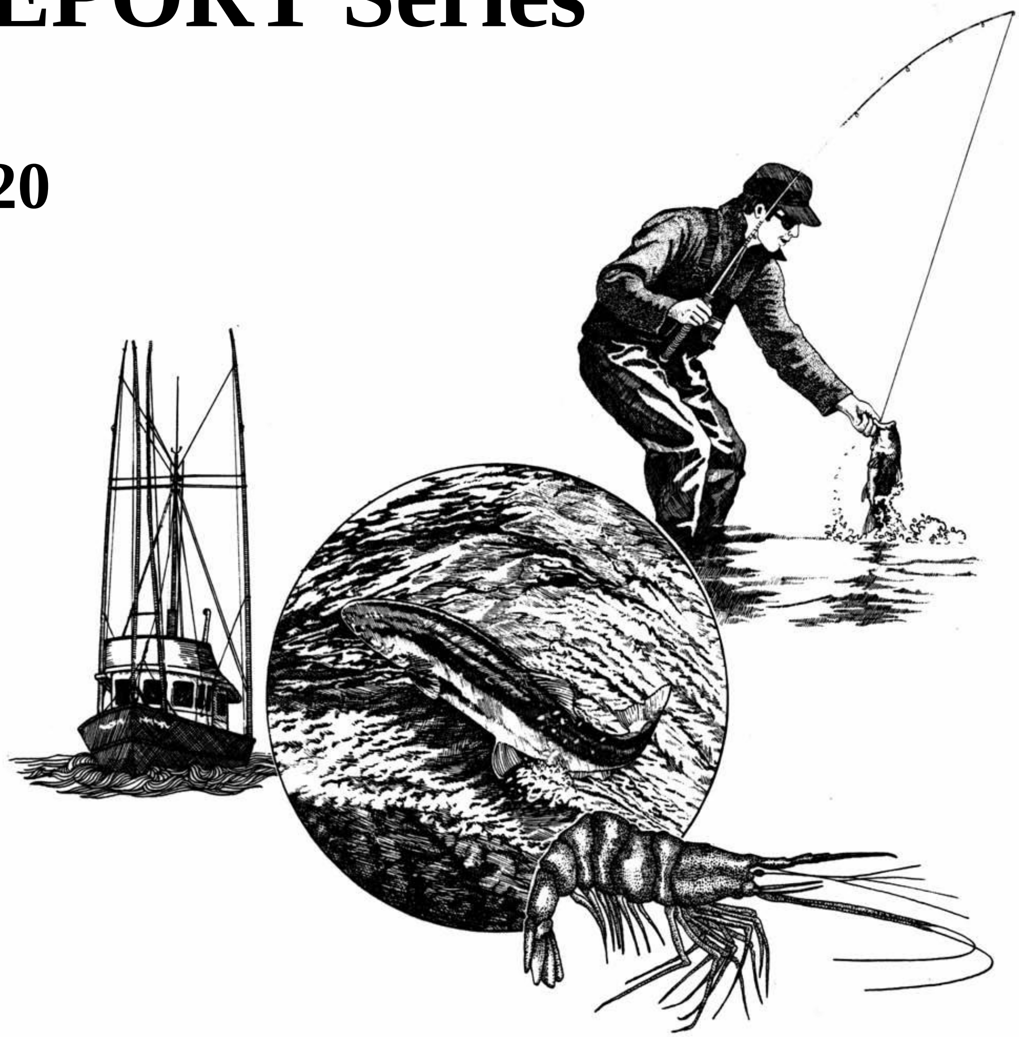
ODFW PROGRESS REPORT Series

2020



Oregon Department of Fish and Wildlife

2017-2019 Borax Lake Chub Investigations

F16AC00822

Oregon Department of Fish and Wildlife prohibits discrimination in all of its programs and services on the basis of race, color, national origin, age, sex, or disability. If you believe that you have been discriminated against as described above in any program, activity, or facility, or if you desire further information, please contact ADA Coordinator, Oregon Department of Fish and Wildlife, 4034 Fairview Industrial Drive SE, Salem, OR 97302; (503)947-6000.

This material will be furnished in alternate format for people with disabilities if needed. Please call 541-757-4263 to request

ANNUAL PROGRESS REPORT
FISH RESEARCH PROJECT
OREGON

PROJECT TITLE: *2017-2019 Borax Lake Chub Investigations*

PROJECT NUMBER: *U.S. Fish and Wildlife Service F16AC00822*

PROJECT PERIOD: *2017-2019*

Photo: Alexis Harrison, ODFW

Prepared by: *Brian L. Bangs[1], Paul D. Scheerer[1], James T. Peterson[2], and Alexis S. Harrison[1]*

[1]Oregon Department of Fish and Wildlife, 28655 Highway 34, Corvallis, Oregon 97333
[2]USGS Oregon Cooperative Fish and Wildlife Research Unit, 104 Nash Hall, Oregon State University, Corvallis, OR 97331

Oregon Department of Fish and Wildlife
4034 Fairview Industrial Drive SE
Salem, OR 97302

This project was funded in part by the U.S. Fish and Wildlife Service

CONTENTS

Abstract

The Borax Lake chub is a small minnow found only in Borax Lake in the Alvord Basin in Harney County, Oregon. Concern over threats to the chub's unique and fragile habitat led to the designation of this species as federally endangered in 1982. Recovery measures implemented since listing have addressed many of the threats to Borax Lake chub. In June of 2020 the Borax Lake chub was removed from the endangered species list due to recovery, making it the fourth species in Oregon to achieve this distinction. The Oregon Department of Fish and Wildlife has played a large role in monitoring the population and habitat of Borax Lake chub since the time of listing. This report describes the results of monitoring conducted in 2017 and 2019, and relates these results to previous years of monitoring. Our major findings include: 1) The population of Borax Lake chub is large, relative to historic numbers. In 2019, the population size was estimated at 80,267 individuals, a record high. 2) The condition of the habitat in Borax Lake remains good, with no evidence of unauthorized vehicle access or other shoreline degradation, water levels and water temperatures remaining similar to historic values over this time period, and there is no evidence of nonnative species in the lake. Future monitoring of population abundance and habitat conditions is planned, in accordance with the Cooperative Management Plan and Post-delisting Monitoring Plan for this species.

Introduction

Borax Lake is a natural 4.1 ha lake fed by multiple geothermal alkaline springs. It is perched 10m above the desert floor on borosilicate deposits formed by evaporation of the spring water. The main spring input, at the bottom of a 27m-deep vent, varies in temperature from 40-148°C (Perkins et al., 1996). Despite the depth of the vent, most of the lake is only about 1m deep; surface temperatures range from 22-39.2°C (Scheerer and Jacobs, 2005; Scheerer et al. 2013). The substrate of the lake includes rocky outcroppings, stromatolites formed by colonial cyanobacteria, bedrock, gravels, sand, and silt (Williams and Bond, 1983).

