002. Subchronic toxicity of low dissolved oxygen concentrations, elevated pH, and elevated ammonia concentrations to Lost River suckers. Transactions of the American Fisheries Society 131:656–666.

Miller, R. R., and G. R. Smith. 1967. New fossil fishes from Plio-Pleistocene Lake Idaho. Occasional Papers of the Museum of Zoology, University of Michigan 654:1–24.

Miller, R. R., and G. R. Smith. 1981. Distribution and evolution of *Chasmistes* (Pisces: Catostomidae) in western North America. Occasional Papers of the Museum of Zoology, University of Michigan 696:1–48.

Morace, J. L. 2007. Relation between selected water-quality variables, climatic factors, and lake levels in Upper Klamath and Agency Lakes, Oregon, 1990-2006: Scientific Investigations Report 2007-5117. U.S. Geological Survey, Reston.

Moyle, P. B. 2002. Inland fishes of California. University of California Press, Berkeley, California.

National Research Council. 2004. Endangered and threatened fishes in the Klamath River Basin: Causes of decline and strategies for recovery. Page (The National Academies Press, Ed.). The National Academies Press, Washington, D.C.

Nelson, J. S., E. J. Crossman, H. Espinosa-Perez, L. T. Findley, C. R. Gilbert, R. N. Lea, and J. D. Williams. 2004. Common and scientific names of fishes from United States, Canada, and Mexico. Sixth LB. American Fisheries Society, Bethesda, Maryland.

O'Connor, J. E., P. F. McDowell, P. Lind, C. G. Rasmussen, and M. K. Keith. 2014. Geomorphology and flood-plain vegetation of the Sprague and lower Sycan Rivers, Klamath Basin, Oregon. Scientific Investigation Report 2014-5223. U.S. Geological Survey, Department of Interior, Reston, Virginia.

PacifiCorp. 2013. PacifiCorp Klamath hydroelectric project interim operation habitat conservation plan for Lost River and Shortnose Suckers. Prepared by PacifiCorp Energy Inc., Portland, OR. Submitted to the U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office, Klamath Falls, Oregon.

Parker, M. S., D. L. Perkins, and G. G. Scoppettone. 2000. Feeding habitats of endangered Lost River and

shortnose suckers from Clear Lake Reservoir, California. Ashland, Oregon.
Peel, M. C., B. L. Finlayson, and T. A. McMahon. 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and earth system sciences discussions 4:439–473.
Perkins, D. L., J. Kann, and G. G. Scoppettone. 2000a. The role of poor water quality and fish kills in the decline of endangered Lost River and shortnose suckers in Upper Klamath Lake. Page (U. S. G. Survey, Ed.). U.S. Geological Survey, Reno, Nevada.
Perkins, D. L., G. G. Scoppettone, and M. Buettner. 2000b. Reproductive biology and demographics of endangered Lost River and shortnose suckers in Upper Klamath Lake, Oregon. U.S. Geological Survey, Reno, Nevada.
Piaskowski, R., and M. Buettner. 2003. Review of water quality and fisheries sampling conducted in Gerber Reservoir, OR with emphasis on the shortnose sucker and its habitat needs.
Plaul, S. E., N. G. Romero, and C. G. Barbeito. 2010. Distribution of the exotic parasite, *Lernaea cyprinacea* (Copepoda, Lernaeidae) in Argentina. Bull Eur Ass Fish Pathol 30:65–73.
Rasmussen, J. E., and E. S. Childress. 2018. Population Viability of Endangered Lost River Sucker and Shortnose Sucker and the Effects of Assisted Rearing. Journal of Fish and Wildlife Management 9:582–592.
Reiser, D. W., M. Loftus, D. Chapman, E. Jeanes, and K. Oliver. 2001. Effects of water quality and lake level on the biology and habitat of selected fish species in Upper Klamath Lake. Klamath Falls, Oregon.
Rhymer, J. M., and D. Simberloff. 1996. Extinction by hybridization and introgression. Annual Review of Ecology and Systematics 27:83–109.
Risley, J., L. E. Hay, and S. . Markstrom. 2012. Watershed scale response to climate change--Sprague River Basin, Oregon: U.S. Geological Survey Fact Sheet 2011-3120. U.S. Geological Survey.
Robinson, A. T., P. P. Hines, J. A. Sorensen, and S. D. Bryan. 1998. Parasites and fish health in a desert stream, and management implications for two endangered fishes. North American Journal of Fisheries Management 18:599–608.
Saiki, M. K., D. P. Monda, and B. L. Bellerud. 1999. Lethal levels of selected water quality variables to larval and juvenile Lost River and shortnose suckers. Environmental Pollution 105:37–44.
Scoppettone, G. G., and G. L. Vinyard. 1991. Life history and management of four endangered lacustrine Suckers. Pages 359–377 *in* W. L. Minckley and J. E. Deacon, editors. Battle Against Extinction. The University of Arizona Press, Tuscon.
Scoppettone, G., S. Shea, and M. Buettner. 1995. Information on population dynamics and life history of shortnose suckers (*Chasmistes brevirostris*) and Lost River suckers (*Deltistes luxatus*) in Tule and Clear Lakes. Reno, Nevada.
Seale, A. 1896. Notes on Deltistes, a new genus of catostomid fish. Proceedings of the California Academy of Science 6:269.
Shively, R. S., E. B. Neuman, A. E. Kohler, and B. J. Peck. 2000. Species composition and distribution of fishes in the Lost River, Oregon. Klamath Falls, Oregon.
Simon, D. C., and D. F. Markle. 1997. Interannual abundance of nonnative fathead minnows (*Pimephales promelas*) in Upper Klamath Lake, Oregon. Western North American Naturalist 57:142–148.
Simon, D. C., and D. F. Markle. 2007. Ecology of Upper Klamath Lake shortnose and Lost River Suckers: Annual survey of abundance and distribution of age-0 shortnose and Lost River Suckers in Upper Klamath Lake. Oregon Cooperative Research Unit, Oregon State University, Corvallis, Oregon.
Simon, D. C., and D. F. Markle. 2013. Larval and juvenile ecology of Upper Klamath Lake suckers: 2012. Page Annual report to the U.S. Bureau of Reclamation, Klamath Project, Klamath Falls, OR for Great Basin Cooperative Ecosystems Studies Unit Agency Program USBR#2-FG-81-0813. Oregon State University, Department of Fisheries and Wildlife, Corvallis, Oregon.

