Transactions of the American Fisheries Society 138:153–168, 2009

DOI: 10.1577/T07-252.1

Distribution and Habitat Associations of Radio-Tagged Adult Lost River Suckers and Shortnose Suckers in Upper Klamath Lake, Oregon

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Abstract.—Radiotelemetry was used to investigate the summer distribution and diel habitat associations of endangered adult Lost River suckers *Deltistes luxatus* and shortnose suckers *Chasmistes brevirostris* in northern Upper Klamath Lake, Oregon. From 2002 to 2004, Lost River and shortnose suckers were tracked by boat, and water depth and water quality were measured at each fish location. A series of water quality monitors were deployed in northern Upper Klamath Lake to provide temporal information on ambient temperature, pH, and dissolved oxygen, and water samples were collected to assess chlorophyll *a* concentration. Suckers moved into northern Upper Klamath Lake during June and began to leave in late September each year. Kernel density estimates revealed differences in the distribution in the northern portion of Upper Klamath Lake in 2002 and 2004. In 2003, however, both Lost River and shortnose suckers were commonly located within and offshore from Pelican Bay, a shallow (1.0–2.0 m), groundwater-influenced area of Upper Klamath Lake. This was especially obvious beginning in late July of 2003, concurrent with reduced dissolved oxygen levels (<4.0 mg/L) in the northern portion of Upper Klamath Lake that resulted from a die-off of the cyanobacterium *Aphanizomenon flos-aquae*. Both Lost River and shortnose suckers were generally associated with water depths greater than the mean depth (2.8 m) of northern Upper Klamath Lake. Evidence ratios did not suggest diel differences in depth, temperature, dissolved oxygen, or pH at sucker locations. Both Lost River and shortnose suckers generally occupied depths greater than 2.0 m, except when suckers sought refuge in Pelican Bay during periods of poor water quality. Despite the potential for increased avian predation, suckers appeared to benefit from moving into Pelican Bay rather than staying in areas where dissolved oxygen was low. Pelican Bay appears to be an important refugium and thus may be important for sucker conservation.

Lost River suckers *Deltistes luxatus* and shortnose suckers *Chasmistes brevirostris* are presumably declining throughout their range. Both species are endemic to the upper Klamath River basin of California and Oregon (Moyle 2002). Previous records indicate that suckers were once widespread in the upper Klamath River basin and were important to subsistence, commercial, and recreational fishers (USFWS 1993; Moyle 2002). Lost River and shortnose suckers have been extirpated from portions of their historic range (Moyle 2002), and previous efforts to monitor angler catch rates have indicated extreme population declines relative to former levels (NRC 2004). Putative factors for declines include introduction of exotic species and habitat alteration, primarily via construction of dams, water diversions, and draining of wetlands (Scoppettone and Vinyard 1991; USFWS 1993). As a result of the declines in sucker distribution

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[5] The Washington Cooperative Fish and Wildlife Research Unit is jointly sponsored by the University of Washington, the U.S. Geological Survey, the Washington State Departments of Ecology, Fish and Wildlife, and Natural Resources, and the Wildlife Management Institute.

Received November 26, 2007; accepted August 24, 2008
Published online January 29, 2009

and abundance, both species were placed on the endangered species list by the U.S. Fish and Wildlife Service (USFWS) in 1988.

Lost River and shortnose suckers are long-lived (from 30 to 40 years), obligate lake dwellers that use tributary rivers for spawning during late winter and spring (Scoppettone and Vinyard 1991; Moyle 2002). Upper Klamath Lake, Oregon, appears to be the most critical remaining habitat for both species (NRC 2004). Lost River suckers typically mature at 8 or 9 years; shortnose suckers mature earlier, usually at 5–7 years (NRC 2004). Data on the feeding habits of Lost River and shortnose suckers are limited. These limited data suggest both Lost River and shortnose suckers consume zooplankton, benthic macroinvertebrates, and detritus, implying they may feed in close association with the lake bottom (Scoppettone and Vinyard 1991; Moyle 2002; NRC 2004). Knowledge of adult sucker distribution and habitat use in Upper Klamath Lake is incomplete; however, the few data that exist suggest suckers tend to occupy water depths from 0.9 to 4.5 m (Reiser et al. 2001).

Poor water quality conditions have been identified as one of the most significant threats to sucker recovery, particularly in Upper Klamath Lake (NRC 2004). A variety of water quality problems exist in Upper Klamath Lake that are predominantly associated with a near monoculture of the cyanobacterium, *Aphanizomenon flos-aquae*. High pH (9.0–10.5), high unionized ammonia levels (>0.5 mg/L), and a wide range of dissolved oxygen concentrations (anoxic to supersaturated) are related to the growth and decomposition of *A. flos-aquae* (Kann and Smith 1999; Wood et al. 2006). These extreme water quality conditions are a source of stress to Lost River and shortnose suckers and may contribute to periodic mass mortality events (Perkins et al. 2000).

Historical records indicate that fish die-offs in Upper Klamath Lake have occurred sporadically, but the frequency of fish kills has increased in the last 20 years (Perkins et al. 2000). Increasing fish die-offs as a result of poor water quality have been recognized as a recovery threat to both Lost River and shortnose sucker populations (USFWS 1993; NRC 2004). Refugia from poor water quality exist in Upper Klamath Lake near tributaries and in areas of groundwater input (NRC 2004), though their use by suckers during periods of poor water quality remains unclear.

Conservation of imperiled suckers requires an understanding of their habitat use during different life stages (Cooke et al. 2005). Despite the importance of identifying distribution and habitat associations of adult Lost River and shortnose suckers, little is known about habitat use during this life history stage. The only known study describing the summer habitat use and distribution of adult Lost River and shortnose suckers in Upper Klamath Lake was conducted by the U.S. Bureau of Reclamation from 1993 to 1999 (Reiser et al. 2001). This study provided preliminary information on adult sucker distribution and associations with water depth and several water quality variables. Results indicated that suckers congregated in the northern portion of Upper Klamath Lake during summer months. Suckers used tributaries and areas of groundwater influence during periods of poor water quality and dispersed from the northern portion of Upper Klamath Lake in the fall.

