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2012 Borax Lake Chub Investigations

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INTRODUCTION

The Borax Lake chub (*Gila boraxobius*) is a small minnow endemic to Borax Lake and adjacent wetlands in the Alvord Basin in Harney County, Oregon (Williams and Bond 1980). Borax Lake is a natural, 4.1 hectare, geothermally-heated alkaline lake which is perched 10 meters above the desert floor on borosilicate deposits. The Borax Lake chub was listed as endangered under the federal Endangered Species Act in 1982 (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 and alteration of the lake shore crust to provide irrigation to surrounding pasture lands. The Borax Lake chub federal recovery plan, completed in 1987, advocated protection of the lake ecosystem through the acquisition of key private lands, protection of groundwater and surface waters, controls on access, and the removal of livestock grazing (U.S. Fish and Wildlife Service 1987).

Population abundance estimates obtained since 1991 have fluctuated from approximately 4,100 to 37,000 fish (Salzer 1997; Scheerer and Bangs 2011). The basis for the Borax Lake chub's listed status was not population size, but the vulnerability of a very limited, unique, and isolated, habitat (U.S. Fish and Wildlife Service 1982). Because Borax Lake is shallow (average depth $\underset{\sim}{~}$1 m) and situated above salt deposits on the desert floor, alteration of the salt crust shoreline could reduce lake levels and have a dramatic effect on the quantity and quality of habitat available to Borax Lake chub.

Recovery measures implemented since listing have improved the conservation status of Borax Lake chub, primarily by protecting the habitat (Williams and Macdonald 2003). When the species was listed, critical habitat was designated on 259 hectares of land surrounding the lake, including 129 hectares of public lands and two 65-hectare 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. 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 within the critical habitat. 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. In addition, detailed studies of the chub and their habitat have added substantially to our knowledge of basic Borax chub biology and the Borax Lake ecosystem (Scoppettone et al. 1995, Salzer 1992, Perkins et al. 1996).

In a 2003 conservation review, Williams and Macdonald (2003) listed three primary threats, which remain, for Borax Lake chub: 1) the threat to the fragile lake shoreline, wetlands, and soils from a recent increase in recreational use around the lake (particularly off-road vehicle usage), 2) the threat of introduction of nonnative species, and 3) potential negative impacts to the aquifer from geothermal groundwater withdrawal if groundwater pumping were to occur on private lands outside the protected areas. This last threat resurfaced in 2009, when Pueblo Valley Geothermal proposed a geothermal energy project on 2,000 acres of private property within 5 km of Borax Lake.

In 2012, the U.S. Fish and Wildlife Service completed a draft, multi-agency "Borax Lake Chub (*Gila boraxobius*) Cooperative Management Plan" to manage and protect the Borax Lake area for the conservation and recovery of the Borax Lake chub.

The Cooperative Management Plan (CMP) was developed to establish a strategy and framework to identify responsibilities for collaboration to complete conservation related tasks to delist the species. Under the CMP, the cooperators (BLM, TNC, U.S. Fish and Wildlife Service, and Oregon Department of Fish and Wildlife) will work together to achieve the delisting criteria, stated in the recovery plan (U.S. Fish and Wildlife Service 1987) as follows: “The Borax Lake chub will be recovered when complete control exists over management of surface and subsurface waters by The Nature Conservancy or a public resource agency within the 640 acres of critical habitat; and when a self-sustaining population of Borax Lake chubs has been maintained free of threats for five consecutive years”. To reach recovery, Borax Lake 1) must be protected from disturbance, 2) historic wetlands must be restored, 3) disturbance to the fragile salt-crust shoreline must be prevented, 4) the geothermal aquifer must be maintained in its natural condition, and 5) Borax Lake chub must exist throughout its native ecosystem without threats (U.S. Fish and Wildlife Service 1987).

In 2012, the U.S. Fish and Wildlife Service also completed a 5-Year Review of Borax Lake chub and recommended downlisting of the species from endangered to threatened status (U.S. Fish and Wildlife Service 2012).

This report describes results from monitoring conducted by Oregon Department of Fish and Wildlife’s Native Fish Investigations Program (NFIP) in 2012. The NFIP initiated a study in 2005 to develop methods for monitoring the biological status of Borax Lake chub and their habitat. This year marks the eighth consecutive year of this effort. In 2012, our objectives were to: 1) estimate the abundance of Borax Lake chub, 2) evaluate the suitability of various mark/recapture models for estimating the abundance at this site, and 3) evaluate habitat conditions at Borax Lake, including a description of annual fluctuations in water levels and the condition of the fragile lake shoreline and outflows.

METHODS

We captured chub using baited minnow traps (N=120, 1/16” mesh). We distributed the traps approximately 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 associated wetland and in the outflow channel. In addition, we fished a small fyke net (1/8” mesh) at the mouth of the wetland channel, which also acted as a block net to prevent movement of chub in and out of the wetland. Following capture, we marked fish with partial upper caudal fin clip, recorded the number fish in each of three size categories (small <35 mm TL, medium 35-59 mm TL, and large $\geq$60 mm TL), and measured the total length (TL) of a sub-sample of fish (N=265). After all fish were marked, we returned them to the water by distributing them evenly throughout the lake. The same night, we set the traps at approximately the same locations. The following morning, we pulled the traps, recorded the number of marked and unmarked fish in each size category, and marked all fish with a partial lower caudal clip. The same night, we set the traps at approximately the same locations. The following morning, we cleared the traps and recorded the total number of unmarked and marked fish (upper caudal, lower caudal, or both clips) in each size category. We conducted the trapping on the nights of 18-20 September 2012.