The Borax Lake chub (*Siphateles boraxobius*) is a small minnow endemic to Borax Lake and adjacent wetlands and outflow channels in the Alvord Basin in Harney County, Oregon (Williams and Bond 1980). They are found throughout the lake except in the immediate vicinity of the hot spring inflows, but seem to prefer the shallow habitats along the margins of the lake (Perkins et al., 1996). Adults are typically 33-50mm standard length, but may grow over 90mm. Borax Lake chub are opportunistic omnivores, with diatoms, small crustaceans, and chironomid larvae comprising a large portion of the diet (Williams and Williams, 1980; Scoppetone et al., 1995). Spawning is thought to occur year-round, with peak activity in the fall and spring (Williams and Bond, 1983; Scoppettone et al., 1995). While most Borax Lake chub are thought to live for about a year, some individuals may live several years, with opercle bone aging indicating some individuals over 10 years in age (Scoppettone, 1995).

The Borax Lake chub was listed as endangered under the federal Endangered Species Act in 1982 (U.S. Fish and Wildlife Service 1982). Population abundance estimates obtained from 1991-2016 fluctuated from approximately 1,200 to 37,000 fish (Salzer 1997; Scheerer et al. 2012, 2015, 2016). However, the basis for the Borax Lake chub's listed status was not population size, but the vulnerability of their unique and isolated habitat (U.S. Fish and Wildlife Service 1982). At the time of the listing, Borax Lake was threatened by habitat alteration from proposed geothermal energy development. In addition, the lake shore crust had been altered to provide irrigation to surrounding pasture lands, and damaged by off-road vehicles and grazing livestock. The recovery plan for the Borax Lake chub advocated for protection of the lake ecosystem through the acquisition of key private lands, protection of groundwater and surface water, control of vehicle access, and the removal of livestock grazing (U.S. Fish and Wildlife Service 1987).

Recovery measures implemented since listing have addressed many of the threats to Borax Lake chub, primarily by protecting their habitat. These efforts were summarized by Scheerer and Clements (2015). When the species was listed, critical habitat was designated on 259 ha of land surrounding the lake, including 129 ha of public lands and two 65-ha parcels of private land. In 1983, the U.S. Bureau of Land Management (BLM) designated the public land as an Area of Critical Environmental Concern, which directs protection of threatened and endangered species habitats in need of special management attention. The Nature Conservancy (TNC) began leasing the private lands in 1983 and purchased them in 1993, bringing the entire critical habitat into public or conservation ownership. TNC ended water diversion from the lake for irrigation and livestock grazing. In 1991, The Oregon Department of Fish and Wildlife (ODFW) obtained a water right to maintain the lake pool elevation. Passage of the Steens Mountain Cooperative Management and Protection Act of 2000 removed the public BLM lands from mineral and geothermal development within a large portion of the basin and provided additional protections from development on private lands. The BLM and TNC fenced the area surrounding the lake to exclude vehicular access in 2011 and installed locked gates in 2013. Additionally, detailed studies of Borax Lake chub and their habitat in the 1990s improved knowledge about the biology of Borax Lake chub and the Borax Lake ecosystem (Scoppettone et al. 1995, Salzer 1992, Perkins et al. 1996).

Due in large part to these efforts, the Borax Lake chub 5-Year Review recommended downlisting the species from endangered to threatened status in 2012 (U.S. Fish and Wildlife Service, 2012). In June of 2020, the Borax Lake chub was removed from the endangered species list due to recovery (U.S. Fish and Wildlife Service, 2020). While the Borax Lake chub is no longer listed as endangered, monitoring efforts will continue into the foreseeable future. In 2018, BLM, ODFW, and the U.S. Fish and Wildlife Service (Service) finalized a Cooperative Management Plan for the Borax Lake chub. The plan outlines the long-term management actions necessary to ensure this conservation-reliant species and its unusual habitat persist. This plan has no termination date. Additionally, a post-delisting monitoring plan for Borax Lake chub, appended to the delisting decision by the U.S. Fish and Wildlife Service, outlines a 10-year plan to monitor the population and habitat at Borax Lake (U.S. Fish and Wildlife Service, 2019). This plan includes periodic estimates of population abundance and habitat condition (see Appendix B).

This report describes results from monitoring conducted by Oregon Department of Fish and Wildlife's Native Fish Investigations Program in 2017 and 2019. Our objectives were to obtain a population estimate of Borax Lake chub, and evaluate habitat conditions at Borax Lake, including monitoring of annual fluctuations in water temperatures and water levels, and the condition of the fragile lake shoreline and outflows. These results provide an important baseline to ensure that this species will continue to thrive.

METHODS

Sampling for population estimation in 2017 occurred over four days, from Oct. 2 – Oct. 5. We captured Borax Lake chub using baited minnow traps (n=114; 1.6 mm mesh). On the first day of sampling we distributed the traps roughly every 25 m along transects that crossed the lake and along the shoreline (Figure 1) and left them in place overnight (~16 h). We also placed traps in the wetland channel and in the outflow channel (the wetland pond was excluded because it was dry). On day two we collected the traps in the morning, recorded the number of Borax Lake chub in each of three size categories (small

<35 mm total length (TL), medium 35-59 mm TL, and large ≥60 mm TL), and measured TL of a sub-sample of fish (n=233). Individual fish were marked with a partial upper caudal fin clip. In addition, we recorded the habitat type and separated fish capture data by habitat type (shoreline, offshore, or outflow) before releasing fish near the location where they were collected. Traps were re-deployed in the same locations in the afternoon. On the third day, traps were collected and the number of fish was recorded for each size category and habitat type, as on day two. Additionally, we recorded whether captured fish had been marked with a partial upper caudal fin clip, and marked all fish with a partial lower fin clip. As on day two, the fish were released near the site of capture, and the traps were redeployed in the afternoon. On the final day of sampling, we collected traps, recorded the number of captured Borax Lake chub in each size category and habitat, whether each fish was marked (upper, lower, or both caudal fins clipped) or unmarked, before releasing fish near the site of capture.