However, several gaps in knowledge remain. The U.S. Bureau of Reclamation study was conducted only during daylight when dissolved oxygen and pH tended to be at the high end of the diel range. Furthermore, few suckers were tagged throughout the study ($N = 76$). Small sample sizes in telemetry studies, coupled with tag failure and mortality, can allow the behavior of a small number of individuals to disproportionately influence the patterns in the data. The small sample sizes in the U.S. Bureau of Reclamation study resulted in lumping annual data, precluding species-specific intra-annual analyses. Moreover, a lack of data from areas of Upper Klamath Lake where suckers were not located hampered an evaluation of how radio-tagged suckers used habitat in relation to availability.

Conservation of endangered Lost River and shortnose suckers will require elucidating their distribution patterns, identifying species-specific habitat associations, and understanding how poor water quality influences behavior. Further, identification of key water quality refuge areas might aid resource managers in protection and restoration efforts. Therefore, the objectives of this study were to (1) determine the spatiotemporal distribution of radio-tagged adult Lost River and shortnose suckers in the northern portion of Upper Klamath Lake; (2) compare the depths associated with radio-tagged adult Lost River and shortnose sucker locations with the available depths in the northern portion of Upper Klamath Lake; and (3) determine the diel depth and water quality conditions associated with the locations of radio-tagged adult Lost River and shortnose suckers in the northern portion of Upper Klamath Lake.

Study Area

Upper Klamath Lake is a large, polymictic lake in south-central Oregon (Wood et al. 2006). At full capacity, Upper Klamath Lake has a surface area of 232 km^2 and a mean depth of 2.8 m. A narrow trench up to 15 m deep (Eagle Ridge trench) occurs along the western shore adjacent to Eagle Ridge and along the

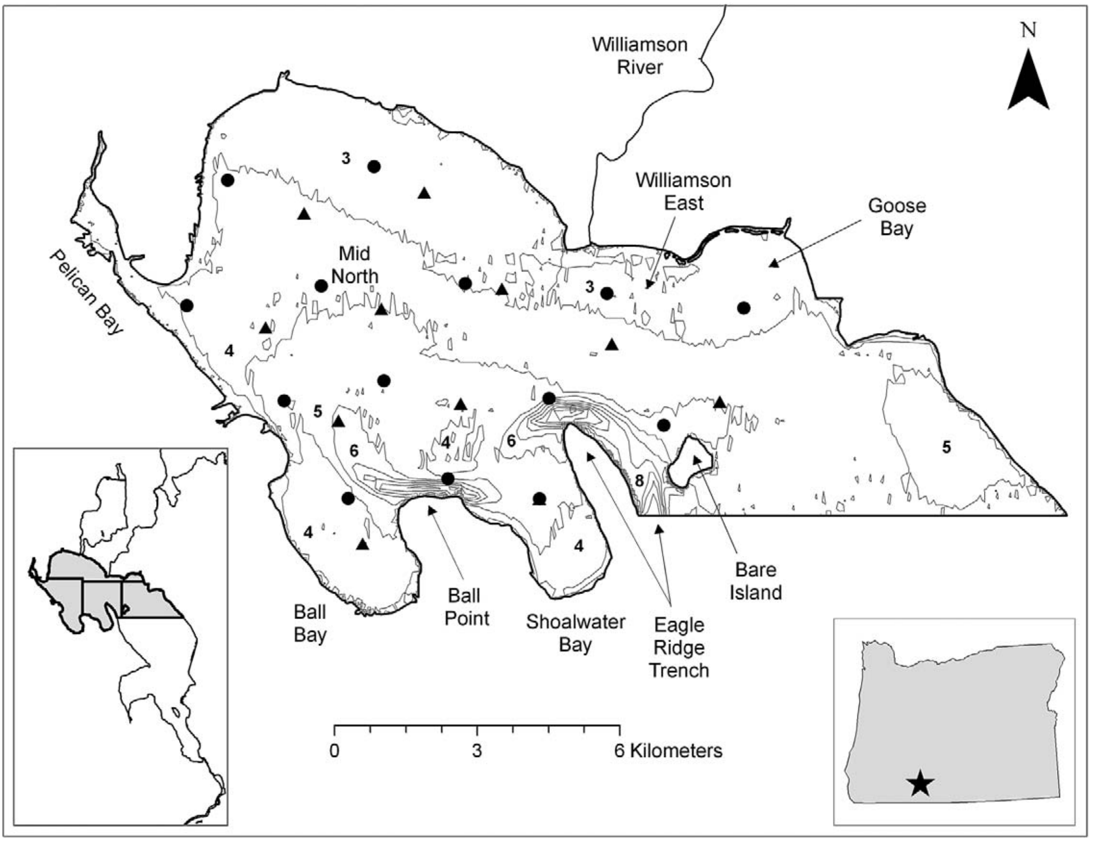

FIGURE 1.—Bathymetric map at full pool (1,262.9 m) of the study area in Upper Klamath Lake, where tracking of radio-tagged adult Lost River and shortnose suckers occurred from 2002 to 2004. The numbers within the study area represent the depths (m) of the isobaths. Triangles indicate water quality monitoring station locations in 2002 and circles locations in 2003 and 2004. The water quality monitoring station in Shoalwater Bay was at the same location during each year of the study. Insets represent the state of Oregon and Upper Klamath Lake; the highlighted portion of the inset of Upper Klamath Lake shows the study area, including the quadrants that guided the tracking of radio-tagged suckers.

northern side of Ball Point (Figure 1). Historically, a natural reef outlet to the Link River in Upper Klamath Lake occurred at 1,261.9 m above sea level. In 1921, the outlet was lowered by 1.2 m when Link River Dam was constructed to allow lake level manipulations for irrigation (Perkins et al. 2000). Water level regulation also has changed the temporal signature of lake elevation such that both the highest elevation in early spring and the lowest elevation in late summer now occur earlier than they did before the dam was built. Consequently, the period of low water levels now starts earlier in the summer and extends longer into the fall (Kann and Welch 2005).

