Warner Basin Strategic Action Plan - Technical Report

Warner Basin Aquatic Habitat Partnership

October 31, 2019

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Executive Summary

The Warner Basin Aquatic Habitat Partnership (WBAHP) was formally established in 2017 to complete fish passage, screen, and habitat restoration projects with the goal of recovering Warner Sucker and expanding Warner Lakes Redband Trout populations in the Warner Basin. To meet these goals, the Warner Basin Strategic Action Plan (Plan) was developed to identify the WBAHP members and their responsibilities, acknowledged the important relationships with local ranchers and water users who rely on surface water diversions for their economic livelihood, and identified the actions that will be necessary to improve stream corridor conditions for Warner Sucker and Warner Lakes Redband Trout. The Plan formed the basis for an Oregon Watershed Enhancement Board Focused Investment Partnership (FIP) application in 2018. WBAHP was awarded FIP funding intended to achieve the fish passage, screening, habitat enhancement, and water availability improvement goals outlined in the Plan.

WBAHP was also awarded a "Telling the Story" OWEB grant to prepare a technical document that will be used as a stand-along document and as an appendix to the Plan. This technical document includes a review of the Warner Basin, completed fish passage projects, monitoring results for fish passage projects, and other investigations that have improved understanding of Warner Sucker ecology and population demographics. Information gathered from project monitoring and fisheries investigations is used by WBAHP members to better understand limiting factors affecting Warner Sucker and to develop solutions to address limiting factors with the ultimate goal of recovering Warner Sucker populations in the basin.

Three completed fish passage projects have been monitored to assess Warner Sucker passage. Biological monitoring has documented passage at each of the fish passage structures located on Twentymile Creek (2 structures) and Honey Creek (1 structure). Similar fish passage projects that have not been monitored, have also been completed on upper Honey Creek. Additional projects are currently underway on Deep Creek and Honey Creek. Fish passage projects on Twentymile Creek have restored passage to approximately 33 miles of habitat. Projects to be completed on Deep Creek and Honey Creek will restore access to approximately 3 miles and 51 miles of habitat, respectively.

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Table of Contents

Tables

Figures

1 Introduction

The Warner Basin Aquatic Habitat Partnership (WBAHP) is a collaboration of local, state, and federal partners committed to the recovery of Warner Sucker (*Catostomus warnerensis*) and Warner Lakes Redband Trout (*Oncorhynchus mykiss newberrii*). The State of Oregon and federal government recognize the Warner Sucker as a threatened species, and Warner Lakes Redband Trout is a State of Oregon sensitive species and a federal species of concern. The WBAHP is comprised of seven organizations including the Lake County Umbrella Watershed Council (LCUWC), Lakeview Soil and Water Conservation District (LSWCD), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), U.S. Bureau of Land Management (BLM), U.S. Forest Service (USFS), and River Design Group, Inc. (RDG). The WBAHP members have completed fish passage, screening, and habitat enhancement projects in the Warner Basin, and have a goal of expanding these efforts to address fish passage and habitat limiting factors across the three focal tributary watersheds that support Warner Sucker and Warner Lakes Redband Trout. Long-term population monitoring completed by ODFW, USFWS, and BLM, and more recent fish passage project monitoring completed by ODFW, provide informative data sets that WBAHP members use for Warner Sucker and Warner Lakes Redband Trout management.

The Warner Basin Strategic Action Plan – Technical Document is intended to be a companion document to the Warner Basin Strategic Action Plan (Plan) and provide more detailed information on the Warner Basin's geography, hydrology, and fish community. Additionally, the technical document summarizes completed fish passage projects and lessons learned from geomorphic and biological effectiveness monitoring completed for the fish passage projects. Monitoring results have been, and will continue to be used by WBAHP members to refine fish passage, screening, and habitat enhancement designs that will be implemented on the three focal tributaries in the Warner Basin. Finally, the technical document outlines partnership opportunities for stakeholder engagement, program funding, and project execution.

2 Warner Basin – Geographic Context

2.1 Physical Geography

The Warner Basin is located in south-central Oregon, northwestern Nevada, and extreme northeastern California. The basin is an endorheic (i.e., no outlet) basin approximately 60 miles long and 8 miles wide within the Basin and Range ecoregion (Figure 2-1). The valley has two regions commonly referred to as the South Warner Valley and the North Warner Valley with the area of separation between Crump Lake and Hart Lake, known as the Narrows.

Figure 2-1. The Warner Basin within the Basin and Range ecoregion.

Similar to adjacent endorheic basins, the Warner Valley was formed by horst and graben geology whereby a central downward-trending block of ground is bordered by two adjacent uplifted blocks of ground in a general north-south orientation (USFWS 1998). During the last two pluvial periods of the late Pleistocene, the Warner Basin was inundated by Pluvial Lake Warner. The first pluvial, synchronous with the Tahoe glaciation, was well advanced 46,000 years before present (BP) and lasted until 32,000 years BP (Flint and Gale 1958; Hansen 1961 *cited in* Taylor 1978). At its maximum extent, Pluvial Lake Warner reached an elevation of about 4,749 ft, whereas the lowest point in the basin boundary is 4,800 ft, located in Mule Springs Valley (Phillips and Van Denburgh 1971). If this pluvial lake ever did overflow, the water would have drained north through the Mule Springs Valley and eventually into the Malheur Basin (Van Winkle 1914 *cited in* Taylor 1978).

A second pluvial period, associated with the Tioga glaciation, commenced about 24,000 years BP and ended 10,000 or 12,000 years BP (Flint and Gale 1958; Hansen 1947 *cited in* Taylor 1978). Lakes again filled the basins of south-central Oregon, but not to the depths attained during the first pluvial period. Following the end of the last glaciation, the climate became progressively more arid. The warming increased to a maximum 4,000 to 8,000 years BP (Hansen 1947). Desiccation was widespread and the lakes of south-central Oregon dried completely. Cooler, moister conditions have prevailed for the last 4,000 years, although large fluctuations in lake levels have occurred (Phillips and Van Denburgh 1971 *cited in* Taylor 1978).

Pluvial periods resulted in biological exchange between basins, while drying periods were times of isolation. Over time, these periodic episodes of joining and isolation of habitats resulted in fish community differentiation, and in some instances, speciation of the native fishes of the region. Today (a period of isolation), the fish assemblage in the Warner Basin shows varying levels of differentiation relative to fish assemblages in adjacent endorheic basins.

Both sides of the South Warner Valley have steep cliffs rising from 1,000 to 2,000 ft above the valley floor (Figure 2-2). The eastern cliffs run the entire length of the valley, while the western wall turns into rolling hills at the north end of the valley. The Coyote Hills are the western boundary through the middle of the North Warner Valley, with the Rabbit Hills bounding the northwest corner of the valley. From the hills, the ground slopes west up to the crest of Abert Rim (Warner Ridge). The eastern boundary of the valley is Hart Mountain, a massive cliff face that rises 3,600 ft above the valley floor. Warner Peak with an elevation of 8,065 ft is the highest point on Hart Mountain.

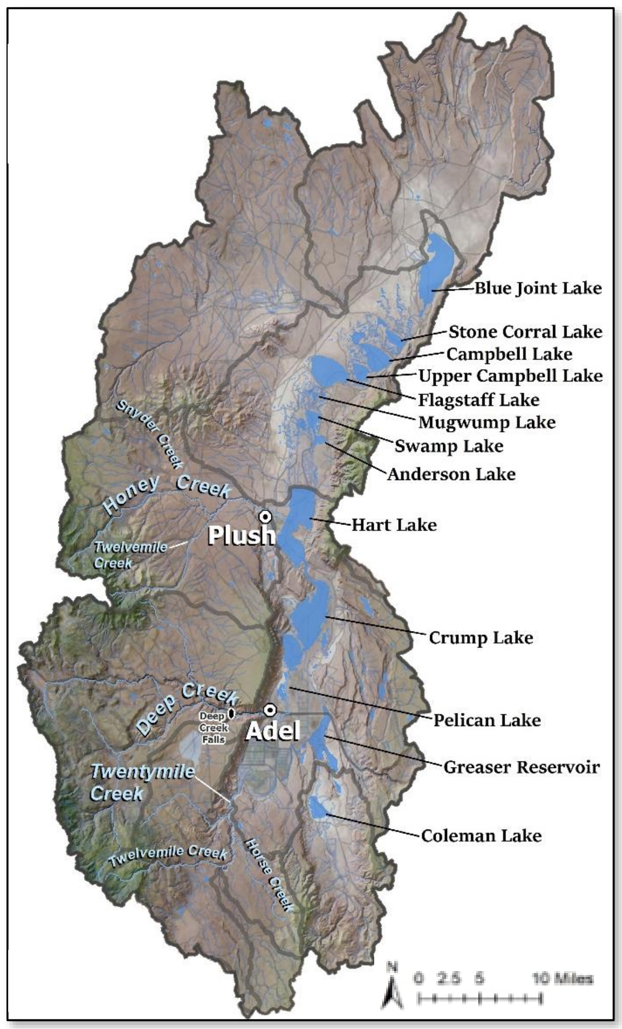


Figure 2-2. The Warner Basin including primary waterbodies.

The valley floor is occupied by a chain of lakes known collectively as the Warner Lakes (see Figure 2-2). Starting at the south end of the valley, the largest of the Warner Lakes are Pelican Lake, Crump Lake, Hart Lake, Anderson Lake, Swamp Lake, Mugwump Lake, Flagstaff Lake, Upper Campbell Lake, Lower Campbell Lake, Stone Corral Lake, Turpin Lake, and Bluejoint Lake. The three primary tributaries in the basin include, from north to south, Honey Creek, Deep Creek, and Twentymile Creek.

Historical Stream Corridor Conditions

European-American sheep herders and cattlemen settled in the Warner Basin in the late 1800s, capitalizing on the lush valley bottoms for pasturing livestock. Agricultural activities focused on the lower reaches of the focal tributaries where the streams emerge from confined canyon reaches into the broad pluvial Warner Valley. The transition from confined canyon reaches to the broader valley, occurs over a relatively short distance in each tributary watershed, resulting in the formation of alluvial fans and distributary channel networks (Figure 2-3). Twentymile Creek and Deep Creek historically flowed through extensive wetlands that filtered runoff as tributary flow gradually progressed towards Pelican Lake and Crump Lake. Compared to the southern tributaries, Honey Creek has a more defined, higher gradient alluvial fan and likely smaller historical wetland complex. Flow from Twentymile Creek and Deep Creek likely intermingled in the expansive wetland that exceeded 20,000 acres.

The historical stream network was modified as early as the late 1800s as settlers altered stream networks to facilitate land draining and flood irrigation. To improve agricultural efficiency, the mainstem channels in the lower valleys were straightened and cleared. Irrigation diversion structures were installed to divert water from the mainstem channels into diversion channel networks that used the distributary channel network and excavated ditches to route irrigation

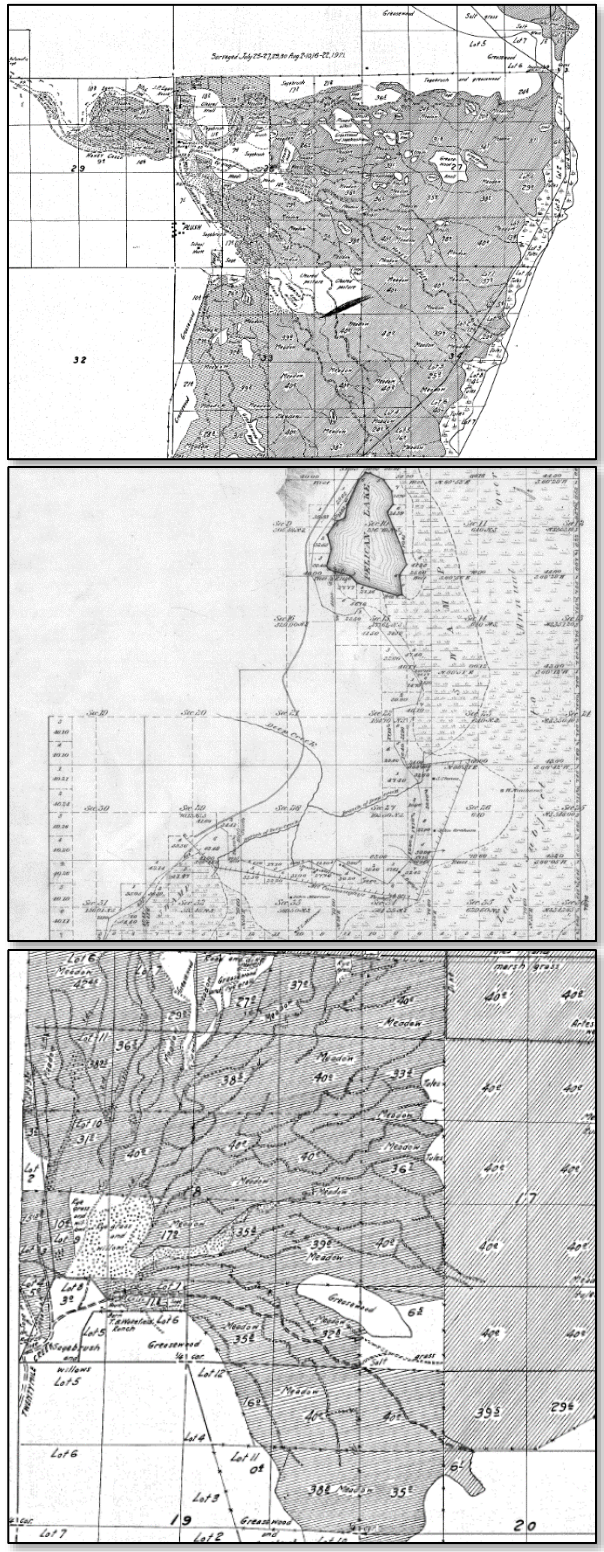


Figure 2-3. Relict alluvial fan channel patterns on Honey Creek (top; 1921), Deep Creek (middle; 1888) and Twentymile Creek (bottom; 1921).

water. Rock, earthen, and log dams (later replaced by concrete structures) were built to create hydraulic head necessary for diversion operations especially during summertime low flows. Diverted streamflow continues to be used to flood irrigate pasture, hay, and other livestock feed, and provide stockwater.

2.2 Climate

In the rain shadow of the Cascades and Klamath mountains, the Warner Basin is in Oregon's driest ecoregion. Marked by extreme ranges of daily seasonal temperatures and precipitation patterns, precipitation and runoff events can also be highly variable on an interannual basis. Table 2-1 includes summary climate data for the weather stations in Plush and Adel, the two population centers located on the floor of the Warner Basin (WRCC 2019a).

Table 2-1. Average annual climate summary for weather stations at Plush and Adel, OR.

Average Annual	Plush	Adel
Max Temp (°F)	61.8	63.3
Min Temp (°F)	34.0	35.0
Total Precip (in)	7.4	8.9
Total Snowfall (in)	12.8	15.6
Period of Record	1910-1961	1956-2016

In contrast to the climate metrics for the valley floor weather stations, weather stations at higher elevations may receive considerable precipitation especially as snow in the winter. For example, the Warner Mountain Refuge weather stations, located 1,000 ft higher than the Adel and Plush weather stations, has an average annual total snowfall of 49.3 inches, over three times the total for the valley floor stations (WRCC 2019b).

Years with high elevation snowpack typically produce sustained streamflow into the summer irrigation season. Conversely, years with minimal snowpack or early snowmelt runoff may yield low streamflow and irrigation water demand exceeds supply by early summer. Warm storms between November and April can also result in high intensity rain-on-snow events which rapidly melt low and mid-elevation snowpack. Due to the basins' thin mineralized soils, snowmelt quickly raises streamflow periodically resulting in record floods in the basin.

2.3 Hydrology

Warner Basin tributaries experience similar hydrologic conditions characterized by low year-round precipitation, spring high flow, summer low flows, and periodic rain-on-snow events in late winter to early spring. Rain-on-snow events account for most of the largest floods on record. The Twentymile Creek subbasin is more susceptible to flooding during winter rain events due to its lower watershed elevation. Oregon Water Resources Department (OWRD) maintains real-time streamflow gages on Honey, Deep, and Twentymile creeks. These gages are located upstream of the primary irrigation diversions and each gage has a 100+ year period of record.

Honey Creek

OWRD maintains a real-time stream gage (Honey Creek near Plush, OR, gage #10378500) on Honey Creek located upstream of the JJ diversion, the most upstream diversion on lower Honey Creek. The gage has been in operation since 1910 and currently reports instantaneous, mean daily, and annual peak flows. The watershed area upstream of the gage is 168.0 square miles, the gage elevation is 4,550.0 ft (NAVD88). Peak flows and mean daily flows for the Honey Creek gage are presented in Figure 2-4. The December 1964 flood (11,000 cfs) is the flood of record on Honey Creek. The mean daily hydrograph is characterized by a late spring to early summer peak flow followed by low flows from August through October when fall rains increase streamflow. Table 2-2 includes the flood frequency analysis and Table 2-3 includes flow duration output including the 5% and 95% fish passage flows.

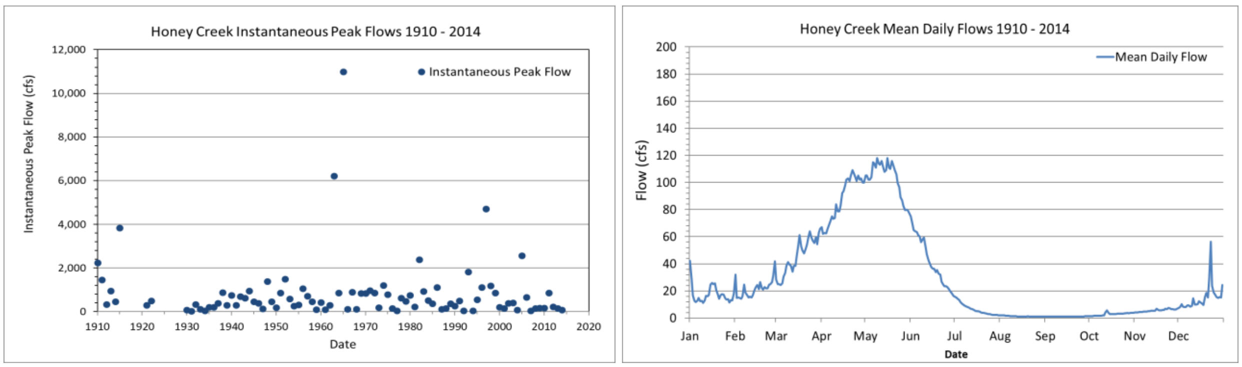


Figure 2-4. Instantaneous peak flows (left) and mean daily flows (right) for the period of record for the Honey Creek gage.

Table 2-2. Peak flows for the Honey Creek Near Plush, Oregon gage (#10378500) operated by OWRD.

Return Period (Years)	Station Calculation		
	Peak Flow (cfs)	95% Confidence	
		Lower (cfs)	Upper (cfs)
2	453	362	566
5	1,210	951	1,600
10	2,020	1,530	2,810
20	3,060	2,250	4,480
25	3,460	2,510	5,130
50	4,890	3,440	7,570
100	6,650	4,550	10,700
500	12,400	7,960	21,800

Table 2-3. Annual flow exceedance for the Honey Creek Near Plush, Oregon gage (#10378500) operated by OWRD. Annual flow exceedance values associated with fish passage flows are highlighted.

Annual Flow Exceedance (%)	Flow (cfs)	Significance
95	0.24	Low Fish Passage Flow
90	0.46	
75	1.81	
50	6.26	Median Flow
25	26.2	
20	38.0	
10	85.3	
5	146.0	High Fish Passage Flow

Deep Creek

OWRD maintains a real-time stream gage (Deep Creek near Adel, OR, gage #10371500) on Deep Creek located downstream from Deep Creek falls and upstream from the first diversion on Deep Creek. The gage has been in operation since 1922 and currently reports instantaneous, mean daily, and annual peak flows. The watershed area upstream of the gage is 254.0 square miles and the gage elevation is 4,980.0 ft (NAVD88). Peak flows and mean daily flows for the Deep Creek gage are presented in Figure 2-5. The December 1964 flood (9,420 cfs) is the flood of record on Honey Creek. The mean daily hydrograph is characterized by a late spring to early summer peak flow followed by low flows from August through October when fall rains increase streamflow. Table 2-4 includes the flood frequency analysis and Table 2-3 includes flow duration output including the 5% and 95% fish passage flows.

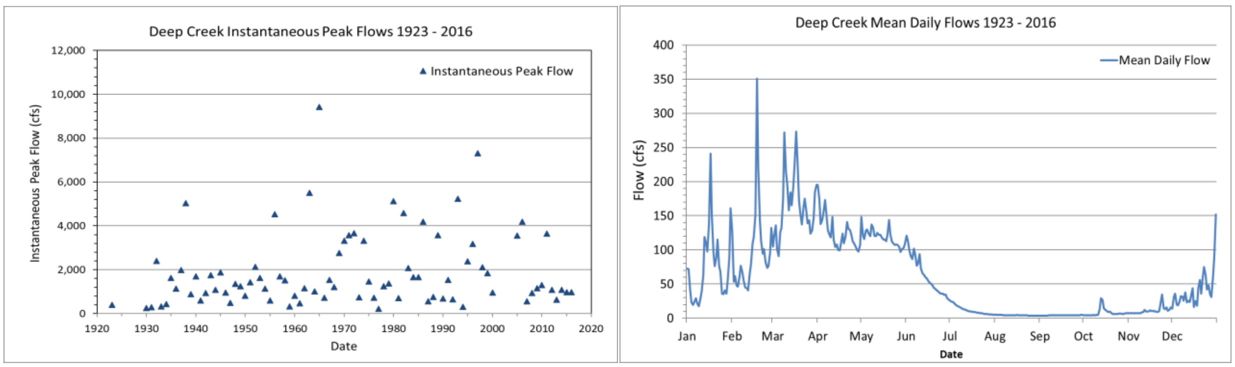


Figure 2-5. Instantaneous peak flows (left) and mean daily flows (right) for the period of record for the Deep Creek gage.

Table 2-4. Peak flows for the Deep Creek Near Adel, Oregon gage (#10371500) operated by OWRD.

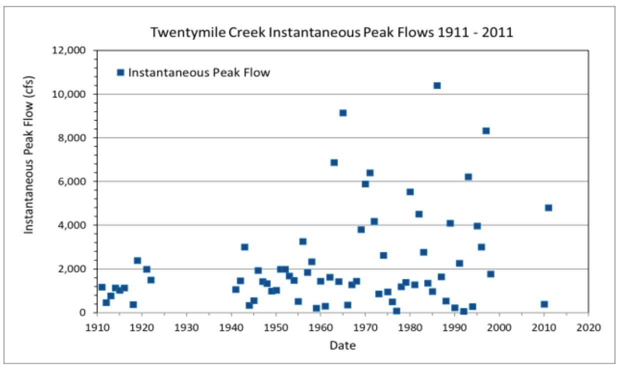
	Station Calculation		
		95% Confidence	
Return Period (Years)	Peak Flow (cfs)	Lower (cfs)	Upper (cfs)
2	1,350	1,140	1,590
5	2,770	2,310	3,410
10	4,030	3,280	5,170
20	5,510	4,370	7,340
25	6,030	4,750	8,130
50	7,830	6,020	10,900
100	9,910	7,430	14,300
500	15,900	11,400	24,600

Table 2-5. Annual flow exceedance for the Deep Creek Near Adel, Oregon gage (#10371500) operated by OWRD. Annual flow exceedance values associated with fish passage flows are highlighted.

Annual Flow Exceedance (%)	Flow (cfs)	Significance
95	7.15	Low Fish Passage Flow
90	9.78	
75	17.4	
50	32.3	Median Flow
25	144	
20	202	
10	392	
5	576	High Fish Passage Flow

Twentymile Creek

OWRD maintains a real-time stream gage (Twentymile Creek near Adel, OR, gage #10366000) on Twentymile Creek located upstream of the Dyke diversion, the most upstream active diversion on Twentymile Creek. The gage has been in operation since 1911 and currently reports instantaneous, mean daily, and annual peak flows. The watershed area upstream of the gage is 189.0 square miles, the gage elevation is 4,580.0 ft (NAVD88). Peak flows and mean daily flows for the Twentymile Creek gage are presented in Figure 2-6. The February 1986 flood (10,400 cfs) is the flood of record on Twentymile Creek. The mean daily hydrograph is characterized by a late spring to early summer peak flow followed by low flows from August through October when fall rains increase streamflow. Table 2-6 includes the flood frequency analysis and Table 2-7 includes flow duration output including the 5% and 95% fish passage flows.



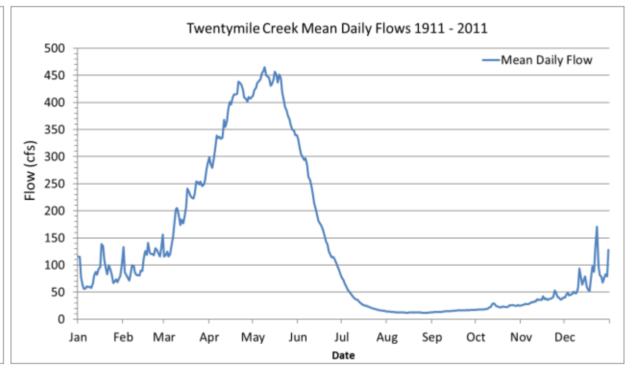


Figure 2-6. Instantaneous peak flows (left) and mean daily flows (right) for the period of record for the Twentymile Creek gage.