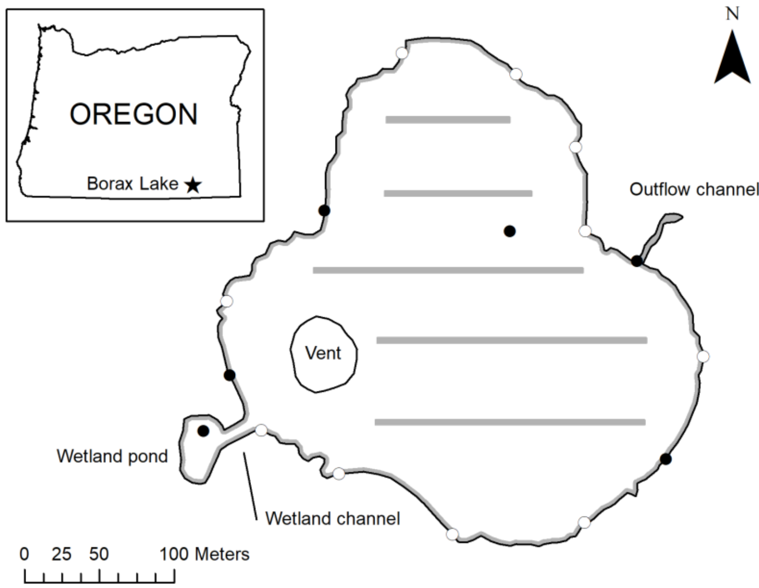


Figure 1. Map of Borax Lake showing the outline of the lake (black), main vent, outflow channel, wetland pond, wetland channel, shoreline photo points (all circles), and data loggers (black circles only). Gray lines note the approximate locations of trapping transects in open water and around the lake perimeter. Transects were based on those established by Scoppettone et al. (1995).

Total population size in 2017 was estimated using a Huggins closed-capture, capture-recapture estimator with a random effect for habitat type following the method used in previous investigations conducted by ODFW (e.g. Scheerer et al. 2012). We used the program MARK (White and Burnham 1999) with two consecutive encounter occasions and three attribute groups (small <35 mm, medium 35-59 mm, and large fish >59 mm). This model requires a minimum of two sampling occasions to estimate capture probabilities and can include covariates that are known to affect capture probabilities (e.g., fish size and habitat characteristics) (Peterson and Paukert 2009). We calculated 95 percent confidence intervals for this estimate according to Chao (1987). We calculated abundance estimates separately for each habitat type.

In 2019, sampling was conducted over three days, from Oct. 28 – Oct 30. On the first day of sampling, baited minnow traps were distributed throughout Borax Lake as in 2017 (Figure 1). On day two we collected the traps in the morning, recorded the number of Borax Lake chub in each of three size categories (using the same thresholds as in 2017) for each habitat type, and measured TL of a sub-sample of fish (n=250). Individual fish were marked with a partial caudal fin clip. Fish were released near the location where they were collected and traps were re-deployed in the same locations in the afternoon. On the third day, traps were collected and the number of fish was recorded for each size category and habitat type. Additionally, we recorded whether captured fish had been marked with a fin clip. As on day two, the fish were released near the site of capture.

The key difference between sampling in 2017 and 2019 was that only a single recapture event was completed in 2019. Since the Huggins closed-capture, capture-recapture estimator requires two consecutive recapture events to produce a population estimate, the population estimation for 2019 was generated using the state space model (Bolker 2008; Scheerer et al. 2015, 2016), using capture probabilities estimated from 2017 sampling.

We assessed the condition of the lake's shoreline, the wetland, and the outflow channels by revisiting and photographing the shoreline at photo points that we established in 2005 (Scheerer and Jacobs 2005). We looked for evidence of damage to the shoreline crust from vehicular trespass, manipulation of the crust to alter water outflow, and assessed other qualitative changes in the habitat.

We monitored water temperatures (˚C) at five locations with Onset® Computer Corporation Hobo® data loggers configured to record at 1-h intervals. One of these data loggers also recorded water elevation. We downloaded data (water elevations and temperatures) from a water level data logger that we installed in 2011 (Scheerer and Bangs 2011). Temperature data was summarized for each location by selecting the maximum daily temperature recorded at each data logger. In order to characterize the water temperature in terms of thermal stress for the fish, we considered both the maximum daily temperature at the warmest location in the lake (indicating the most stressful habitat potentially experienced by the fish), and the maximum daily temperature of the coolest location in the lake (indicating the least stressful potential habitat available). Water depth was calculated from the difference in maximum barometric pressure measured in the lake and the maximum barometric pressure recorded at a logger on shore, using the formula provided by Onset. The depth measured at the data logger in the lake, 0.7875m, was used to calculate a correction factor, reflecting the position of the data logger in the water column.

RESULTS AND DISCUSSION

Population abundance

In 2017, we estimated the abundance of Borax Lake chub at 76,931 fish (95% CI: 68,444-86,952; Table 1). In 2019, we estimated the abundance of Borax Lake chub at 80,267 (95% CI: 74,285-88,209). Borax Lake chub catch history by size category and location for the 2017 and 2019 sampling events are provided in APPENDIX A.

Borax Lake chub Population abundance estimates have been obtained regularly since 1986. In 2017 and 2019, Borax Lake chub population abundance was substantially higher than any previous estimate, which is remarkable given that we documented the low recorded population abundance in 2015 (Table 1, Figure 2). One caveat to this observation is that differences in the method of estimating abundance prevent a direct comparison of estimated abundance across all years (Salzer 1992, Salzer 1997, Scheerer and Bangs 2011, Scheerer et al. 2012, 2015, 2016). To facilitate the comparison of our population estimates from 2017 and 2019 to earlier estimates, we calculated the Lincoln-Peterson population estimate. Scheerer et al. (2012) demonstrated that the Lincoln-Petersen formula underestimates the abundance of Borax Lake chub (Scheerer et al. 2012), thus the Huggins estimate should be considered closer to the true population abundance for 2017 and 2019; the Lincoln-Peterson estimates are provided only for comparison to estimates from 1986 - 2012. Even accounting for the difference in methodology, it is clear that the population of Borax Lake chub was larger in 2017 and 2019 than at any other time in the last 15 years (Figure 2).

Table 1. Estimated population abundance of Borax Lake chub, 1985-2019.

Year	Agency	Method of estimation	Estimated population abundance	95% confidence interval of population estimate
1986	USGS	Lincoln-Peterson	15,276	13,672 – 17,068
1987	USGS	Lincoln-Peterson	8,578	7,994 – 9,204
1988	USGS	Lincoln-Peterson	4,132	3,720 – 4,589
1989	USGS	Lincoln-Peterson	14,052	13,016 – 15,172
1990	USGS	Lincoln-Peterson	19,165	18,117 – 20,273
1991	USGS	Lincoln-Peterson	33,000	31,795 – 34,251
1992	TNC	Lincoln-Peterson	25,255	24,170 – 26,388
1993	TNC	Lincoln-Peterson	35,650	34,154 – 37,212
1994	TNC	Lincoln-Peterson	13,421	12,537 – 14,368
1995	TNC	Lincoln-Peterson	35,465	33,533 – 37,510
1996	TNC	Lincoln-Peterson	8,259	7,451 – 9,153
1997	TNC	Lincoln-Peterson	10,905	10,377 – 11,459
2005	ODFW	Lincoln-Peterson	14,680	12,585 – 17,120
2006	ODFW	Lincoln-Peterson	8,246	6,715 – 10,121
2007	ODFW	Lincoln-Peterson	9,384	7,461 – 11,793
2008	ODFW	Lincoln-Peterson	12,401	10,681 – 14,398
2009	ODFW	Lincoln-Peterson	14,115	12,793 – 15,573
2010	ODFW	Lincoln-Peterson	25,489	23,999 – 27,071
2011	ODFW	Lincoln-Peterson	26,571	24,946 – 28,301
2012	ODFW	Lincoln-Peterson	7,835	7,298 – 8,410
	ODFW	Huggins	9,702	9,042 – 10,452
2015	ODFW	State Space	1,242	1,077 – 1,456
2016	ODFW	State Space	9,003	8,045 – 10,560
2017	ODFW	Lincoln-Peterson	28,832	28,155 – 29,524
	ODFW	Huggins	76,931	68,444 – 86,952
2019	ODFW	Lincoln-Peterson	40,019	37,112 – 43154
	ODFW	State Space	80,267	74,285 – 88,209