The watershed of Upper Klamath Lake is about 9,842 km^2 in area (Snyder and Morace 1997) and the land cover of its principal tributary drainages, the Williamson and Sprague rivers (Figure 1), is primarily forest (70%) with some (6%) agriculture (NRC 2004). Upper Klamath Lake also receives groundwater input from springs around the lake. Pelican Bay is a large groundwater-influenced area along the northwestern portion of Upper Klamath Lake that provides good water quality relative to the remainder of the lake (NRC 2004). From early July to early October of 2004, the average dissolved oxygen concentration in Pelican Bay was 11.6 mg/L, temperature was 14.7°C, and pH was 8.1 (U.S. Geological Survey, unpublished data). By contrast, during this same period, the average dissolved oxygen level at Mid North (Figure 1) was 8.3 mg/L, temperature was 19.5°C, and pH was 9.2. Phosphorus within the lake comes from internal loading (i.e., lake sediments) and external sources (100 μg/L inflow), about 40% of which is anthropogenic (NRC 2004). Total phosphorus concentrations during the summer can be as high as 300 μg/L (Wood et al. 2006). At peak concentrations, chlorophyll *a* can reach 400 µg/L (Wood et al. 2006). The residence time of the water in the lake is approximately 6 months (NRC 2004).

Paleolimnological evidence has revealed that Upper Klamath Lake has been eutrophic for the last 1,000 years (Eilers et al. 2004). During the 20th century, nutrient loading and sedimentation rates in Upper Klamath Lake increased while the N:P ratio of incoming nutrients decreased (Eilers et al. 2004). Over the same period, the cyanobacterium, *A. flos-aquae*, has become increasingly dominant. Upper Klamath Lake currently experiences massive annual blooms of this cyanobacterium and is now considered hypereutrophic (USFWS 1993; Kann 1998; Kann and Smith 1999).

The U.S. Bureau of Reclamation study indicated that more than 90% of adult sucker observations occurred in the northern third of Upper Klamath Lake (Reiser et al. 2001). Based on the distribution of adult suckers observed by Reiser et al. (2001), the current study area was limited to the northern portion of Upper Klamath Lake. This study area included Shoalwater and Ball bays (Figure 1).

Methods

Bathymetry.—To compare the proportional use of bottom depths occupied by suckers to the proportions available, depth was calculated using bathymetric maps and lake surface elevation data. Bathymetry was mapped from a tunnel-hull boat equipped with a transducer and a Trimble 4000 Global Positioning System (GPS) receiver that produced point depth estimates accurate to within 1.0 m. Full-capacity bathymetric data of the study area were obtained from an ArcInfo digital elevation model with 30-m-grid resolution (USBR 1997). Daily surface elevations of Upper Klamath Lake were obtained from a U.S. Geological Survey (USGS) gauge (site 11507001). Bathymetric maps were generated with lake surface elevations and the bottom elevation map.

Depth intervals were assigned to fish locations using the same bathymetric map that was used to assign depths over the entire study area in order to maintain consistency with the depth interval calculations. Using this method of assigning depths to sucker locations based on bathymetric maps provided an accurate overall picture of the available depths and depth use by suckers in the study area. The local accuracy of the bathymetric map was verified using the depths measured at sucker locations. The mean of the residuals of measured depth versus the depth assigned using the bathymetric map were not significantly different from zero in each year, indicating good agreement between the two depth values.

Ambient water quality monitoring.—Continuous water quality monitors were evenly distributed in the study area to provide spatiotemporal data on temperature, dissolved oxygen (DO), and pH. In 2002, 11 monitors were positioned whereas 14 monitors were deployed in 2003 and 2004 (Figure 1). Monitors were located 1.0 m off of the lake bottom and collected water quality data hourly. Monitors were cleaned each week and replaced with newly calibrated units every 3 weeks. Spline interpolations of DO values from the water quality monitoring network were created using ArcGIS to provide spatiotemporal information on fish distribution and behavior in response to ambient conditions. From the interpolations, the percentage of the study area that fell below 4.0 mg/L was calculated. A DO concentration of 4.0 mg/L is notable in that it represents a high stress threshold for suckers developed by Loftus (2001) based on U.S. Environmental Protection Agency criteria for warmwater fishes. Chlorophyll *a* concentrations also were assessed from water samples in each year to characterize bloom dynamics of *A. flos-aquae*. Detailed interpolation and water quality and chlorophyll *a* collection methods are provided in Wood et al. (2006).

Fish collection, tags, and surgical procedures.—Adult Lost River and shortnose suckers were captured as part of an ongoing USGS program monitoring the spawning populations of adult suckers (Janney et al., in press). Suckers were collected with 30.5-m-long × 1.8-m-tall trammel nets at several locations in Upper Klamath Lake and the Williamson and Sprague rivers (Figure 1; Janney et al., in press). Suckers were held in net-pens near the site of capture before surgical implantation of the transmitters. Holding times ranged from 1 to 3 h for suckers captured in the Sprague River and 8–15 h for suckers captured in Upper Klamath Lake and the Williamson River. All tagging was completed between the following dates: March 20 and May 17, 2002; February 28 and March 21, 2003; and March 10 and April 16, 2004.

From 2002 to 2004, 91 adult Lost River suckers and 121 adult shortnose suckers were implanted with digitally encoded radio transmitters manufactured by Lotek Wireless (Table 1). The weight of the transmitter did not exceed 2% of fish weight (Winter 1996). All transmitters emitted a unique coded signal. Transmitter cycles were either programmed to run continuously or turned off from October to February to conserve battery life. This allowed tracking of some suckers over several years. In 2003 and 2004, adult suckers were surgically implanted with transmitters as early as possible in an effort to limit thermal stress and reduce risk of infection (Bunnell et al. 1998; Walsh et al. 2000). For consistency, 1:1 ratios of Lost River to

TABLE 1.—Total number (*N*), fork length (mm), and weight (g) of Lost River (LRS) and shortnose suckers (SNS) surgically implanted with radio transmitters in Upper Klamath Lake, from 2002 to 2004. Transmitter cycles were either programmed to run continuously or turned off from October to February to conserve battery life (given in months).