Table 2-6. Peak flows for the Twentymile Creek Near Adel, Oregon gage (#10366000) operated by OWRD.

	Station Calculation		
		95% Confidence	
Return Period (Years)	Peak Flow (cfs)	Lower (cfs)	Upper (cfs)
2	2,230	1,660	3,020
5	4,970	3,640	7,340
10	7,250	5,130	11,400
20	9,680	6,650	16,100
25	10,500	7,140	17,700
50	13,100	8,670	23,100
100	15,900	10,200	29,100
500	22,600	13,800	44,600

Table 2-7. Annual flow exceedance for the Twentymile Creek Near Adel, Oregon gage (#10366000) operated by OWRD. Annual flow exceedance values associated with fish passage flows are highlighted.

Annual Flow Exceedance (%)	Flow (cfs)	Significance
95	2.34	Low Fish Passage Flow
90	2.98	
75	4.41	
50	8.32	Median Flow
25	50.3	
20	70.4	
10	131	
5	228	High Fish Passage Flow

3 Fish Community

Native fish species found in the Warner Basin planning area include Warner Sucker, Warner Lakes Redband Trout, Tui Chub (*Siphateles bicolor thalassinus*), and Speckled Dace (*Rhinichthys osculus*). Non-native species including White Crappie (*Pomoxis annularis*), Black Crappie (*P. nigromaculatus*), and Largemouth Bass (*Micropterus salmoides*) were planted by ODFW into the Warner Lakes between 1971 and 1973 (White et al. 1990), and were well established by the late 1970s. Brown Bullhead (*Ameiurus nebulosus*) also inhabit the basin, although the year of introduction is unknown. The following sections include additional information on Warner Sucker and Warner Lakes Redband Trout.

3.1 Warner Sucker

The following information is largely adapted from Scheerer et al. (2016). A more extensive study of Warner Sucker life history is provided *Warner Sucker Life History: A Review* (Monzyk 2019).

The abundance and distribution of Warner Sucker has declined over the past century, and the species was listed as threatened under the U.S. Endangered Species Act in 1985 due to habitat fragmentation from impassable irrigation diversions and threats posed by the proliferation of piscivorous non-native game fishes (USFWS 1985).

The Warner Sucker inhabits the lakes and low gradient stream reaches of the Warner Valley. The species exhibits two life-history forms: lake and stream morphs (Figure 3-1). The lake-residing Warner Sucker has a lacustrine-adfluvial life history, spending most of the year in a lake environment but migrating into tributary streams in large aggregations to spawn (USFWS 1998). The adfluvial form generally matures later, lives longer, and is much larger and more fecund than the stream form. When upstream migration of lake-residing suckers is hindered by low stream flows during drought years or by irrigation diversion weirs, lake-residing suckers may spawn in nearshore areas of the lakes (White et al. 1991).

Large lake-residing populations of introduced fishes may reduce Warner Sucker recruitment by preying upon young suckers (USFWS 1998). Periodic lake drying also threatens the lake-residing suckers, and suckers from the tributaries have recolonized the lakes after past drying events (mid-1930s and early 1990s; Allen et al. 1994). The stream-residing suckers have a fluvial life-history pattern and rear-spawn in the three major tributary drainages (Twentymile, Deep, and Honey Creeks). Threats specific to the stream form include water withdrawals for irrigation and habitat degradation associated with grazing and agricultural practices. Both the lake- and stream-residing Warner Sucker spawn in the spring (April–June) (Coombs et al. 1979) in response to temperature and flow cues (Scheerer et al. 2016). Warner Sucker in the lakes are long-lived (17 years; White et al. 1991) and mature at 3 to 4 years of age (Coombs et al. 1979).

Figure 3-1. Stream form (top) and lake form (bottom) male Warner Suckers in spawning condition. Photos courtesy ODFW.

Warner Sucker Distribution

The following Warner Sucker distribution information is adapted from USFWS (1998).

Historical - The probable historical range of the Warner Sucker includes the main Warner Lakes (Pelican, Crump, and Hart), and other accessible standing or flowing water in the Warner Valley, as well as the low to moderate gradient reaches of the tributaries which drain into the Warner Valley. The tributaries include Deep Creek, up to the Deep Creek falls 3.1 miles west of Adel, the Honey Creek drainage, and the Twentymile Creek drainage. In Twelvemile Creek, a tributary to Twentymile Creek, the historical range of Warner Suckers extended through Nevada and back into Oregon, but the sucker occupied habitat probably did not extend into the California portion of Twelvemile Creek.

Early collection records document the occurrence of the Warner Sucker from Deep Creek below the falls west of Adel, the sloughs south of Deep Creek, and Honey Creek (Snyder 1908). Andreasen (1975) reported that long-time residents of the Warner Valley described large runs of suckers in the Honey Creek drainage, even far up into the canyon reach.

Current – Figure 3-2 includes the current Warner Sucker distribution and designated critical habitat in the basin. Eight studies between 1977 and 1991, and more recent investigations since 2010, have examined the range and distribution of the Warner Sucker throughout the Warner Valley. These surveys showed that when adequate water is present, Warner Sucker may inhabit all the lakes, sloughs, and potholes in the Warner Valley. The documented range of the sucker extended as far north into the ephemeral lakes as Flagstaff Lake during high water in the early 1980s, and again in the 1990s. The northern-most lake where suckers have been found was Stone Corral Lake in the early 2000s.

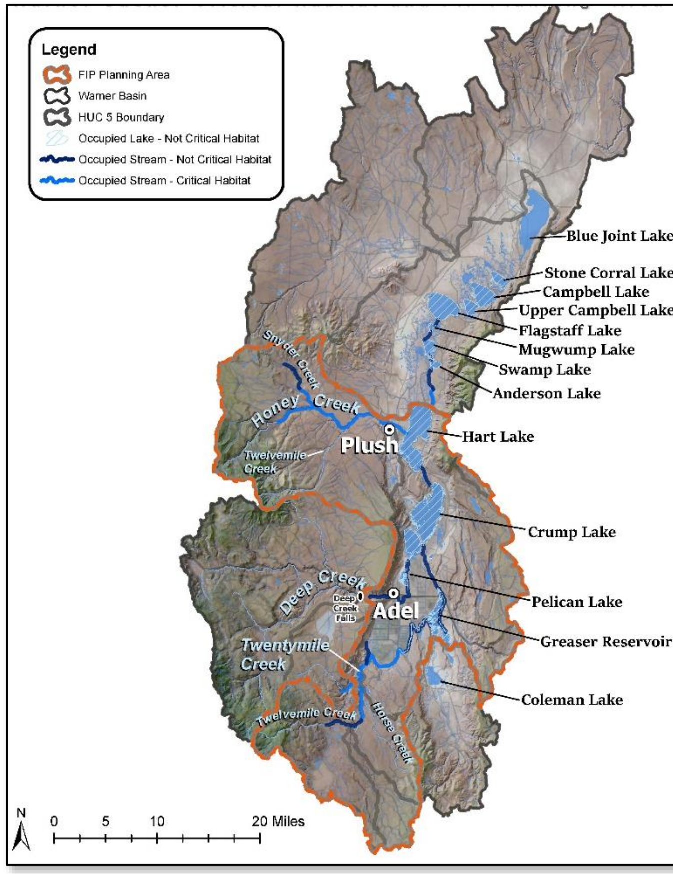


Figure 3-2. Warner Sucker occupied and designated critical habitat, and the Focused Investment Partnership planning area.

Stream resident populations are found in Honey Creek, Snyder Creek, Twentymile Creek and Twelvemile Creek. Intermittent streams in the drainages may support small numbers of migratory suckers in high water years. No stream resident suckers have been found in Deep Creek since 1983 (Allen et al. 1994), although a lake resident female apparently trying to migrate to stream spawning habitats was captured and released in 1990 (White et al. 1990). Juvenile suckers have also been found downstream of the Starveout diversion (Scheerer et al. 2007), suggesting spawning occurred in the vicinity of the diversion. The known upstream limit of the Warner Sucker in Twelvemile Creek is through the Nevada reach and back into Oregon (Allen et al. 1994). However, the distribution appears to be discontinuous and centered around low gradient areas that form deep pools with protective cover. In the lower Twentymile Slough (i.e., flood ditch) on the east side of the Warner Valley, White et al. (1990) collected adult and young suckers throughout the slough and Greaser Reservoir. This area dried up in 1991, but because of its marshy character, may be important sucker habitat during high flows. Larval, young-of-year, juvenile and adult suckers captured immediately below Greaser Dam suggest either a slough resident population, or lake resident suckers migrating up the Twentymile Slough channel from Crump Lake to spawn (White et al. 1990, Allen et al. 1996).

Life Stages

The following Warner Sucker life stages information is adapted from Monzyk (2019).

Egg and Larval Stage – Eggs are partially buried in gravel substrate during stream spawning. After approximately one month of incubation, larval suckers hatch at 7-8 mm and emerge from the gravel at approximately 10 mm in late spring and early summer (White et al. 1991; Kennedy and Vinyard 1997). In streams, larvae occupy vegetated areas with low to moderate flow and relatively shallow depths along stream margins or backwater areas during the first few months after hatching (~10-17 mm TL) (Coombs et al. 1979; Kennedy and Vinyard 2006). As the larvae grow in size, they move into mid-water habitats with moderate flows (Coombs et al. 1979; Kennedy and Vinyard 2006). Larvae select microhabitats with focal point velocities (FPV) between 3-6 cm/s and avoided areas with FPV >15 cm/s (Kennedy and Vinyard 2006). They feed on invertebrates in the upper half of the water column with planktonic cladocerans dominating the diet (Coombs et al. 1979; Tait and Mulkey 1993a). They also appear to segregate from larval Speckled Dace (*Rhinichthys osculus*) by feeding higher in the water column (Coombs et al. 1979). At night larvae move closer to shore, presumably to avoid entrainment into swift currents when visual orientation in the stream is lost (Kennedy and North 1993; Kennedy and Vinyard 1997).

Larval suckers are rarely collected in drift samples (Coombs et al. 1979; Kennedy and Vinyard 1997; Kennedy and North 1993; Bosse et al. 1997; Richardson 2009) and express a distinct drift avoidance behavior. Kennedy and Vinyard (1997) measured the response of larval suckers to artificial entrainment in mid-channel current and found larvae of all sizes (16-30 mm TL) resisted downstream displacement. Once released into the current, fish would immediately seek current refugia behind rocks and vegetation. Warner Suckers are unique from other western suckers in that larvae do not drift downstream after hatching in streams (Cooperman and Markle 2011; Kennedy and Vinyard 1997).

Juvenile Stage – As larvae develop into juveniles they become more bottom orientated. During the day juveniles associate with macrophyte beds, while at night they move into riffles and open areas to feed (Tait and Mulkey 1993a). Several other studies have noted that movements of both juvenile and adult Warner Suckers are primarily nocturnal (Richardson et al. 2009; Scheerer et al. 2015; Scheerer et al. 2016). Most juvenile foraging time (75%) occurs over large gravel or boulders, where they likely feed on diatoms, filamentous algae, and detritus (Tait and Mulkey 1993a).

Adult Stage – Warner Sucker adults reside in both tributaries and the lakes. Suckers born in tributaries, may migrate to the lakes when they are 3-4 years old. The more productive lake environments support faster growth and lake resident suckers reach larger sizes compared to stream type suckers. Spawning takes place in both stream and lake environments. Monzyk (2019) provides extensive information on adult spawning habitat, timing, and behavior.

Population Abundance

ODFW periodically estimates Warner Sucker population abundance in the Warner Basin. Stream populations are sampled using backpack electrofishing (Scheerer et al. 2011; and multiple gear types are used to estimate lake populations (Scheerer et al. 2016). Scheerer et al. (2011) provides a summary of population abundance estimates completed in Honey, Deep, and Twentymile Creeks from the mid-1990s through 2011. Table 3-1 includes summary Warner Sucker abundance estimates for the three Warner Basin tributaries.

Table 3-1. Warner Sucker abundance estimates completed for Honey, Twentymile, and Deep Creeks.

Stream	Reach	Year	Distance Surveyed (km)	Fish per km	Abundance Estimate (95% CI)
Honey Creek		2007[1]	2.9	59	2,202 (418 - 3,986)
		2011[2,6]	25.6	176	4,495 (3,668 - 5,448)
		2011[2,7]	25.6	148	2,105 (1,372 - 3,201
Twentymile Creek		2007[1]	2.0	237	4,746 (0 - 12,529)
		2009[3]	21.3	219	4,612 (3,820 - 5,567)
	Lower	2014[4]	3.15	153	482 (368 - 638)
	Lower	2015	1.7	478	813 (761 - 861)
	Lower	2016[5,8]	1.5	642	963 (860-999)
Deep Creek		2007[1]	0.7	19	150 (0 - 438)

[1] Scheerer et al. 2007; [2] Scheerer et al. 2011; [3] Richardson et al. 2009; [4] Scheerer et al. 2014; [5] Scheerer et al. 2017; [6] Estimate for Warner Suckers >59 mm; [7] Estimate for Warner Suckers >99 mm ; [8] Estimate for MC Canal/Twentymile Creek

Habitat Use

In addition to completing population abundance estimates, ODFW has also surveyed and documented habitat conditions in the sampling reaches. Pools and aquatic vegetation are primary habitat variables, water temperature and undercut banks are secondary habitat variables (Scheerer et al. 2011). Deep pools provide an important refuge habitat during low flow periods especially during drought. Scheerer et al. (2014) sampled lower Twentymile Creek from the Dyke diversion to the Cahill Wing Deflector located in the Twentymile Creek bypass. Warner Sucker were only captured in pools with the majority (65%) captured in a single deep pool (>2 m).

Genetic Diversity

DeHaan and VonBargen (2012) completed a genetic analysis of Warner Suckers in Honey Creek, Deep Creek, Twentymile Creek and a translocated population that occupies a naturalized irrigation ditch on the Summer Lake Wildlife Management Area managed by ODFW. The investigators found no differences in the levels of genetic variation between tributary populations, suggesting that no population currently faces an increased risk of threats from reduced genetic diversity. DeHaan and VonBargen also found that Warner Sucker exhibited a relatively high level of genetic variation among the different tributaries (Twelvemile, Deep, Honey, and Snyder Creeks) and tests of allele frequency heterogeneity suggested that each tributary contained a genetically independent spawning population. Warner Sucker in Deep Creek had the highest levels of genetic diversity, suckers in Twentymile Creek had the lowest genetic diversity. These results suggest the higher degree of population connectivity between lower Deep Creek and Crump Lake, and the isolation of the Twentymile Creek stream population from Deep Creek and Honey Creek populations potentially caused by the modification of lower Twentymile Creek.

Conservation History

Conservation actions in the Warner Basin are relatively recent. Fish passage projects have been completed on upper and lower Honey Creek (2008 and 2010, and 2013 and 2017, respectively), Twentymile Creek (2014 and 2017), and as of 2019, the Town diversion fish passage project is underway on Deep Creek. WBAHP is currently working with landowners, individual irrigators, and irrigation districts on fish passage projects on the three focal tributaries.

ODFW completed biological monitoring on fish passage projects on Twentymile Creek (Dyke diversion) and Honey Creek (Rookery diversion) and confirmed passage of Warner Sucker in the completed fish passage structures using Warner Suckers implanted with passive integrated transponder (PIT) tags. A fish passage project completed at the MC diversion on Twentymile Creek is currently being studied (2019). A second fish passage project on lower Honey Creek (Flood Ditch) was completed in 2017 and has not been studied by ODFW.

The continued pursuit of fish passage, screening, and habitat enhancement work on the three focal tributaries in the Warner Valley, is anticipated to result in the future recovery of Warner Sucker and improved conditions for Warner Lakes Redband Trout. Lessons learned on each project are discussed among the WBAHP members and applied during the development of future projects.

3.2 Warner Lakes Redband Trout

Warner Lakes Redband Trout are endemic to the Warner Basin and the species management unit (SMU) includes four populations (Honey, Upper Deep, Lower Deep, and Twentymile). Although Warner Lakes Redband Trout are widely distributed among perennial streams, lakes, and reservoirs in the basin, irrigation diversions and stream dewatering affect Warner Lakes Redband Trout population connectivity and resilience. These limiting factors are most pronounced in the lower reaches of Honey, Deep, and Twentymile Creeks which are influenced by agricultural production. Non-native warm water predatory fish species inhabiting the Warner Lakes, may also impact Warner Lakes Redband Trout through predation and competition for food resources.

Distribution of Warner Lakes Redband Trout varies according to annual fluctuation of instream flows. During drought years, fish distribution constricts as streams and lakes dry and become uninhabitable. Warner Lakes Redband Trout recolonize these streams during wet cycles, restoring their basin-wide distribution. Many of the large lakes in Warner Valley dried in 1992 and redband trout were found in the lakes before and after the dry period (USFWS 1998).

Redband trout in Honey, Lower Deep, and Twentymile Creek populations have access to the Warner Lakes and express multiple life histories. However, irrigation diversions and irrigation canal networks hinder upstream and downstream passage of migrating Warner Lakes Redband Trout. Water availability and climatic conditions determine stream flow and irrigation needs, which in turn, influence the migratory success of redband trout between the lakes and upper stream reaches.

Inter-population connection is possible between the Honey Creek and Lower Deep Creek via Hart, Crump, and Pelican Lakes. These populations may interact when hydrologic connectivity is sufficient for Warner Lakes Redband Trout to access stream spawning habitats. Twentymile Creek is more isolated from the other populations due to agricultural modification of the stream network and Twentymile

Creek fish are unlikely to mix with the Honey Creek and Lower Deep Creek populations. Deep Creek Falls is a natural fish passage barrier that isolates the Upper Deep Creek population. Both the Twentymile Creek and Upper Deep Creek populations lack the opportunity for genetic mixing which creates a greater risk of extinction due to the effects of inbreeding if the populations become very small.

4 Warner Basin Limiting Factors

Warner Basin fish populations are subjected to factors that limit the historical expression of physical and ecological conditions. Limiting factors are defined as the impacted physical, biological, or chemical conditions and associated processes and interactions experienced by fish that may limit population parameters including abundance, productivity, spatial structure, and genetic diversity.

The following limiting factors have been identified for the Warner Basin (USFWS 1988).

- Habitat connectivity
- Habitat quality
- Water quantity (decreased instream flows)
- Water quality (water temperature)
- Introduced fish species

Primary threats to Warner Basin fish populations directly addressed by this document include fish passage barriers, unscreened diversion infrastructure, and improving water efficiency. Migration timing for Warner Basin species is tied to the hydrograph, fish migrate and spawn during the spring when there is sufficient flow in most tributaries for fish to navigate migration corridors to reach spawning grounds. Warner Sucker and Warner Lakes Redband Trout typically ascend tributary streams from April to late June to locate mates and spawning habitat. Historically, fish were able to migrate throughout the Warner Basin during years with sufficient flow in the spring. Adult fish residing in the Warner Lakes and tributary streams spawned in desirable locations.

The construction of irrigation diversions on Honey, Deep, and Twentymile Creeks from the late 1800s to the early 1900s, severed watershed connectivity. Eight diversion weirs on the lower 3.5 miles of Honey Creek create partial or complete fish passage barriers, restricting fish access to 24 miles of upstream habitat. The lower six weirs may be passable during high flows and before diversion stoplogs are installed in the weirs. However, no large lake form suckers have been reported passing the seventh diversion (Town diversion at Hogback Road), approximately 2.2 miles upstream from the mouth of Honey Creek (Coombs et al. 1979; Scheerer et al. 2006). The lowermost diversion (Rookery diversion) was rebuilt in 2015 and the Flood diversion was rebuilt in 2018, both with fish passage-friendly structures. The remaining diversions continue to affect upstream adult passage and may route adult and juvenile suckers into diversion networks.

Deep Creek has six diversions along its 9 miles of Warner Sucker habitat from the mouth of Deep Creek at Crump Lake to Deep Creek Falls. Upstream movement of lake-dwelling suckers is blocked at Starveout diversion based on results of radio-telemetry studies (Scheerer et al. 2006). Warner Suckers appear to have been extirpated above this diversion located 7.6 km upstream from the mouth based on the lack of observations during past surveys (White et al. 1990; Allen et al. 1994).

In the Twentymile Creek subbasin, Warner Suckers occupy 13 miles of stream habitat from the Cahill diversion up to the headwaters of Twelvemile Creek (F. Monzyk, ODFW, personal communication). Recently added fish passage at the Dyke diversion (2016) and the MC diversion (2018) allows free movement of suckers in this reach. Providing connectivity to the lake system through the irrigation canals in the valley remains a challenge.

Diversion weirs create vertical blockages in most years. Combined with the physical obstructions, diversions also reduce instream flows during the irrigation season. Improving diversion network efficiency may provide an opportunity to increase instream flows especially during low flow periods when water temperature and water quality are important for aquatic resources. Improving fish passage at irrigation diversions, screening diversion canals, and increasing instream flows through water efficiency, are goals for Warner Sucker recovery and improving conditions for other Warner Basin fish species.

5 Fish Passage and Screening Design

5.1 Fish Passage

Fish Passage Goals

The USFWS (1998) recovery plan for Warner Sucker outlines steps designed to recover the Warner Basin and Alkali Subbasin aquatic ecosystems with specific goals for Warner Sucker and other listed species (Hutton Tui Chub and Foskett Speckled Dace) which are located outside of the Plan area. USFWS delisted Foskett Speckled Dace in 2019 (USFWS 2018). The primary recovery objective for the Warner Sucker is the eventual delisting of the species. Species delisting is an administrative process overseen by USFWS. While WBAHP can execute projects that achieve recovery criteria, WBAHP does not have the authority to delist the species.

USFWS is currently (2019) reviewing threats and recovery criteria for Warner Sucker, however, based on the 1998 recovery plan, USFWS may consider delisting the Warner Sucker when the following recovery criteria are met:

1. A self-sustaining metapopulation (a group of populations of one species coexisting in time, but not in space) is distributed throughout the Twentymile Creek, Honey Creek, and Deep Creek (below the falls) drainages, and in Pelican, Crump, and Hart Lakes. Self-sustaining populations will be determined based on parameters such as:
    - Multiple age-classes, including adults, juveniles, and young of the year, which approximate normal frequency distributions,
    - A stable or increasing population size,
    - Documented reproduction and recruitment, and
    - Self-sustaining populations form a viable metapopulation, large enough to maintain sufficient genetic variation to enable it to evolve and respond to natural habitat changes.
2. Passage is restored within and among the Twentymile Creek, Honey Creek, and Deep Creek (below the falls) drainages so that the individual populations of Warner Sucker can function as a metapopulation.

3. No threats exist that would likely threaten the survival of the species over a significant portion of its range.

Actions needed for Warner Sucker recovery include:

- Protect and rehabilitate Warner Sucker populations and habitat.
- Conserve genetic diversity of Warner Sucker populations.
- Ensure adequate water supplies are available for Warner Sucker recovery.
- Monitor Warner Sucker populations and habitat conditions.
- Evaluate long-term effects of climatic trends on the recovery of Warner Sucker.

Fish Passage Criteria

Oregon Administrative Rules 412 administered by ODFW, outlines fish passage criteria for Oregon's native fish that migrate to meet their lifecycle needs. Fish passage criteria are available for Warner Sucker and Warner Lakes Redband Trout (Table 5-1). Since Warner Sucker passage criteria are more limiting than passage criteria for trout, sucker criteria are used as the basis for Warner Basin fish passage project designs.

Table 5-1. ODFW fish passage criteria (Oregon Administrative Rules 2006) for trout and sucker. Since sucker criteria are more conservative, sucker criteria are used for fish passage designs in the Warner Basin.

Parameter	Trout	Sucker	Limiting Value
Fishway Slope (%)	-	<4%	<4%
Velocity (feet per second [ft/s])	1-2 ft/s in transport channels <8 ft/s in discrete fishway transitions	4 ft/s max	1-2 ft/s for juveniles
Minimum Water Depth (inches)	6 inches juvenile 12 inches adult	12 inches	12 inches
Jump Height (inches)	6 inches	No jump	No jump
Jump Pool Depth (inches)	6 inches juvenile 12 inches adult	No jump	No jump

Fish Passage Concepts

The following section outlines fish passage considerations and fish passage structures that may apply to Warner Basin diversions. Fish passage considerations are reviewed during the fish passage alternatives review and address water user management goals and biological criteria.

Fish Passage Alternatives Considerations

The following considerations have been encountered during planning for Warner Basin fish passage projects.

- Maintain existing point of diversion and diversion management.
- Improve diversion operational safety and efficiency.

- Meet fish passage criteria for Warner Sucker and Warner Lakes Redband Trout and provide volitional fish passage for the four native fish species in the Warner Basin.
- Execute cost-effective and robust designs that minimize annual operational demands and future maintenance needs.

Fishways are differentiated into two categories, technical fishways and nature-like fishways. Technical fishways include structural solutions like concrete fish ladders, while nature-like fishways may include roughened channels and bypass channels that are analogous to higher gradient stream reaches in the vicinity of the project site. The following sections provide an overview of technical and nature-like fishways that may be considered for improving passage in Warner Basin tributaries.

Technical Fishways

Technical fishways include a concrete fish ladder framework with varied interior structural orientations designed to meet fish passage criteria within the constraints of flow limitations. The following information is adapted from *Fish Passes: Design, Dimensions, and Monitoring* (FAO 2002).