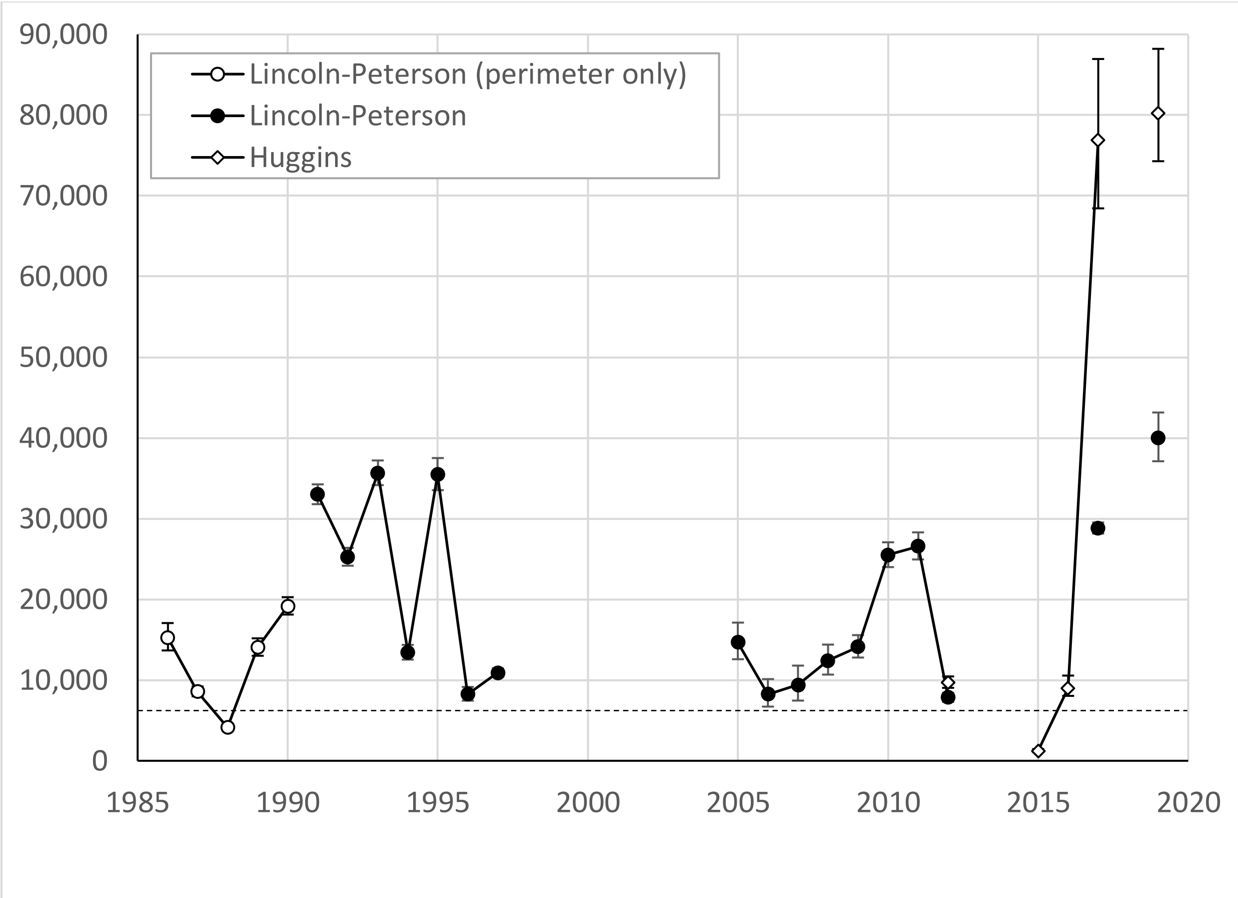


Figure 2. Borax Lake Chub population abundance estimates from 1986-2019. Error bars represent 95% confidence intervals. In 1986-1990 (open circles), only the perimeter of the lake was sampled, and population size was estimated using the Lincoln-Peterson method. After 1990 (black circles), the entire lake including the wetland, wetland channel, and outflow channel were sampled. Estimates using the Lincoln-Peterson method are shown. Starting in 2012, population sizes were estimated using the Huggins closed-capture model. These estimates are shown with open diamonds. The dashed line represents the population threshold (6,500 adult fish) identified by the PDM as a trigger for conservation action.

In addition to estimates of the total population size, we also collected information on the size distribution of Borax Lake chub in 2017 and 2019 (Figure 3). Of note, large fish (>59mm) were significantly more common in 2019 than in 2017. In 2017, Borax Lake chub varied in length from 20 to 72 mm with two apparent size classes; these size classes may represent different age classes of Borax Lake chub. We observed differences in habitat use among size classes, with small fish predominantly using the south shoreline and large fish the north. In 2019, Borax Lake chub varied in length from 29 to 100 mm total length, without the apparent break in size class nor habitat preference that we observed in 2017. In 2019, we captured smaller fish in the wetland channel and outflow channel than in the lake, and in 2017 observed many young-of-the-year Borax Lake chub (≤20 mm TL) in the outflow channel, which were not captured in minnow traps.