Smith, D. R., N. L. Allan, C. P. McGowan, J. A. Szymanski, S. R. Oetker, and H. M. Bell. 2018. Development of a species status assessment process for decisions under the US Endangered Species Act. Journal of Fish and Wildlife Management 9:302–320.

Smith, G. R. 1992. Phylogeny abd biogeography of the Catostomidae, freshwater fishes of North America and Asia. Page *in* R. L. Mayden, editor. Systematics, historical ecology, & North American freshwater fishes. Stanford University Press, Stanford.

Smith, M., and J. VonBargen. 2015. Genetic information needs assessment for Lost River suckers (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) of the Klamath River basin. Longview, WA.

Snieszko, S. F. 1974. The effects of environmental stress on outbreaks of infectious diseases of fishes. Journal of Fish Biology 6:197–208.

Snyder, D. T., and J. L. Morace. 1997. Nitrogen and phosphorus loading from drained wetlands adjacent to Upper Klamath and Agency Lakes, Oregon: Water Resources Investigations Report 97-4059. U.S. Geological Survey, Portland, Oregon.

Solomon, C. T., S. E. Jones, B. C. Weidel, I. Buffam, M. L. Fork, J. Karlsson, S. Larsen, J. T. Lennon, J. S. Read, S. Sadro, and J. E. Saros. 2015. Ecosystem consequences of changing inputs of terrestrial dissolved organic matter to lakes: Current knowledge and future challenges. Ecosystems 18:376–389.

Sorenson, S. K., and S. E. Schwarzbach. 1991. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Klamath Basin, California nd Oregon, 1988-89. U.S. Geological Survey Water Resources Investigations Report 90-4203.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18:1136–1155.

Stone, R., J. L. Jacobs, N. A. Som, J. S. Foott, B. Phillips, J. Ross, D. Taylor, and T. J. Tyler. 2017. Lost River Sucker fry sentinel survival in Upper Klamath Lake (July - September 2015). California Nevada Fish Health Center, U.S. Fish and Wildlife Service, Anderson, California.

Sullivan, A. B., D. M. Snyder, and S. A. Rounds. 2010. Controls on biochemical oxygen demand in the upper Klamath River, Oregon. Chemical Geology 269:12–21.

Sutphin, Z., and T. J. Tyler. 2016. Entrainment of early life-stages of fish from Clear Lake Reservoir into Lost River. U.S. Bureau of Reclamation, Denver, CO.

Terwilliger, M., T. Reece, and D. F. Markle. 2010. Historic and recent age structure and growth of endangered Lost River and shortnose suckers in Upper Klamath Lake, Oregon. Environmental Biology of Fishes 89:239–252.