Pool and Weir with Orifice Fishway

Pool and weir fishways are fish ladders with cross-walls that create a series of stepped pools. Stream flow enters the upstream entrance of the ladder and passes downstream through orifices and over cross-walls. The potential energy of the water is dissipated in each pool and fish migrate from one pool to the next. Migrating fish encounter higher water velocities while passing through orifices or over the weir notch at the top of the cross-wall, but experience lower velocities in the intervening pools. A rough channel bottom is added to the fish ladder and orifices are placed near the bottom of each cross-wall to enhance passage conditions for Warner Sucker.

Conventional pool and weir fishways are characterized by vertical cross-walls located at right angles to the pool axis (Figure 5-1). Cross-walls may be constructed from concrete or wood, wood cross-walls may be modified in response to fish passage monitoring data. Wooden cross-walls may need to be replaced periodically as the wood degrades. Incorporating orifices in the cross-wall provides submerged openings that facilitate passage of benthic species like the Warner Sucker. Alternating orifice locations on subsequent cross-walls reduces velocities through the cross-walls. Grouting cobble to the bottom of the fishway creates a stable, continuous nature-like channel bottom through the fishway. The rougher fishway bottom creates a lower velocity zone that is used by benthic species to navigate the fishway.

Pool and weir fishways have low water requirements and may be a preferred fish passage solution in streams like the Warner Basin tributaries where low flows are an annual occurrence. The fishways also address passage needs for both surface-oriented and bottom-oriented, as well as small fish species. In contrast to these benefits, pool and weir fishways may also require more maintenance than other fishway types. Fishways need to be monitored during and following high flow periods to ensure sediment and debris do not block orifices. Fishway entrances can be blocked and the fishway drained in order to provide a comprehensive review of fishway conditions. Wooden cross-walls may need to be replaced over time as wood degrades. At replacement, managers should determine if cross-wall design should be modified in accordance with fish passage and hydraulic monitoring results.

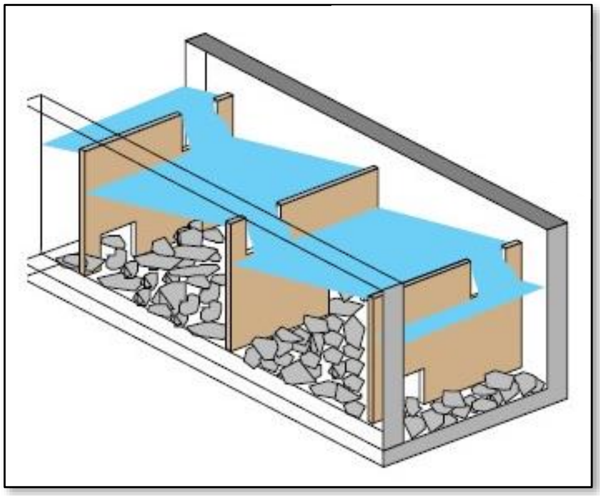



Figure 5-1. A pool and weir with orifice and streambed simulation material (FAO 2002, left). The downstream extent of the Dyke diversion fishway on Twentymile Creek.

Vertical Slot Fishway

The vertical slot fishway (Figure 5-2) is a variation of the pool and weir fishway whereby the cross-walls are notched by vertical slots extending over the entire height of the cross-wall. In comparison to the alternating orifice positions in a pool and weir fishway, vertical slots are placed on the same side of the fishway. Vertical slot fishways allow energy dissipation as a function of the pool, longitudinal slope, baffle and vertical slot design.

In particular, slot width and the number of slots (one or two), and the resulting discharge, determine the pool dimensions required. As with pool and weir fishways, velocities and turbulence are highest through the slot and lowest in intervening pools. The shape of the cross-walls must be such that no short-circuit current, that would pass through the pools in a straight line from slot to slot, is formed but rather a main current is created that curls back on itself such that the entire pool volume is used for energy dissipation. Such current regimes are encouraged by incorporating a hook-shaped projection into the cross-walls that deflects the flow in front of the slot entrance.

Like the pool and weir fishway, cross-walls may be constructed from concrete or wood. Wooden cross-walls require the installation of steel channel in the concrete formwork of the fishway. The cross-walls should be sufficiently high so that at mean discharge the water does not flow over the cross-walls.

Like the pool and weir bottom orifices, the vertical slot fishway includes a vertical slot pass that allows the creation of a continuous bottom substrate through the whole fish ladder. Grouting cobble to the fishway bottom provides additional roughness and velocity breaks within the fishway.

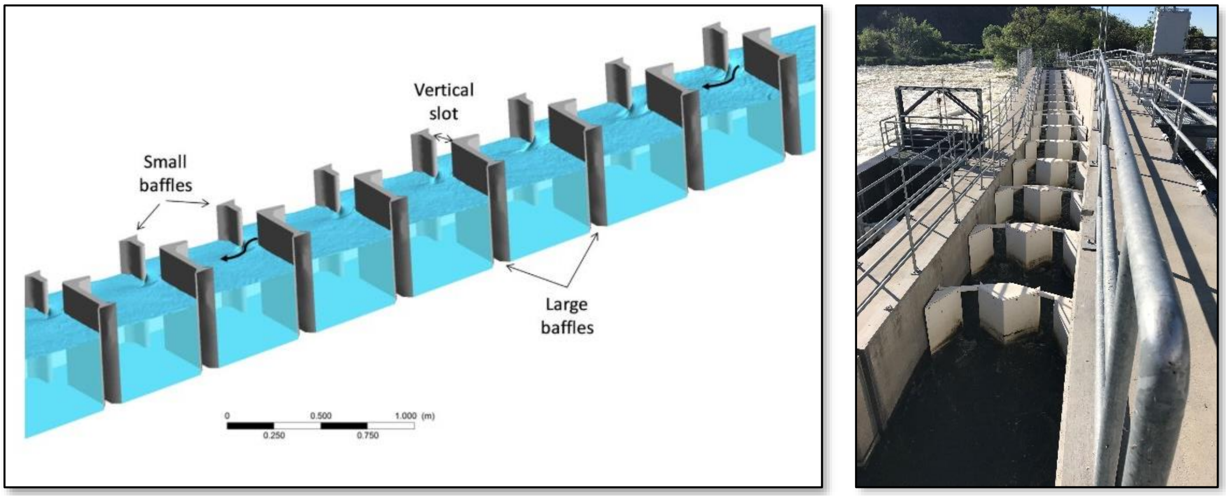


Figure 5-2. A vertical slot fishway schematic (Sanagiotto et al. 2019; left) and the vertical slot fishway on the Link River Dam in the Klamath Basin (right). The Link River Dam fishway has two slots and chevron-shaped baffles to reduce water velocities for Klamath Lake sucker passage.

In addition to facilitating upstream passage of Warner Sucker, the bottom substrate considerably reduces flow velocities near the fishway bottom and through the vertical slots. The roughness created by the grouted bed materials makes it possible for species with low swimming performance to migrate through the fishway. It is important to ensure that the bottom substrate in the fishway is connected to the bottom substrate of the stream at the upstream and downstream extents of the fishway. Adding rock fill to the channel at the inlet and outlet of the fishway may be necessary.

Vertical slot fishways have many advantages including:

- Providing passage opportunities for water column and bottom-oriented fish species,
- Fishways allow for the installation of natural channel materials to emulate streambed hydraulic and habitat conditions,
- Vertical slots are less sensitive to headwater and tailwater levels,
- Vertical slots are less susceptible to sediment or debris build-up compared to pool and weir with orifice fishways.

Vertical slot fishways may require more water to operate compared to pool and weir fishways. Operational flow requirements are affected by the vertical slot opening width which in turn is determined by the target fish species to be passed.

Table 5-2 includes advantages and disadvantages of technical fishways.

Table 5-2. Advantages and disadvantages associated with technical fishways.

Advantage	Disadvantage
• Accepted fish passage technology • Long-term persistence • Design certainty • Maintains existing point of diversion and can be retrofitted to diversion weir • Designed to pass range of fish species with varied swimming abilities • No effect on irrigation water delivery • May be easier to monitor fish passage and hydraulic conditions	• Often the most expensive alternative • Technical construction • Aesthetics • Potentially frequent maintenance following high flows

Nature-like Fishways

Nature-like fishways include roughened channels and bypass channels. These fishways incorporate natural materials and apply geomorphic and hydraulic conditions similar to nearby steeper channel reaches as design analogues. Nature-like fishways are designed to be site-specific as the structures are more sensitive to site conditions than technical fishways. The construction approach and building materials are similar for the three types of nature-like fishways that will be reviewed. For example, roughened channels and bypass channels are constructed using boulder sills or ribs, and single or clusters of boulders to increase channel bed roughness for energy dissipation and habitat complexity.

Roughened Channel

A roughened channel is a mechanism to disperse the hydraulic head (i.e. the vertical difference in water level between the upstream and downstream water surfaces) over a certain distance by keeping the hydraulic gradient of the slope as gradual as possible. Roughened channels provide a range of velocity and water depth conditions as influenced by flow, stage, and channel bed roughness (Figure 5-3). Roughened channel gradients may be between 2% and 10%, with the steeper the channel, the larger the bed material that is needed to resist bed material erosion.

The roughened channel should be constructed as a multi-layered rockfill comprised of a rock matrix and larger boulders. The rock matrix should be comprised of angular and subangular materials that are more resistant to erosion. Larger boulders that are incorporated to increase roughness, should be rounded for aesthetics.

The downstream transition from the roughened channel to the natural channel bed may require additional attention to avoid scour in this transitional area. A transition to a coarse bed or a channel bed that has been armored as a result of pre-project conditions, may require minimal treatment. Conversely, a channel bed characterized by finer materials may necessitate extending a coarse channel bed downstream of the roughened channel slope transition. Transitioning the roughened channel into a pool is another option for dissipating stream energy downstream of the steeper roughened channel. Planting the banks of the roughened channel with appropriate vegetation enhances streambank resistance to erosion and promotes the main flow axis in the center of the roughened channel during floods.

Rock matrix and boulder placement should accommodate fish passage routes at all stages. Openings between surface boulders and placing boulders in clusters, create fish passage routes and variable hydraulic conditions that fish use to pass steeper channel features. Clustered boulders are also more resistant to scour as joined boulders are more resistant to hydraulic forces.

From the ecological point of view, low to moderate slope roughened channels offer the best means for restoring fish passage in streams where diversion weir cannot be removed. Maintenance is relatively low and can be limited to the occasional replacement of scoured rockfill, additional streambank plantings, and removal of debris. Maintenance may follow large floods or ice floes that damage the roughened channel surface. When constructed correctly, the Warner Basin's native fish species will be able to freely pass the roughened channel and irrigation diversion infrastructure.

Figure 5-3. An irrigation diversion weir on Whychus Creek near Sisters, Oregon before (left) and after (right) the construction of a roughened channel.

The most important advantages of roughened channels are as follows:

- Roughened channels provide diverse flow pathways and habitat conditions.
- The diverse flow pathways can be negotiated by bottom-oriented fish species, small fish species, and juvenile fish since they have a nature-like morphology.
- In some systems like the Warner Basin where adjacent stream reaches are backwatered by the diversion weir or are otherwise low gradient, the roughened channel may provide a higher gradient habitat.
- Relative to technical fishways, roughened channels may require less maintenance with maintenance mainly related to replacing scoured bed material and maintaining riparian vegetation.

Potential roughened channel disadvantages include:

- Potential large volume of imported materials for the rock matrix and boulders.
- Attention to construction techniques and ensuring the rock matrix is sufficiently compacted and void spaces are filled to avoid roughened channel dewatering.
- The potential for periodic maintenance to address roughened channel bed scour.
- Poor passage conditions during low flows if flow volumes and roughened channel surface roughness do not maintain minimum water depths for passage.

Bypass Channels

Bypass channels provide passage around a diversion weir and may be used singularly or in combination with other fishways. The bypass channel is typically constructed to resemble a natural channel within the constraints of the project site. Bypass channels are particularly suitable for sites where in-line fishways integrated into the diversion weir is not possible. Additionally, a bypass channel may provide fish passage during the diversion season when an adjustable weir is an impassable structure, but passage over the weir is possible during the non-irrigation season when fish can migrate over the structure.

Bypass channels are designed to pass a portion of the streamflow, and therefore the channel design is tailored to the design flow range. Only a proportion of the discharge is diverted through the bypass channel, and in Oregon, a minimum of 10% of the stream flow is targeted for bypass channel operation. The main disadvantage of a bypass channel is the relatively large surface area required for the construction. Therefore, the application of a bypass channel is in part predicated on available surface area and the landowner's agreement to remove that land area from production.

The slope of the bypass channel should be as gentle as possible, and a channel slope of less than 5% is preferable (Figure 5-4). A steeper slope can be broken up by incorporating steeper riffles and lower gradient pools, or a step pool morphology for the steepest channels. Proposed bypass channel designs should be hydraulically modeled to assess water velocities and depths. The headwater condition at the upstream end of the bypass channel must also be known for appropriate function of the bypass channel. The downstream extent of the bypass channel may be a slightly steeper slope to accentuate attraction flow at the transition from the bypass channel to the stream. Similarly, the downstream end of the bypass channel should enter the stream near the diversion weir so that the bypass channel entrance is easy for upstream-migrating fish to find.

Like the roughened channel, natural substrate should be used to build the channel bed. A range of substrate sizes forms the channel bed matrix, larger boulders are used for energy dissipation and to create a channel framework similarly to the approach described for the roughened channel. Channel bed material should be sized according to the modeled hydraulic conditions. Streambank treatments should likewise be tailored to the hydraulic conditions. Streambank treatments should include roughness elements and live vegetation so that over time, vegetation will colonize the bypass channel banks and provide habitat, shading, and material inputs to the channel.

Figure 5-4. A moderate gradient bypass channel (left) on Sevenmile Creek and a steeper riffle and pool bypass channel (right) on Brownsprings Creek, Upper Klamath Basin.

Large boulders and boulder sills provide stability for the constructed nature-like fishway and create hydraulic shadows used by migrating fish. Placing large boulders in an offset, irregular arrangement increases channel roughness that influences water depth and velocity. During medium and low stream flows, the water flows around or only slightly over such boulders. The boulders also increase the water depth and reduce flow velocity, providing flow shadows fish use during upstream migration. Local alternations in the flow regime may occur in the narrowed cross-section.

Boulders should be embedded into the channel bed matrix by up to one third or one half of the boulder's height. The boulders must be big enough to resist hydraulic and ice floe displacement and should be irregularly spaced and vertically positioned for fish passage and aesthetics (if a concern). Boulder sills can also be used to create habitat features while ensuring grade stability. Boulder sills should include boulders set at variable depths and incorporate notches over the length of the sill to ensure fish passage at low flows.

The most important advantages of bypass channels are as follows:

- Bypass channels can be located to complement the existing landscape.
- They can be negotiated by small fish species and juvenile fish since they have a nature-like morphology and bypass flows can be selected to meet swimming abilities of target species.
- In some systems like the Warner Basin where adjacent stream reaches are backwatered by the diversion weir or are otherwise low gradient, the bypass channel may provide a higher gradient habitat.
- Bypass channels may require less maintenance compared to with maintenance mainly related to replacing scoured bed material and maintaining riparian vegetation.
- Bypass channels may be used singularly or in combination with other fish passage techniques. Inclusion of a bypass channel may also allow fish to avoid passing over the irrigation diversion.

Potential bypass channel disadvantages include:

- Dedication of land surface area for bypass channel placement.
- The potential for periodic maintenance if bypass flows exceed the intended operational flow range.
- Sensitivity of bypass channel operation relative to headwater elevations and diversion operation.
- Potential excavation requirements to locate the bypass channel in the adjacent land surface.

Table 5-3 includes advantages and disadvantages of nature-like fishways.

Table 5-3. Advantages and disadvantages associated with nature-like fishways.

Advantage	Disadvantage
• Creates more natural channel conditions for passage • Potentially lower implementation cost than technical fishway, requires less technical construction • Maintains existing point of diversion and weir	• May require additional land area • Attention to construction detail to avoid channel dewatering • Attention to boulder placement for stability and fish passage pathways

Table 5-3. Advantages and disadvantages associated with nature-like fishways.

Advantage	Disadvantage
• Designed to pass range of fish species with varied swimming abilities • No effect on irrigation water delivery	• Periodic maintenance to replace channel bed material • Periodic removal of debris • Low flow conditions may not meet fish passage criteria

Fishway Constructability and Costs

Project site location and site conditions influence fishway constructability and implementation costs. In the Warner Basin, project sites may be influenced by topography and geology. Site access and project construction may require unique techniques due to restrictive landforms and bedrock exposures. Additionally, the remote nature of the Warner Basin project locations may elevate project costs relative to projects in other more accessible locations. For example, basalt quarries may be up to 10 miles away and concrete providers may be up to 50 miles away from some project sites. Project construction costs should be developed during the alternatives analysis to provide stakeholders with an understanding of anticipated project costs for each alternative. Costs should be updated as designs are progressively refined through the multi-step design process.

Fishway Operation and Maintenance

Optimal fishways minimize operational and maintenance effort and require minimal change from existing diversion operations. Operation and maintenance needs vary between technical and nature-like fishways. Technical fishways require regular monitoring to ensure passage is maintained through submerged orifices. Sediment and debris may obstruct submerged orifices, leading to poor hydraulic function and physical blockage of fish passage routes. Depending on the blockage source and flows in the ladder, the blockage may be removed by working from above or outside of the ladder, or the manager may need to enter the fishway to remove more persistent blockages. Since blockages are most likely to form during or following high flow events, the manager may not be able to remove the blockage until after flows have receded, potentially impacting the fish passage period. Technical fishway designs should incorporate debris exclusion devices such as trash racks, access structures like ladders, and means for blocking flow from entering the fishway in order to access the fishway interior.

Compared to technical fishways, nature-like fishways are less affected by debris, but may be influenced by flood flows and ice floes that destabilize fishway materials. Appropriate rock sizing and adhering to construction methods during fishway construction is important for nature-like fishway persistence. Sediment supply and transport are typically disrupted by surface water diversions as the diversion weir creates a backwater. Sediment transported in the reach may deposit upstream from the weir, necessitating periodic removal of the deposited material. The roughened channel located downstream from the weir is typically steeper than adjacent channel gradients, increasing the stream’s sediment transport efficiency in the project reach. Roughened channel bed erosion may result if the size of placed rock is not sufficient to resist hydraulic forces. As smaller diameter materials are mobilized, large boulders may then move and eventually form boulder clusters. Periodic maintenance of the roughened channel surface may be necessary to ensure fish passage conditions and roughened channel stability persist.

In summary, flood and ice floe events have the potential to impact both technical and nature-like fishways. Technical fishways are likely to require more regular monitoring and low-cost maintenance to remove debris from submerged orifices. Nature-like fishways require less frequent monitoring, but erosion of the roughened channel requires more costly repairs. Incorporating potential operation and maintenance costs during the project alternatives analysis is recommended to ensure stakeholder understanding of future maintenance responsibilities.

Diversion Operation

Fishways should either complement or neutrally affect diversion operations. Fishway locations, hydraulic control elevations, and operation should be planned with an understanding of diversion operations. It is imperative that the fishway design team meets with water users throughout the design development process to ensure the fish passage design accounts for water users' concerns and management. An operational manual should be prepared so that water users and other stakeholders understand the purpose of the fishway, fishway operation and maintenance directions, and contingency plans for correcting fishway deficiencies.

Completed Warner Basin Fishways

Both technical and nature-like fishways have been constructed in the Warner Basin. Technical pool and weir with submerged orifice fish ladders have been constructed on Honey Creek (Rookery diversion) and Twentymile Creek (Dyke diversion). Nature-like fishways have been built on Twentymile Creek (MC diversion bypass channel) and Honey Creek (Middle Taylor diversion roughened channel, Flood diversion roughened channel). Table 5-4 provides a summary of completed Warner Basin fishways. Monitoring information is presented in Section 6 - Effectiveness Monitoring.

Table 5-4. Completed fishways in the Warner Basin.

Location	Fishway Type	Construction Cost	Year Completed	Fish Passage Monitored
Honey Creek – Rookery diversion	Technical – Pool and Weir	$306,000	2013	Yes*
Honey Creek – Lower Taylor diversion	Nature-like – Roughened Channel	$20,000	2008	No
Honey Creek – Middle Taylor diversion	Nature-like – Roughened Channel	$20,000	2010	No
Honey Creek – Flood Ditch diversion	Nature-like – Roughened Channel	$270,000	2018	No
Twentymile Creek – Dyke diversion	Technical – Pool and Weir	$355,000	2015	Yes
Twentymile Creek – MC diversion and two culverts	Nature-like – Bypass Channel	$332,000	2018	Yes

5.2 Irrigation Diversion Screening

Screening Goals

Irrigation diversion screens are intended to exclude fish from entering the diversion canal network as fish entering the diversion network may be lost from the population through predation, canal dewatering, or declining water quality over time. The variable hydrology of Warner Basin streams is noted by periodic extreme high flows and more regular extreme low flows. Additionally, Warner Basin irrigators hold water rights that exceed streamflow during the summer in most years, allowing for the diversion of all streamflow. Diversion headworks and screening systems should be designed to account for the extreme flow variability, and innovative screen designs are encouraged to maximize screen performance and minimize the effort necessary to operate and maintain screens.

The screen design team should coordinate screening projects with project stakeholders and regulatory agencies to ensure fish screens meet design criteria or are screens are given variances to deviate from criteria. Two conditions that may require innovate approaches include first, how to address fish bypass when all streamflow is diverted and the stream channel immediately downstream from the diversion dewaters, and secondly, how to size screens to exclude fish during common irrigation flows rather than extreme flows which may only occur during short periods of the year.

Screen Criteria

Fish screen criteria developed by ODFW (2016) and NOAA-Fisheries (2011) are used to develop and evaluate fish screens. Although there are no anadromous species in the Warner Basin, the U.S. Fish and Wildlife Service defers to NOAA-Fisheries screening criteria for evaluating screen designs. NOAA-Fisheries' screening criteria are also the industry standard for screen design in the Pacific Northwest. A summary of pertinent guidelines fish screen design is included in Table 5-5.

Table 5-5. Fish screen criteria based on ODFW (2016) and NOAA-Fisheries (2011) guidance.

Consideration	Standard / Guidance / Note	Site Specific Criteria (if applicable)
Screen Placement	Canal Installation with bypass system	Placement to accommodate sediment, debris, access, and fish bypass
Design Flow	All installation types to consider 5% to 95% hydraulic conditions	Account for extreme flow range, typical diversion flows, and screen cost
Screen Area	Sized for approach velocity and diversion rate	Account for typical diversion flows
Screen Hydraulics	Approach velocity: 0.4 ft/s for active screen	0.8 ft/s acceptable for fingerling size and larger salmonids
Sweeping Velocity	Greater than approach velocity (Optimally: 0.8-3 ft/s)	-
Submergence	Consideration for roll drum	65% to 85% of roll drum diameter submerged in water
Screen material	3/32" perforations or 1.75 mm slots Minimum 27% open area Corrosion resistant	FCA screen: <3/32" perforations Pitman screen: 3/16" perforations 50% open area assumed for preliminary design

Table 5-5. Fish screen criteria based on ODFW (2016) and NOAA-Fisheries (2011) guidance.

Consideration	Standard / Guidance / Note	Site Specific Criteria (if applicable)
Bypass Flow	For diverted flows of 0 - 25 cfs, minimum 5% of diverted flow	Estimate 10% - 15% of diverted flow
Bypass Location	For screens > 6 ft, end of screen terminates at bypass entrance	-
Bypass Pipe Diameter / Geometry	The bypass pipe should be designed to maintain velocity of 6 - 12 ft/s with a minimum depth of 40% of the bypass pipe diameter	For diverted flows of 0 - 25 cfs, this equates to a 10 inch diameter with slope of 1.3%. Other designs should meet depth and velocity criteria. Bypass operation should reflect diversion flow vs. instream flows

Fish Screen Alternatives

The following fish screen alternatives discussion provides example active and passive fish screens that maybe used to meet screening needs in the Warner Basin. Active screens rely on mechanical cleaning while passive screens rely on flow seeping along the screen surface to limit debris impingement. Active screen mechanical cleaning systems may be driven by water, solar, or electrical power. While most screens would be placed downstream from the irrigation headworks to protect the screen from debris and sediment, screens may also be placed either in front of headworks or on the channel margin. The following sections contain a general description of each screen type.

Rotary Drum Screen

Rotary drum screens are a common screen design used in the Warner Basin. Diverted flow enters the screening bay and passes through the drum screen (Figure 5-5). The drum screen, which may be water, solar, or electrically powered, rotates and passes debris into the diversion canal on the other side of the screen forebay. Fish, sediment, and debris may also be returned to the stream via the bypass pipe. The screen rotates continuously when operational.