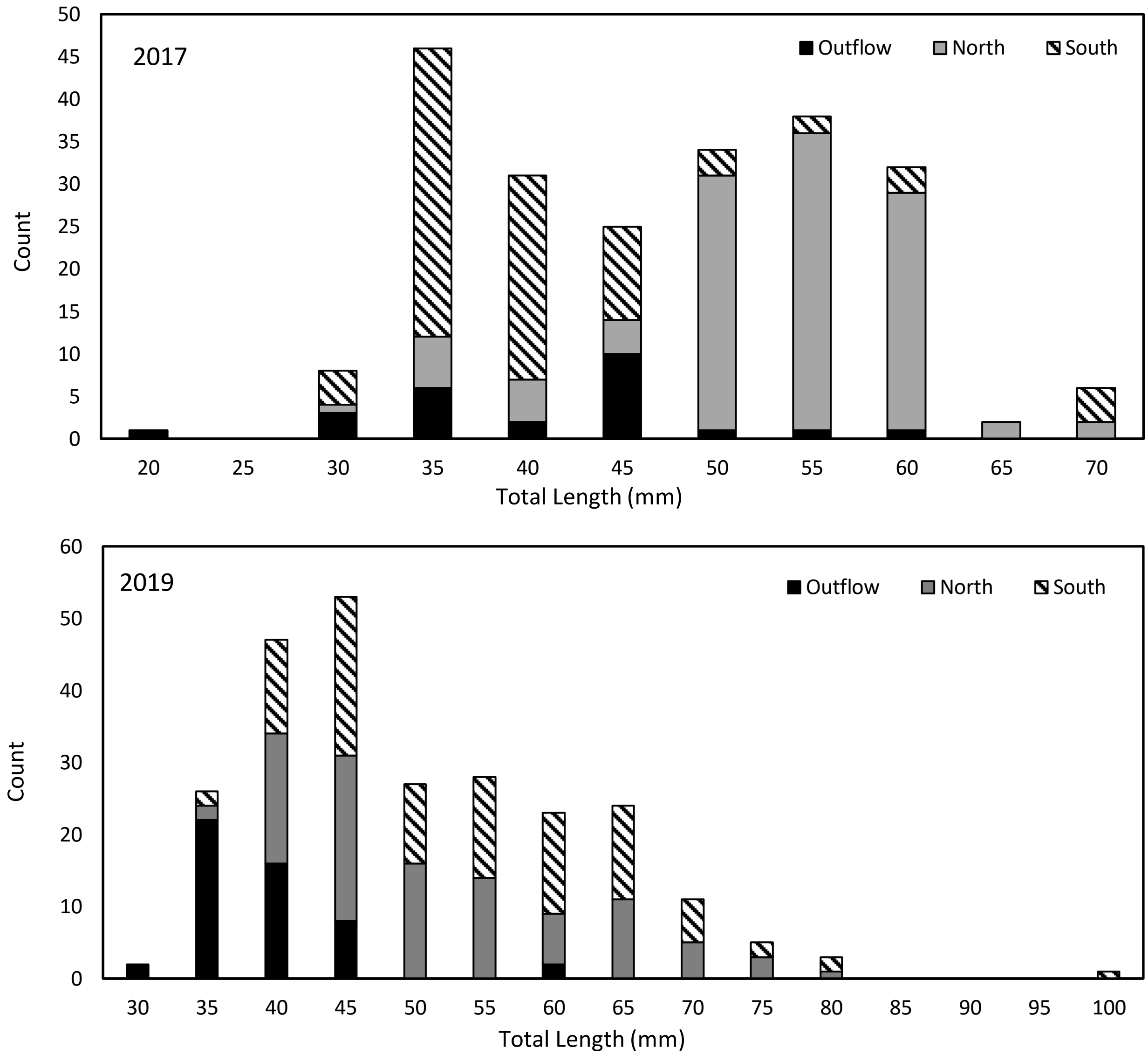


Figure 3. Length frequency histogram for Borax Lake Chub collected in the north and south shoreline of the lake and outflow channel of Borax Lake in 2017 (top panel) and 2019 (bottom panel). The wetland channel is included in the south shoreline.

Shoreline surveys

We have not observed evidence of off-road vehicle trespass or damage to areas near the lake since 2015 (Scheerer et al. 2016). Additionally, we have not documented any substantial changes in the shoreline crust at Borax Lake since Oregon Department of Fish and Wildlife's monitoring began in 2005 (Scheerer and Jacobs 2005; 2006; 2007; 2008; 2009; 2010; Scheerer and Bangs 2011, Scheerer et al. 2012; 2015; 2016). A visual comparison of the appearance of the shoreline habitat in 2019 and 2015 shows minimal changes in the shoreline configuration and vegetation (representative photographs are shown in Figure 4).

Figure 4. Representative photographs from photo points at Borax Lake, comparing habitat in 2015 and 2019. Photos in 2015 were taken October 14-15th, while photos in 2019 were taken October 30th. Photos labeled a, b, and c were taken in 2015. Photos labeled d, e, and f were taken in 2019. Photos a and d were taken from photo point 5, on the southeast shoreline just south of the outflow, facing north. Photos d and e were taken from photo point 7, on the southwest shore just north of the wetland channel, facing south. Photos c and f were taken from photo point 5, on the southeast shoreline just south of the outflow, facing south.

Water temperatures

Daily maximum water temperatures in 2017, 2018, and 2019 were consistent with trends observed from 2005-2016 (Figure 5). Peak temperatures are consistently recorded from June-September, with an approximately 5°C difference between the warmest and coolest parts of the lake. In 2017, the recorded temperature exceeded 34.5°C (see discussion of why this threshold was selected below) on 39 days in the coolest measured spot in the lake, and on 88 days in the warmest spot (Table 2). In 2018, the temperature exceeded this threshold on 20 and 66 days, respectively. In 2019, the temperature exceeded the threshold on 22 days in the coolest spot and 75 days in the warmest spot. For the period from 2005-2016, the lake exceeded 34.5°C on an average of 18.8 days in the coolest spot measured, and 70.9 days in the warmest spot measured, meaning that 2017 could be considered an above-average temperature year while 2018 and 2019 were fairly typical.

We also calculated the average daily maximum temperature of the hottest 14-day period in the warmest and coolest spots measured in the lake for all the years for which data was available (Table 2). In the coolest lake location where a data logger was deployed, the average was 35.2°C in 2017, 35.5°C in 2018, and 35.0°C in 2019, compared with an average of 34.5°C from 2005-2016. In the warmest lake location where a data logger was deployed, the average daily maximum temperature over the warmest 14-day period was 37.4°C in 2017, 37.7°C in 2018, and 37.5°C in 2019, compared with an average of 38.1°C from 2005-2016. These values reflect that the study period, 2017-2019, were fairly typical in terms of the thermal habitat available in Borax Lake.

Table 2. Temperature metrics 2005-2019.