Year	Species	*N*	Mean length (range)	Mean weight (range)	Tag type	Tag cycle	Battery life
2002	LRS	45	567 (466–686)	2,166 (1,300–4,500)	MCFT-3A	On–off	36.0
	LRS	5	587 (510–680)	2,240 (1,550–3,000)	MCFT-3EM	Continuous	12.0
	SNS	45	424 (372–520)	1,228 (750–2,300)	MCFT-3A	On–off	36.0
	SNS	5	431 (406–454)	1,285 (1,075–1,550)	MCFT-3EM	Continuous	12.0
2003	LRS	7	561 (499–638)	2,129 (1,350–2,850)	MCFT-3FM	On–off	20.0
	SNS	23	444 (401–496)	1,347 (800–2,000)	MCFT-3FM	On–off	20.0
2004	LRS	27	575 (491–650)	2,087 (1,250–2,950)	MCFT-3A-IM	On–off	36.0
	LRS	5	549 (467–629)	2,100 (1,500–2,600)	SR11-25PT	Continuous	6.8
	LRS	2	558 (556–600)	1,900 (1,700–2,100)	SR18-25PT	Continuous	4.7
	SNS	41	439 (393–552)	1,240 (900–2,200)	MCFT-3A-IM	On–off	36.0
	SNS	4	407 (386–433)	988 (900–1,200)	SR11-25PT	Continuous	6.8
	SNS	3	432 (405–467)	1,117 (1,050–1,200)	SR18-25PT	Continuous	4.7

shortnose suckers and males to females were attempted during tagging.

Suckers were anesthetized in a 100–133 mg/L solution of tricaine methanesulfonate (MS-222) before transmitters were surgically implanted. Fish gills were continually irrigated with the MS-222 solution during the surgical procedure. Transmitters and surgical instruments were disinfected with a 10% solution of Nolvasan and rinsed with a 1% solution of sodium chloride. Surgical implantation of transmitters was performed following a variation used by Isaak and Bjornn (1996) based on the shielded needle procedure (Ross and Kleiner 1982). Transmitters were inserted into the peritoneal cavity along with a dose of Promycin or oxytetracycline (50 mg/kg body weight) to prevent infection (Summerfelt and Smith 1990). Incisions were closed with 3–6 individual sutures and covered with a cyanoacrylate tissue adhesive. One suture was used to hold the trailing antenna to the side of the sucker to aid in exit-wound healing. The entire operation time ranged from 4 to 10 min. Radio-tagged suckers were returned to a freshwater holding tank until they swam upright, transferred to a floating net-pen and held for up to 3 h, and released near their site of capture. All suckers actively swam away following their release.

Boat tracking.—Boat tracking in the study area was conducted 4 d per week during two consecutive 9-h shifts each day. Starting times were staggered weekly to ensure sampling over the entire diel period. Tracking was completed between July 1 and September 28, 2002, June 23 and September 27, 2003, and June 21 and October 1, 2004. The study area was partitioned into four quadrants of equal area and each quadrant was searched at least 1 d per week in random order without replacement. The quadrants partitioned the study area into northern, southeastern, south-central, and southwestern areas that were used to guide tracking. If the selected quadrant was searched completely in a day, the remaining time was spent tracking in another quadrant that was randomly selected with replacement. Selection for additional tracking did not preclude a quadrant from being sampled as part of the normal design later in the week. Some quadrants were not searched completely on all tracking days due to the concentration of radio-tagged suckers in a particular quadrant. As the summer progressed, sections of some quadrants became shallow (<1.0 m) and tracking was performed as close as possible to the selected transect. In addition, aerial surveys periodically covered these shallow locations.

Individual transects within each quadrant were selected at random and sampled without replacement for each day of effort. Based on transmitter distance testing, from five to nine parallel transects were established in each quadrant at 1-km intervals. Depending on transect length, from 1 to 13 points ($N = 133$) were established at 1-km intervals along each transect and offset from adjacent transects so that the distance between points along adjacent transects was a maximum of 560 m. To increase the probability of detecting suckers occupying deep water, crews continuously scanned all frequencies while slowly cruising in waters over Eagle Ridge trench and near Ball Point, where water depths exceeded 4.6 m (Figure 1).

At each transect point, crews monitored for the presence of radio-tagged suckers from a 5.8-m aluminum hull boat equipped with a 360° rotating six-element Yagi antenna mounted on a 3-m mast. Receivers were programmed to scan all frequencies in use. When a signal was detected, the objective was to move as close as possible to the tagged sucker without influencing its behavior. Crews followed the direction of the signal and determined sucker location with increasing precision by reducing receiver gain (i.e., sensitivity; range 0–99). An underwater antenna was used in the immediate vicinity of the sucker. Based on preliminary transmitter tests that measured signal strengths at known distances, the estimated proximity of each sucker located was qualified by assigning it to one of three levels. Locations were classified as level 1 (actual location estimated within 10 m) when the receiver decoded the tag with the underwater antenna at a gain of no more than 55; level 2 (actual location estimated within 25 m) when a unidirectional power signal of at least 180 was obtained with a Yagi antenna at a gain of 50; and level 3 (actual location estimated within 50 m) when a unidirectional signal strength of at least 180 was obtained with a Yagi antenna at a gain of 85–90.

Once a sucker's position was determined, its location was recorded in Universal Transverse Mercator coordinates determined by means of a GPS. Water depth and water quality were recorded each time at the estimated sucker location. Water depth was defined as the bottom depth, not the depth where the sucker was located. However, Lost River and shortnose suckers are benthic-oriented, especially for feeding (Scoppettone and Vinyard 1991; Moyle 2002); thus, bottom depth measurements should reflect sucker depth. Temperature, DO, and pH were collected from 0.7 to 1.3 m above the substrate with multiparameter datasondes at the location of best detection level for the fish. This range was selected to limit comparisons to similar portions of the water column and avoid possible confounding effects of bottom sediments. Instruments were calibrated daily and water quality data were collected according to USGS protocols and procedures (USGS 1997).

Sunrise and sunset data were downloaded from the U.S. Naval Observatory Web site (http://aa.usno.navy.mil/) with the place name for Klamath Falls, Oregon, and used to distinguish day and night observations. Suckers located between sunrise and sunset were considered day contacts and those located between sunset and sunrise were considered night contacts.