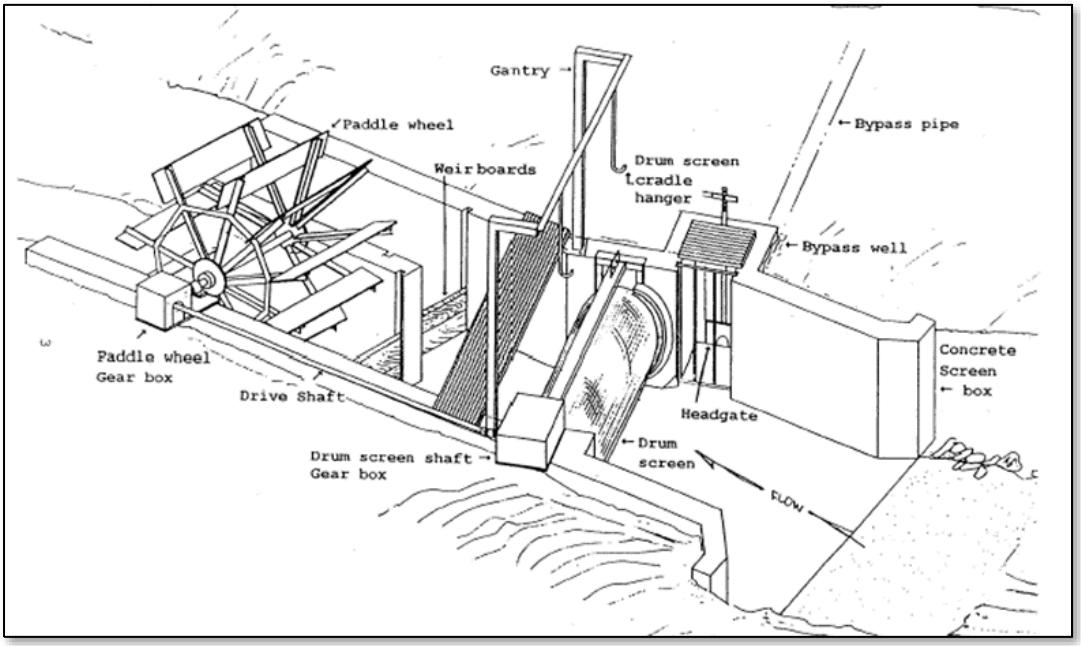


Figure 5-5. Rotary drum screen schematic for a screen typically fabricated by ODFW. Flow enters the screen structure from the right. A portion of flow passes through the rotary drum fish screens and down the irrigation canal, and a portion of flow passes down the fish return bypass pipe and is returned to the stream.

Screens can be designed to pass up to 15 cfs and multiple drum screens may be included to accommodate variable flows similar to those experienced in the Warner Basin (Figure 5-6). Operation and maintenance is comparable to other screen types, although streams with high fine sediment and debris loads may result in more maintenance effort to ensure proper screen function.

Figure 5-6. Example paddle wheel-driven rotary drum screens at the O'Keeffe diversion on Deep Creek (left) and the Taylor diversion on Honey Creek (right).

Vertical Flat Plate Screen

Like the rotary drum screen, vertical flat panel screens are active screens placed in a concrete vault downstream of a headworks. A powered brush arm continuously sweeps across the screen face to dislodge debris. Multiple brush arms may be installed depending on the screen length. Screen orientations include both single and double "vee" style vertical screens (Figure 5-7). Water flows through the screen while fish, return flow, sediment, and debris are returned to the stream via a bypass pipe. Screen maintenance often focuses on replacing the moving parts of the brush trolley including the cable and pullies that run the trolley and the brushes themselves. Deposited sediment may also be periodically removed to ensure proper screen function and water delivery.

Figure 5-7. Example vertical flat plate screens in single (left) and double or "vee" orientation (right). Screens are actively cleaned by powered brush systems.

FCA Horizontal Plate Screen

The FCA horizontal flat plate screen was invented by the Farmers Conservation Alliance (FCA) of Hood River, Oregon. FCA screens have no moving parts and require relatively little maintenance. The FCA screen is installed in the existing ditch and consists of a screen box constructed from plate steel and a fish screen constructed from perforated stainless steel plate (Figure 5-8). Water flows over the screen and most of the water is screened and delivered downstream to the irrigation ditch. A portion of the diverted flow returns fish, sediment, and debris from the screen face, back to the stream via the bypass pipe. The FCA screen is considered a passive screen since there are no moving parts and screen cleaning is accomplished by flow over the screen. A minimum ditch or screen slope is necessary to ensure proper screen function. Minimal screen maintenance may be required to remove sediment and debris from the screen forebay and conveyance flume.

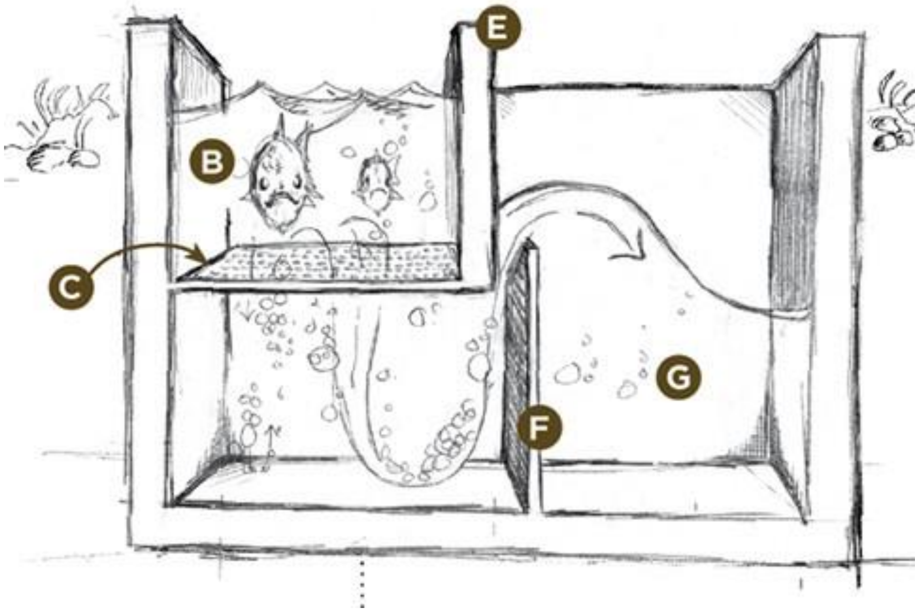


Figure 5-8. Schematic of a Farmers Screen, courtesy of FCA. View of schematic is facing upstream. Water flows over the screen (C) approximately 16 times faster than it flows through the screen, which passes fish and debris downstream. Screened water passes over a weir wall (F) and is conveyed to the irrigation ditch (G). Fish and debris are returned to the channel.

Modular screens may be used for smaller diversions while larger diversions may require site-specific designs (Figure 5-9). Depending on diversion volume, the screen size may require a land surface area larger than the diversion ditch. Larger screens can be adapted with sediment drains to reduce screen maintenance.

Figure 5-9. The 6.25 cfs modular FCA screen at the Dyke diversion on Twentymile Creek (left) and the 150 cfs custom fabricated FCA screen at the Three Sisters Irrigation District diversion on Whychus Creek near Sisters, Oregon (right).

Fish Screen Concepts Discussion

The fish screen concepts provide a range of screen types that have been successfully applied on other projects in the Warner Basin and in adjacent high desert watersheds. While there are other available screen types that stakeholders may choose to investigate, the three reviewed screens presented in the previous section, have a history of success in meeting irrigator water needs and excluding fish from diversion networks. Table 5-6 includes a relative comparison of the three screen types.

Screens would be designed to meet ODFW and NOAA-Fisheries criteria or a variance on screening criteria would be pursued if necessary. Screen design and construction could be completed by ODFW where appropriate. Other screen fabricators could also be contracted to design and construct screens.

Screen maintenance considerations for all screens involve periodic (daily to weekly) observations of the screen during the irrigation season to adjust flow rates, examine the screen for debris and to remove any accumulated debris. Management of fine sediment will likely be required for all designs. Fine sediments tend to accumulate in the forebay of the rotary drum and vertical plate screens, and on and below the screen surface in the FCA screen. Fines can be removed with a shovel or agitated and washed down the bypass pipe or the diversion canal. Closing the ditch headgate once the irrigation season is over is recommended as it will reduce sediment accumulation for any of the screen alternatives. Rotary drum screens are typically raised above the screen bay to reduce wear when the screen is not in use. The FCA screen has no moving parts and therefore the mechanical maintenance requirement on this screen is lower than on the rotary drum and vertical plate screens that have mechanical parts as part of the cleaning systems.

Diversion structures, headgates and sluice gates also require periodic inspection and maintenance. Fine sediment may accumulate near the entrance to the headworks due to expansion of the channel area and the flatter slope that often leads to the diversion canal. Sediment may also accumulate at the headworks inlet during the non-irrigation season when the headworks are closed. A sluice gate set lower than the headgate invert (i.e., bottom) elevation and connected to a sluice pipe is recommended to provide a means to flush the accumulated fine sediments out of the headworks inlet during high flows. Headgates and sluice gates require annual inspection and maintenance of moving parts.

Table 5-6. Relative comparison of fish screen alternatives for diversions less than 15 cfs.

Metric	Rotary Drum Screen	Vertical Flat Panel Screen	FCA Screen
Fish Screening Performance	Good	Excellent	Excellent
Approach Velocity	< 0.4 ft/s	< 0.4 ft/s	< 0.2 ft/s
Debris Maintenance	Medium (weekly check)	Low (scrub 1-2x per month to remove algae if present)	Medium (weekly check)

Table 5-6. Relative comparison of fish screen alternatives for diversions less than 15 cfs.

Metric	Rotary Drum Screen	Vertical Flat Panel Screen	FCA Screen
Screen Maintenance	Medium (periodically remove drum to flush sediment, annual mechanical, periodically replace bushings)	Medium (periodically flush sediment, annual mechanical, replace brushes every ~6 yrs)	Low (annual sediment flush)
Constructability	Moderate ~2 - 3 weeks	Simple ~2 weeks	Simple ~2 weeks

Fish screen construction costs vary by screen size, type and location. However, construction unit costs typically range from $10,000 to $15,000 per cfs of diverted flow.

Completed Warner Basin Fish Screens

Fish screens have been completed on each of the three focus tributaries in the Warner Basin (Table 5-7). Rotary drum screens have been constructed on Honey Creek (3) and Deep Creek (2), an FCA screen was installed on Twentymile Creek, and a vertical plate screen was built on Honey Creek. These screen types were selected based on site conditions, water user input, and funding support. These screens have generally been sized for less than 20 cfs. Primary maintenance obligations have included sediment and debris removal (e.g., counteract beaver activity) on the rotary screens. The FCA screen has required seasonal maintenance to remove sediment and brush. The vertical plate screen is in its first season of use.

Table 5-7. Completed screens in the Warner Basin.

Location	Screen Type	Construction Cost	Year Completed	Typical Maintenance
Honey Creek – Lower Taylor diversion	Rotary Drum	$70,000	2008	Debris
Honey Creek – Middle Taylor diversion	Rotary Drum (2)	$70,000	2010	Debris
Honey Creek – Flood Ditch diversion	Vertical Plate	$45,000	2018	New
Deep Creek – O'Keeffe Ditch diversion	Rotary Drum	$138,000	2007	Fine Sediment
Twentymile Creek – Dyke diversion	FCA Horizontal Plate	$45,000	2015	Fine Sediment, Debris

Planned Warner Basin Fish Passage and Screening Locations

Figure 5-10 includes the locations of planned fish passage and screening projects in the Warner Basin. Planned projects are located in the Honey Creek and Deep Creek drainages. Once the planned fish passage projects are completed, Warner Basin fish will have restored connectivity and access to over 50 miles in Honey Creek, 3 miles in Deep Creek, and 33 miles in Twentymile Creek (Table 5-8).

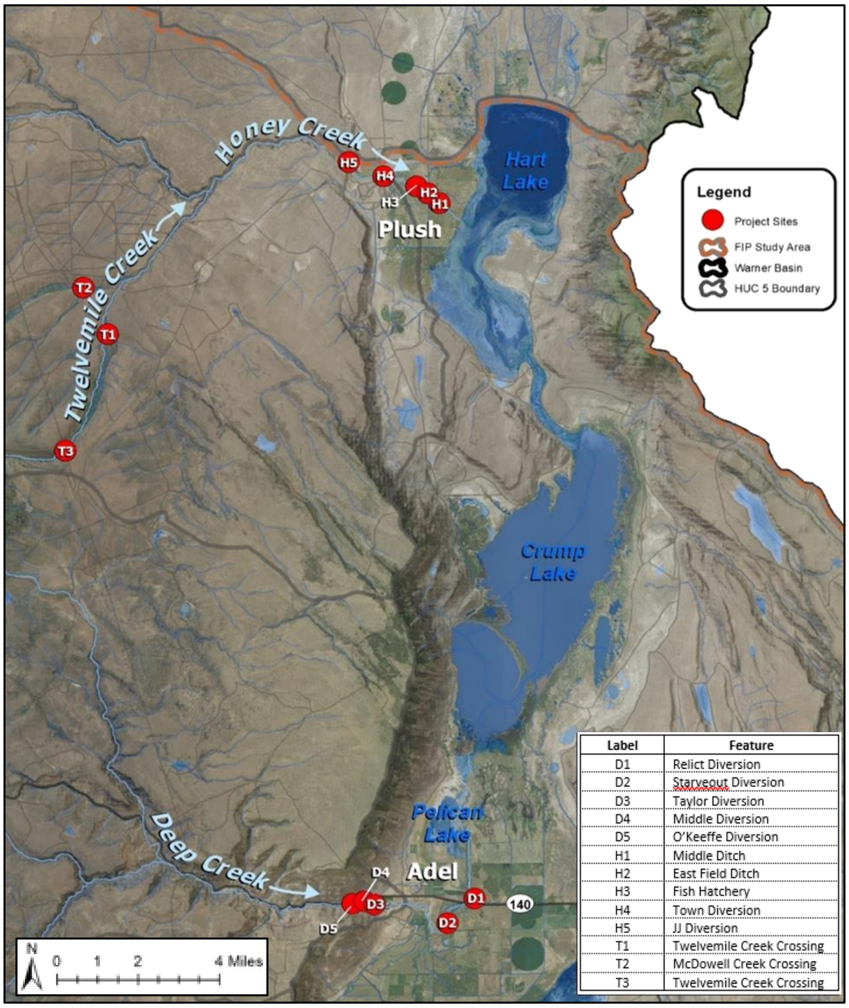


Figure 5-10. Planned fish passage projects in the Deep Creek and Honey Creek drainages.

Table 5-8. Addressing fish passage barriers will restore habitat connectivity in the three tributaries.

Stream	Stream Length from Mouth (mi)	First Diversion	Diversion Location (river mile)	Restored Access (mi)
Honey Creek	53.2	Rookery Diversion	0.25	53.0
Deep Creek (lower)	7.1	Relict Diversion	3.9	3.2
Twentymile Creek	35.1	MC Diversion	1.3	33.8

6 Effectiveness Monitoring

The following section provides an overview of the biological and hydraulic effectiveness monitoring that has been conducted on technical and nature-like fishways completed in the Warner Basin.

6.1 Methods

The criterion to determine the effectiveness of fishways is the demonstration of successful upstream passage by Warner Suckers. The monitoring approach is based on tagging suckers with Passive Integrated Transponder (PIT) tags, releasing them downstream of the fishway, and the detection of suckers by antennas mounted at the downstream and upstream ends of the structure. For some evaluations, additional antennas are located farther downstream or upstream of the fishway, depending on the design of the structure. Beacons are installed on at least one antenna to monitor the functional continuity of the antenna system. Passage metrics assessed include the number of successful passage events and travel time through the fishway. We also evaluate the effect of fish size on passage metrics.

Water velocity at points within a technical fishway have been measured with a portable flow meter and compared to predicted design velocities. Velocities through orifices of fish ladders are measured at three heights along the vertical centerline corresponding to 20%, 50%, and 80% of the orifice height from the fishway floor. Water velocities and water depths in nature-like fishways have also been measured and compared to criteria.

A limitation of the biological effectiveness monitoring approach is the assumption that tagged adult suckers will want to migrate upstream when they are released below the fishway. Fish that do not enter the fishway, or enter but fall back, may not reflect a limitation of the fishway's effectiveness, but rather variability in fish behavior. To increase the likelihood that fish will attempt to pass through the fishway, the general approach has been to tag adult suckers (>130 mm fork length) in early spring with the assumption that they would be more likely to migrate upstream to spawn. When possible, suckers are sampled from upstream of the fishway and translocated downstream of the fishway (F. Monzyk, ODFW, personal communication).

Passage information is occasionally supplemented with detections of fish residing downstream of the fishway that were previously tagged as part of other PIT-tag studies occurring in the basin. These fish can provide an unbiased estimate of travel time through the fishway since they do not experience the same tagging and translocation effects that fish released specifically for effectiveness monitoring may exhibit.

To date, three fishways have been evaluated for passage including the Dyke and MC diversions on Twentymile Creek, and the Rookery diversion on Honey Creek. Below, is a brief description of the structures and the specific approaches used to monitor passage at each structure, and a summary of the monitoring results.

6.2 Site Descriptions and Results

Dyke Diversion

The Dyke diversion is a concrete diversion weir located near the downstream end of a bedrock canyon on Twentymile Creek. The weir was recast in 1991 and a steel Denil fish ladder was installed on the downstream river-right side of the weir. ODFW monitored the Denil fish ladder for fish passage and determined that Warner Sucker were unlikely to pass the ladder due to the steep gradient and turbulence. The Lake County Umbrella Watershed Council, U.S. Bureau of Land Management, and River Design Group, Inc. coordinated a fish passage and screening alternatives analysis with the landowner. The preferred alternative included a technical fishway and FCA horizontal fish screen.

The technical fishway is a concrete fish ladder consisting of 10 pools created by wooden stoplog cross-walls. Each weir wall has a 12-inch square orifice set at the bottom of the weir wall. Cobble was added to the fish ladder floor to simulate a natural channel bed with the expectation the cobble floor would improve passage conditions for the benthically-oriented Warner Sucker. Cobble was grouted in the vicinity of each orifice, but was loosely placed elsewhere in each pool (Figure 6-1).

Figure 6-1. The existing Dyke diversion weir showing the weir, Denil fish ladder, and headwall with irrigation canal (left). The fish ladder completed in 2015, includes wooden weir walls with a 12-inch square orifice and streambed simulation material (right, photo during construction).

The ladder was designed to meet fish passage criteria (e.g., water velocity and depth) between 35 cfs and 148 cfs which are the 95% and 5% fish passage flows during the April 1 to July 1 Warner Sucker spawning period, respectively. Warner Sucker passage criteria included a maximum water velocity of 4 ft/s, minimum depth of 12 inches, a ladder floor slope of less than 4%, and no jumps.

The following information is largely adapted from Scheerer et al. (2015; 2017). Passage at the Dyke diversion was evaluated in 2015 and 2016. PIT-tag antennas were positioned at the downstream-most and upstream-most orifices of the ladder, and near the OWRD gage approximately 800 ft upstream from the ladder (Figure 6-1). A flat-plate antenna was also positioned along the stream bottom approximately 10 ft downstream from the ladder entrance. Suckers were captured from reaches upstream of the fish ladder, measured, tagged, and either released in a pool approximately 140 ft downstream of the ladder (n=20) or in the downstream-most pool of the ladder (n=8, 2015 only) in April and May.

A total of 19 of the 28 suckers successfully migrated upstream through the ladder, including all 8 released into the ladder (Table 6-1). In addition, 13 previously tagged suckers residing downstream of the Dyke diversion were detected successfully passing upstream through the ladder.

Table 6-1. Summary of PIT-tagged Warner Suckers detected successfully passing upstream through the Dyke diversion fish ladder by release location and year. The extant downstream fish were previously tagged suckers that were residing downstream of the structure and detected passing through the ladder.

Year	Release location	Number Released	Number Passing	% Passed
2015	Pool downstream of ladder	12	6	50
	In ladder	8	8	100
	Extant downstream	n/a	6	--
2016	Pool downstream of ladder	8	5	62.5
	Extant downstream	n/a	7	--

Passage times through the ladder were more variable for smaller suckers than for larger suckers (Figure 6-2), requiring a log transformation of passage time to normalize the residuals before performing regression statistics. A significant negative relationship was found between the passage timing and fish size, but no relationship was found between passage time and stream discharge. The mean passage time for suckers >160 mm fork length (FL) was 6.4 hours (range: 0.62-36.4 hours). Passage time for previously tagged fish were not significantly different from those tagged and released during the study year.

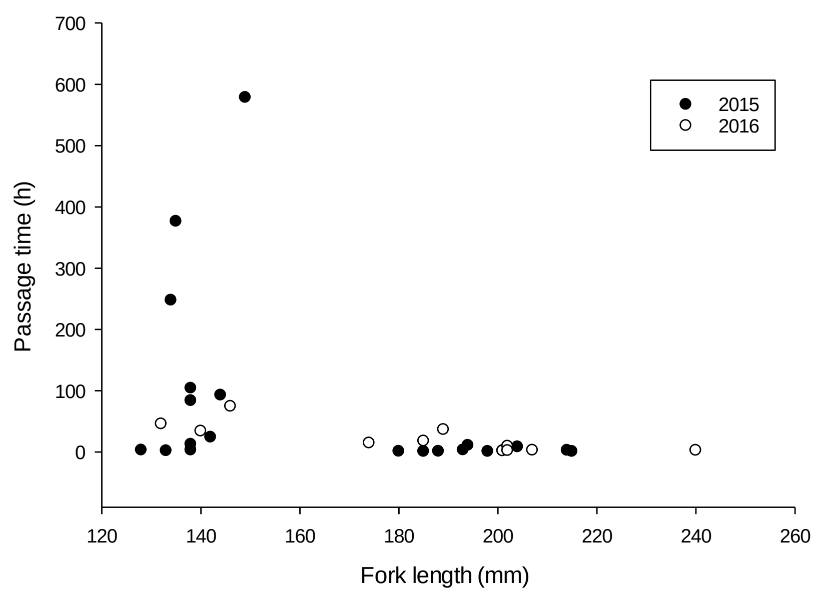


Figure 6-2. Relationship between passage time and size of Warner Suckers ascending the Dyke diversion fish ladder in 2015 and 2016. Passage time was measured as the duration between the first detection at the antenna 10 ft downstream of the ladder to the first detection at the antenna positioned at the upstream-most orifice of the ladder. Data and graphic from Scheerer et al. (2017).

Average stream discharge in Twentymile Creek was lower in 2015 compared to 2016. In 2015, passage events occurred at discharge ranging from 5 cfs to 62 cfs, whereas discharge during passage events in 2016 ranged from 33 cfs to 93 cfs. Water velocities through the ladder orifices were measured on two occasions under different stream discharge conditions: in 2015 with stream discharge approximately 4 cfs and in 2016 with discharge approximately 57 cfs. Measured water velocities through the orifices were generally higher than the designed maximum velocity of 4 ft/s. However, velocities measured near the bottom of the orifice were close to or less than the design criterion (Table 6-2).

Table 6-2. Measured orifice water velocities at the Dyke diversion fishway. Velocity measurements were taken on 16 June 2015 and 04 May 2016 with a Marsh-McBirney meter at the centerline of each orifice.

Water Column Measurement Location Relative to Orifice Bottom	2015 (4 cfs)		2016 (57 cfs)	
	Mean (ft/s)	Range (ft/s)	Mean (ft/s)	Range (ft/s)
20%	2.89	0.89 - 3.71	4.30	1.41 - 5.18
50%	4.79	4.00 - 5.51	6.10	2.10 - 7.90
80%	4.79	4.20 - 5.18	5.67	3.51 - 7.51

Additional information on fish passage effectiveness monitoring for the Dyke diversion is included in Scheerer et al. 2015, Scheerer et al. 2016, and Scheerer et al. 2017.

The former irrigation canal headgate was replaced with a new headgate that sufficiently seals to exclude leakage when the diversion is not in use. The first approximately 95 ft of the irrigation canal was piped and an FCA screen was installed at the end of the piped section of the canal (Figure 6-3). The screen has delivered sufficient flow to the landowner and maintenance has been relatively minimal (e.g., periodic fine sediment and debris removal). Other project elements including the removal and filling of the former Denil fish ladder, and the installation of a headgate in the diversion weir sluiceway, are operating as intended.

Figure 6-3. The FCA fish screen on the Dyke diversion irrigation canal (left) and the open canal downstream of the screen (right).

MC Diversion

The MC diversion is located on Twentymile Creek approximately 1 mile downstream from the Dyke diversion. The existing diversion infrastructure includes a 5 ft high concrete weir that creates sufficient head to divert water through a headworks located in the Twentymile Creek dike. Three 36-inch culverts with headgates located in the headworks allow water users to manage water diverted from Twentymile Creek into the MC canal. The MC canal includes both natural and excavated segments, but only conveys flow bypassed by the headworks. Twentymile Creek flow that exceeds water users' needs, flows over the MC weir and into the Twentymile Flood Ditch. Figure 6-4 includes a panoramic schematic of the MC diversion infrastructure.

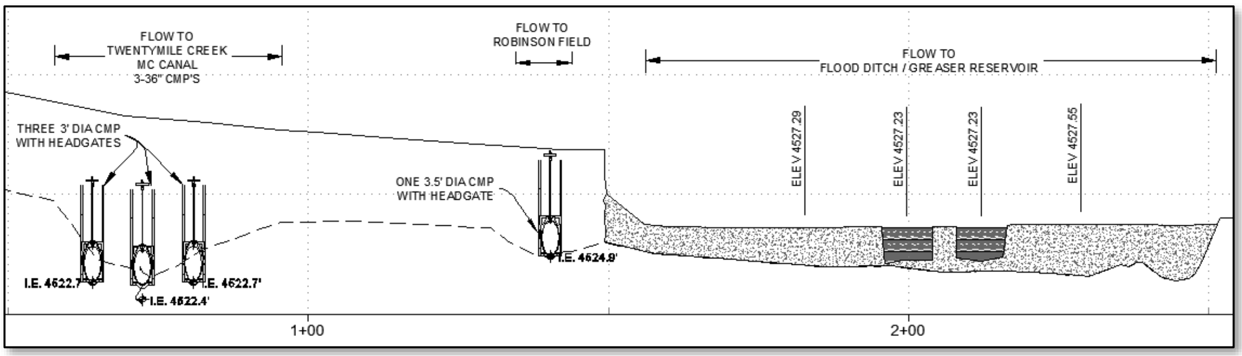


Figure 6-4. A panoramic schematic of the MC diversion weir, three headgates in the MC diversion headworks and a single headgate that delivers water to the Robinson field. Flow exceeding water users' needs flows over the MC weir and into the Twentymile Flood Ditch.