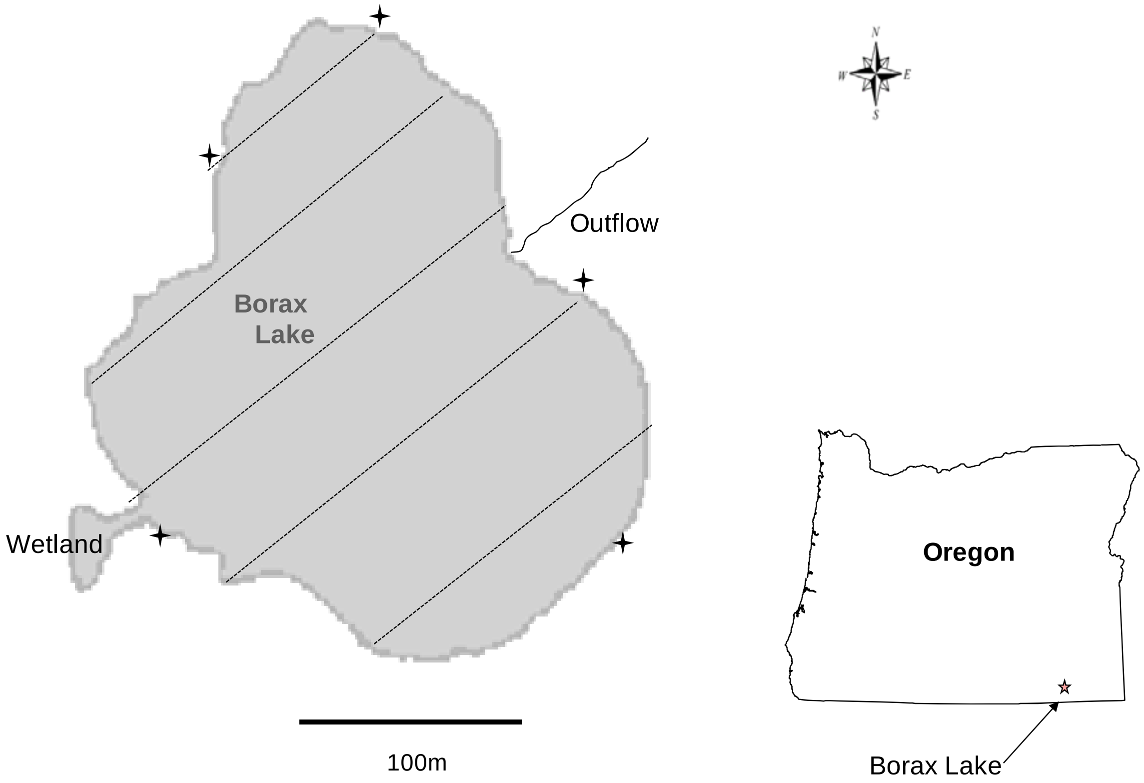

Figure 1. Map of Borax Lake showing the locations of shoreline transects (bounded by stars), open water transects (dotted lines), the outflow channel, and the wetland. Transects were based on those developed by Scoppettone et al. (1995).

In past years, ODFW NFIP has used the Lincoln-Peterson model to obtain abundance estimates of Borax Lake chub. This model assumes that capture probability is constant among individuals within a population, i.e., the probability of recapture is not affected by previous capture and all fish are equally vulnerable to the gear. This assumption is typically violated when the most catchable individuals are caught first and more often, and leads to overestimation of capture probabilities and underestimation of abundance. To estimate the magnitude of this bias and to determine the most appropriate protocol for future sampling, we compared two models in 2012, the single-sample Lincoln-Peterson model (Ricker 1975) and a Huggins closed-capture model. Specifically, we compared these methods to assess whether: 1) marked fish were more likely to be captured compared to unmarked fish, 2) capture efficiency varied among size classes, and 3) capture probabilities varied by trapping occasion.

For the Huggins closed-capture model, we used the program MARK (White and Burnham 1999) with three 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 three 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 evaluated the effect of capture, body size, location, and time of capture by systematically fitting alternative capture probability models with and without predictors (e.g., body size) and selected the best using with Akaike's Information Criteria with small sample bias adjustment (AICc; Burnham and Anderson 2002).

In contrast to the Lincoln-Peterson model, the Huggins model does not directly estimate abundance, but rather abundance (N) is derived using the following formula:

$$N = M_t / (1 - [(1-p_1)(1-p_2)(1-p_3)]),$$

> *where M_t is the total number of marks in the populations, p_1 is the estimated probability of capture for occasion one, p_2 is the estimated probability of capture for occasion two, and p_3 is the estimated probability of capture for occasion 3.*

We calculated 95 percent confidence intervals for this estimate according to Chao (1987) and calculated 95 percent confidence intervals for the Ricker model using a Poisson approximation (Ricker 1975). We calculated abundance estimates separately for the lake, the outflow, and the wetland. We assessed the recent trend in population abundance by calculating a linear regression of abundance over time for the past eight years. We determined whether the slope of this regression was significantly different from zero ($P \leq 0.10$) to assess whether there was no trend (not significantly different from zero), an increasing trend (positive and significantly different from zero), or a declining trend (negative and significantly different from zero).

To evaluate which of the independent variables in our Huggins closed-capture model (sampling occasion, fish size, or habitat locations) had a greater effect on the dependent variable (capture probability), we examined the parameter estimates for the best approximating capture probability model. The parameter estimates were on a logit scale, so to facilitate interpretation of the parameters we calculated the odds ratios by exponentiating the parameter estimates (Hosmer and Lemeshow 2000). Odds ratios are an estimate of the odds of an event occurring (here, capture of a fish) in response to increasing the predictor variable one unit or the relative differences between two groups. An odds ratio of one is interpreted as no effect on the response or no differences between groups. An odds ratio estimate is greater than one is interpreted as a positive effect. For example, if the odds ratio is 1.24 for small vs. large fish, then small fish are 24% more likely to be captured than large fish. An odds ratio estimate less than one is interpreted as a negative effect. For example, if the odds ratio is 0.322 for sampling occasion 1 vs. 2, then fish are approximately 3 times (1/0.322) less likely to be captured on occasion 2, compared to occasion 1.

We monitored water temperatures (^oC) at five locations with Hobo® recording thermographs deployed from 22 September 2010 to 28 September 2011. The thermographs recorded temperature at 1 h intervals.

We assessed the condition of the lake's shoreline, the wetland, and the outflow channels from pedestrian surveys and photo points that we established in 2005 (Scheerer and Jacobs 2005). We downloaded data (water elevations and temperatures) from the piezometers we installed in 2011 (Scheerer and Bangs 2011), to describe the changes in wetted area and water volume that occur due to seasonal fluctuations in water elevation. We also remapped and recorded the water elevations (depths) where the wetland joins the lake, at the lake outflows, and on the staff gage. We used ArcGIS® (version 9.3.1) to generate a Triangulated Irregular Network file from the previously surveyed geographic coordinates and measured depths. We used this file to generate bathymetric contour maps using ArcGIS®.

RESULTS

Population Estimate

We estimated the 2012 abundance of Borax Lake chub to be 9,702 fish (95% CI: 9,042-10,452) with the Huggins closed-capture model and 7,835 fish (95% CI: 7,316-8,433) with the Lincoln-Peterson model. For the Huggins estimate, the best approximating capture probabilities model contained fish length, sampling occasion, and habitat location (lake, wetland, and outflow). The 2012 estimates were significantly lower ($p<0.05$) than estimates we obtained in 2005 and from 2008 to 2011, but were similar to the estimates from 2006 to 2007 (Figure 2). The population has exhibited a stable trend in abundance over the past eight years ($p=0.280$), regardless of which model we used to calculate the 2012 abundance. When we pooled data for all sites and size classes, the Lincoln-Peterson model underestimated the abundance of fish by 24%, compared to the Huggins closed-capture model (Table 1). We found the same was true in the wetland (18% underestimate when all size classes were combined). However, when we estimated abundance for the lake alone, the bias was minimal (5% higher when all size classes were combined). This reduced estimation bias in the lake can be explained by the lack of heterogeneity in capture probabilities between capture and recapture events, i.e., there was no apparent effect of the first capture on the recapture probability in the lake (fish were not trap happy or trap shy) (Table 2).