To determine the fate of the suckers, contact locations of individual fish were plotted in ArcGIS. A sucker was classified as dead when three or more contacts were within a 110-m-diameter area or if the signal was continually detected in a shallow area (i.e., <0.5 m). This threshold was chosen for classifying a sucker as dead since suckers did not exhibit sedentary behavior during the summer. Once a sucker was classified as dead, data collected after the last known live contact were eliminated from subsequent analyses.

Aerial and land-based tracking.—Aerial and land-based tracking were completed once per week during the study to assist in locating tagged suckers that might have moved outside the study area or into areas of shallow water inaccessible by boat. In addition, aerial tracking was completed periodically 3 weeks before the study and 2 weeks after the study was completed to verify sucker movement into and out of the study area. Aerial surveys searched Upper Klamath Lake, Agency Lake, and the lower Williamson and Sprague rivers. In 2002 and 2003, the aircraft was equipped with a four-element Yagi antenna attached to a wing strut and mounted in a vertical orientation with a 45° downward angle. In 2004, two whip antennas attached to the wings or the struts were used. Land-based tracking consisted of driving to elevated areas around Upper Klamath Lake and locating tagged suckers with a handheld four-element Yagi antenna. Land-based tracking was used only in 2002 to compensate for the limited availability of aircraft due to forest fires in southern Oregon and northern California. Aerial and land-based locations were not used in the analysis of species distribution, but helped in classifying suckers as dead and for finding suckers that had moved out of boat-tracking areas.

Data analyses.—To describe sucker distributions and distribution overlap in the study area, 50% kernel estimates (Worton 1989) of sucker density were calculated and displayed using ArcGIS. Kernel density estimation is a nonparametric technique wherein a kernel (a probability density) is averaged across the observed data points to create a smooth approximation of intensity of use within an area (Seaman and Powell 1996). There were fewer than 30 observations per individual, which is a recommended minimum for accurate kernel estimates (Kernohan et al. 2001). However, there were more than 30 observations per species. Therefore, the species was treated as the individual and composite kernel estimates of species distributions were calculated by month for each year of the study. Too few contacts existed to calculate weekly kernel estimates of sucker distribution. Since there were fewer than 30 locations of each species in June in 2003 and 2004 and October of 2004, these months were not included for analysis. The 50% estimates were chosen because they are accurate for defining heavily used areas relative to 95% or 99% estimates (Vokoun 2003).

In 2003, water quality and depth measurements from a random subset ($N = 50$) of sucker contacts were recorded at levels 1, 2, and 3 to examine whether differences in habitat use could be detected. Depth and water quality variables collected at the three detection levels were compared with one-way analysis of variance (ANOVA) (Sokal and Rohlf 1995) for each species and were considered statistically significant at $P \leq 0.05$. No statistical differences were evident between mean water depth, DO, pH, or temperature among level 1, level 2, or level 3 for Lost River or shortnose suckers in 2003 ($P > 0.70$). Since no significant difference was observed in the depth or water quality variables collected at the various detection levels, the single highest-quality level at each fish location was used for analyses.

Evidence ratios are useful for evaluating the strength of evidence of any two models in a data set (Anderson 2008). Therefore, evidence ratios were calculated to examine the support for diel differences in depth and water quality at sucker locations during July, August, and September in each study year. Only individual suckers with paired day and night contacts were included for analysis. Two models (hypotheses) were first formulated: one expressing no diel difference in depth or water quality (equivalent to a null hypothesis, H_0) and the second expressing a diel difference (equivalent to an alternative hypothesis, H_a). Following Anderson (2008), the residual sum of squares (RSS) for each model in a paired design was used to calculate the Akaike information criterion (AIC) adjusted for small sample size (AIC_c) as

$$AIC_c = n \cdot \left(\frac{RSS}{n}\right) + 2K + \frac{2K(K+1)}{n-K-1},$$

where K is the number of parameters and n is the sample size. The model with the lowest AIC_c value was considered to be best and was compared with the other model using simple differences as

$$\Delta_i = AIC_{c,i} - AIC_{c,\min}.$$

Next, the likelihood (ℓ) of each model (g), given the data (x), was computed by

$$\ell(g_i|x) = \exp[-(1/2)\Delta_i],$$

and evidence ratios were calculated by dividing the likelihood of the model with the lowest AICc value by the likelihood value of the other model. Calculations were performed in Microsoft Excel, and observations with missing values were omitted.

Box plots of the water quality at sucker locations also were created and compared with ambient water quality to provide information on the central tendency, dispersion, and change in water quality at sucker locations during the study (Sokal and Rohlf 1995).

Results

Eighty-one percent of Lost River suckers ($N = 74$) and 64% of shortnose suckers ($N = 78$) were contacted alive at least once during tracking. The number of detections per individual over the three tracking years averaged 10 for Lost River suckers (range, 1–25) and 9 for shortnose suckers (range, 1–32). Twenty-four suckers tagged in 2002 (18 Lost River and 6 shortnose suckers) were contacted alive in all three tracking years. Thirty-six percent of tagged suckers were classified as dead in 2002 (9 Lost River and 27 shortnose suckers), 23% in 2003 (7 shortnose suckers), and 44% in 2004 (8 Lost River and 28 shortnose suckers).

General and Seasonal Distribution

In each year, aerial, boat, and land-based tracking confirmed that the majority of suckers were located in the study area from late June to September. Only 2% of all sucker contacts in 2002, 3% in 2003, and 2% in 2004 were located outside the study area. Nearly all of the Lost River and shortnose suckers contacted outside the study area from late June to September through aerial or land-based surveys were located in the lower Williamson River less than 3.2 km upstream from Upper Klamath Lake.

Seasonal distribution differences between species were evident, although some overlap occurred each year. The amount of overlap between species based on the 50% kernel density estimates ranged from 7% in July of 2002 to 54% in August of 2003 and in September of 2004. Lost River suckers were frequently located near Ball Point in August and September, offshore from Pelican Bay in July and August, and adjacent to Bare Island in September (Figure 2). Shortnose suckers were regularly located at Williamson East in July and within Ball Bay and adjacent to Bare Island in September. During July and August of 2003, both species were distributed within Pelican Bay when ambient DO was less than 4.0 mg/L for several days following a die-off of *A. flos-aquae*.