Thurston, R. V, R. C. Russo, and K. Emerson. 1979. Aqueous ammonia equilibrium - tabulation of percent un-ionized ammonia. Duluth, Minnesota.

Tranah, G. J., and B. May. 2006. Patterns of intra- and interspecies genetic diversity in Klamath River Basin suckers. Transactions of the American Fisheries Society 135:306–316.

U.S. Environmental Protection Agency. 2008. Lost River, California total maximum daily loads: Nitrogen and biochemical oxygen demand to address dissolved oxygen and pH impairments. U.S. Environmental Protection Agency, Region IX.

USBR. 2000. Klamath Project historic operation. Klamath Falls, Oregon.

USBR. 2001. Inventory of water diversions in the Klamath Project Service Area that potentially entrain endangered Lost River and shortnose suckers. Klamath Falls, Oregon.

USFWS. 1988. Endangered and threatened wildlife and plants: determination of endangered status for the shortnose sucker and Lost River sucker, Final Rule. Federal Register 53:27130–27134.

USFWS. 1993. Lost River and shortnose recovery plan. U.S. Fish and Wildlife Service, U.S. Department of Interior, Portland, Oregon.

USFWS. 2007a. Lost River sucker (*Deltistes luxatus*) 5-year review: Summary and evaluation. Klamath Falls, Oregon.
USFWS. 2007b. Shortnose sucker (*Chasmistes brevirostris*) 5-year review: Summary and evaluation. Klamath Falls, Oregon.
USFWS. 2013a. Revised recovery plan for the Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*). U.S. Fish and Wildlife Service, Pacific Southwest Region, Sacramento, California.
USFWS. 2013b. Lost River sucker (*Deltistes luxatus*) 5-year review: Summary and evaluation. Klamath Falls, Oregon.
USFWS. 2013c. Shortnose sucker (*Chasmistes brevirostris*) 5-year review: Summary and evaluation. Klamath Falls, Oregon.
USFWS. 2018. Biological opinion on the issuance of recovery permits pursuant to Section 10(a)(1)(A) of the Endangered Species Act for actions involving Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*). Klamath Falls, Oregon.
VanderKooi, S. P., S. M. Burdick, K. R. Echols, C. A. Ottinger, B. H. Rosen, and T. M. Wood. 2010. Algal toxins in upper Klamath Lake, Oregon: Linking water quality to juvenile sucker health: U.S. Geological Survey Fact Sheet 2009-3111, 2 p.
Walker, W. W., J. D. Walker, and J. Kann. 2012. Evaluation of water and nutrient balances for the Upper Klamath Lake Basin in water years 1992-2010. Technical Report to the Klamath Tribes Natural Resources Department, Chiloquin, Oregon.
Walters, G. R., and J. A. Plumb. 1980. Environmental stress and bacterial infection in channel catfish, *Ictalurus punctatus* Rafinesque. Journal of Fish Biology 17:177–185.
Wetzel, R. G. 2001. Limnology: Lake and river ecosystems. Third. Academic Press, San Diego.
Wherry, S. A., T. M. Wood, and C. W. Anderson. 2015. Revision and proposed modification of a total maximum daily load model for Upper Klamath Lake, Oregon: Scientific Investigations Report 2015-5041. U.S. Geological Survey, Reston, Virginia.
Wherry, S., and T. Wood. 2018. A metabolism-based whole lake eutrophication model to estimate the magnitude and time scales of the effects of restoration in Upper Klamath Lake, south-central Oregon . Scientific Investigations Report 2018-5042. U.S. Geological Survey, Reston, VA.
Wilkens, A. 2010. Klamath Project: Link River endangered sucker trap and haul efforts, 2009. Klamath Basin Area Office, U.S. Bureau of Reclamation, Klamath Falls, Oregon.
Williamson, R. S., and H. L. Abbot. 1855. Explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean. War Department.
Wood, T. M., G. R. Hoilman, and M. K. Lindenberg. 2006. Water-quality conditions in Upper Klamath Lake, Oregon, 2002-04: Scientific Investigations Report 2006-5209. U.S. Geological Survey, Reston.

APPENDIX I: GLOSSARY

Age-0 – in fish, the first year of life is called age-0.

Allele – one of two or more alternative forms of genes that are found at the same place on a chromosome.

Anthropogenic – referring to a condition or effect that has originated from human activities.

Bathymetry – the description of contours of the bottom of lakes to permit measurement of the depth of water.

Branched Gill Rakers – The gill structure of fish are comprised of three components: gills (the outermost) which function in breathing; a middle bony gill arch that supports the gills; and the gill rakers (the innermost) which are small bony projections that point into the mouth cavity. These can be simple nubs or highly branched structures that serve to protect the gills and filter food particles.