Year	Days over 34.5°C (coolest spot)	Days over 34.5°C (warmest spot)	Average daily max (coolest spot), hottest 14-day period	Average daily max (warmest spot), hottest 14-day period
2005	48	55	36.0	36.6
2006	17	90	35.2	38.2
2007	2	106	32.1	39.7
2008	11	93	33.6	39.2
2009	6	69	32.9	38.2
2010	10	35	34.2	36.1
2011	9	43	33.6	35.9
2012	30	65	35.4	37.2
2013	32	72	35.5	37.7
2014	27	73	35.0	37.7
2015	25	66	36.0	41.1
2016	9	84	33.9	39.1
2017	39	88	35.2	37.4
2018	20	66	35.5	37.7
2019	22	75	35.0	37.5

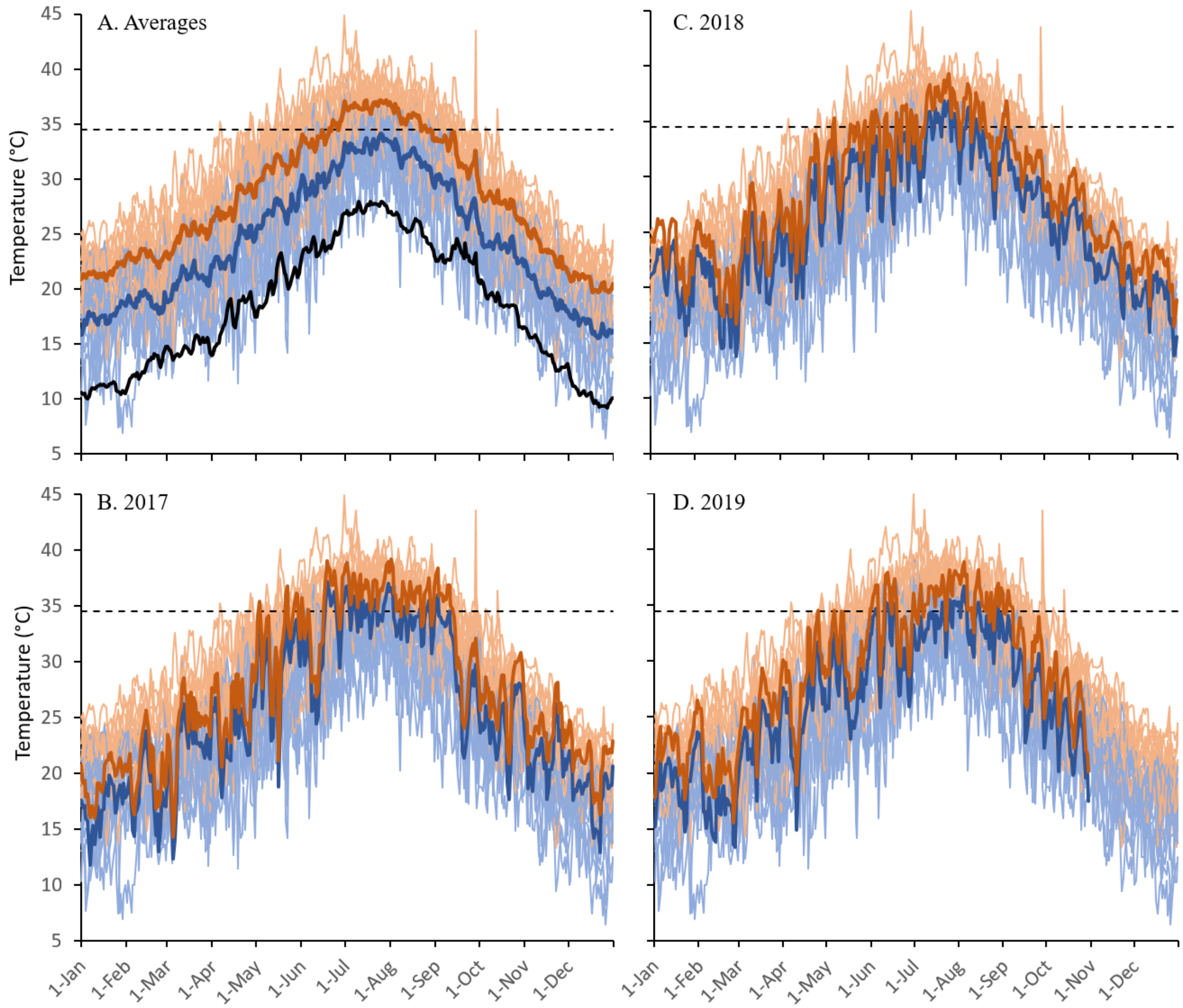


Figure 5. Water temperatures in Borax Lake. All panels include the daily maximum temperature of the warmest (pale orange) and coolest spot measured in the lake (pale blue), with each line representing a single year of data, 2005-2019. All panels also show the critical thermal maximum of Borax Lake chub reported in the literature (black dashed line). A. The daily maximum temperature of the warmest (dark orange) and coolest (dark blue) spots in the lake averaged across all years, along with the average temperature of the wetland habitat (2007-2016; solid black line). B. The daily maximum temperature recoded in the warmest (dark orange) and coolest (dark blue) spots in Borax Lake in 2017. C. The daily maximum temperature recoded in the warmest (dark orange) and coolest (dark blue) spots in Borax Lake in 2018. D. The daily maximum temperature recoded in the warmest (dark orange) and coolest (dark blue) spots in Borax Lake in 2019 through October 30.

The maximum thermal tolerance of Borax Lake chub is not well understood. Williams and Bond (1983) observed that fish avoided water above 34°C, and in an aquarium they lost equilibrium when the temperature was raised to 34.5°C, indicating a critical thermal maximum around this temperature. However, over the 15 years that ODFW has conducted temperature monitoring in Borax Lake, even the coolest location in the lake has routinely exceeded this threshold, including in years where the population was thriving (Table 2). One potentially heat-related population reduction was observed over this time period, in 2015. This year stands out as an exceptionally hot year, both in terms of the maximum water temperatures observed and the prolonged duration of high temperatures. Another potentially heat-related mortality event in 1987, before water temperature monitoring was in place, led to the mortality of a significant portion of adult fish, but juvenile fish were found to be plentiful in fall sampling (Williams et al., 1989; Scoppetone et al., 1995). After both the 1987 and 2015 declines, the population quickly rebounded (Figure 2).

It is not clear how Borax Lake chub weather the thermal stress of lake conditions in average years. Perhaps they are able to gradually acclimate to higher temperatures, as has been observed in the Mohave Tui chub (Gila bicolor mohavensis; McClanahan et al., 1986). Perhaps cool spring inflows provide a refugia when lake temperatures rise. Perhaps juvenile fish or larvae are able to weather high temperatures more readily than older fish, as Williams et al. (1989) and Scoppetone et al. (1995) hypothesized. Another possibility is that during severe heat waves Borax Lake chub were able to persist in the cooler wetland habitat and to recolonize Borax Lake when conditions returned to a lower temperature. The wetland channel and pond adjacent to Borax Lake is typically cooler than many areas of the lake (Figure 5a). Since the fall of 2015, the wetland pond has occasionally desiccated. While the wetland pond was associated with a secondary cool water vent, we do not know if reduced input from the vent, a change in connectivity with the main lake, a combination of factors, or other unknown reasons are the cause for the desiccation of the wetland pond. To better understand these relationships, a water elevation data logger was installed in the wetland pond in 2017, but was stolen before we were able to retrieve any data. Given that the wetland pond once maintained a sizable refugia for Borax Lake chub, research into the cause for the ephemeral nature of the pond should be further evaluated.