The fish passage project was designed to pass fish between the MC canal and Twentymile Creek upstream of the MC diversion weir. The nature-like fishway included a new headgate and box culvert, and bypass channel (Figure 6-5**)**. Streambed simulation material was placed in the box culvert and a bypass channel was constructed downstream of the box culvert. The bypass channel was connected with a remnant low gradient channel segment with dense willows and woody debris (Figure 6-6). The bypass channel was designed to meet fish passage criteria between 6 cfs and 150 cfs. Water users are able to use the bypass channel to meet most of their water needs although the original headgates can also be managed to supplement water delivered by the bypass channel.

Figure 6-5. Upstream (left) and downstream (right) views of the MC bypass channel in March 2019.

Figure 6-6. Low elevation aerial photo showing the MC diversion area features.

ODFW evaluated fish passage in 2018 and 2019 using methods similar to those described for the Dyke diversion. The bypass channel did not convey sufficient flow in 2018 and fish passage monitoring only document one 1 of 21 tagged Warner Suckers passing through the bypass channel (Monzyk and

Meeuwig 2018). The bypass channel box culvert was modified in early 2019 by removing a weir wall that was originally cast at the downstream end of the box culvert. The weir wall was intended to regulate the amount of flow entering the box culvert and the weir was determined to be overly restrictive. Removal of the weir increased flow conveyance and improved fish passage conditions.

ODFW monitoring in 2019 documented passage of Warner Suckers through the bypass pass channel and box culvert (F. Monzyk, ODFW, personal communication). Nearly half of the Warner Suckers (13 of 30) tagged and released downstream of the bypass channel in 2019, migrated up through the bypass channel and culvert to Twentymile Creek. In addition, a sucker tagged in 2018 migrated through the bypass channel in 2019. The remaining 17 suckers tagged in 2019 appear to have remained downstream of the bypass channel and did not attempt to enter the box culvert. Warner Suckers that migrated upstream through the bypass channel tended to be larger (mean = 178 mm FL, range 142-248 mm) than the fish that had not attempted to pass (mean = 122 mm FL, range 95-162 mm) (Monzyk and Harrison 2019). Passage may have also been influenced by periodic closure of the box culvert that prohibited flows from entering the box culvert and the bypass channel. Future coordination with the water users will focus on maintaining surface flows through the bypass channel during the Warner Sucker spawning migration period.

Rookery Diversion

Sucker passage at the Rookery diversion was evaluated in 2017 (Scheerer et al. 2017). The Rookery diversion is the farthest downstream diversion of eight diversions on lower Honey Creek, the diversion is located 0.2 mi upstream from Hart Lake. The new fishway is ~130 ft long with 12 pools (cells) that are divided by cross-walls that each have 9 inch square orifices on the fishway floor for Warner Sucker passage, 12 inch weir drops, and a simulated streambed floor (artificial boulders) in the downstream half of the fishway (Figure 6-7). The fishway was designed for a passage period of April to June with fishway discharges ranging from 0.35 - 167 cfs, maximum orifice velocities of 3.81 ft/sec, cross-wall v-slot velocities ranging from 0.95 - 4.43 ft/s, a minimum pool depth of 6 inches, and no vertical jump.

Figure 6-7. The reconstructed Rookery diversion weir on lower Honey Creek (left), includes wooden cross-walls, a 9-inch square orifice in each cross-wall, and artificial boulders on the ladder floor to reduce velocities (right).

Antennas were installed around the upstream-most and downstream-most orifices of the ladder to assess sucker passage. Because of concerns about blocking upstream movement through the multiple diversions on lower Honey Creek, adult suckers from upstream of the diversions were not sampled for the evaluation of the Rookery diversion fishway. Instead, adult suckers from an auxiliary population at the ODFW Summer Lake Wildlife Management Area were tagged and translocated to the Rookery diversion on 30 May (n=12). Additionally, four adult suckers were caught and tagged from Hart Lake from 12-20 June. Six of the suckers from the SLMWA were released in the downstream-most pool of the fish ladder. All other suckers (n=10) were released in a pool immediately downstream of the ladder.

Four of the six SLWMA suckers released in the downstream-most pool of the ladder successfully passed upstream with the remaining two passing downstream. Additionally, a SLWMA sucker released in the pool below the ladder successfully passed upstream through the ladder. Overall, the mean fork length of the five fish that successfully passed upstream was 178 mm (range: 155 - 215 mm), whereas the mean fork length of the 11 fish that did not pass through the structure was 143 mm (range: 110 -160 mm). Passage duration through the fishway varied from 1.1 hours to 46.2 days, with a mean of 21.1 days. None of the Hart Lake suckers released in June passed the ladder. However, the propensity of these fish to move upstream may have been lessened by the fact that they were tagged and released relatively late in the spawning season.

Stream discharge during the passage events ranged from 25 - 93 cfs as measured at the Honey Creek gage near Plush (gage #10378500). Because of the seven diversions upstream of the Rookery diversion, discharge through the fishway was likely less than recorded at the gage. Water velocities measured at the upstream-most orifice on 01 June when the stream discharge at the Plush gage was 102 cfs were close to or below the designed maximum velocity of 3.81 ft/s. Velocities measured at the 20%, 50%, and 80% centerline height were 2.89 ft/s, 3.81 ft/s, and 3.90 ft/s, respectively.

7 Summary

The Warner Basin in southcentral Oregon is a large endorheic basin influenced by the geologic forces that formed the basin. Three tributaries and numerous lakes in the basin provide habitat for the four native fish species that inhabit the watershed. Warner Sucker and Warner Lakes Redband Trout are the two focal fish species that have spurred a program to restore fish passage in the basin. The fish passage program is a collaborative effort among organizations comprising the Warner Basin Aquatic Habitat Partnership, and the three water user associations that oversee water distribution for agricultural production. The WBAHP has completed fish passage and screening projects on each of the three tributaries, and the Partnership will oversee the development and implementation of at least 10 more passage and screening projects as part of an Oregon Watershed Enhancement Board Focused Investment Partnership grant. Proposed projects will include restoring fish passage, screening diversion canals, enhancing habitat, and improving water use efficiency. Biological, hydraulic, and structural performance monitoring data will be collected, analyzed, and used to refine future project designs. Restoring system connectivity is anticipated to improve population dynamics for both Warner Sucker and Warner Lakes Redband Trout, leading to the ultimate goal of Warner Sucker recovery and Warner Lakes Redband Trout population resiliency.

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APPENDIX A

WARNER SUCKER LIFE HISTORY: A REVIEW

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Oregon Department of Fish and Wildlife

Warner Sucker Life History: A Review

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Native Fish Investigations Project

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Table of Contents

List of Tables

List of Figures

Introduction

The Warner Sucker *Catostomus warnerensis* is endemic the Warner Basin, a semi-arid endorheic basin that encompasses 6,858 km^2 in southeastern Oregon, northwestern Nevada, and extreme northeastern California (Figure 1). As a result of the horst and graben topography that typifies the Great Basin, the Warner Basin has a north-south orientation bounded by Hart Mountain and Poker Jim Ridge on the east and the Abert Rim (Warner Rim) on the west. Three major tributaries streams (Honey, Deep, and Twentymile creeks) flow from the Warner Mountains into a chain of shallow ephemeral lakes and marshlands on the valley floor that are the remnants of pluvial Lake Warner. Hart and Crump lakes comprise the largest lakes in the valley. Between these lakes, a ridge extends from the west, constricting the valley in an area known as "the Narrows" (Figure 1), and separates the valley into two regions commonly referred to as the South Warner Valley and the North Warner Valley.

The Warner Sucker was first described by Snyder (1908) from specimens collected in Deep and Honey creeks during surveys of the Warner Basin in 1897 and 1904. The presumed historical range of the Warner Sucker consists of the low- to moderate-gradient reaches of the tributaries, the three relatively permanent lakes (Hart, Crump, and Pelican lakes), and several ephemeral lakes during periods of abundant precipitation (U.S. Fish and Wildlife Service 1985; Williams et al. 1990).

Following its initial description, there was little study of the Warner Sucker until the 1970s when efforts were carried out to provide information on the status and distribution of the species; these studies also provided insights into the species' life history. It became quickly evident from these studies that self-sustaining populations of suckers reside in the tributaries (Hayes 1978). Warner Suckers express two life history types: stream-residents and lake-residents. The stream-resident populations complete their entire life-cycle in the tributaries, with the exception of occasional migrants to the lakes. Lake-resident suckers express an adfluvial strategy in which they reside in lakes most the year but return to the tributaries each spring to spawn. Lake-residents have also been observed spawning in Hart Lake (White et al. 1990). Because of this, lake-residents have been described as exhibiting facultative-potamodromy (Berg 1991): during normal to wet water years, adults ascend the tributaries to spawn, but they will attempt to spawn in the lakes when low tributary flows are insufficient for upstream migration. The lake population has been frequently extirpated by prolonged droughts that desiccated the lakes. Over the last century desiccation of Hart Lake has occurred roughly once every thirty years (1934, 1961, 1992, and 2015). After refilling, the lakes are recolonized by downstream migrants from the stream populations (Allen et al. 1994; Scheerer et al. 2016).

Bond (1966) was the first authority to suggest that Warner Sucker were endangered, due to their limited range and the negative effects of drought. Some of the studies in the 1970's suggested that the range and abundance of suckers had decreased, likely due to the numerous irrigation diversions that fragmented its habitat (Andreasen 1975; Kobetich 1977; Coombs et al. 1979). The species was listed as threatened under the federal Endangered Species Act in 1985, with habitat fragmentation and the proliferation of piscivorous nonnative game fishes in the lakes identified as the primary threats to its persistence (U.S. Fish and Wildlife Service 1985).

Since the time of listing, several studies have been conducted on the Warner Sucker, significantly increasing the available information regarding the species' biology. This report reviews information on the distribution, abundance, genetic structure, age and growth, early life history, and spawning of the Warner Sucker based on investigations conducted from the 1970s to the present.

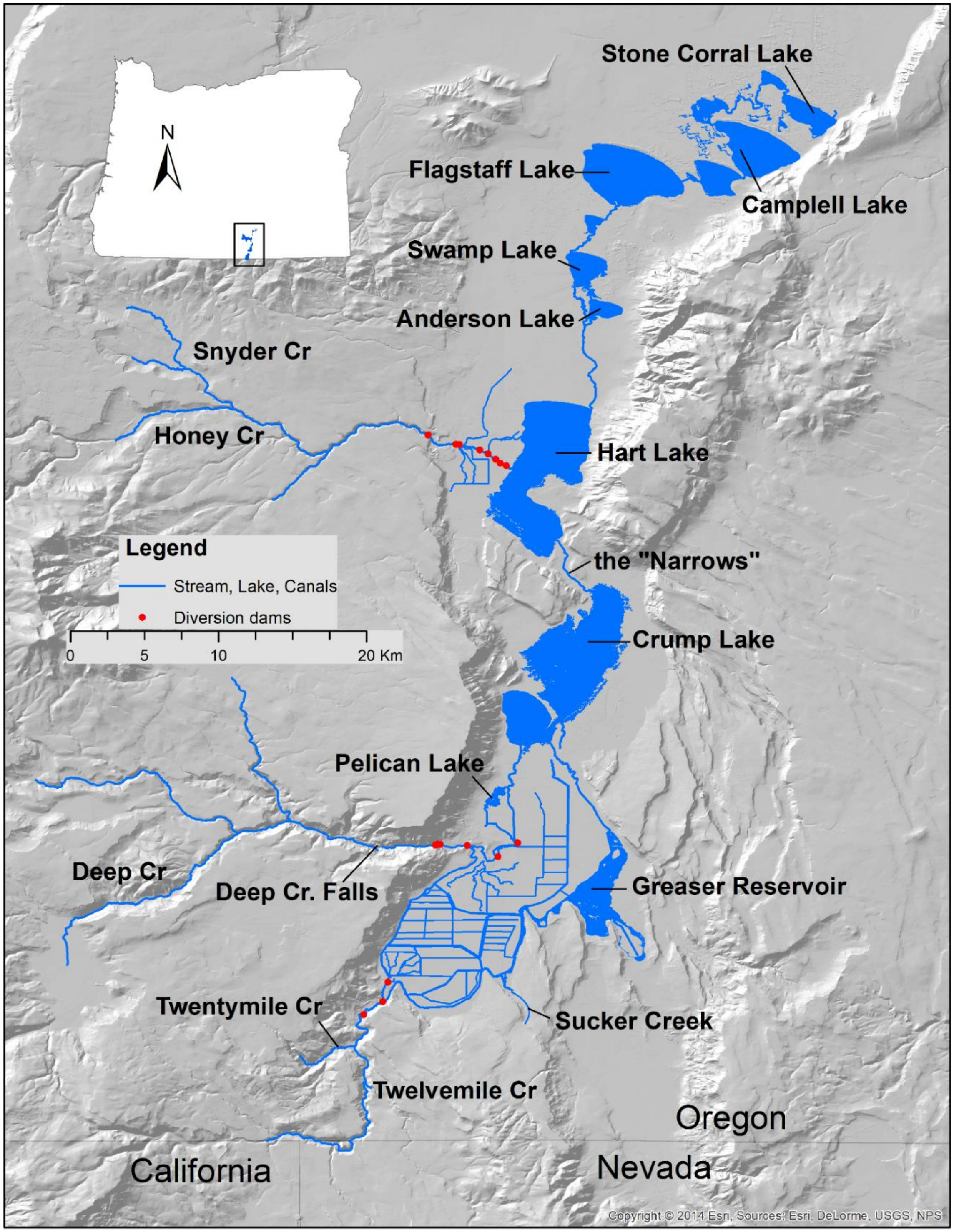

Figure 1. Map of the Warner Basin showing lakes, canals, streams, and irrigation diversion dams**.** Not shown is Bluejoint Lake, the northern-most lake in the basin.

Natural Aquatic Environment and Water Development History

The Warner Sucker has become highly adapted to the semi-arid landscape of the Warner Valley since the drying of pluvial Lake Warner at the end of the Pleistocene Epoch over 10,000 years ago. The life history of the species was shaped by the aquatic environment that existed before irrigation development altered the landscape, and an understanding of the natural aquatic conditions is necessary to inform a discussion of Warner Sucker life history. White settlement of the Warner Valley began in 1867 (Hunt 1964) with minor alteration to water courses for irrigation occurring soon after; major irrigation alterations to improve the land for hay and cattle production did not begin until the late 1930's (Hunt 1964). Little information is available describing the aquatic habitats of the Warner Valley prior to settlement, but a general sense of conditions can be discerned from reports by Whistler and Lewis (1916) and Stricklin and Perry (1923) that describe water use in the valley in the early 1900's, when irrigation development was still little changed from natural conditions.

South Warner Valley – Twentymile Creek enters the Warner Valley at the southern-most end. Prior to major irrigation alterations, the creek spread out through several distributary channels into the low-lying marshland upon entering the valley floor and annually flooded a large area in the spring (Figure 2; Appendix Figure 1). A small, shallow lake was located in a tule marsh to the east of the distributary channels of Twentymile Creek, close to where Sucker Creek enters the valley floor (Figure 1 and 2). The lake was about half the size of Pelican Lake when surveyed in the summer of 1921.

Deep Creek enters the valley from the west near the town of Adel and turns south to form a large alluvial fan a short distance downstream. From here the creek spreads out into a large area of low-lying marshland with no well-defined channel (Figure 3; Appendix Figure 1). Remnants of the distributary channels from both creeks are still evident on the valley floor (Appendix Figure 2). During spring high-flow periods, Deep Creek water merged with water from Twentymile Creek to follow the gradual slope of the valley floor north through the marshland to Crump and Pelican lakes (Whistler and Lewis 1916; Stricklin and Perry 1923; Hunt 1964). No well-defined channels connected the creek water to the lakes, but Whistler and Lewis (1916) reported that Pelican and Crump lakes were connected by a deep, meandering slough.

There were limited attempts to control water flow in the valley prior to the 1920's. Where Deep Creek turned south, a large ditch was constructed, known as the Reclamation Ditch, that carried water a short distance to the northeast and drained into the marshland to the east of Adel. Erosive forces enlarged the ditch so that it resembled a natural stream by the 1920's and carried most of the flow during high flow periods (Stricklin and Perry 1923). Other irrigation developments in the South Warner Valley were initially limited to a few canals that diverted creek water to clover and alfalfa fields on land above the annually flooded marshlands. The long periods of saturated soil in the marshlands limited crop production in these areas to native grasses that were cut for hay in the summer. As water receded from the marshland in late spring, a few small check dams comprised of earthen material or hay bales were constructed to spread and hold the water (Stricklin and Perry 1923).

North Warner Valley – Before substantial irrigation development occurred on Honey Creek, the creek spread out into numerous channels to form an alluvial fan once it emerged from the canyon (Stricklin and Perry 1923). The water was well distributed over a wild grass meadowland of approximately 2,000 acres by both natural channels and artificial spur ditches before eventually flowing into Hart Lake. The meadowland sloped from the canyon to the western shore of Hart Lake and was separate from the lower-lying marshland.

Direct connection of the streams to the lakes appeared to only occur during high water periods. Streamflow from the three major tributaries reaches a minimum by late summer (Figure 4). Stricklin and Perry (1923) reported that by September and October of 1921 water from the streams disappeared a short distance after reaching the valley marshland, suggesting that stream connectivity to the lakes was regularly lost by late summer.

Irrigation Development – Beginning in the late-1930's through the 1950's, substantial alterations to the tributaries and valley floor, in the form of irrigation dams, canals, and dykes, improved the land for hay and alfalfa production (Hunt 1964). The most substantial alterations occurred in the South Warner Valley. A 15-mile dike system was constructed along the eastern side of the southern valley, forcing Twentymile Creek flood waters to bypass the marshlands and flow north to Greaser Reservoir (Figure 1). At the head of the flood ditch, a low-head dam (MC Dam) and headworks were constructed to control flow into an irrigation canal that carried water along the west side of the valley (Hunt 1964)(Appendix Figure 3). The valley marshlands were drained by cutting large canals from west to east and then extending them north towards Crump Lake (Hunt 1964) (Figure 1).

In the North Warner Valley, streamflow through the numerous distributary channels of Honey Creek has been confined to a single channel that drains to Hart Lake. To better control flood irrigation of the meadowland, several low-head dams and headworks have been constructed along the length of the channel to divert water into irrigation canals (Appendix Figure 4). The other major alteration to Honey Creek was the construction of a flood ditch in the 1950s that conveyed flood water to marshland north of Hart Lake (Campbell-Craven Environmental Consultants 1994). This ditch was constructed to prevent the lower fields in the meadow from flooding as the level of Hart Lake rose, a phenomenon that occurred more frequently following efforts by the U.S. Army Corps of Engineers in the 1940's to increase water storage in the lake by raising the height of the natural berm and spillway along the north shore.

Prior to these developments, it is probable that Warner Suckers were periodically able to move between the lakes and streams during spring high water. This connectivity was likely greatest between Hart Lake and Honey Creek, where lake-resident fish would only need to navigate < 5 km of distributary channels before reaching the main creek channel. Connectivity was likely lowest for Twentymile Creek, where fish from Crump Lake would need to navigate at least 13 km of meandering channels and flooded marshland before reaching the main creek channel (Figure 1). The end result of the irrigation development from 1930-1960 was the loss of connectivity between lakes and tributaries, primarily due to diversion dams that operate through the spring. These barriers fragmented the habitat and are presumed to have had a significant impact on the ability of Warner Suckers to carry out many aspects of their life history.

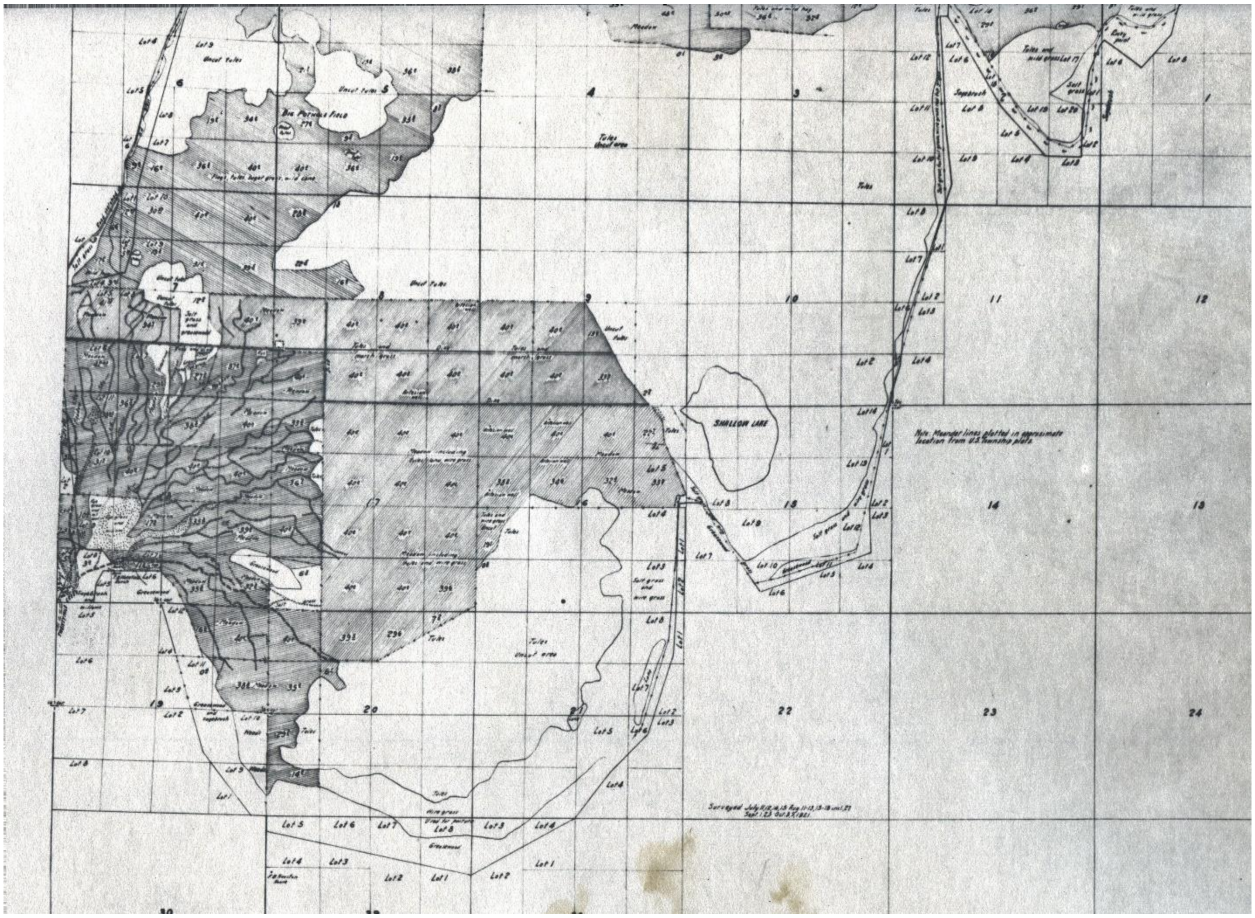

Figure 2. Map of South Warner Valley where Twentymile Creek enters valley floor from a survey conducted in the summer of 1921. Survey from Stricklin and Perry 1923.