We observed heterogeneity in capture probabilities among fish of different size classes. Small fish (<35 mm TL) were three times less likely and large fish (≥60 mm TL) were two times less likely to be captured than medium sized fish (35-59 mm). The trapping location affected the degree of heterogeneity in capture probabilities, whereby fish in the wetland were four times more likely to be captured and fish in the outflow were six times more likely to be captured than fish in the lake.

We captured a broad range of sizes in 2012 with no discernible age-class structure, which was similar to results from prior years (Figure 3). The fish captured in 2012 ranged in size from 31–111 mm TL with lower proportions of fish smaller than 45 mm and of fish larger than 59 mm compared to most prior years (~80% of the fish were in our medium size category). This truncated distribution suggests that the decline we documented in the 2012 Borax Lake chub abundance may have resulted from reductions in both 2012 recruitment and survival of 2011 fish. We captured the largest fish in the wetland (Figure 4).

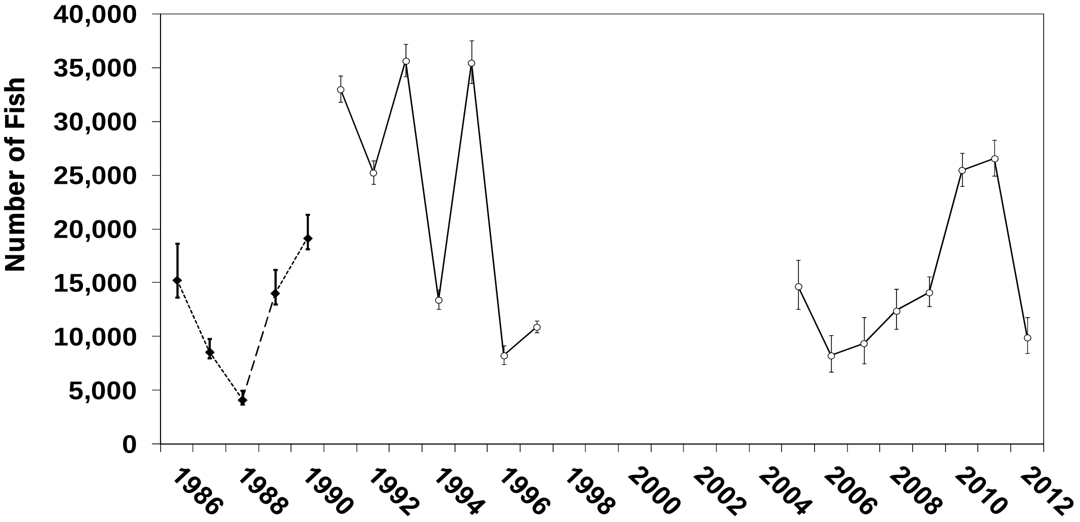

Figure 2. Borax Lake chub population abundance estimates obtained since 1986. Horizontal bars represent 95% confidence limits. In 1986-1990 (solid symbols), only the perimeter of the lake was trapped. After 1990 (open symbols), the entire lake was trapped. Estimates are not directly comparable across these time periods (Salzer 1992).

Table 1. Comparison of Borax Lake chub abundance estimates obtained using the Huggins closed-capture and Lincoln-Peterson models. Bias represents results from the Lincoln-Peterson model relative to those from the Huggins closed-capture model.

	Huggins closed capture model	95% Confidence Intervals		**Lincoln-Peterson model**	95% Confidence Intervals		
		Lower	Upper		Lower	Upper	Bias
All sites							
small	**2,716**	2,470	2,997	**2,091**	1,687	2,749	-30%
medium	**6,432**	6,018	6,910	**5,639**	5,237	6,108	-14%
large	**553**	507	609	**452**	351	594	-22%
All sizes	**9,702**	9,042	10,452	**7,835**	7,316	8,433	-24%
Lake							
small	**1,890**	1,671	2,145	**1,914**	1,340	3,344	1%
medium	**5,313**	4,712	6,068	**5,384**	4,843	6,061	1%
large	**276**	227	341	**600**	251	1,188	54%
All sizes	**7,479**	6,647	8,492	**7,898**	6,427	7,984	5%
Wetland							
small	**584**	476	727	**370**	236	852	-58%
medium	**813**	675	1,575	**787**	698	903	-3%
large	**272**	256	292	**259**	201	364	-5%
All sizes	**1,669**	1,342	2,300	**1,416**	1,135	2,119	-18%
Outflow							
small	**243**	205	311	**261**	196	387	7%
medium	**306**	282	461	**342**	288	420	10%
large	**5**	4	104	**8**	-	-	33%
All sizes	**554**	467	931	**610**	484	807	9%

Table 2. Huggins closed-capture best model beta coefficients, odds ratios, and their interpretations. See "Methods" for a description of these descriptive statistics.

Parameter	Estimate	Standard error	Odds ratio	1/odds ratio	Interpretation
Intercept	-1.534	0.048	-	-	
Occasion 2	0.076	0.040	1.08	0.93	Marked and unmarked fish were 1.1 times more likely to be caught on occasion 2
Small fish	-1.050	0.126	0.35	2.86	Small fish were (1/0.35) 2.9 times less likely to be captured than medium fish
Large fish	-0.755	0.348	0.47	2.13	large fish were (1/0.47) 2.1 times less likely to be captured than medium fish
Wetland	1.407	0.083	4.08	0.24	Fish were 4.1 times more likely to be caught in the wetland than in the lake
Outflow	1.781	0.097	5.94	0.17	Fish were 5.9 times more likely to be caught in the outflow than in the lake
Wetland - occasion 2 interaction	-0.951	0.087	0.39	2.59	Fish in the wetland were (1/0.39) 2.6 times less likely to be captured on occasion 2 compared to the other occasions
Outflow - occasion 2 interaction	-0.233	0.116	0.79	1.26	Fish in the outflow were (1/0.79) 1.3 times less likely to be captured on occasion 2 compared to the other occasions
Small fish - wetland interaction	-0.915	0.316	0.40	2.50	Small fish were (1/0.40) 2.5 times less likely to be captured in the wetland compared to the other locations
Large fish - wetland interaction	0.581	0.372	1.79	0.56	Large fish were 1.8 times more likely to be captured in the wetland compared to smaller fish