Catastrophic Events – these are widespread events (such as natural disasters) that highly destructive to populations and habitat.

Caudal Peduncle – this is the tail region of the body of a fish, located between the anal fin and the start of the tail fin.

Cohort – a group of fish that share the same birth year.

Converging – this is the process if two separate species becoming similar in traits.

Corridor – an area that links two habitats through which fish travel to reach habitats where they will reside for different purposes, such as a link between rearing and spawning habitat.

Cyanobacteria – are a type of bacteria that obtain their energy from photosynthesis. These organisms are also known as “blue-green algae,” but are not strictly algae because of their internal cell structure.

Demographic Effects – demography is the study of population-level statistics such as birth and death rates, or the proportion of males and females in the population. Changes in these rates and values are demographic effects.

Die-Offs – localized mass mortality of fish within a relatively short period.

Divergence – the process by which two or more populations of an ancestral species change over time to become different in some ways from each other.

Effective Population Size – the number of individuals in a population who contribute offspring to the next generation. This pertains to genetics related to the diversity of alleles contributed to the next generation.

Emergent Vegetation – plants that are rooted in the lake bottom but have leaves and stems that extend out of the water. These are often found in relatively shallow areas along the shorelines of the lake and typically do not tolerate prolonged inundation of the entire plant.

Endemic – a species that is native to and restricted to a certain area of interest.

Entrainment – in this case, when organisms, especially larval or juvenile suckers, are pulled along with the force of moving water. This may be through natural features, such as a river corridor or into irrigation canals or other similar structures, such as dams and hydroelectric facilities.

Evenness – a measure of biodiversity that refers to the relative proportions of species in an environment. A community with nearly equal numbers from each species will be more even than one in which one species makes up the majority of biomass.

Exotic – a species that is not native to an environment; introduced.

Extant – still in existence; not destroyed, lost, or extinct.

Founder Effect – the reduced genetic diversity that results when a population descends from a small number of individuals.

Genera – the plural of genus, which is the principal taxonomic (identification) category that ranks above species and below family and comprises the first part of a scientific name.

Genetic Bottleneck – a sharp reduction in the size of a population due to natural or anthropogenic causes. This can result in a dramatic loss of genetic diversity.

Genetic Introgression – the incorporation of genes from one species into the gene pool of another by repeated hybridization and backcrossing.

Genetic Loci (singular **Locus)** – a fixed location on a chromosome, such as the position of a specific gene

Genotype – the genetic makeup of an organism.

Heterozygosity – when a gene locus of an organism contains different alleles.

Hybridization – interbreeding between two species.

Introgression – see genetic introgression

Introgressive Hybridization – see genetic introgression

Lacustrine – relating to or associated with lakes.

Metapopulation Dynamics – the dynamics of a group of populations of the same species, which are separated by space but can interact when individuals move among the populations.

Microsatellite Markers – short, repetitive DNA sequences that typically have a relatively high mutation rate than other areas of the genome and so can be relatively diverse.

Mitochondrial DNA – DNA found within the mitochondria of the cell rather than the chromosomes of the nucleus.

Monotypic – having only one representative, such as a genus with only single species.

Obligate – (adjective) restricted to a particular function or mode of life.

Outmigrating – to leave one region to settle in another, especially as part of a large-scale and continuing movement of population.

Papillose – bearing or covered with small round projections or bumps on a part of the body.

Phenotypical Variants – individuals with alternative forms or states of a specific characteristic.

Quantitative – related to the measuring of something by the quantity rather than the quality.

Reproductive Isolation – the condition whereby individuals from different species are unable to interbreed because various evolutionary mechanisms, behavior, or physiology prevents successful reproduction.

Richness – a measure of biodiversity; the absolute number of species within a community regardless of their relative numbers (evenness).

Senescence – the condition or process of deterioration with age that produces reduced survival or reproductive rates.

Sondes – devices with sensors used to measure various water parameters, such as temperature or dissolved oxygen concentrations.

Subterminal – in fish, a mouth that is oriented intermediate to a mouth that points directly forward (terminal) and one that points down (inferior).

Swim-Up – the event when larval fish emerge from the gravel to enter the water column, often in masse.

Tailwaters – waters in the channel below a dam

Terminal – in fish, a mouth that points forward.

Tetraploid Genomes – a genome that is comprised of four homologous sets of chromosomes. In other words, a set of chromosomes that is comprised of four copies of each type of chromosome, two copies from each parent.

Total Length – in fish, the distance between the snout of the fish and the trailing tip of the tail fin.