Based on uniquely radio-tagged individuals, there was a general trend for the majority of Lost River suckers to be distributed in the northern and southwestern quadrants in July (70% in 2002, 60% in 2003, and 80% in 2004) and to shift to the south-central and southeastern quadrants in September (87% in 2002, 58% in 2003, and 78% in 2004). The majority of uniquely radio-tagged shortnose suckers were similarly located in the northern and southwestern quadrants in July (63% in 2002, 67% in 2003, and 89% in 2004). In September, however, the majority of shortnose suckers were distributed in the southwestern and south-central quadrants (80% in 2002, 65% in 2003, and 78% in 2004).

Water Depth Association

Within-year water depth use varied among weeks by species (Figure 3). In 2002, mean bottom depths at Lost River sucker locations were consistently near 3.0 m each week. Mean bottom depths at shortnose sucker

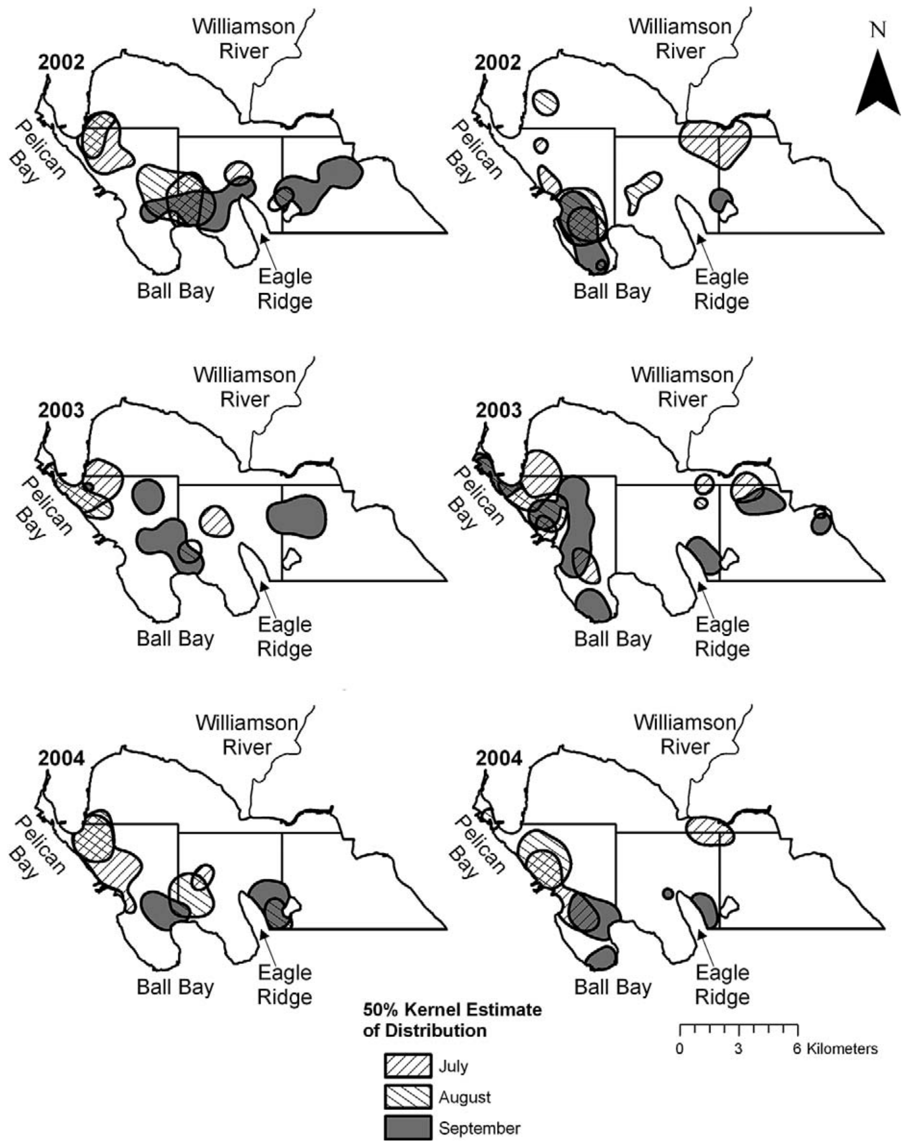

FIGURE 2.—Kernel density estimates (50%) of Lost River sucker (left panels) and shortnose sucker (right panel) distributions in the study area of Upper Klamath Lake, 2002–2004. The shaded and hatched portions represent monthly core use areas.

locations were as shallow as 2.0 m early in 2002, but remained near 2.8 m for the rest of the year except the week of September 15 when depth use was deepest. In 2003, suckers were located at greater bottom depths during June and early July, and depth associations became shallower as the year progressed. However, during the week of September 14, both species were located in deeper water. In 2004, weekly mean depths at sucker locations remained near 3.0 m for Lost River suckers and 2.8 m for shortnose suckers and were deepest the week of September 19. Based on bathymetric maps, depths of at least 2.0 m comprised 68% of the available depth in Upper Klamath Lake at a lake elevation of 1,262.66 m, but only 23% at a lake elevation of 1,261.66 m (Figure 4).

Evidence ratios primarily suggested that there were no diel depth differences at Lost River sucker locations during the study (Table 2). The evidence ratios implied that the model of no diel depth differences (H_0) was 1.12–8.02 times more likely than the alternative model (H_a). However, in September of 2002 the evidence ratio for the model suggesting a diel depth difference