Water Temperatures

The pattern of seasonal fluctuations in Borax Lake water temperature was similar at all monitoring sites from September 2011 to September 2012. Daily temperature fluctuations were typically less than 5^{o}C. Peak water temperatures (29.6–43.5^{o}C) were observed in July and August (Figure 5). Average water temperatures in the main portion of the lake ranged from 25.5–27.1^{o}C, whereas the average water temperature (17.2^{o}C) and range of temperatures (8.3–29.6 ^{o}C) in the wetland were substantially lower. We observed intra-annual differences in the 7-day running average maximum daily temperatures recorded on the northwestern shoreline of Borax Lake. Water temperatures were cooler in the summers of 2008, 2010, and 2011 compared to those recorded in 2005, 2006, 2007, 2009, and 2012 (Figure 6). We also observed intra-annual changes in temperature in different regions of the lake in recent years (Table 3). Average temperatures in the wetland have declined by nearly 6^{0}C in the past four years, whereas average temperatures along the southeastern shoreline have increased by more than 3°C. Average temperatures in the outflow have been remarkably constant. Along the northwestern shoreline, we recorded significantly warmer temperatures in 2009 and 2012 and along the northeastern shoreline, we recorded significantly warmer temperatures in 2009 ($p<0.05$). The 7-day average maximum temperatures in the lake in 2012 represent some of the most extreme conditions that exist in the lake, and exceeded the species critical thermal maximum of 34.5^{o}C (Williams and Bond 1983) during most of the summer. However, fish can seek refuge from the warmest temperatures by moving to cooler areas of the lake, including the wetland. This behavioral thermoregulation was noted by Williams et al. (1989) in July 1987, when presumed high temperature induced mortality was observed and chubs congregated in cooler portions of the lake.

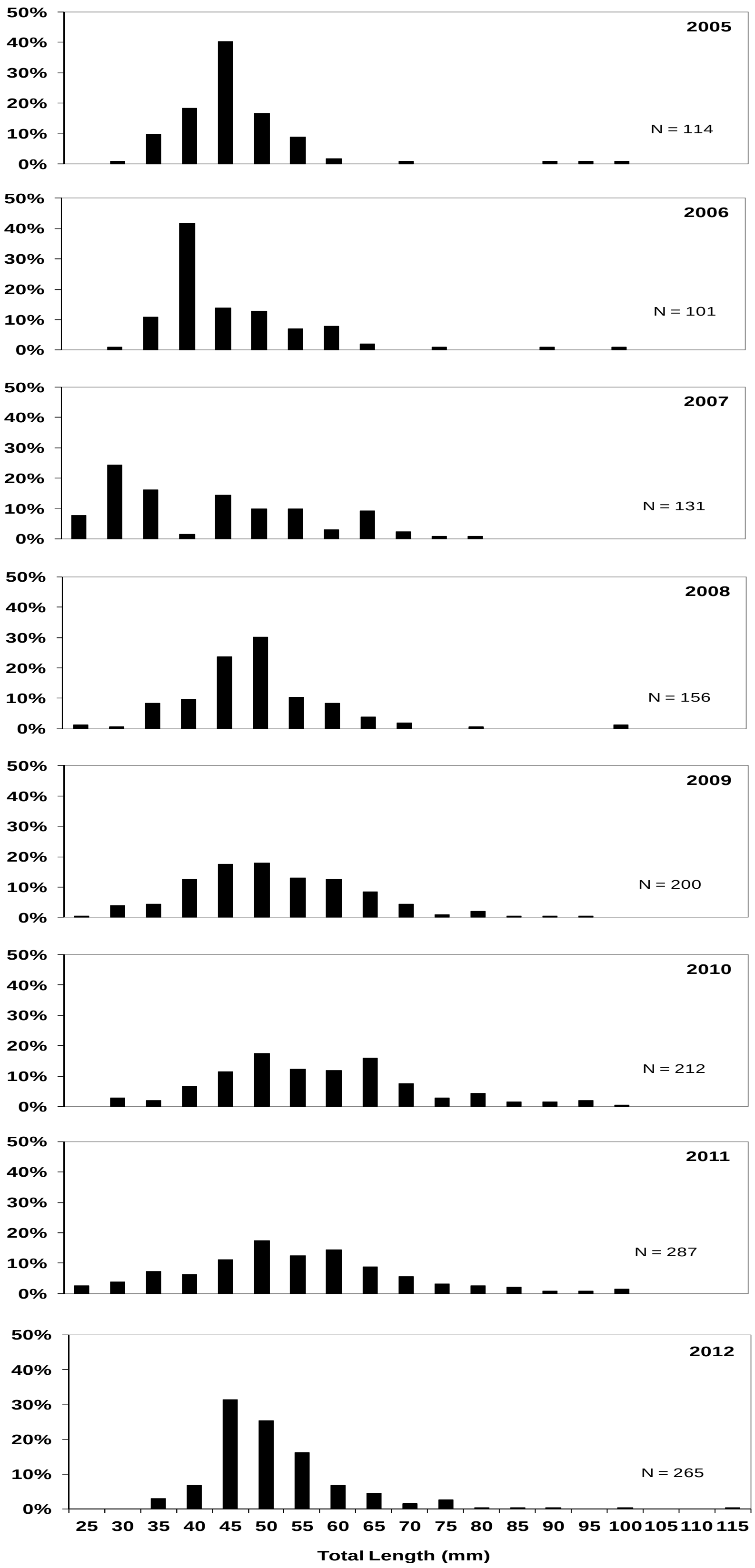

Figure 3. Length-frequency histograms for Borax Lake chub, 2005-2012.

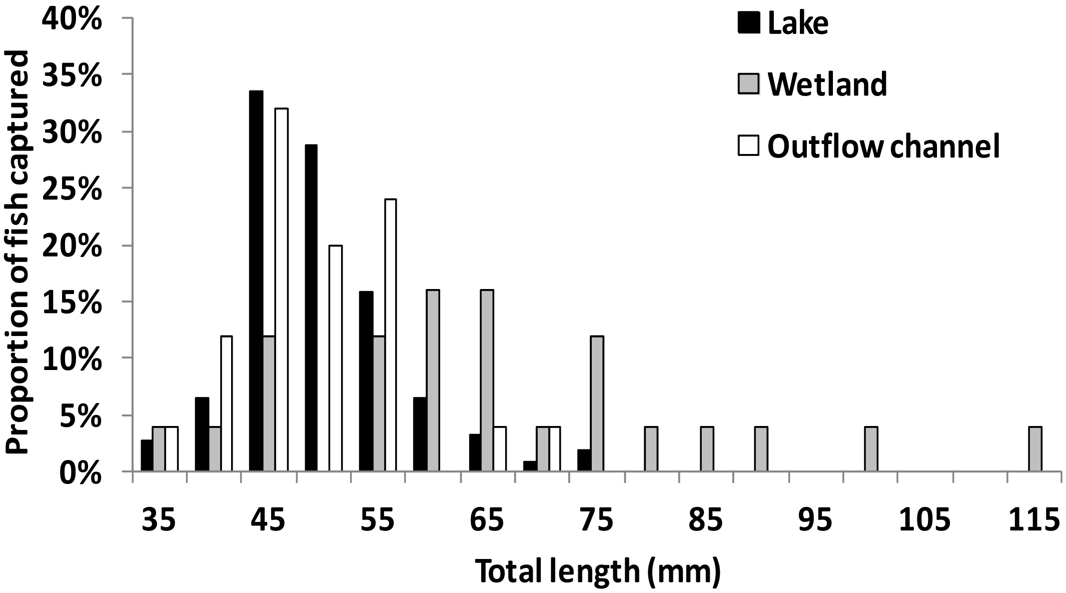

Figure 4. Length frequency histograms for Borax lake chub collected in the lake, wetland, and outflow channel of Borax Lake in 2012.