Further investigation of the relationship between water temperature and population size could clarify how this species persists in a uniquely challenging environment, and what risk, if any, is posed by future heat waves. A related issue that could be a subject for further research is the complex relationship between the water temperature in Borax Lake and climate. Some of the forces that increase the temperature in the lake include the temperature and volume of geothermal spring inflows and solar heating of the water and adjacent substrates. Some of the forces that cool the water include the temperature and inflow from cool-water springs, heat loss to the substrate, and evaporative cooling via wind. The variation in these forces make it challenging to extrapolate the conditions in the lake from surrounding weather. A better understanding of how these forces interact would help managers predict when this population may be threatened by severe heat stress.

Water levels

We collected water elevation from August 2016 until a data logger failed in August 2018. During that period, we observed minimal fluctuation in lake water elevations. The difference between the minimum and maximum lake elevations was 0.1 m, representing an approximate 2% fluctuation in surface area and a 6% fluctuation in water volume (see Scheerer and Bangs 2011). While overall water level fluctuations were minimal, ongoing water-level monitoring remains an important priority for this species.

Delisting and post-delisting monitoring

On June 11, 2020, the Borax Lake chub was removed from the list of Endangered and Threatened Species (delisted) due to recovery (U.S. Fish and Wildlife Service 2020). The delisting publication noted that the threats that led to the Borax Lake chub being listed under the ESA (primarily proposed recreational development, geothermal development and habitat degradation) have been removed or ameliorated by the actions of multiple conservation partners over the past 30 years. These actions included securing the property to conservation ownership, securing water rights, and developing and implementing long-term management strategies to ensure that appropriate habitat is protected and maintained. The Borax Lake chub is the fourth fish to be delisted due to recovery, following on the success of three other Oregon nongame fish species: Oregon Chub, Modoc Sucker, and Foskett Speckled Dace. Effective partnerships and ongoing collaboration have been the foundation of the recovery of these species.

A component of the ESA is that species will be monitored following delisting to ensure that they remain secure without the protections of the ESA. The Service prepared the Borax Lake chub post-delisting monitoring (PDM) plan, in coordination with ODFW, BLM, and TNC, based largely on monitoring methods refined by these agencies during the recovery of the species (U.S. Fish and Wildlife Service 2019). The PDM plan outlines monitoring Borax Lake chub population abundance, and potential impacts such as changes in lake elevation, unauthorized vehicle access, geothermal permit applications, the presence of nonnative species, and periods of unusually warm air temperature. The PDM provides thresholds and suggested responses to potential impacts, should they occur, and outlines how the status of the species will be determined at the conclusion of the PDM. A summary of the components of the PDM is provided in APPENDIX B. The PDM will consist of annual monitoring of all components, except surveys to estimate population abundance, which will be conducted once every three years over a ten year period (four population surveys total). Following the conclusion of the PDM, the monitoring and management of the species will continue through the Cooperative Management Plan.

Future research directions

As discussed above, the mechanisms that enable Borax Lake chub to persist during periods when water temperatures exceed 34.5˚C are not well understood. A better understanding of the relationship between water temperature and population abundance may be beneficial for future management, as would a better understanding of the relationship between climatic conditions and water temperature. Additionally, the causes of the occasional desiccation of the wetland habitat, which may have served as a thermal refugium in the past, could provide management opportunities if this habitat could be restored. Finally, the parasite and disease ecology Borax Lake chub has been poorly documented. As a part of an ongoing investigation of the role of disease and parasites in Oregon’s nongame fish species, ODFW plans to study the pathogens in Borax Lake chub during the PDM period.

ACKNOWLEDGEMENTS

We gratefully thank Alan Mauer (Service), Amy Anderson (ODFW), Matt Collver (ODFW), Paul Henson (Service), and Fred Monzyk (ODFW) for their assistance completing the field work.

REFERENCES

Bolker, B. 2008. Ecological models and data in R. Princeton University Press, Princeton, NJ.

Chao, A. 1987. Estimating the population size for capture-recapture data with unequal catchability. Biometrics 43(4):783-791.

Perkins, D. L., C. E. Mace, G. G. Scoppettone, P. H. Rissler. 1996. Identification of spawning habitats used by endangered Borax Lake chub (*Gila boraxobius*). Final Report to: The Nature Conservancy, Portland, Oregon. Submitted by: U.S. Geological Survey, Biological Resources Division, Reno, Nevada. 37 p.

McClanahan, L.L., C.R. Feldmeth, J. Jones, and D.L. Soltz. 1986. Energetics, salinity and temperature tolerance in the Mohave tui chub, *Gila bicolor mohavensis*. Copeia 1986: 45-52.

Peterson, J. T., and C. P. Paukert. 2009. Converting nonstandard fish sampling data to standardized data. Pages 195-215 in S. A. Bonar, W. A. Huber, and D. W. Willis, editors. Standards methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland.

Salzer, D. 1992. Population estimates for the Borax Lake chub: 1991 results and a comparison of sampling procedures. A report to: Oregon Department of Fish and Wildlife, Portland, Oregon. Submitted by: The Nature Conservancy, Oregon Field Office, Portland, Oregon.

Salzer, D. 1997. Results of the 1997 Borax Lake chub population sampling. Memorandum from The Nature Conservancy, Oregon Field Office, Portland, Oregon.

Scheerer, P. D., and S. E. Jacobs. 2005. Borax Lake chub Population Assessment and Monitoring Strategy. Fish Research Project E-2-40, Contract #134204M129, Annual Progress Report, Corvallis. 15 p.

Scheerer, P. D., and S. E. Jacobs. 2006. Borax Lake chub Investigations. Fish Research Project E-2-40 and supplement, Annual Progress Report, Corvallis. 16 p.

Scheerer, P. D., and S. E. Jacobs. 2007. 2007 Borax Lake chub Investigations. Fish Research Project E-2-41, USFWS contract 134206M085, and BLM Contract HAP074439, Annual Progress Report, Corvallis. 8 p.

Scheerer, P. D. and S. E. Jacobs. 2008. 2008 Borax Lake chub Investigations. USFWS contract 13420-08-J814, Annual Progress Report, Corvallis. 9 p.

Scheerer, P. D. and S. E. Jacobs. 2009. 2009 Borax Lake chub Investigations. USFWS contract 13420-08-J814 and BLM contract L07PX02726, Annual Progress Report, Corvallis. 14 p.

Scheerer, P. D. and S. E. Jacobs. 2010. 2010 Borax Lake chub Investigations. USFWS contract 13420-08-J814 and BLM contract L07PX02726, Annual Progress Report, Corvallis. 12 p.

Scheerer, P. D., and B. L. Bangs. 2011. 2011 Borax Lake chub investigations. USFWS contract 13420-08-J814 and BLM contract L10AC20301, Annual Progress Report, Corvallis. 14 p.

Scheerer, P. D., B. L. Bangs, S. Clements, and J. T. Peterson. 2012. 2012 Borax Lake chub investigations. USFWS contract 13420-08-J814 and BLM contract L10AC20301, Annual Progress Report, Corvallis. 19 p.