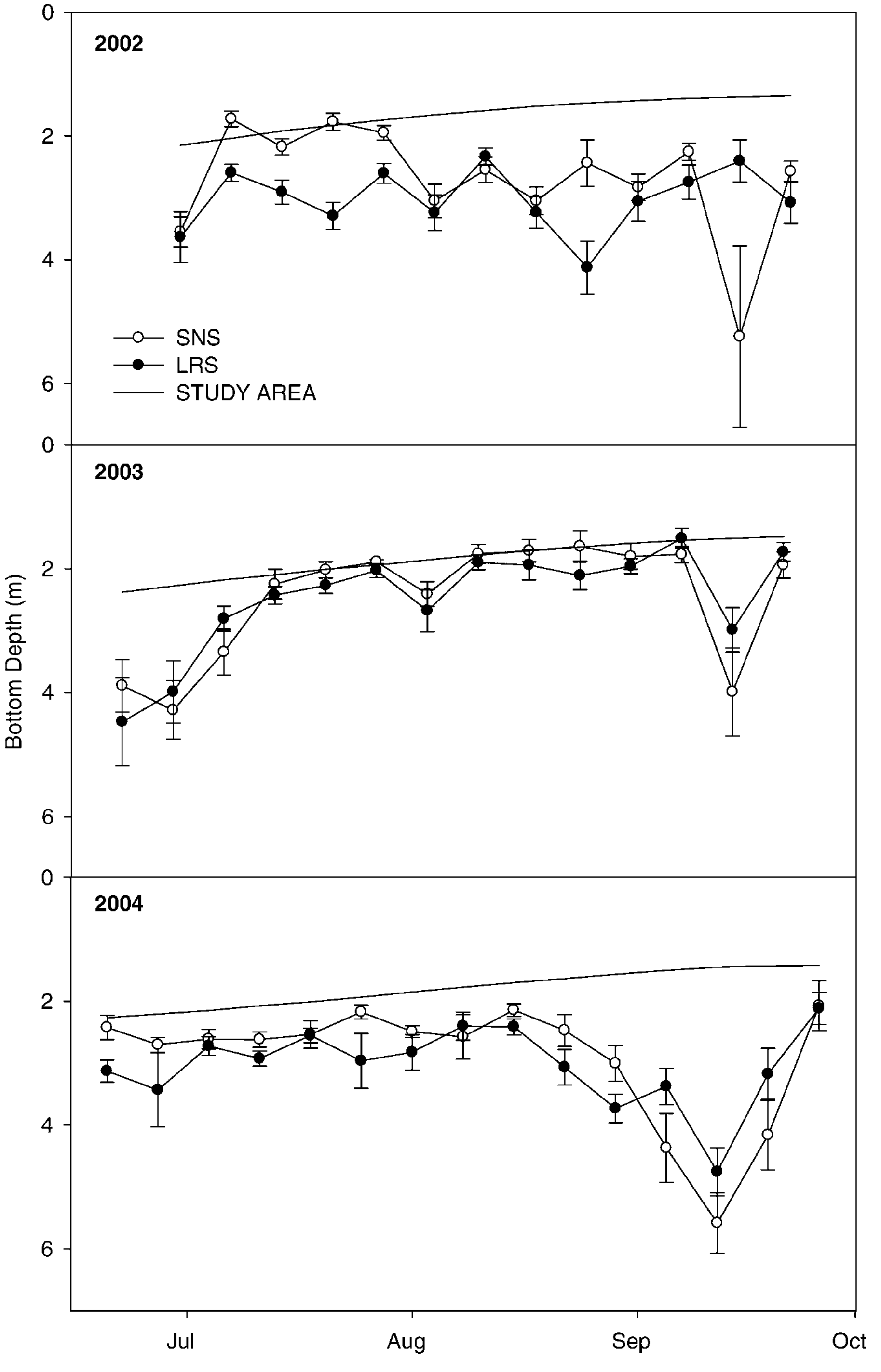

FIGURE 3.—Mean ± SE depth of the study area and bottom depths at Lost River sucker (LRS) and shortnose sucker (SNS) locations during each week of tracking in Upper Klamath Lake, 2002–2004.

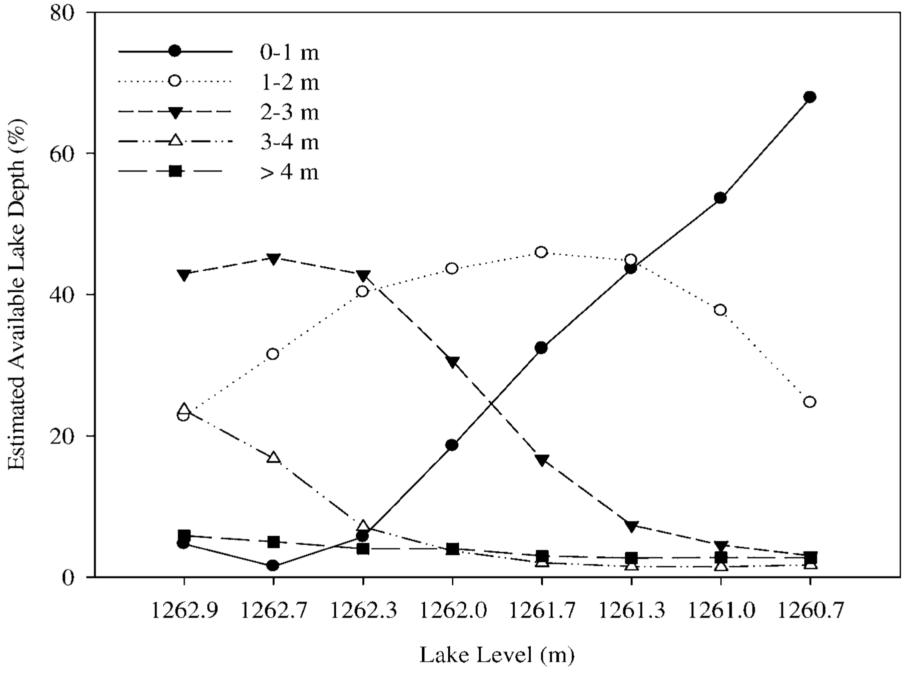

FIGURE 4.—Estimated percentages of available depths at specified lake elevations within the study area of Upper Klamath Lake. Full pool = 1,262.9 m, minimum pool = 1,260.7 m.

was 1.05 times more likely than model H_0. The evidence ratios similarly suggested no diel depth differences at shortnose sucker locations during the study. An exception was that model H_a was 4.71 times more likely than model H_0 in September of 2004.