Table 3. Mean water temperatures recorded in different areas of Borax Lake, 2009-2012. The numbers in parentheses represent the 95% confidence limits. Mean temperatures were significantly different between years at any given location ($p < 0.05$) when superscripted letters were different; mean temperatures were not significantly different when superscripted letters match.

	Location				
Year	Wetland	NE	Outflow	SE	NW
2009	**23.0**^{a} (22.4-23.6)	**27.9**^{a} (27.2-28.5)	**24.6**^{a} (24.0-25.3)	**22.9**^{a} (22.2-23.5)	**27.3**^{a} (26.7-28.0)
2010	**20.0**^{b} (19.5-20.5)	**25.6**^{b} (25.1-26.1)	**24.3**^{a} (23.8-24.9)	**25.9**^{b} (25.3-26.4)	**26.0**^{b} (25.4-26.6)
2011	**18.4**^{c} (17.9-18.9)	**26.3**^{b} (25.6-26.9)	**24.1**^{a} (23.4-24.7)	**25.3**^{b} (24.6-25.9)	**25.6**^{b} (25.0-26.2)
2012	**17.2**^{c} (16.7-17.9)	**25.7**^{b} (25.0-26.3)	**25.5**^{a} (24.6-26.1)	**26.1**^{b} (25.4-26.8)	**27.1**^{a} (26.8-27.7)

Shoreline Pedestrian Surveys

The majority of the shoreline was in good condition. However, we did observe localized areas on the northern shore with recent off-road vehicle damage and noted several vehicles which had bypassed the gates (drove over a downed section of fence) and entered the vehicle restricted area when we were sampling in September. However, we have not documented any substantial changes in the shoreline habitat conditions at Borax Lake in recent years (Scoppettone et al. 1995; Scheerer and Jacobs 2005; 2006; 2007; 2008; 2009; 2010; Scheerer and Bangs 2011).

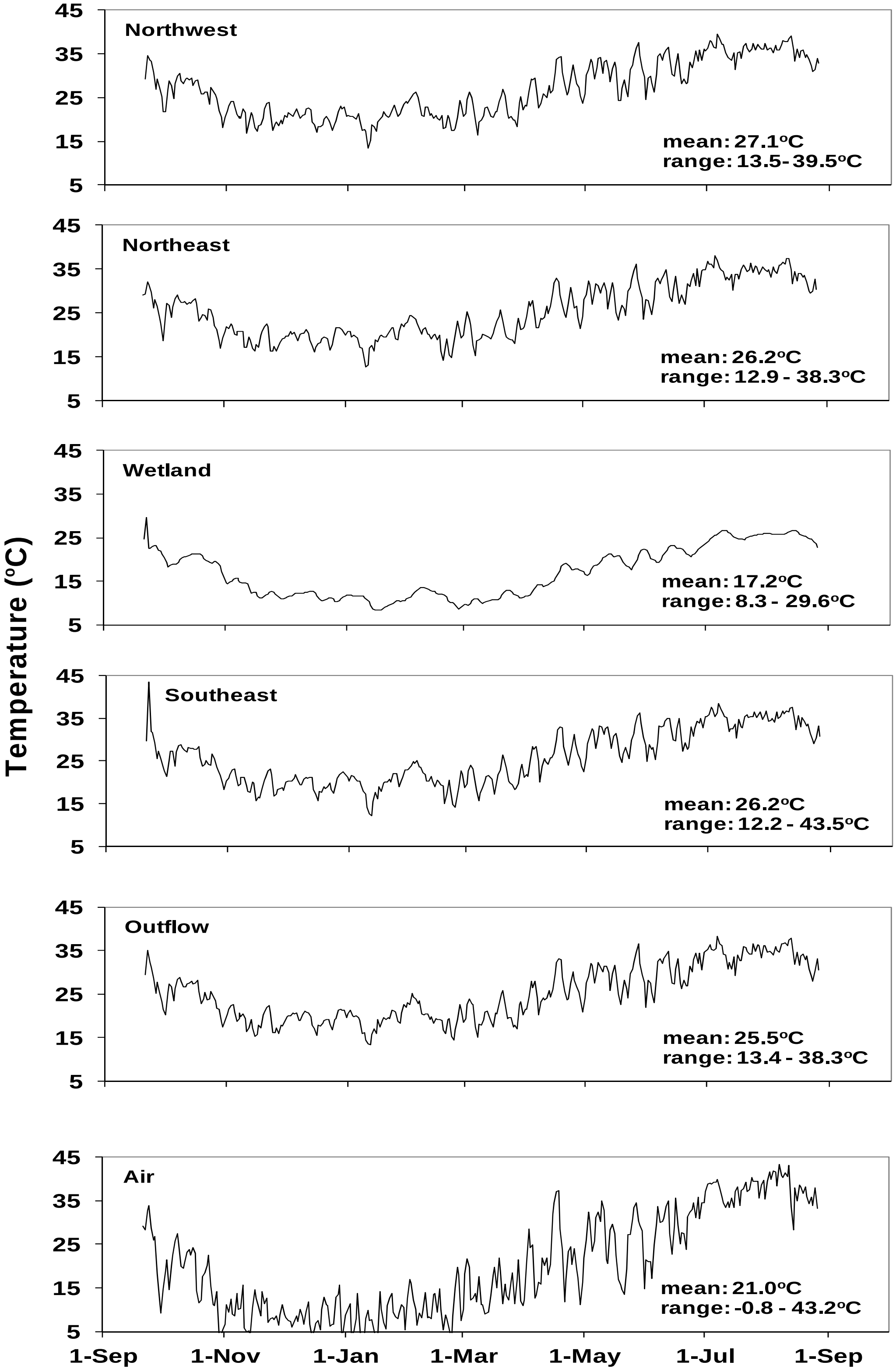

Figure 5. Water temperatures recorded at five locations in Borax Lake from September 2011 through September 2012. Also included are air temperatures.