Scheerer, P.D., B.L. Bangs, and S. Clements. 2013. 2013 Borax Lake chub investigations. Oregon Department of Fish and Wildlife, Annual Progress Report, Corvallis. 13 p.

Scheerer, P. D., J. T. Peterson, and S. Clements. 2015. 2015 Borax Lake chub investigations. Oregon Department of Fish and Wildlife, Annual Progress Report, Corvallis. 11 p.

Scheerer, P. D., and S. Clements. 2015. 2014-2015 Borax Lake chub Investigations: An analysis of recovery actions and current threats, with recommendations for future management. BLM Cooperative Agreement L10AC20301. 14 p.

Scheerer, P. D., J. T. Peterson, and M. H. Meeuwig. 2016. 2016 Borax Lake chub investigations. Oregon Department of Fish and Wildlife, Annual Progress Report, Corvallis. 12 p.

Scoppettone, G. G., P. H. Rissler, B. Nielsen, and M. Grader. 1995. Life history and habitat use of Borax Lake chub (*Gila boraxobius* Williams and Bond) with some information on the Borax Lake ecosystem. U.S. Geological Survey, Northwest Biological Science Center, Reno, Nevada.

U.S. Fish and Wildlife Service. 1982. Endangered and threatened wildlife and plants; endangered status and critical habitat for Borax Lake chub (*Gila boraxobius*). Federal Register 47(193):43957-43963.

U.S. Fish and Wildlife Service. 1987. (Williams, J. E.) Recovery plan for the Borax Lake chub, *Gila boraxobius*. U.S. Fish and Wildlife Service, Portland, Oregon.

U.S. Fish and Wildlife Service. 2012. Borax Lake chub (*Gila boraxobius*) 5-year Review: Summary and Evaluation. Portland, Oregon. 33 p.

U.S. Fish and Wildlife Service. 2019. Post-delisting Monitoring Plan for the Borax Lake chub (*Siphateles boraxobius*). Portland, Oregon. 43 p.

U.S. Fish and Wildlife Service. 2020. Endangered and Threatened Wildlife and Plants; Removing the Borax Lake chub From the List of Endangered and Threatened Wildlife. Federal Register 85(113):35574-35594.

White, G.C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement: 120-138.

Williams, J.E. and C.D. Williams. 1980. Feeding ecology of *Gila boraxobius* (Osteichthyes: Cyprinidae) endemic to a thermal lake in southeastern Oregon. Great Basin Naturalist 40(2): 101-114.

Williams, J. E., and C. E. Bond. 1980. *Gila boraxobius*, a new species of cyprinid fish from southeastern Oregon with a comparison to *G. alvordensis* Hubbs and Miller. Proceeding of the Biological Society of Washington. 93:291-298.

Williams, J. E., and C. E. Bond. 1983. Status and life history notes on the native fishes of the Alvord Basin, Oregon and Nevada. Great Basin Naturalist 43:409-420.

Williams, J. E., C. A. Macdonald, and M.A. Stern. 1989. Populations changes and seasonal abundance of the endangered Borax Lake chub, *Gila boraxobius*. U. S. Fish and Wildlife Service, Progress Report, Davis, California. 31 p.

APPENDIX A. RAW SAMPLING DATA FOR 2017 AND 2019.

2017 Sampling Event:

Location	Size Category	Day 1	Day 2		Day 3			
		No Mark	No Mark	UC Mark	No Mark	UC Mark	LC Mark	Both
Shoreline	Small	198	41	3	101	17	10	0
	Medium	2,389	3,032	1,598	1,559	579	1,293	879
	Large	887	195	179	138	131	180	161
	Total	**3,474**	**3,268**	**1,780**	**1,798**	**727**	**1,483**	**1,040**
Offshore	Small	21	93	13	84	4	14	2
	Medium	3,515	4,566	2,000	3,276	631	1,731	768
	Large	266	241	135	160	84	108	89
	Total	**3,802**	**4,900**	**2,148**	**3,520**	**719**	**1,853**	**859**
Outflow	Small	280	70	95	29	33	14	35
	Medium	232	59	90	46	17	10	23
	Large	3	1	1	3	0	0	0
	Total	**515**	**130**	**186**	**78**	**50**	**24**	**58**
All Areas	Small	499	204	111	214	54	38	37
	Medium	6,136	7,657	3,688	4,881	1,227	3,034	1,670
	Large	1,156	437	315	301	215	288	250
	Total	**7,791**	**8,298**	**4,114**	**5,396**	**1,496**	**3,360**	**1,957**

2019 Sampling Event:
Note: Size category was only collected on day 1 during the 2019 sampling event

Location	Size Category	Day 1	Day 2	
		No Mark	No Mark	Mark
Shoreline	Small	187	-	-
	Medium	3,797	-	-
	Large	638	-	-
	Total	**4,622**	**1,236**	**314**
Offshore	Small	4	-	-
	Medium	1,391	-	-
	Large	194	-	-
	Total	**1,589**	**1,756**	**179**
Outflow	Small	86	-	-
	Medium	252	-	-
	Large	8	-	-
	Total	**346**	**457**	**180**
All Areas	Small	277	-	-
	Medium	5,440	-	-
	Large	840	-	-
	Total	**6,557**	**3,449**	**673**

APPENDIX B. POST-DELISTING MONITORING PLAN DETAILS

Summary of monitoring type, responsibility, frequency, threshold, and response for post-delisting monitoring of the Borax Lake chub.

Component	Monitoring Type	Responsibility	Frequency	Threshold	Response
Abundance	Population estimate	ODFW and the Service	Years 1, 4, 7, and 10.	6,500 adult fish	Enhance management; increase survey frequency.
Potential Threat or Monitoring Component	Lake elevation	ODFW will monitor with data logging equipment	Ongoing	Lake water surface elevation <4,081 ft, or if the wetland is not connected to the lake	Determine cause of lake elevation change; remedy by enhanced management.
	Unauthorized vehicle access	BLM and TNC constructed and maintain the fence and gates.	Quarterly	Breach by unauthorized motor vehicle.	Repair fence or gate and enhance monitoring and enforcement.
	Geothermal exploration or development	ODFW will monitor activities through the DOGAMI.	Ongoing	DOGAMI notification of permit application or review.	Review proposed permitting action for effects on Borax Lake; propose re-listing if necessary.
	Nonnative species	All collaborators	Twice per year, and during population estimates	A nonnative species observed during shoreline or fish surveys	Determine potential impacts; develop an appropriate, timely response
	Thermal stress	ODFW will monitor weather forecasts	Ongoing	Maximum air temperature >37.8˚C (100˚F) for 7 consecutive days, 45˚C (113˚F) on a single day	Assess population health; increase survey frequency

4034 Fairview Industrial Drive SE
Salem, OR 97302