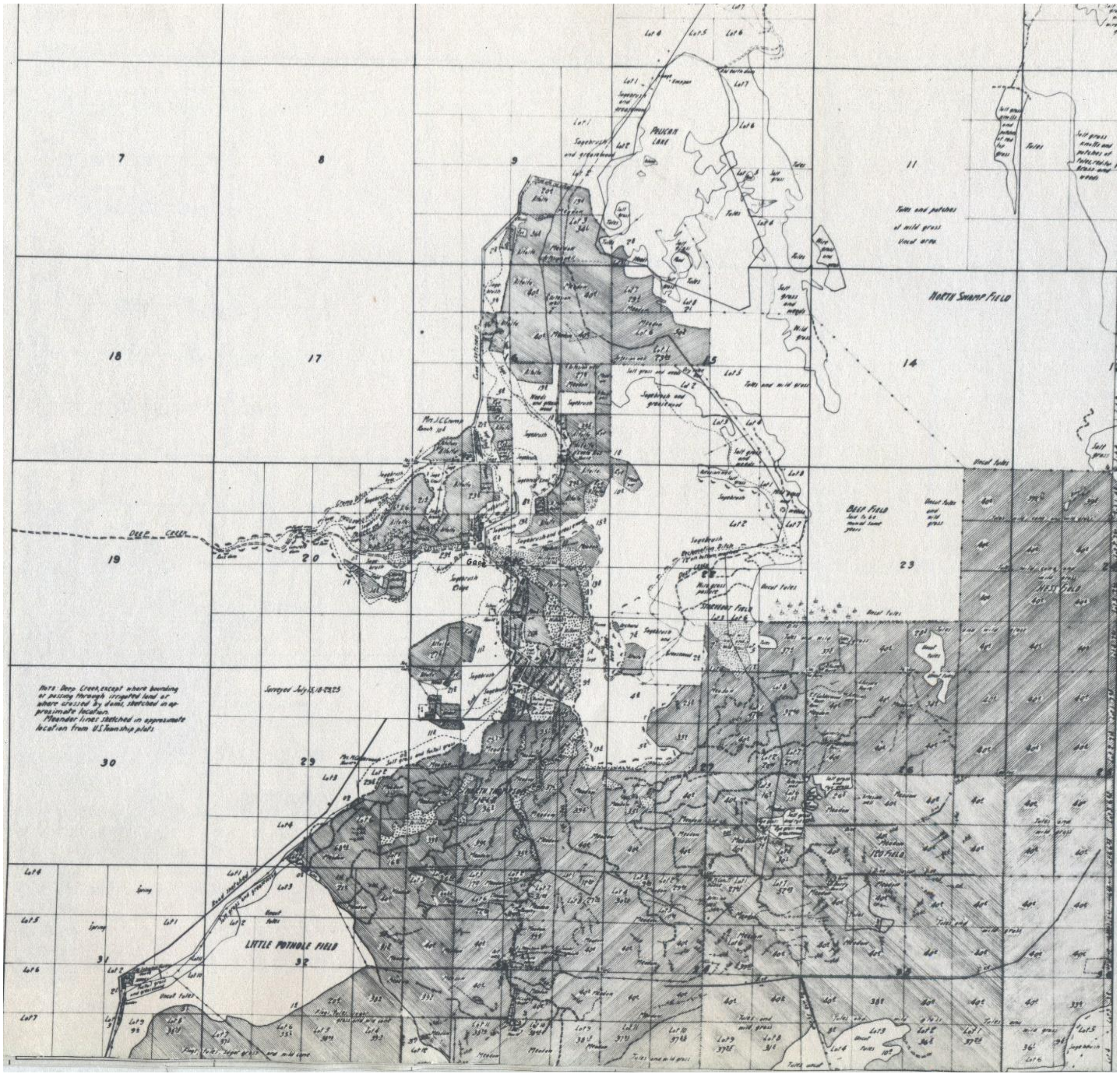

Figure 3. Map of South Warner Valley where Deep Creek enters valley floor from a survey conducted in the summer of 1921. Survey from Stricklin and Perry 1923.

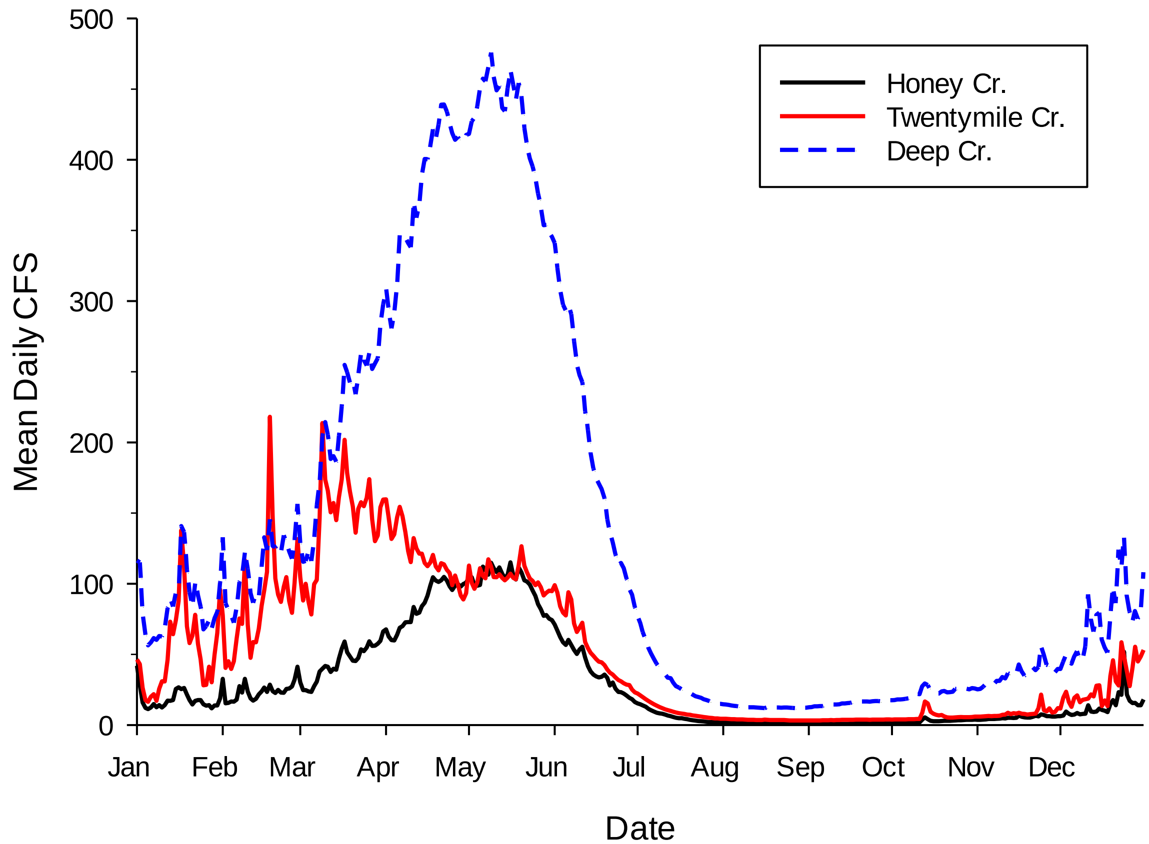

Figure 4. Mean daily streamflow in Honey, Twentymile, and Deep creeks. Streamflow based on average mean daily streamflow from Oregon Water Resources Department historic records from 1931-2018 for Honey Creek (Station ID 10378500) and Deep Creek (Station ID 10371500) or 1941-2018 for Twentymile Creek (Station ID 1036600). All gauging stations were upstream of irrigation diversions.

Distribution and Range

Twentymile Creek – In the Twentymile Creek subbasin, no Warner Suckers have been observed in the canal system between the distributary channels and Crump Lake (Coombs et al. 1979; Scheerer et al. 2007), with the exception of a few individuals collected <1 km downstream of the Cahill diversion (Scheerer et al. 2007)(Appendix Figure 3). The upstream-most occurrence recorded in the subbasin is in upper Twelvemile Creek downstream of the confluence with Cowhead Slough (Allen et al. 1994; Tait et al. 1995). However, there is a report of a single Warner Sucker (93 mm FL) captured in West Barrel Creek, a tributary of Cowhead Slough in northeastern California, approximately 9 km upstream from the Cowhead Slough confluence with Twelvemile Creek (Scoppettone and Rissler 2003).

The greatest density of Warner Suckers in the Twentymile Creek subbasin appears to be in lower Twelvemile Creek. Tait and Mulkey (1993b) surveyed several reaches in the Twentymile Creek subbasin and observed the greatest number of adult and juvenile suckers in a 1.6-km reach directly below the

O'Keefe Dam on Twelvemile Creek, located 2.5 km upstream from the confluence with Twentymile Creek (Appendix Figure 3). Tait et al. (1995) found a similar distribution of adults in 1994, but the greatest number of juveniles were found in the Nevada reach located 7 km upstream from the confluence. Richardson et al. (2009) evaluated the distribution of adult and juvenile suckers and found the majority of the population (86%) in the reach from the Dyke diversion on Twentymile Creek upstream to the old O'Keefe Dam on Twelvemile Creek. This low-gradient reach was characterized by a wide channel and deep pools, with abundant aquatic macrophytes and gravel-sized and smaller substrate.

In Twentymile Creek upstream of the confluence with Twelvemile Creek, Hayes (1978) collected adult suckers approximately 2 km upstream of the confluence. Juvenile suckers have been observed in the lower few hundred meters of stream upstream of the confluence (Coombs et al. 1979; Richardson et al. 2009).

Honey and Snyder Creeks – Swenson (1978) was the first to document adult suckers residing in the upper reaches of the Honey Creek subbasin with six fish (170-380 mm FL) collected from Snyder Creek. The upper extent of Warner Sucker distribution in Snyder Creek was documented the following year when postlarval suckers were found in a 100-m section of an unnamed tributary upstream of the "source" springs of the creek (Coombs et al. 1979). The authors report that the tributary, with snow melt as its major water source, was dry except for this 100-m section. Taylor's Meadows appears to be the upper extent of sucker distribution in Honey Creek (Coombs et al. 1979; White et al. 1990; Scheerer et al. 2007; 2011b). Warner Suckers have a somewhat discontinuous distribution in Honey Creek with higher numbers occurring upstream of the Twelvemile Creek confluence (not to be confused with Twelvemile Creek in the Twentymile Creek subbasin[1]) and lower numbers generally occurring in the 6-km canyon reach located directly upstream of the valley floor (Tait et al. 1995; Scheerer et al. 2007; 2011b). Lake-resident suckers are currently unable to migrate upstream past the 7th diversion (Plush-Town diversion) located 3.7 km upstream from the mouth of Honey Creek (Coombs et al. 1979)(Appendix Figure 4), so suckers residing downstream of the diversion are likely a mixture of fish from the lake population and downstream migrants from Honey and Snyder creeks. Few studies have investigated fish use of the irrigation canals in the lower Honey Creek system. Coombs et al. (1979) observed two larval suckers in an irrigation canal south of the fourth diversion but did not provide information on the spatial extent of surveys in the canal system. Scheerer et al. (2008) detected a radio-tagged adult in the canal system north of the same diversion. Overall, the extent that suckers occur in the canal system remains unknown.

Deep Creek – Nearly all suckers collected in Deep Creek, including all adults, have been in the lower 7.6-km reach from the mouth to Starveout diversion, the second diversion upstream from the mouth (White et al. 1990; Scheerer et al 2007). Historically, Deep Creek terminated in the marshland south of the town of Adel, but for the purpose of this report, the mouth of Deep Creek is considered to be located north of Pelican Lake where the meandering channel joins a short east-west ditch (UTM: 11T 0263158

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[1] The numerical-distance naming convention of many creeks in the Warner Basin is based on the trail distance from various U.S. Army forts that were once located in the basin. Twentymile Creek was encountered 20 miles along the trail from Fort Bidwell. Twelvemile Creek in the Twentymile Creek subbasin was encountered 12 miles from the same fort whereas Twelvemile Creek in the Honey Creek subbasin was located 12 miles along a trial from Fort Warner.

E, 4678708 N). The only recent evidence of suckers occurring above Starveout diversion was a single sucker (116 mm FL) captured in 2007 in the pool formed by the diversion dam (Scheerer et al. 2007). The diversion dam appears to block upstream movement of lake-resident adults from Crump Lake based on radio-telemetry studies (Scheerer et al. 2006). Juvenile suckers residing below Starveout diversion are likely progeny of lake-resident spawners.

White et al. (1990) found no indication of a stream-resident population in Deep Creek during surveys in 1990. Warner Suckers have not been collected above the barrier falls located 15 km upstream from its mouth with Crump Lake (Snyder 1908; Andreasen 1975; White et al. 1990). Additionally, no adults were observed during snorkel surveys in the 2.9-km reach below the falls (O'Keefe diversion to Deep Creek Falls) in 1994 (Allen et al. 1994) or during electrofishing surveys in 2007 (Scheerer et al. 2007). Access to private land has not been granted in the reach from the Starvevout diversion upstream to the O'Keefe diversions, so the existence of a resident population in this reach is uncertain.

Warner Lakes – In the lake system Warner Suckers are most commonly found in Crump and Hart lakes, the two largest and more permanent lakes in the Warner Valley. When adequate water is present, Warner Suckers inhabit nearly all the lakes, sloughs, and potholes in the valley. The northern-most lake where suckers have been found was Stone Corral Lake (Hartzell et al. 2002)(Figure 1).

Distribution of suckers within Hart Lake appears to shift seasonally. Adult suckers congregate near the mouth of Honey Creek in the spring when there is sufficient creek flow (Allen et al. 1996; Bosse et al. 1997; Scheerer et al. 2012), presumably in preparation for a spawning run. Hartzell et al. (2002) noted that when creek flow was low in the spring, suckers were less congregated near the mouth but still present along the western shore. Scheerer et al. (2016) noted a similar distribution of suckers along the western shore in the spring and suggested that during dry years fish may be falsely attracted to irrigation return flow, thus limiting successful spawning migrations.

Considerable movement within the lakes occurs in the spring. Allen et al. (1996) noted that an adult sucker captured near the mouth of Honey Creek was recaptured the next day over 5 km away near the spillway and again near Honey Creek two weeks later. In the summer months, suckers are more widely dispersed in the lake (Allen et al. 1995) or near the east shore (Allen et al. 1994).

Abundance

Abundance of Warner Suckers has been estimated for the tributaries and Hart Lake (Table 1). Estimates in tributaries include fish as small as 60 mm FL (~age1) whereas only larger fish (~age 3 or greater) were collected during abundance estimates in the lakes.

Streams – Warner Sucker abundance in the tributaries has been evaluated by ODFW since 2007 using a variety of estimation techniques (Table 1). Estimates of Warner Suckers residing in the Honey Creek system have ranged from 2,202 fish in 2007 to 4,495 in 2011 (Table 1). These estimates do not include fish in the lower 3.7-km reach or most of Snyder Creek. A population assessment in the lower 3.7-km of Honey Creek in 2013 estimated 410 suckers (Scheerer et al. 2013). Scheerer et al. (2011b) reported that the highest density of suckers in Honey Creek were in the reach from Twelvemile Creek upstream to Snyder Creek.

Sucker populations in Twentymile Creek have been estimated at approximately 4,700 fish in both 2007 and 2009 (Table 1). Most suckers were observed in the reach from the Dyke diversion upstream to the old O'Keefe Dam on Twelvemile Creek, located 2.5 km upstream from the confluence with Twentymile Creek (Table 1). Based on the length of fish collected, the majority of fish in the population were age-1 or age-2 in 2007 and age-2 and older in 2009 (Figure 5)

Table 1. Warner Sucker population estimates in tributaries and Hart Lake.

Year	Reach	Population estimate	95% CI	Study
		Honey Creek		
2007	All except lower 3.7 km and most of Snyder Cr	2,202	81% [a]	Scheerer et al. 2007[b]
2011	All except lower 3.7 km and Snyder Cr	4,495	3,668 - 5,448	Scheerer et al. 2011b[d]
2013	Town diversion to mouth (lower 3.7 km)	410	169 - 721	Scheerer et al. 2013[e]
		Deep Creek		
2007	Relic Diversion to Starveout diversion (1.3 km)	150	192% [a]	Scheerer et al. 2007[b]
		Twentymile Creek		
2007	All	4,746	164%[a]	Scheerer et al. 2007[b]
2009	All	4,612	3,820 - 5,567	Richardson et al. 2009[c]
2009	Cahill wind deflector to Dyke diversion	677	299 - 1,334	Richardson et al. 2009[c]
2009	Upstream of Twelvemile Cr confluence	49	15 - 85	Richardson et al. 2009[c]
2009	Dyke diversion to O'Keefe Dam	3,779	3,112 - 4,603	Richardson et al. 2009[c]
2009	O'Keefe Dam to Cowhead Slough (Twelvemile Cr)	155	63 - 311	Richardson et al. 2009[c]
2014	Cahill wing deflector to Dyke diversion	482	368 - 638	Scheerer et al. 2014 [f]
2015	MC diversion to Dyke diversion	813	761 - 861	Scheerer et al. 2015 [f]
2016	Cahill diversion to MC diversion (MC canal)	963	860 - 999	Scheerer et al. 2017 [f]
		Hart Lake		
1996	n/a	493	439 - 563	Allen et al. 2006 [g]
2008	n/a	565	250 - 1,114	Scheerer et al. 2008[c]
2012	n/a	1,378	705 - 2,650	Scheerer et al. 2012[g]

[a] Relative confidence intervals.

[b] Multi-pass depletion sampling.

[c] Single-census mark-recapture technique.

[d] Bayesian logistic regression capture-recapture model.

[e] Bayesian closed-capture population estimator.

[f] Bayesian Jolly-Seber open-population model.

[g] Schnabel estimator.

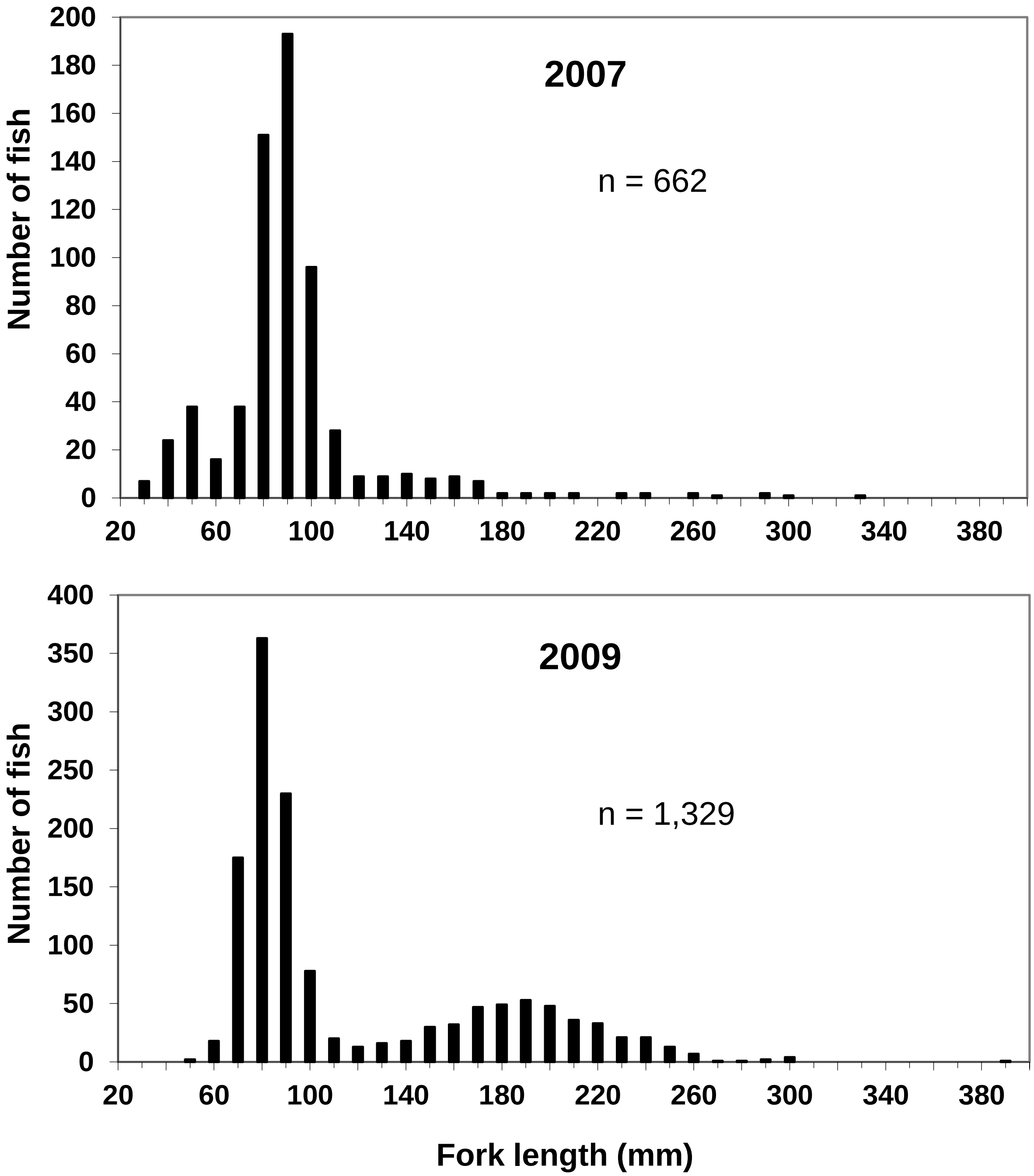

Figure 5. Length frequency distribution of suckers collected from Warner basin tributaries in 2007 (Scheerer et al.).

Lakes – Several studies have attempted to estimate Warner Sucker abundance in the lakes (Coombs et al. 1979; White et al. 1990; Allen et al. 1994; Allen et al. 1995; Allen et al. 1996; Bosse et al. 1997; Hartzell et al. 2001; Scheerer et al. 2006; Scheerer et al. 2008; Scheerer et al. 2012), but recapture rates were only sufficient to estimate abundance in 3 out of 10 years (1996, 2008, and 2012). Although quantitative abundance estimates were not always possible, Hart Lake typically produced greater catch rates of suckers than Crump Lake (Allen et al. 1994; Allen et al. 1995; Hartzell et al. 2002; Scheerer et al 2012).

Allen et al. (1996) estimated 493 (95% CI: 439-563) suckers in Hart Lake in 1996, four years after the lake was completely desiccated (Table 1). The smallest sucker captured was 180 mm SL, or approximately age 4 (see Figure 7). Scheerer et al. (2008) estimated 565 suckers (95% CI: 250-1,114) larger than 155 mm FL based on recaptured fish initially tagged in 2006, with an estimated mortality rate of tagged fish of 33%. In 2012, Scheerer et al. (2012) estimated 1,378 suckers (95%CI: 705-2,650) in Hart Lake with the smallest fish around 125 mm FL. The only other population estimate for fish residing in the lake system was an estimate of 1,316 suckers (95%CI: 666-66,667) in the spillway canal north of Hart Lake (Coombs et al. 1979). The authors caught 198 suckers in the canal over the course of their study, with several appearing spawned out in May.

Genetic Structure

DeHaan and coauthors (2012; 2017) conducted an analysis of genetic variation among Warner Suckers residing in the tributaries by genotyping 164 fish from the three tributaries at 16 microsatellite loci. There was evidence of significant genetic structure among tributary populations (DeHaan and VonBargen 2012; DeHaan et al. 2017). Tests of the genetic fixation index (F_{ST}), genetic assignment tests, and patterns of allele frequency heterogeneity all suggested that each tributary contains a genetically distinct spawning population. Interestingly, suckers residing in Snyder Creek likely represented a genetically distinct population from Honey Creek fish, despite their close geographic proximity and the apparent connectivity of their habitat. Overall, the authors concluded that gene flow among populations was low.

All of the tributary populations had high levels of genetic diversity. The Deep Creek population had the highest level of genetic diversity among the tributary populations, while Honey Creek had the lowest level of genetic diversity, but these differences were not substantial. In one population, Twentymile Creek, a statistically significant excess of heterozygotes suggested that this population may have experienced a recent bottleneck.

The same suite of nuclear microsatellite markers was used to determine the genetic origins of suckers residing in Hart and Crump lakes (DeHaan and VonBargen 2012; DeHaan et al. 2017). Of the 92 fish collected in Crump Lake, all but two were assigned to Deep Creek (the remaining two fish assigned to Honey and Snyder creeks). Nearly two-thirds of the suckers collected in Hart Lake (n=232) were also assigned to Deep Creek with the remainder assigning to Honey Creek, although the proportion was variable among collection years. Overall, their study indicated that Deep Creek is the primary source for lake-resident individuals. The low assignment of lake-resident suckers from the Honey Creek subbasin (and Twentymile Creek) was presumably due to the limited connectivity between these populations and the lake.

Some of the results of the genetics study may be attributable to the sampling location of the tributary sites. Nearly all the Deep Creek genetic samples came from juveniles collected in the lower reach below Starveout diversion where lake-resident suckers purportedly spawn (Coombs and Bond 1980); it is possible that the Deep Creek samples in this study represent the lake population, rather than a distinct tributary population. The reach where the samples were collected, which has a direct connection to the lakes, may be the only reach in Deep Creek where suckers are extant, due to spawning by lake-resident suckers. Additional sampling throughout Deep Creek could clarify the relationship between populations in the lakes and this tributary.

DeHaan et al. also genotyped 68 individuals that were collected from the irrigation canal in the Summer Lake Basin (DeHaan and VonBargen 2012; DeHaan et al. 2017). These fish originated from the salvage of approximately 75 suckers from Hart Lake in 1991, when a drought caused the lake to desiccate. The fish were held temporarily at Summer Lake prior to being transferred to a hatchery. Before the transfer occurred the adult fish spawned in the canal, and their offspring persisted to form a new population. Surprisingly, given their origin, the genotype analysis suggests that the fish at Summer Lake are genetically distinct from the populations found in the tributaries, although more genetically similar to Deep Creek fish than the other tributaries populations based on pairwise F_{ST} estimates. Although this population was founded by a small number of individuals, the genetic diversity of the population was not reduced (relative to tributary populations), did not show genetic evidence of a recent bottleneck, and did not show evidence of increased pairwise relatedness.

Age and Growth

Warner Sucker are thought to live for 20-25 years in the wild. The oldest Warner Suckers collected in the basin were lake-resident fish estimated to be 17 years old based on the aging of opercular bones (White et al 1991). Richardson et al. (2009) compared the precision of aging Warner Suckers with various hard structures and found that opercular bones underestimated age compared to otoliths, so it's likely these fish were actually older. White et al. (1991) suggested that the maximum life span of Warner Suckers may be in the low to mid-twenties. The Warner Sucker is considered to be a sister species of the Tahoe Sucker *Catostomus tahoensis* (Smith 1978), which has a longevity of 27 years based on the aging of otoliths (Scoppettone 1988).