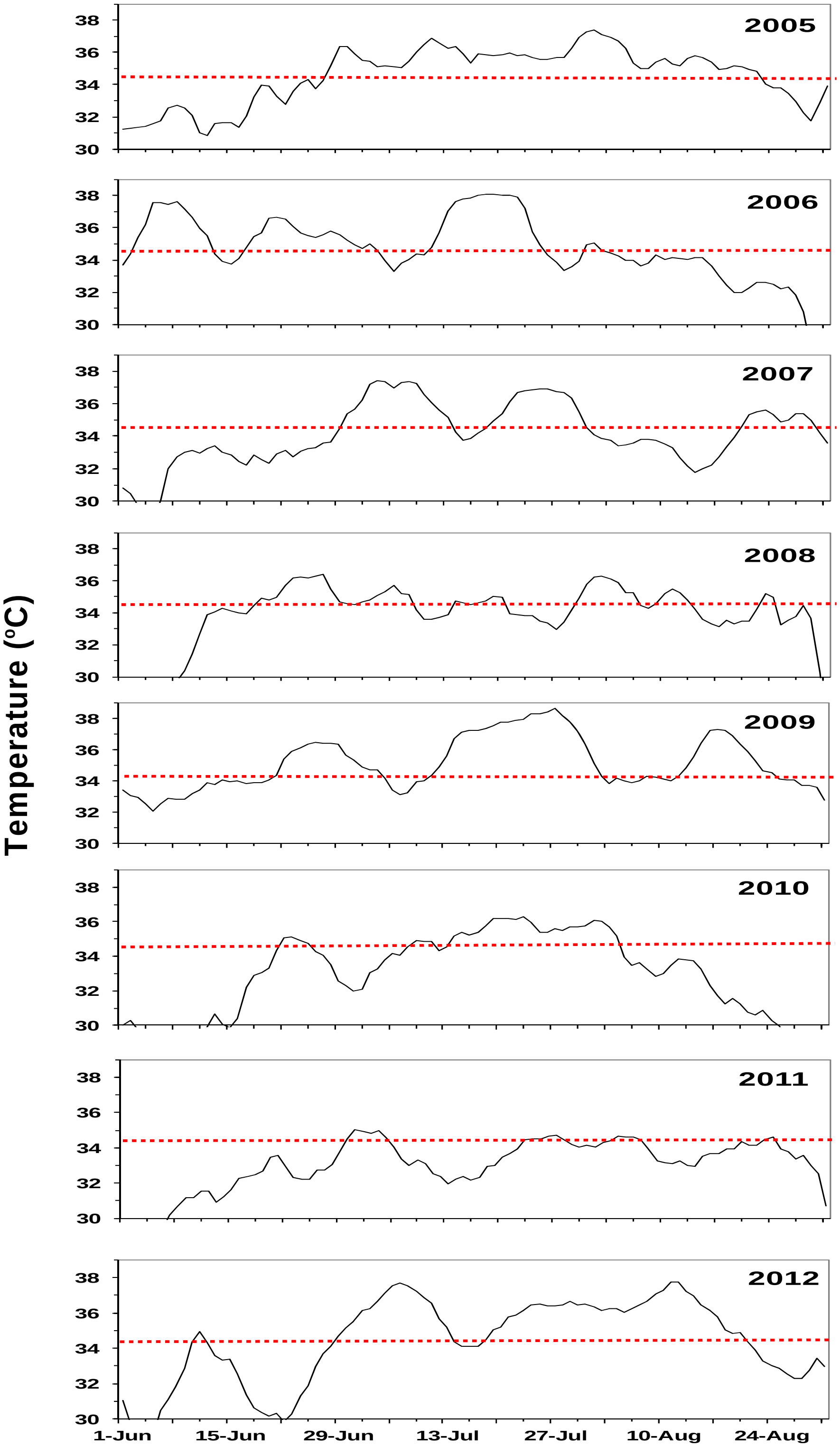

Figure 6. Seven-day running average of the maximum daily temperature recorded on the northwestern shoreline of Borax Lake, 2005-2012. Red lines denote the critical thermal maximum temperature of 34.5°C for Borax chub. Note: temperatures in early-June 2007, 2008, 2010, and 2011 were less than 30°C.

Seasonal Water Level Fluctuations

In 2011, we mapped the bathymetry of Borax Lake, including the wetland, and created maps showing the spatial distribution of lake depths and temperatures (Figures 7-8). The wetted surface area and volume of the lake were 39,117 m^2 and 15,460 m^3, respectively. The lake substrate was dominated by flocculent silt substrate (76%), with smaller proportions of bedrock/stromatolites (22%) and gravel (2%). Bedrock (stromatolites) and gravel were limited to a narrow band on the northern and eastern shores of the lake. Aquatic vegetation in the lake was sparse; however, approximately 61% of the lake had some stonewort (*Chara hornemannii*) growing from the flocculent substrate. Dense aquatic vegetation surrounded the wetland, which was dominated by Olney's rush (*Scirpus olneyi*) and beaked spikerush (*Eleocharis rostellata*). The lake's riparian vegetation was composed of alkali saltgrass (*Distichlis stricta*), greasewood (*Sarcobatus vermiculatus*), Baltic rush (*Juncus balticus)* and shadscale (*Atriplex confertifolia*) (Furnish et al. 2004).

We identified the water elevation when the wetland would disconnect from the lake (0.25 m drop). We also calculated the effects of reduced water elevations on habitat area and volume. For example, if lake elevations were reduced by 0.5 m, then wetted area and volume would decrease 36% and 14%, respectively. If lake elevations were reduced by 1.0 m, then wetted area and volume would decrease by 71 and 61%, respectively (Figure 9). Only the vent and wetland would be wetted if water elevations were reduced by 1.5 m.

In the past year, we observed minimal fluctuation in lake water elevations (Figure 10). The difference between the minimum and maximum lake elevations was 0.11 m (4 in). This represents a 2% fluctuation in surface area and a 6% fluctuation in water volume.

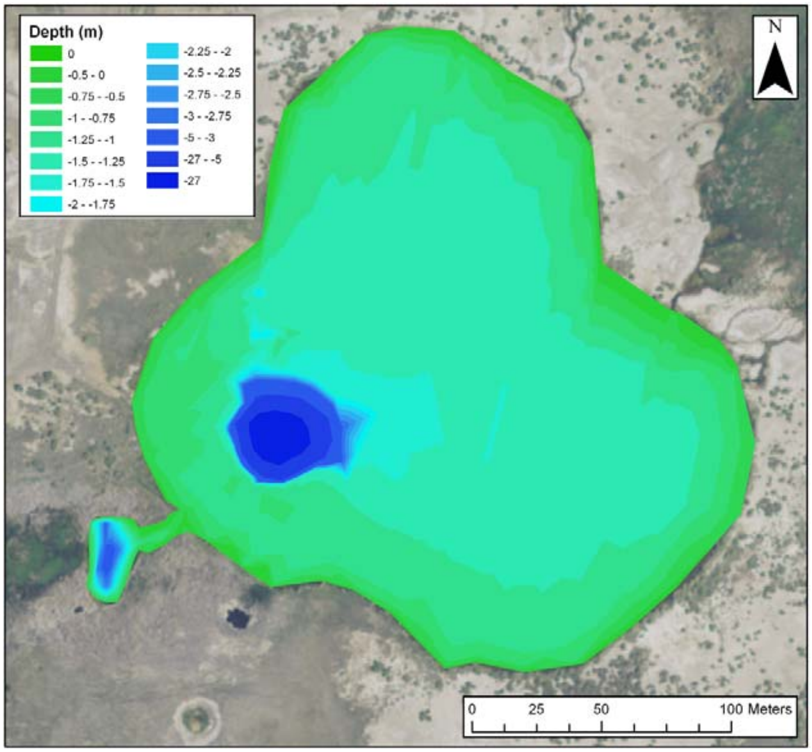

Figure 7. Map of the bathymetry of Borax Lake.