Warner Sucker appear to grow quickly in the first several years of life, with growth continuing at a slower pace past the age of about 8 (Figure 6). Lake-residents attain a larger size compared to stream-residents, presumably due to a richer food source in the lakes, and possibly a longer lifespan.
White et al. (1991) noted considerable variability in growth rate based on the overlap in size between age 17 (320-400 mm FL) and age 10 suckers (310-390 mm FL). The authors attributed the variability to differential growth rates between the faster growing females compared to males, but also likely due to differences in the amount of time fish spent rearing in lakes versus streams. Coombs et al. (1979) also showed growth variability in suckers age 7-8 but not younger fish, based on back-calculated length-at-age derived from scale analysis (Figure 7). This same study noted that sucker growth seems fairly constant at 30-50 mm/yr for fish up to age 8 (Figure 7). Growth rates derived from recaptures of tagged fish show older fish grow at a slower rate. Richardson et al. (2009) reported two suckers in Twelvemile Creek (a Twentymile Creek tributary) were 120-121 mm FL when tagged and grew 90-94 mm after nearly two complete growing seasons, consistent with growth rates reported by Coombs et al. (1979) for age 2-3 year old suckers. A reanalysis of PIT-tag recapture data from Scheerer et al. (2006) found that two suckers that were 323-326 mm FL when tagged grew 52-55 mm over five years, while Scheerer et al. (2008) reported 300-405 FL fish caught in Hart Lake grew only between 0-15 mm over 1.8 to 2.2

years. Slower annual growth rates for older age Warner Suckers is consistent with other western sucker species (Scoppettone et al. 1988).

Warner Sucker likely become reproductively mature at age 3-5. Coombs et al. (1979) reported the presence of spawning checks on scales indicated suckers mature at age 3 to 4. Richardson et al. (2009) cautioned against using scales to age Warner Suckers since they can highly underestimate age compared to otoliths. Scales become more unreliable for aging suckers about the time fish become sexually mature (Scoppettone 1988), so the age at maturity reported by Coombs et al. (1979) may be a slight underestimate.

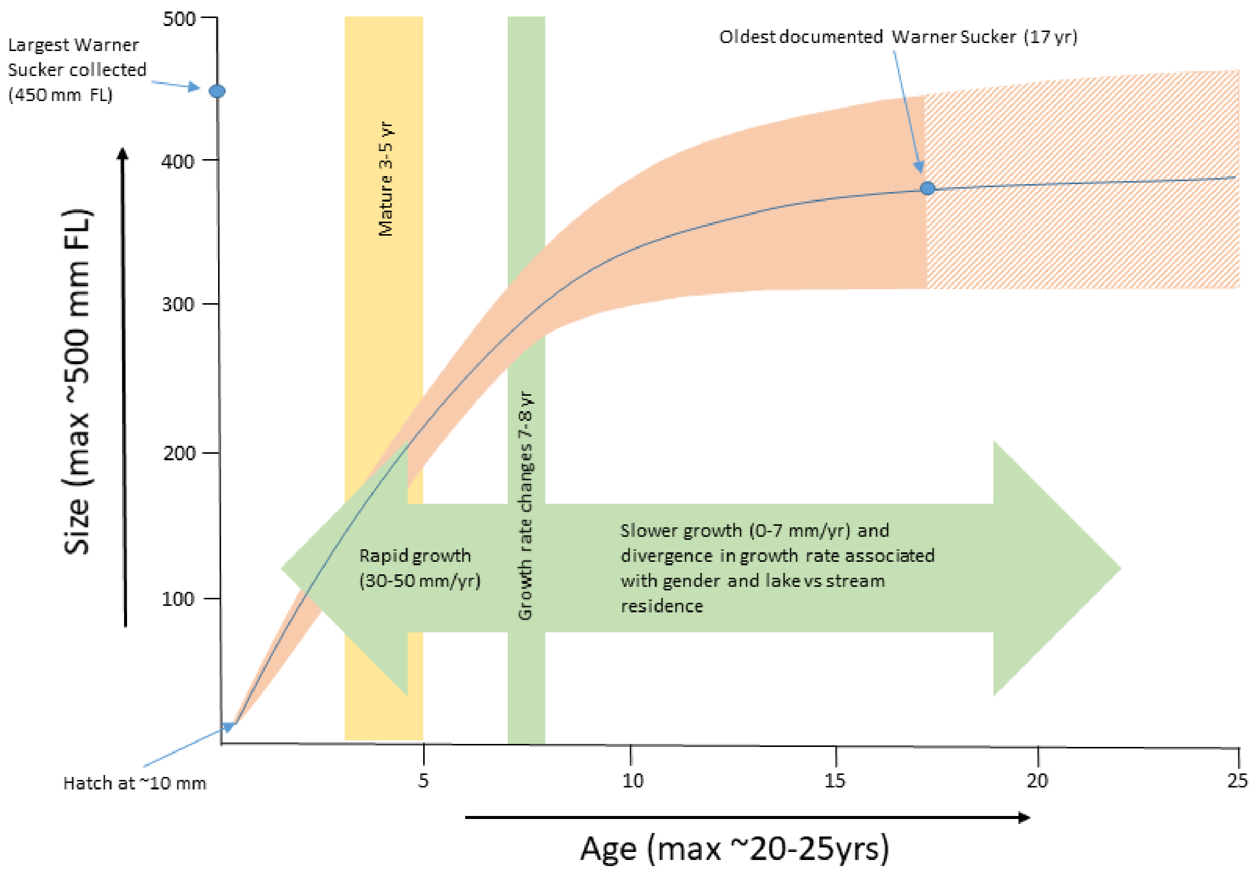

Figure 6. Conceptual model of Warner Sucker age and growth. Growth trajectory based on data presented by Coombs et al. (1979) and White et al. (1991) for lake-resident suckers. Largest sucker collected was from Hart Lake (Scheerer et al. 2006).

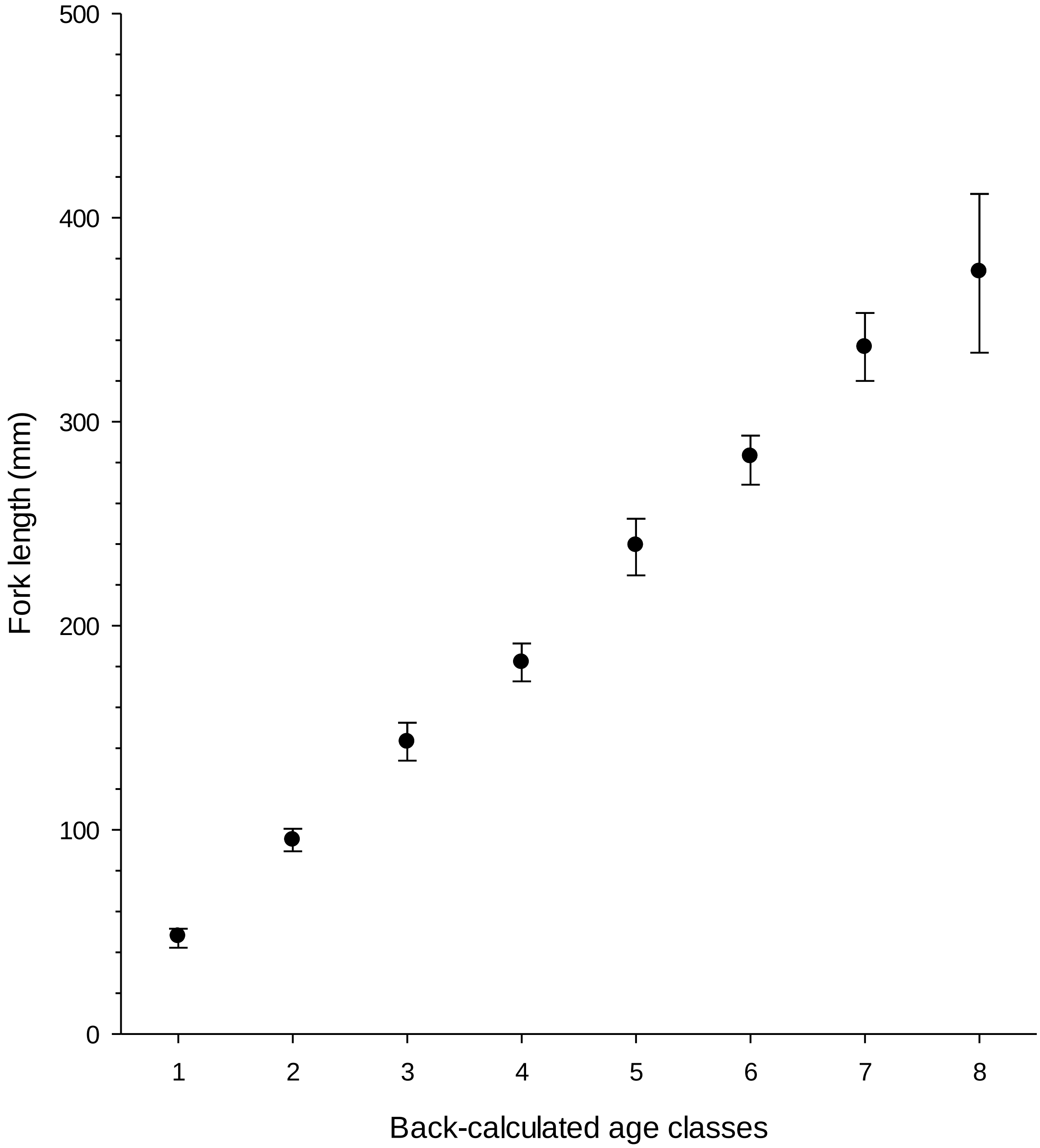

Figure 7. The mean values and 95 percent confidence intervals for back-calculated fork length at the time of each annulus formation (age class) of *Catostomus warnerensis* based on scales (n=50). Figure adapted from Coombs et al. (1979) using the author's reported standard length to fork length conversion. Fish used for aging were captured throughout the Warner Basin with most captured in the spring, so size at age would be prior to expected annual growth.

Early Life history

Larval Warner Suckers emerge from the gravel at a total length of around 10 mm in late spring and early summer (Kennedy and Vinyard 1997). In streams, larvae occupy vegetated areas with low to moderate flow and relatively shallow depths along stream margins or backwater areas during the first few months after hatching (~10-17 mm TL)(Coombs et al. 1979; Kennedy and Vinyard 2006). As the larvae grow in size, they move into mid-water habitats with moderate flows (Coombs et al. 1979; Kennedy and Vinyard 2006). Larvae select microhabitats with focal point velocities (FPV) between 3-6 cm/s and avoided areas with FPV >15 cm/s (Kennedy and Vinyard 2006). They feed on invertebrates in the upper half of the water column with planktonic cladocerans dominating the diet (Coombs et al. 1979; Tait and Mulkey 1993a). They also appear to segregate from larval Speckled Dace *Rhinichthys osculus* by feeding higher in the water column (Coombs et al. 1979). At night larvae move closer to shore, presumably to avoid entrainment into swift currents when visual orientation in the stream is lost (Kennedy and North 1993; Kennedy and Vinyard 1997).

Larval suckers are rarely collected in drift samples (Coombs et al. 1979; Kennedy and Vinyard 1997; Kennedy and North 1993; Bosse et al. 1997; Richardson 2009) and express a distinct drift avoidance behavior. Kennedy and Vinyard (1997) measured the response of larval suckers to artificial entrainment in mid-channel current and found larvae of all sizes (16-30 mm TL) resisted downstream displacement. Once released into the current, fish would immediately seek current refugia behind rocks and vegetation. The farthest downstream displacement was <3 m by the smallest size group studied. The authors speculate that this drift avoidance behavior may have evolved because of the unreliability of downstream lake habitat that periodically desiccate. The natural disappearance of the streamflow into the shallow marshland during the low-flow summer months may also be a selective pressure influencing this behavior. Warner Suckers are unique from other western suckers in that larvae do not drift downstream after hatching in streams (Cooperman and Markle 2011, Kennedy and Vinyard 1997).

As larvae develop into juveniles they become more bottom orientated. During the day juveniles associate with macrophyte beds, while at night they move into riffles and open areas to feed (Tait and Mulkey 1993a). Several other studies have noted that movements of both juvenile and adult Warner Suckers are primarily nocturnal (Richardson et al. 2009; Scheerer et al. 2015; Scheerer et al. 2016). Most juvenile foraging time (75%) occurs over large gravel or boulders, where they likely feed on diatoms, filamentous algae, and detritus (Tait and Mulkey 1993a).

Lake Emigration – The length of time suckers spend in streams before migrating to the lakes is uncertain. Based on the drift avoidance of young-of-year suckers, it is plausible that suckers do not migrate in their first year of life. Coombs et al. (1979) speculated that suckers spend 2-3 years in streams before migrating to the lakes. This would mean they begin to enter the lakes about the time they become sexually mature at age 3 or 4 (130-210 mm FL). Several studies have measured the size of suckers in Hart and Crump lakes to assess recruitment into the lake population (Table 2). The youngest suckers collected among the studies ranged from 1-6 years with age 3 and 4 suckers occurring at the highest frequency (Table 2). Age-1 suckers are particularly rare in lakes; in years when age-1 suckers were collected, only a single individual was recorded in each lake (Table 2). Several studies attributed the lack of smaller fish to reproduction or recruitment failure due to predation by invasive species (White et al 1990; Allen et al. 1995; Bosse et al. 1997; Hartzell et al 2002; Scheerer et al. 2006). An alternative hypothesis is that Warner Suckers do not generally enter lakes until they are age 3 or 4, or in years when densities are high in the streams. In this respect, the lakes may act as a repository for adult fish that increases the overall population size in the basin beyond the carrying capacity of the stream alone.

Table 2. Minimum size and age of Warner Suckers collected in nets from lakes in the Warner Basin. Age determined from length at age data from Coombs et al. (1979) unless otherwise stated. Numbers in parentheses are number of nets deployed by mesh size.

	Hart Lake		Crump Lake			
Year	Minimum size (mm)	Age	Minimum size (mm)	Age	Net mesh size (mm)	Study
1990	275 SL	6	136 SL	3	14; 22	White et al. 1990
1991	264 SL	5[a]			14; 22	White et al. 1991
1994	136 SL	3			14; 22	Allen et al. 1994
1995	215 SL	5	202 SL	5	6; 22	Allen et al. 1995
1996	180 SL	4	70 SL	2	6; 22	Allen et al. 1996
1997	103 SL	3	160 SL	4	6 (41); 22(1)	Bosse et al. 1997
2001	169 SL	4	154 SL	4	6 (1); 22 (5)	Hartzell et al. 2002
2006	~45 FL	1[b]	55 FL	1[b]	6 (1); 13 (5); 19 (6)	Scheerer et al. 2006
2008	241 FL	5	155 FL	3	6 (1); 13 (5); 19 (12)	Scheerer et al. 2008
2012	69 FL	1[b]	155 FL	3	13 (2); 19 (22)	Scheerer et al. 2012
2017	130 FL	3			19 (18)	Scheerer and Meeuwig 2017

[a] Age provided by White et al. 1991.

[b] Only one age-1 individual collected. Next largest suckers were age 4 in Crump Lake in 2006; age 6 in Hart Lake in 2006; age 3 in Hart Lake in 2012.

Spawning

Warner Sucker spawning typically occurs in the tributaries during spring, similar to many sucker species in the western North America (Harris 1962; Scoppettone and Vinyard 1991; Weiss et al. 1998). Many lacustrine suckers are obligate stream spawners (Scoppettone and Vinyard 1991), but some, like the Tahoe Sucker, have been observed spawning in both streams and lakes (Kennedy and Kucera 1978). In normal to wet water years, adult Warner Suckers that are rearing in the lakes ascend the tributaries to spawn, but will attempt to spawn in the lakes when low tributary flows do not allow for upstream migration (White et al. 1990). The frequency of lake spawning prior to irrigation development is unknown, but has likely increased since diversion dams block tributary access and irrigation withdrawals result in more years of low tributary flows.

Lake Spawning – The only direct observation of lake spawning was by White et al. (1990) in Hart Lake in the spring of 1990. Flow from Honey Creek (measured at the gauge above the diversions) was <40 cfs throughout the spring, with irrigation withdrawals likely resulting in little flow at the mouth. During the course of sampling lake-resident fish, the authors reported the following:

> On 9 April 1990, we noticed spawning activity in the shallow water along the east shore of Hart Lake. We first noticed the splashing and thrashing about of what appeared to be small groups of fish digging nest in the substrate gravels. Spawning was observed until the 18th of April, at points all along the east shore of Hart Lake as far south as the rock jetty.

The authors reported that spawning appeared to cease following a cold snap on 18 April and no spawning was observed after water temperatures returned to levels previously recorded during the spawning event (14.4-21.1 °C). The timing of the spawning event was about a month earlier than any other observation of spawning or spawned-out adults in the basin. The only other indication of spawning in April was from Coombs et al. (1979), who reported collecting spawned-out adults in the spillway canal north of Hart Lake from 29 April through 24 June. The early spawning in 1990 may have been the result of unseasonably warm weather that occurred for several days prior to and during the spawning (R. White –personal communication), resulting in lake temperatures reaching levels suitable for spawning.

Direct observation of lake-spawning has not been observed since 1990. The following year (1991) was another dry year and White et al. (1991) did not observe spawning in the lake during sampling from March through June; lake levels had receded to the point that the shoreline was comprised of the muddy substrate that made up the lake bed. The only other direct observation of spawning by lake-resident suckers were of the Hart Lake fish that were translocated to the Summer Lake Wildlife Management Area (SLWMA) in early May 1991. They were first observed spawning on 14 May, with spawning continuing until June. The first larval fish was observed on 17 June. Water temperature in the spring-fed ditch was 17°C. Although lake spawning has not been observed since 1990, other studies have reported catch of adults in Hart Lake that suggest spawning may have occurred along the east shore in other years. Hartzell et al. (2002) sampled Hart Lake in the spring of 2001 when lake elevations and flows from Honey Creek were similar to conditions reported during the 1990 spawning event. They did not observe suckers congregating near the mouth of Honey Creek as in previous years, but reported their largest net catch occurred on 14 May along the east shore where spawning was observed in 1990, with ripe adults comprising much of the catch. Based on these observations, we hypothesize that lake spawning may only occur under the rare environmental conditions where tributary flow is too low for migration upstream, but lake levels are high enough to inundate the cobble along the shoreline.

Lake-resident suckers are often found in the spillway canal of Hart Lake during the spawning season when the lake level is high enough to facilitate spill. Coombs et al. (1979) captured 198 suckers in the canal with many appearing to be ripe or spawned out. Williams et al. (1990) reported suckers entering the canal after water began spilling in mid-May 1989 and collected seven 'spawners' in the canal in June. Two suckers collected from the spillway canal in the spring of 1995 were thin, with eroded anal and caudal fins, indicative of spawned-out fish (Allen et al. 1995). The origin of the suckers captured in the canal is unknown: they may be from Hart Lake or the smaller lakes to the north.

It is unclear whether spawning is actually occurring in the canal or if suckers are attracted to the area for other reasons. Coombs et al. (1979) did not observe sucker larvae in the turbid canal water but visibility was poor. Appropriate spawning substrate may not be present in the canal. Coombs et al (1979) described the substrate as mud-silt with some boulders near the spillway and mainly a hardpan bottom with a thin layering of silt elsewhere. Capture data from Allen et al. (1996) showed 16 adult suckers, many of them ripe, moving between the mouth of Honey Creek and the spillway area in the spring of

1996 (Figure 7). Flow from Honey Creek was relatively low all spring, except for a brief pulse from 17-24 May. Interestingly, several of the suckers originally captured near the spillway were recaptured at the mouth of Honey Creek during or immediately after the flood pulse with some of these fish returning to the vicinity of the spillway in early June (Figure 8). A similar pattern of movement from the north of Hart Lake to Honey Creek and back to the north end of the lake was observed with radio-tagged suckers by Scheerer et al (2008). These observations are consistent with increased streamflow acting as a cue for spawning migration, as occurs in other sucker species (Tyus and Karp 1990; Modde and Irving 1998).

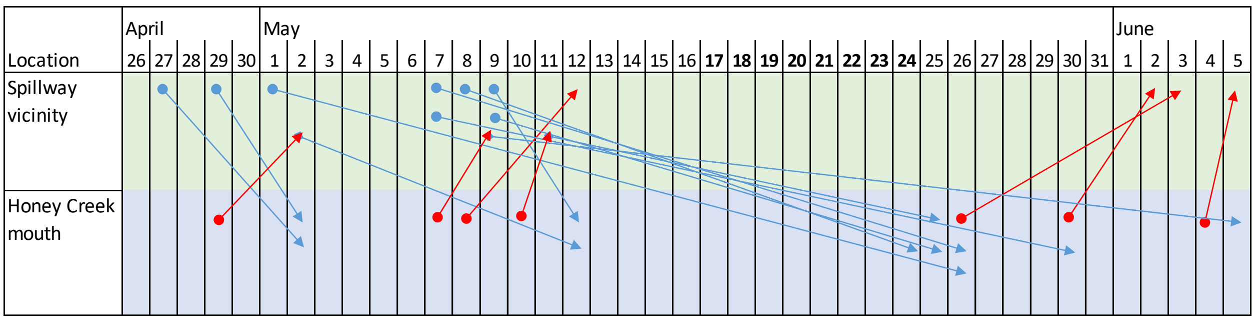

Figure 8. Movement of adult Warner Suckers in Hart Lake between the mouth of Honey Creek and the spillway vicinity based on capture data from Allen et al. (1996). Dots indicate location and date of initial capture and triangles indicate location and date of recapture. The bold dates indicate the period when Honey Creek flows were over 200 cfs. Most suckers were captured within 100 m of the spillway.

Typically, spawning by lake-resident suckers is thought to occur in tributaries when flows are sufficiently high to allow upstream migration. Adult suckers from Hart Lake tend to congregate near the mouth of Honey Creek during the spring, presumably in preparation of a spawning run into the creek (Williams et al. 1990; Allen et al. 1995; Allen et al. 1996; Scheerer et al. 2006; Scheerer et al. 2012). Several reports document lake-resident suckers entering Honey Creek in the spring. Swenson (1978) collected an adult below the 7th diversion from the mouth (Plush-Town diversion) on 02 May, 1978 and speculated that it must have entered Honey Creek sometime in April before stoplogs were added to downstream diversion dams (Appendix Figure 4). Scheerer et al. (2006) detected a radio-tagged adult from Hart Lake just downstream of the Plush-Town diversion in mid-May of 2006. Coombs and Bond (1980) caught an adult sucker ascending the mouth of Honey Creek on 09 April, 1980 and caught another sucker below the 4th diversion (East Field diversion) on 29 April. Scheerer et al. (2006) collected a spawned-out female on 11 May in a screw trap located at the mouth of Honey Creek, presumably reentering the lake after spawning. Passive integrated transponder (PIT) antennas located at the mouth of Honey Creek detected PIT-tagged suckers entering the creek from 25 April to 26 May, 2009 (Richardson et al. 2009) and from 30 April to 18 June, 2012 (Scheerer et al. 2012). Based on these studies, it appears suckers enter Honey Creek in April and May but are unable to ascend farther than the Plush-Town diversion. Spawning likely occurs somewhere in the 3.7 km reach below the Plush-Town diversion, depending on the timing of the spawning run and when stoplogs are installed at the various diversions.

The lower 2 km of the Honey Creek contains poor quality spawning habitat with sparse areas of gravel that are mostly covered with silt (Scheerer et al. 2013), so productivity in this reach may be low. Williams et al. (1990) noted only two riffles between Hart Lake and the first diversion (Rookery diversion) with suitable gravel for spawning (Appendix Figure 4). A fish ladder was installed at the Rookery diversion in 2015, but prior to that year the two riffles were likely the only spawning areas accessible to lake-resident suckers after stoplogs were installed in the spring. Williams et al. (1990) reported collecting a few larval suckers below the diversion in 1989. Scheerer et al. (2006) observed larval suckers in Hart Lake near the mouth of Honey Creek in early-June 2006.

Before the construction of Priday Reservoir, suckers from Hart Lake would spawn in Fish Creek (Coombs and Bond 1980). The authors report that several local ranchers described the creek as having had large runs of spawning suckers. Given that the small creek dries up relatively early in the year, the authors speculated that spawning must have occurred in the lower few miles. It is unclear how much Priday Reservoir and irrigation diversions have altered flows to the lower creek, but it's possible that in wet water years, spawning is still attempted in the creek. Although the literature does not mention other small creeks as potential spawning streams for lake suckers, the intriguingly-named Sucker Creek that currently flows into upper Greaser Reservoir near the southern end of the valley (Figure 1) may be worth further investigation. The lower 1.5 km of the creek is low-gradient with suitable spawning substrate.

Suckers residing in Crump Lake appear to spawn in lower Deep Creek. Scheerer et al. (2006) detected a radio-tagged adult from Crump Lake that had migrated up Deep Creek to a point just downstream of Starveout diversion by mid-May 2006. Coombs and Bond (1980) collected spawned out adults in Deep Creek near Pelican Lake, but none above Starveout diversion, and speculated that spawning is occurring below this diversion. It appears that all spawning by lake-resident suckers in Deep Creek occurs below the impassable Starveout diversion located 7.6 km from the mouth.

There is some evidence that adults from Crump Lake may also spawn in the slough between the lake and Greaser Dam. Young-of-year suckers were collected in the slough in 1989 (Williams et al 1990) and 1990 (White et al. 1990). Allen et al. (1996) captured a 270 mm adult sucker from the base of the dam and suggested that spawning may occur between the impassible dam and Crump Lake.