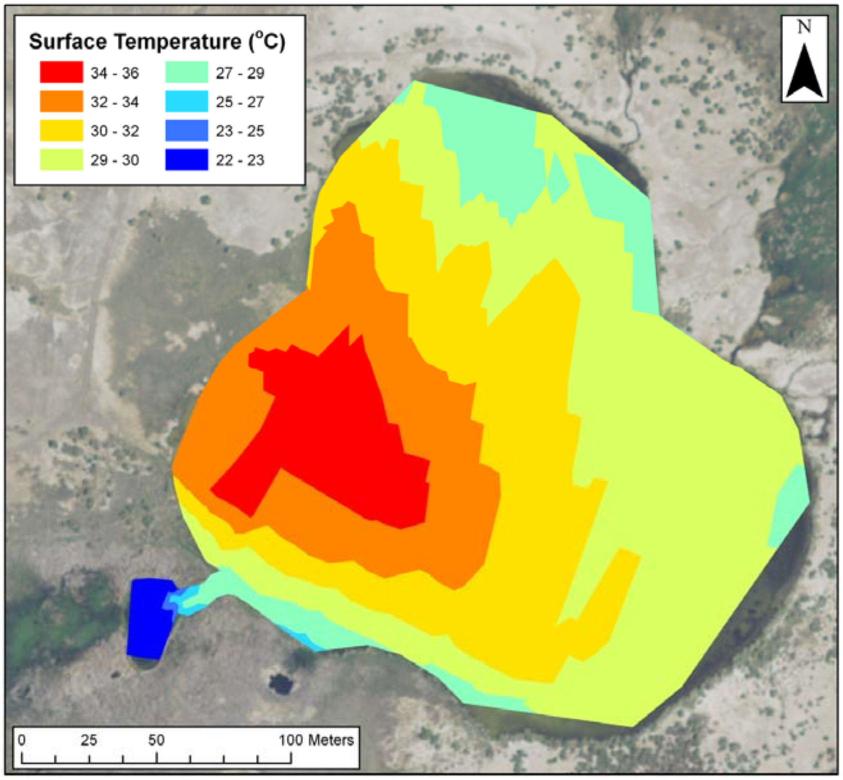

Figure 8. Map showing the surface temperature profile at Borax lake in October 2012.

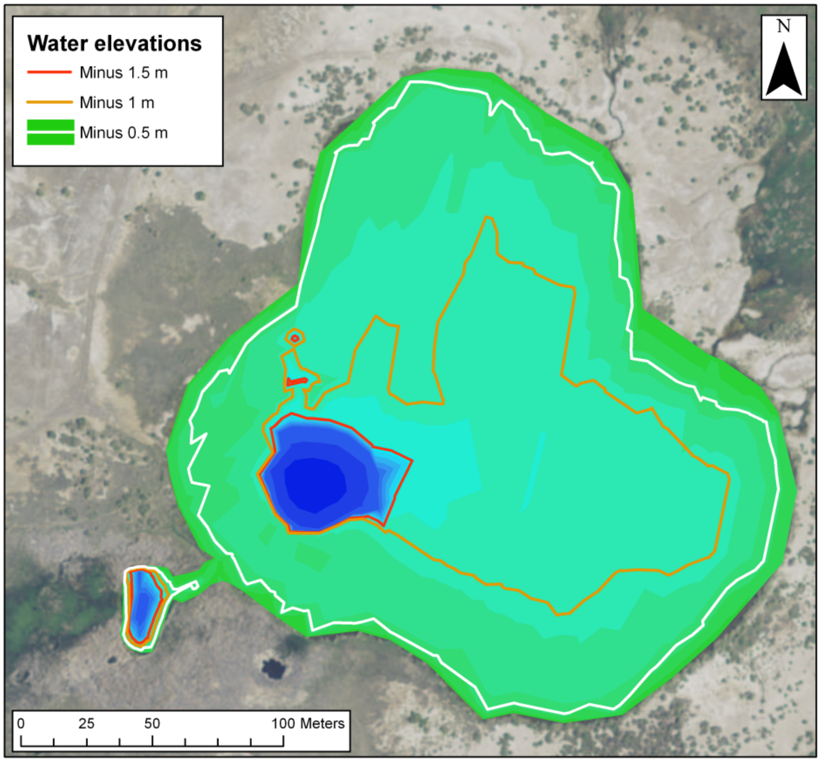

Figure 9. Map showing the limits of wetted surface area if water elevations were reduced by 0.5 m, 1.0 m, and 1.5 m from maximum levels observed in October 2012).

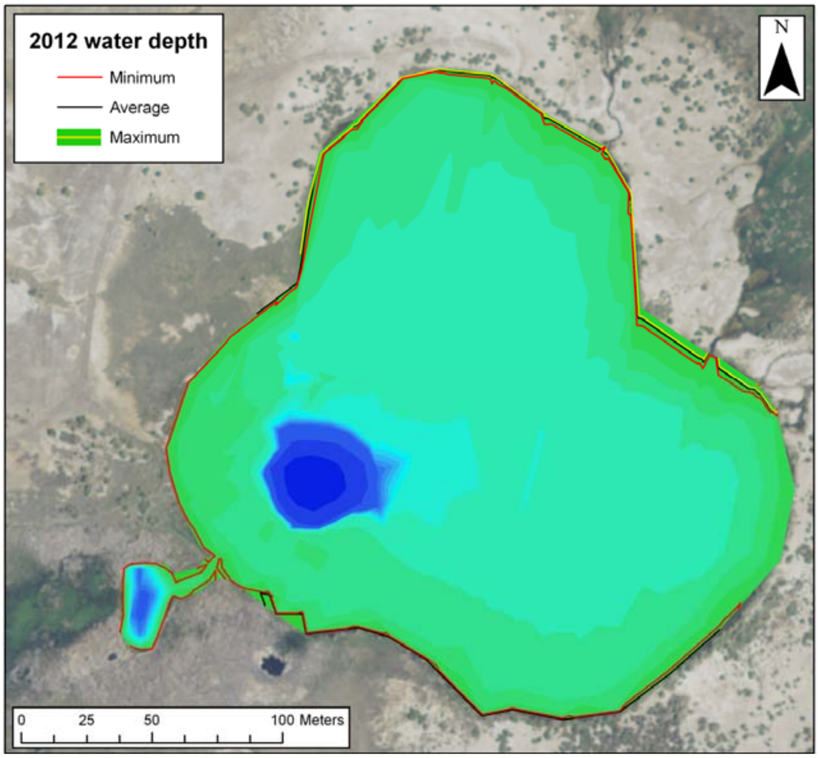

Figure 10. Map showing the minimum (red line), maximum (yellow line) and average (black line) water elevations recorded in 2012.

DISCUSSION

There has been substantial progress made towards recovery of Borax Lake chub since listing. In 2012, the U.S. Fish and Wildlife Service completed a five-year review and recommended downlisting the species from endangered to threatened status (U.S. Fish and Wildlife Service 2012).

Two main threats to the species and its habitat remain. These threats include habitat degradation of the lake shoreline, resulting from recreation use in the area, and impacts to the aquifer from geothermal groundwater withdrawal, if increased groundwater pumping were to occur, as proposed, on private lands outside the protected areas (Williams and Macdonald 2003; Williams et al. 2005).

To address protection of the fragile lakeshore, BLM's Resource Management Plan included implementation actions to restrict vehicle access, recreational boat use, and vehicle parking to protect Borax Lake and its fragile shoreline. In 2011, BLM and TNC completed a perimeter fence to exclude vehicles from the lake. In 2012, a lock was installed on the road entering the lake from the south; however, vehicles were noted driving around the gate and over the fence where a juniper fence post had been knocked down. As of mid-September 2012, no lock had been installed on the gate entering from the north. For years, there have been plans to install educational interpretive signs near the lake (biological, geological, and historical/archaeological). We encourage the BLM and TNC to complete the design and install these signs at the north and south gates in the near future. Hopefully, installation of these signs describing the unique biological characteristics of the lake and explaining why access is restricted, in combination with maintenance of the secure perimeter fence, will greatly reduce the damage and threats from unauthorized vehicles accessing the restricted areas near the lake.

Regarding potential geothermal development on private lands, in 2009 Pueblo Valley Geothermal proposed to develop a geothermal energy project on 2,000 acres of private land within 5 km of Borax Lake. The development of geothermal energy has the potential to have adverse effects on Borax Lake and the Borax Lake chub. If drilling disrupts the hot water aquifer that supplies the lake, it could decrease in the lake's water elevation through changes in lake inflow. In response to this proposed geothermal development and to address concerns outlined in the recovery plan (U.S. Fish and Wildlife Service 1987), a multi-agency recovery team, consisting of representatives from BLM, USFWS, TNC, and ODFW, was assembled in 2010 to identify the information and research needed to assess the potential short and long-term effects of geothermal development on private lands on Borax Lake and the Borax Lake chub.

To monitor the effects of future geothermal development, if it occurs within the aquifer that supplies water to Borax Lake, we mapped the lake bathymetry and installed a water level monitor in 2011. We acquired data in 2012, and will acquire additional data in the upcoming years, that we will use to describe the natural, seasonal variability in: 1) lake elevations, 2) the quantity, quality, and availability of habitat, and 3) the connectivity between the lake and wetland. If needed, we can use this baseline information, in combination with many years of temperature data, to assess the effects of future groundwater mining on Borax chub and their habitat. For example, if groundwater extraction is found to reduce lake inflows and if lake elevations decline, this would restrict the connectivity of the lake and the wetland (the channel connecting the two is very shallow). If connectivity is eliminated, then the chub would not have access to the cooler waters in the wetland during periods of thermal stress (high lake temperatures), which could negatively affect their survival. Also, reduction in water levels could affect recruitment. The sand, gravel, and stromatolite (bedrock) substrates where Perkins et al. (1996) captured the majority of chub protolarvae ($\leq$6 mm), exist only in the shallow, near-shore areas of the lake. These areas are presumably used for spawning and if water levels decline, a reduction in suitable spawning habitat could reduce chub recruitment.

Despite a significant decline in abundance in 2012, the Borax Lake chub population has exhibited a stable abundance trend over the past 8 years and the population continues to be robust with over 9,700 individuals. In 2010 and 2011, the Borax Lake chub population abundance estimates exceeded 25,000. In those years, we recorded substantially cooler lake temperatures than we recorded in 2006 through 2009. Because Borax Lake chub experience water temperatures that are at or near their thermal critical maximum (Williams and Bond 1983), chub survival and recruitment are likely higher during years when lake temperatures are cooler. Our 2012 data are consistent with this premise, in that temperatures were warmer than average and length-frequency data suggests recruitment and survival were reduced.

In 2012, we compared two models for estimating abundance, the Lincoln-Peterson model that we have used since 2005 and the Huggins closed-capture model. We found the Lincoln-Peterson model underestimated Borax chub abundance by 24%, when all lake locations and all size classes were combined. This was primarily due to heterogeneity in capture probabilities among size classes and among areas of the lake. For example, small fish were three times less likely to be captured and large fish were two times less likely to be captured compared to medium sized fish. Also, fish were four times more likely to be caught in the wetland and six times more likely to be caught in the outflow than in the lake. When we compared the models for data from the lake only, the bias was lowest. This was due to a lack of heterogeneity in capture probabilities between capture and recapture events in the lake, i.e., there was no apparent effect of the first capture on the recapture probability. Because the Lincoln-Peterson model assumes homogeneity in capture probabilities between capture events, when this assumption is violated, population abundance is underestimated (bias is higher).

We recommend continuing monitoring at Borax Lake, particularly to monitor trends in population abundance and monitor habitat conditions. Because Borax Lake chub are short lived and presumed to be an annual species, i.e., most fish are <1 year old (Scoppettone et al. 1995), we feel that this sampling should be conducted at least every two years, so that serious declines in population abundance and/or unauthorized introductions of nonnative fish can be detected before the results are irreversible. Research could focus on evaluating which environmental factors and habitat conditions are responsible for the large fluctuations in annual chub abundance. To assess the condition of the fragile lake crust, we recommend continuing annual shoreline pedestrian surveys. To provide baseline data for monitoring the effects of proposed geothermal development on private lands near Borax Lake, we recommend continued monitoring of lake water temperatures and water elevations. To assess changes in Borax Lake chub age structure over time, i.e., to better monitor recruitment and survival, and to identify the size/age-at-maturity and longevity, we recommend initiation of an ageing study. We also recommend the initiation of a genetic study to describe the relationship between Borax Lake and Alvord chub (*Gila alvordensis*); the results of which could have implications on the conservation and listing status of both species.

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