Besides suitable habitat, increases in water temperature and streamflow can both influence spawning in western sucker species (Tyus and Karp 1990; Modde and Irving 1998). The variability in the timing and location of spawning by lake-resident Warner Suckers may be due to the interannual variability in these cues. For example, in years when water temperatures and substrate are suitable in the lake before streams flows increase to levels sufficient to permit migration, some suckers may attempt to spawn in the lake. It is unknown whether a portion of the lake-resident Warner Sucker population will skip spawning in years when spawning conditions are not favorable in the basin (i.e., when lake levels do not inundate cobble shoreline and tributary flows are low). Skipped spawning by a proportion of the adult population can occur in western lacustrine sucker species when drought conditions prevent upstream migration or reduces lake spawning habitat (Scoppettone et al. 2000; Burdick et al. 2015: Scoppettone et al. 2015). Although Warner Suckers are not considered true lacustrine suckers, lake populations may be operating as such since diversion dams and irrigation water withdraws have reduced stream flows and lake levels.

Stream Spawning – Direct observations of Warner Suckers spawning in tributaries are rare. White et al. (1991) observed spawning on 02 June 1991 below the former O'Keefe Dam in Twelvemile Creek, approximately 2.5 km upstream from the confluence with Twentymile Creek. The authors observed a group of adults swimming in 25 cm of water near the shore directly below the outflow of the dam in well oxygenated, 17°C water. A brightly-colored sucker was observed stirring up gravel and silt, and four more fish moved in and further stirred up the sediment. Although egg and milt disposition could not be observed through the suspended sediments, the authors did collect eggs in the area afterwards. Kennedy and North (1993) observed spawning in the same pool the following year on 19 May, 1992. Five males and two female suckers ranging in size from 130-200 mm TL were observed spawning repeatedly in the area. Water temperature was 20.5°C, depth was 46-77 cm, and substrate was gravel covered by detritus. There was no noticeable flow in the area of spawning.

Observed spawning behavior in suckers involves two males approaching each side of a female that is at rest on the substrate. The males spread their fins and press against the female. All three members of the spawning trio arch their backs and vibrate rapidly, releasing eggs and milt. Simultaneously, all three fish dig into the substrate with their anal and caudal fins, partially burying the fertilized eggs (Reighard 1920; Page and Johnson 1990). Additional males in the area may attempt to sneak in to fertilize eggs. The trio spawning behavior was observed in Warner Suckers held in captivity at the High Desert Museum in Bend, Oregon (Jon Nelson–High Desert Museum, pers. comm.; https://www.youtube.com/watch?v=4Ntp9dfObYo).

Although direct observations of stream spawning events are rare, information on the general location of Warner Sucker spawning can be inferred from the presence of postlarval suckers (the stage immediately after yolk sac absorption, 11-17 mm SL). Postlarval Warner Suckers actively avoid drifting downstream (see section on early-life history), therefore the location of fry aggregations may provide an approximate location of spawning. Kennedy and North (1993) did not observe larvae in the pool below the O'Keefe Dam in 1992, but they did observe a distinct concentration of postlarvae approximately 100 m downstream. Another aggregation was observed approximately 200 m upstream of the O'Keefe Dam, suggesting spawning occurs above the old dam site as well. Additional fry aggregations were observed at the confluence of Twentymile and Twelvemile creeks and upstream of the MC diversion in a boulder-strewn pool near an alfalfa field. Coombs et al. (1979) observed postlarvae in Twentymile Creek 50 m upstream of the confluence with Twelvemile Creek, suggesting suckers use this reach to spawn. Tait and Mulkey (1993b) conducted snorkel surveys in 1-mile reaches in the Twentymile Creek system in 1993 and reported the highest concentration of young-of-year (YOY) in the reach that extended from the Twentymile-Twelvemile creeks confluence to one mile downstream. In 1994, the highest snorkel counts of YOY were in a 1.8-mile reach extending downstream from the O'Keefe Dam (Tait et al. 1995). Coombs and Bond (1980) reported larval suckers at the confluence of Twentymile and Twelvemile creeks. These observations suggest spawning occurs in multiple locations in the creek system with most spawning occurring in the lower Twelvemile Creek reach.

In Honey Creek, no direct observations of spawning has been reported. Longtime local residents of the Warner Valley reported that in the late 1930's large numbers of suckers from the lakes would ascend the creek in the spring and travel far up into the canyon to spawn (Andreasen 1975). Information on the spawning locations of the stream population can be inferred from observation of postlarval suckers. Coombs et al. (1979) reported a few postlarval suckers between the eighth diversion (JJ diversion) and the mouth of Honey Creek, none in the 8 km canyon reach between the eighth diversion and Deppy Creek, and a fairly continuous distribution upstream of Deppy Creek to the Taylor Meadows. Although no larval suckers were observed in the canyon reach in 1979, larvae were observed in the reach by Tait and Mulkey (1993) and Tait et al. (1995), with the greatest density just below Deppy Creek. In Snyder Creek, postlarval suckers were observed in the reach directly below the 'source' springs and in an unnamed tributary upstream of the springs, but no larvae were found in the lower 8 km of the creek. This suggests spawning in Snyder Creek occurs within the vicinity of the springs.

Sexual Differences. – Sexual dimorphism in the shape of the anal fin is common in Catostomids (Reighard 1920; Page and Johnston 1990) and is true of Warner Suckers as well. The distal end of the anal fin on male Warner Suckers is very broad and rounded whereas females have narrower fins and the distal edge is angular (Coombs et al. 1979). During the spawning season, tubercles also develop on the anal and caudal fins of male fish. A colored lateral band usually develops during the spawning season ranging in intensity from pink to bright red on both males and females, but more frequently on males (Coombs et al. 1979).

Several studies have documented that females outnumber males in the lakes (White et al 1991; Allen et al. 1994, 1996; Bosse et al. 1997; Hartzell et al. 2002; Scheerer et al. 2006, 2008, 2011a, 2012). The percentage of females in the lakes population has ranged from a low of 52% (Allen et al. 1994; Scheerer et al. 2012) to as high as 73% (White et al. 1991). A greater proportion of females appears to hold for stream populations as well with the percentage of females in Twentymile Creek ranging from 54-60% (Scheerer et al. 2008; Richardson et al. 2009). Females of several sucker species outlive males (Harris 1962; Hauser 1969), which may account for the greater proportion of females in the Warner Sucker population.

Life History Considerations and the Future of the Warner Sucker

Warner Suckers are uniquely adapted to life in the semi-arid landscape of the Warner Basin. The avoidance of downstream drift by larval suckers is an example of a life history characteristic that likely evolved as the landscape became drier. When pluvial Lake Warner existed in the Pleistocene, the ancestral suckers inhabiting the basin likely had an adfluvial life history similar to many western lacustrine sucker species, with larvae immediately drifting downstream into lakes. This strategy would have become less favorable as Lake Warner gradually dried and streams terminated in the shallow marshlands during the period of larval outmigration in the summer.

The plasticity in spawning behavior would also seem to benefit the Warner Sucker in the semi-arid basin that experiences considerable variability in streamflow and lake levels between wet and dry years. Both lake and stream spawning behaviors by lake-resident suckers may be alternate strategies to deal with interannual variability among water years. Each spawning strategy would have a different level of reproductive success depending on the water year and environmental conditions that together would act as an evolutionarily stable adaptation for this long-lived, iteroparous species. The interannual frequency of lake spawning is currently not known. Although occurring rarely at present, these environmental conditions may become more common in the future. Most climate projections predict increased winter runoff and reduced spring and summer streamflows in the western United States (Maurer et al. 2007; Chambers 2008; Hidalgo et al. 2009). This would likely result in an increased frequency of years when the lakes are full but streamflows are insufficient to allow successful upstream spawning migrations in the Warner Basin.

Warner Suckers have been able to adapt over thousands of years to the effects of a drying climate in the Warner Basin. However, recent changes to the aquatic environment, specifically irrigation development and the introduction of invasive species to the lakes, are thought to have reduced the species' range and abundance (U.S. Fish and Wildlife Service 1985). Prior to irrigation development in the basin, there were undoubtedly drought years when low streamflows limited or prevented successful upstream spawning migrations of lake-resident suckers. However, the construction of diversion dams in the lower stream systems has exacerbated the problem by limiting or preventing successful spawning migrations by lake-resident fish. It appears that some diversion dams (i.e., Plush-Town diversion on Honey Creek and Starveout diversion on Deep Creek) are complete barriers to upstream passage, while others are partial or intermittent barriers. Diversion dam operations usually begin in the spring and coincide with upstream spawning migrations, so all the dams have the potential to block upstream migration, depending on when stoplogs are put in place to divert water. If managers desire to improve spawning success of lake-resident suckers then it will be important to address any barriers to upstream movement.

The other major change to the aquatic environment of the Warner Basin has been the introduction of invasive predatory fish species in the lakes. Crappie *Pomoxis* spp. and brown bullhead *Ameiurus nebulosus* are now common in the lakes and are purported to have a negative impact on suckers via predation on juveniles, although actual predation has not been directly observed. The extent that predation impacts suckers depends on the frequency of juvenile production in the lakes and the size of stream-resident suckers that migrate to the lakes. If Warner Suckers typically rear in streams for 2-3 years and enter the lakes at a larger size, then their vulnerability to predation would be limited because they would exceed the gape size of most predators. Understanding the recruitment dynamics of the lake population would help clarify whether predation by invasive species is a threat; however, recruitment dynamics may change as dam modifications increase access by lake suckers to spawning habitat farther upstream.

In summary, Warner Suckers have adapted to thrive in the geographically limited range and harsh semi-arid conditions of the Warner Basin. Relatively recent anthropomorphic alterations to the aquatic environment in the valley presents challenges to the species' ability to express the full suite of its life history characteristics. Recently, there has been a concerted effort among management agencies and landowners to provide fish passage through the numerous diversion dams and to screen irrigation canals in the valley. These changes, along with other habitat improvements, should help Warner Suckers better carry out all aspects of their life history.

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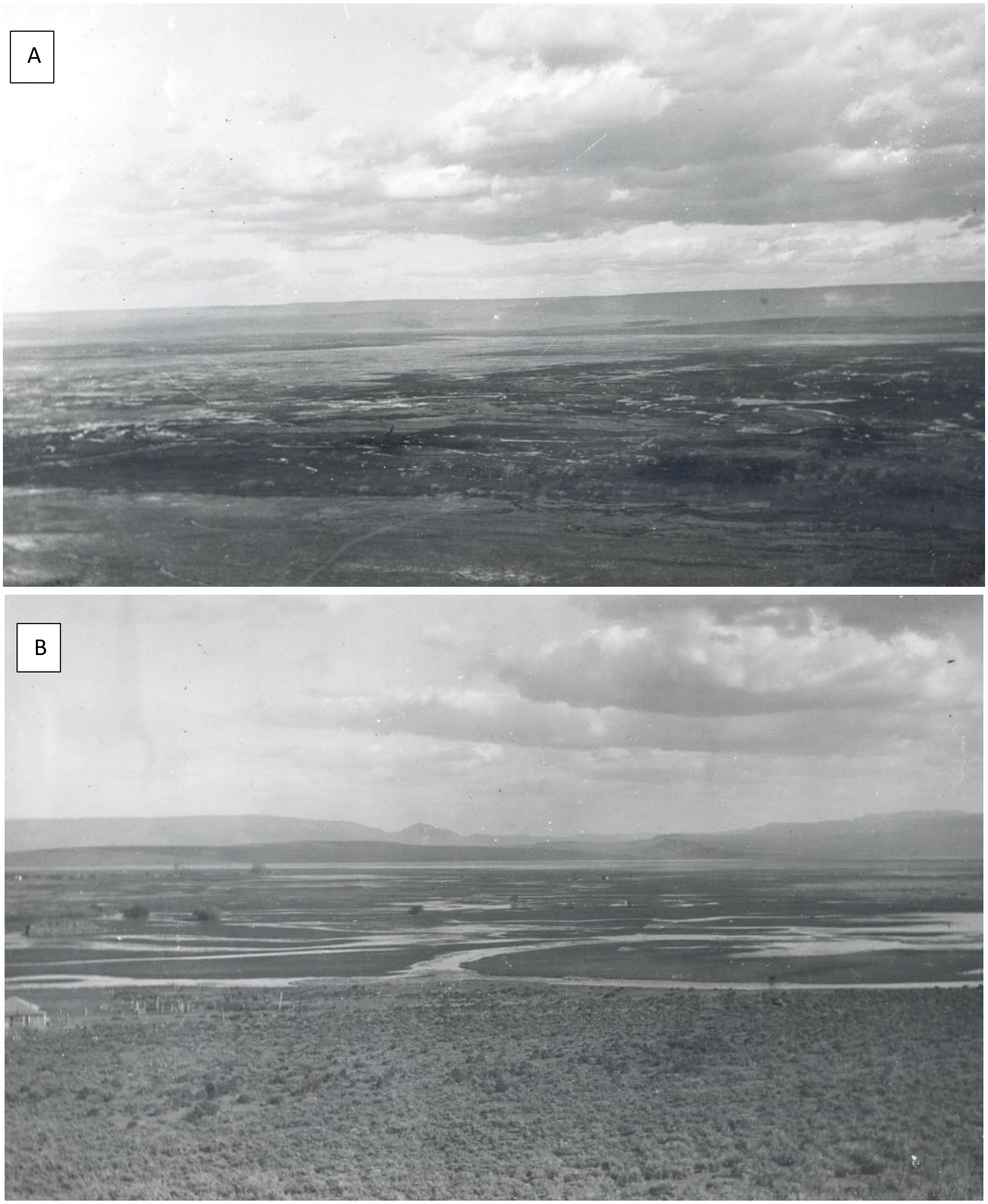
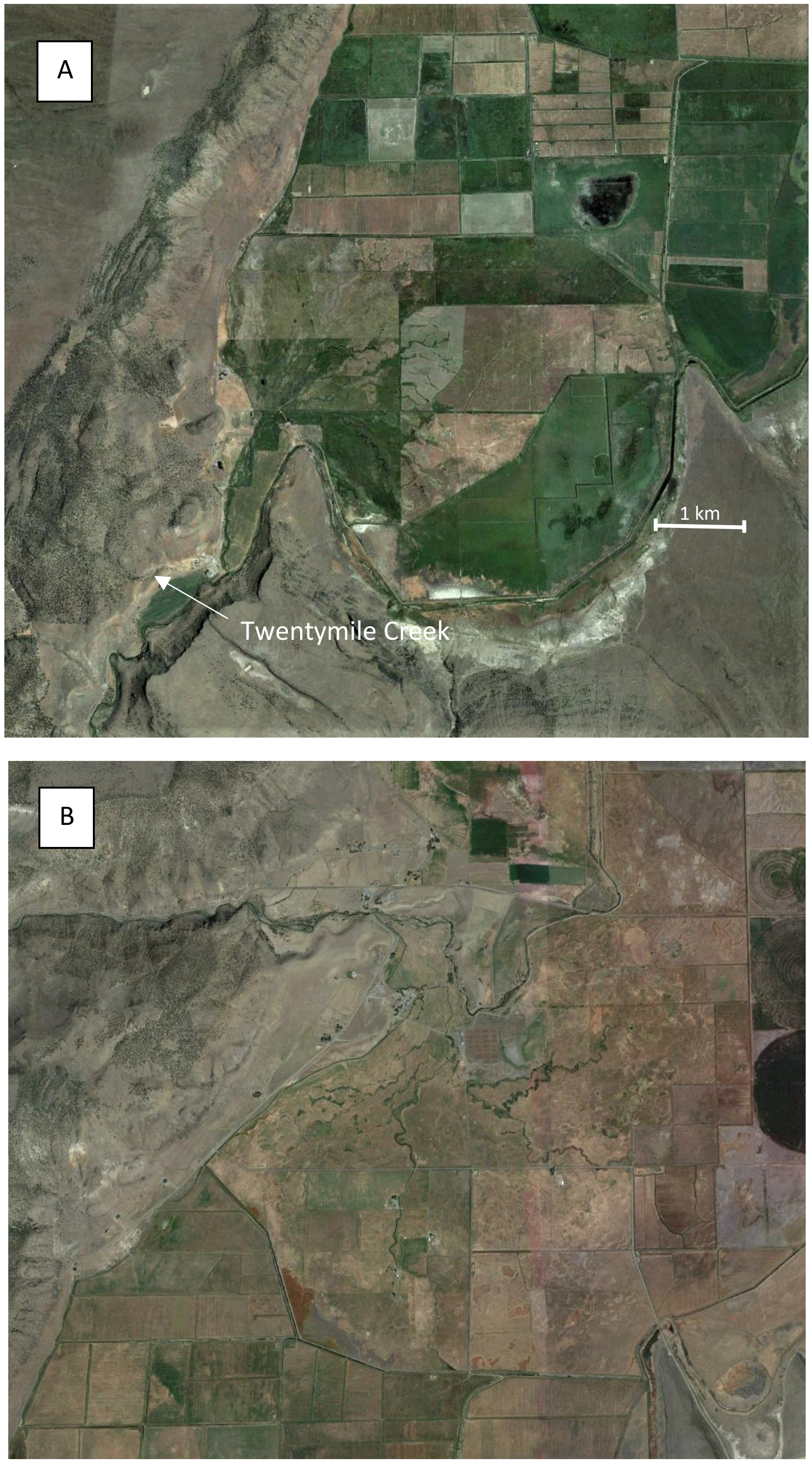
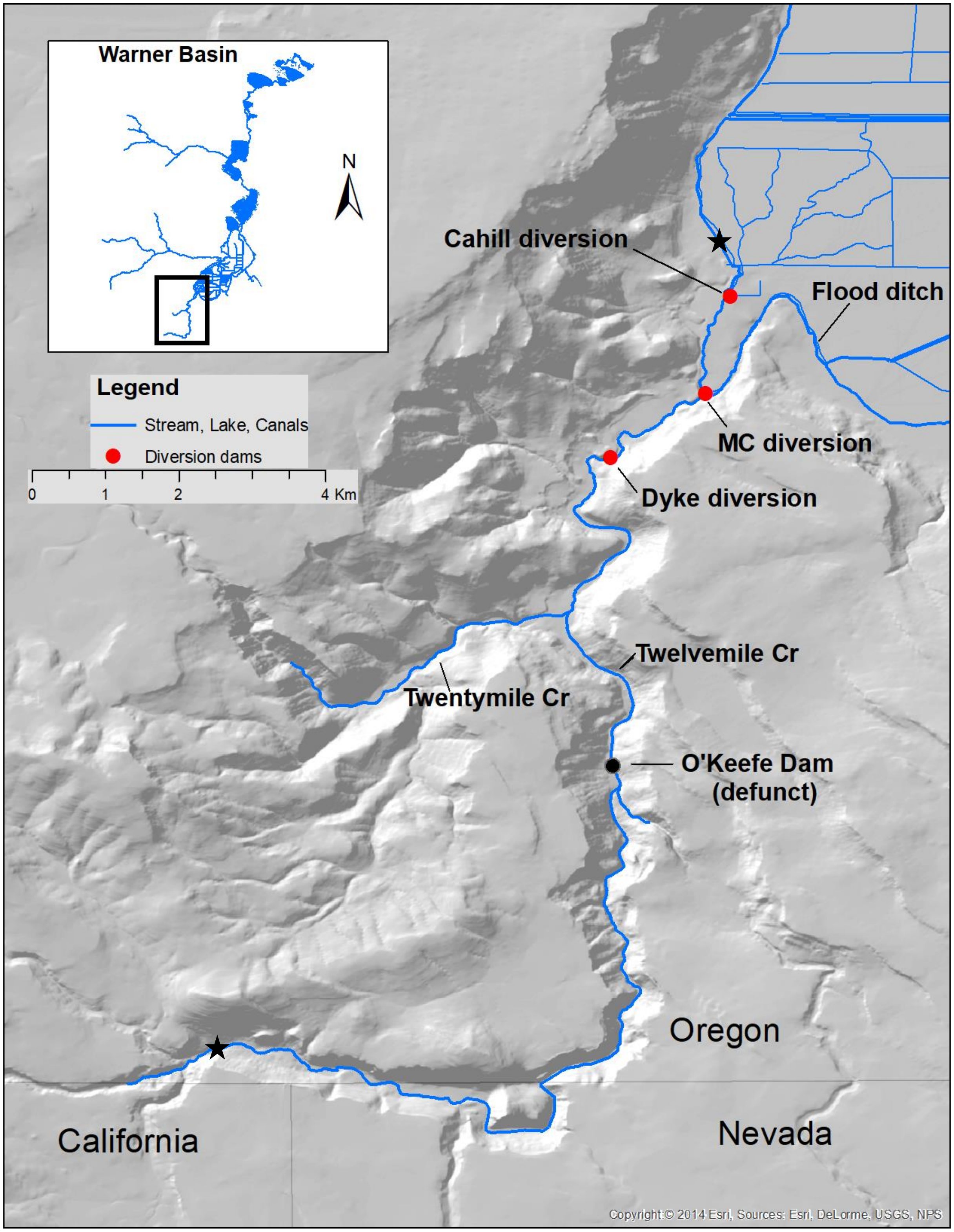
Appendix



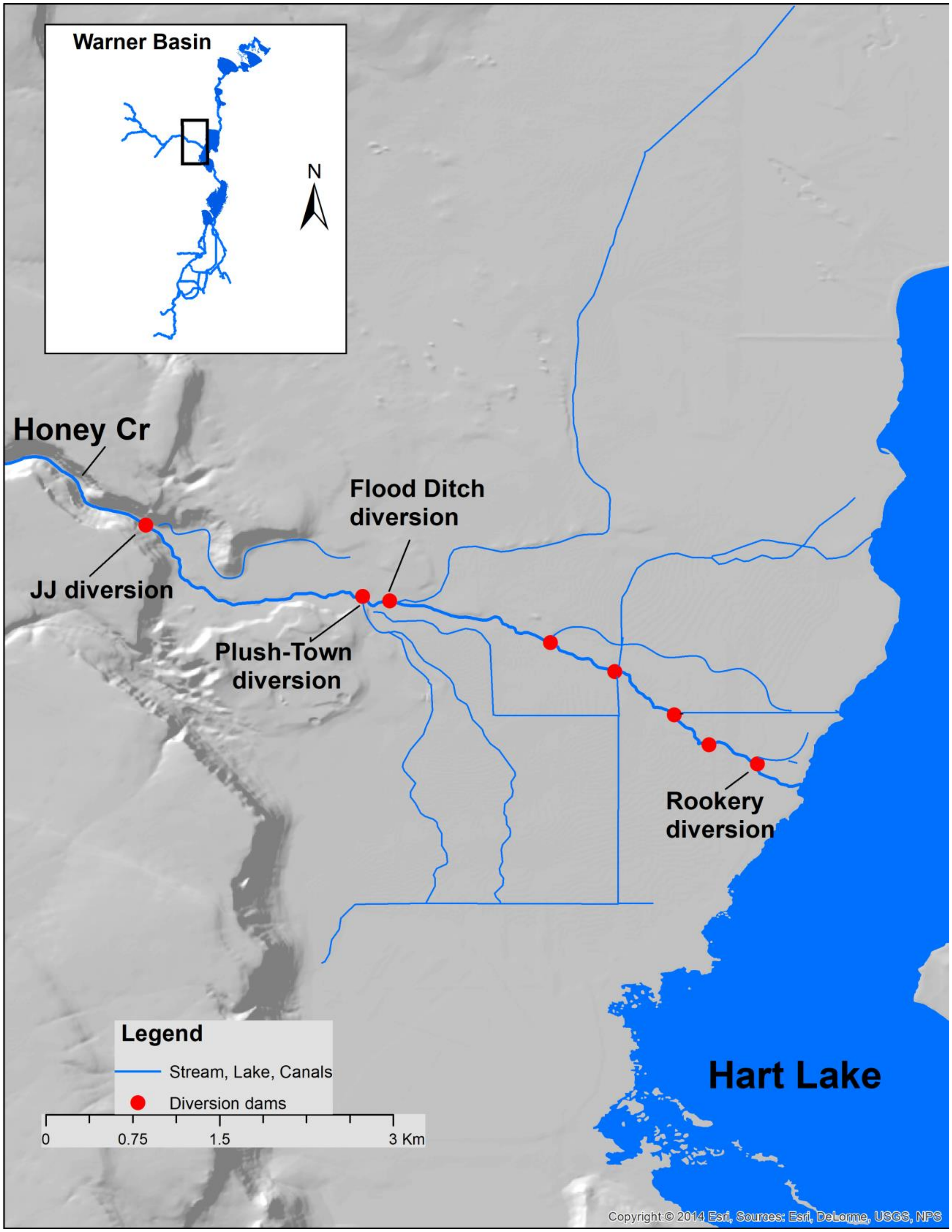
Appendix Figure 1. Photos of South Warner Valley overlooking flooded marshland near Twentymile Creek (A) and Deep Creek (B) taken in the spring of 1921. Twentymile Creek photo taken on 27 April, 1921 looking north-easterly from a point on the hill above Cressler Ranch house with location of photo given as Section 13, Township 40S, Range 23E. Deep Creek photo taken on 07 May, 1921 looking east over part of MC Ranch south of Adel with location given as NW1/4-SE1/4 Section 29, Township 39S, Range 24E. Photos from Stricklin and Perry 1923.



Appendix Figure 2. Satellite imagery showing remnant channels terminating in the marshland on the valley floor for Twentymile Creek (A) and Deep Creek (B). Imagery from Google Earth.



Appendix Figure 3. Map of Twentymile Creek subbasin showing canals, streams, irrigation diversion dams, and upper- and lower-most distribution on Warner Sucker. Star symbols denote lower- and upper-most locations of Warner Sucker, not including the reported observation in West Barrel Creek in the Cowhead Slough subbasin.



Appendix Figure 4. Map of lower Honey Creek showing canals, stream, and irrigation diversion dams.

Warner Basin Strategic Action Plan
Technical Report

Warner Basin Aquatic Habitat Partnership

October 31, 2019