Water Quality Associations

The weekly distribution patterns of suckers resulted in exposures to no greater than ambient median temperatures (Figure 5) and at least ambient median DO concentrations (Figure 6), whereas exposures to pH were seasonally either above or below ambient median values (Figure 7). The DO comparisons exhibited the strongest deviations from the median levels. In 2002 and 2004, 3% of suckers were associated with DO levels less than 4.0 mg/L. However, in 2003, 13% of sucker observations occurred where the DO concentration was less than 4.0 mg/L (Figure 8). Based on DO interpolations, DO levels in 39 km^2 of the study area fell below 4.0 mg/L over the period July 22–31, 2003, which was coincident with a crash in the *A. flos-aquae* bloom. A

TABLE 2.—Evidence ratios relating the model of no diel difference (H_0) in depth, dissolved oxygen (DO), pH, or temperature at Lost River sucker (LRS) and shortnose sucker (SNS) locations to the alternative model (H_a) during July, August, and September, 2002–2004. Evidence ratios in ordinary type were calculated using the model likelihood of no diel difference as the best model whereas those in bold italics used the model likelihood of the alternative as the best model.

		Depth		DO		pH		Temperature	
Year	Month	LRS	SNS	LRS	SNS	LRS	SNS	LRS	SNS
2002	Jul	3.083	3.841	3.595	2.466	4.324	4.275	3.595	2.263
	Aug	3.135	4.292	2.373	3.502	3.967	1.523	3.750	4.151
	Sep	***1.048***	3.004	3.311	3.221	4.219	3.776	1.867	1.692
2003	Jul	4.317	3.320	2.089	3.139	1.767	2.294	3.594	3.120
	Aug	1.121	12.755	3.982	4.685	4.848	3.558	5.547	3.426
	Sep	8.022	4.013	7.747	6.453	6.204	6.187	7.838	1.671
2004	Jul	3.195	2.703	1.279	1.381	2.994	***2.929***	1.799	2.613
	Aug	1.499	1.859	3.204	2.790	1.654	2.906	1.007	2.525
	Sep	2.205	***4.705***	***1.169***	3.361	***2.399***	3.479	1.877	2.275

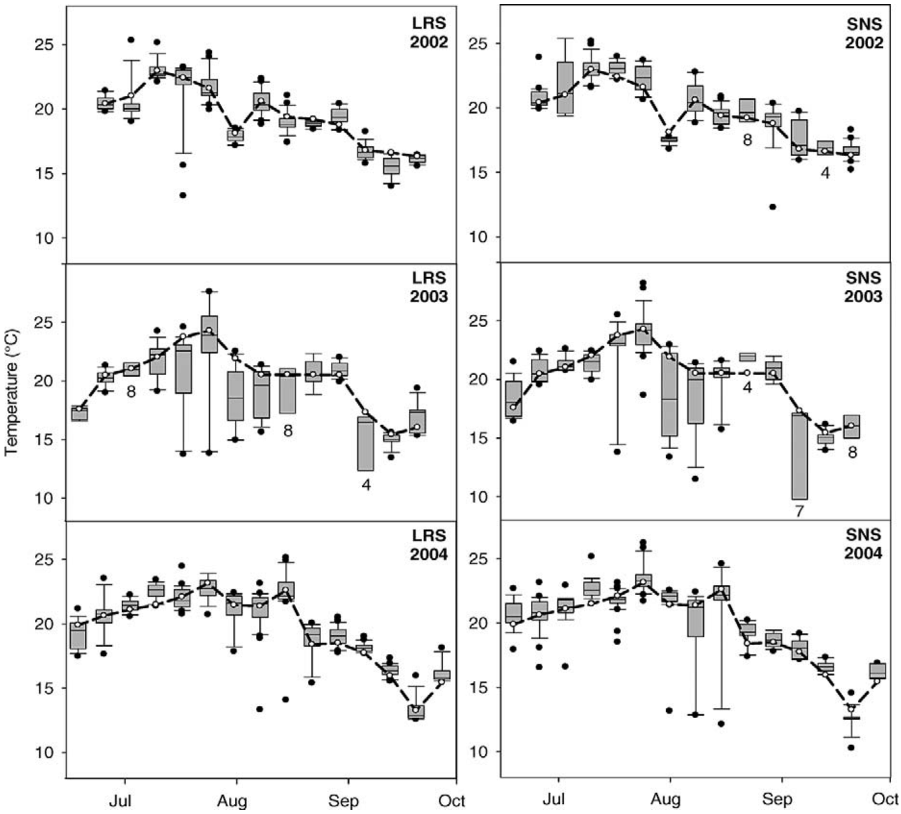

FIGURE 5.—Box plots of temperature at Lost River sucker (LRS) and shortnose sucker (SNS) locations during each week of tracking in the study area of Upper Klamath Lake, 2002–2004. The lower and upper boundaries of each box indicate the 25th and 75th percentiles, respectively, and the median value is shown as a line within the box. The lines (whiskers) below and above each box represent the 10th and 90th percentiles. All outliers are presented. Box plots without error bars result from less than nine observations; the number of sucker observations is presented in these instances. The ambient median temperature of the study area is represented by the dashed line.

less severe die-off occurred in late July 2002 and the second week in August 2004. By contrast, DO in only 11 km^2 in 2002 and 2 km^2 in 2004 of the study area fell below 4.0 mg/L during the cyanobacteria die-off. In each year, median pH at sucker locations was generally greatest at the beginning of routine tracking. Ambient pH tended to be lowest in late July and early August.

During each year, the evidence ratios generally suggested no diel differences in temperature, DO, or pH at Lost River sucker locations (Table 2). However, model H_a implied that the diel differences in DO concentration and pH at sucker locations were 1.70 and 2.40 times more likely, respectively, than those implied by model H_0 in September of 2004. Evidence ratios also suggested no diel differences in water quality existed at shortnose sucker locations, though evidence for a diel difference in pH in July of 2004 was 2.93 times more likely than in model H_0.

Discussion

Lost River suckers and shortnose suckers were generally associated with water depths greater than the mean depth in the study area, which is similar to previous observations (Reiser et al. 2001). However, from early to mid-July 2002, shortnose suckers were located in Goose Bay and Williamson East where depths are shallower (mean depth, 1.0–2.0 m) than in the remainder of the study area. In each year, bottom depths at sucker locations were greatest in mid-September concurrent with movements of some suckers into Eagle Ridge trench, an area with depths of up to 15 m. However, this trend reversed during a low-DO event in late July of 2003. Suckers were located at depths between 1.0 and 2.0 m during this period as they redistributed within Pelican Bay to presumably avoid poor water quality. Despite frequent distribution in depths greater than 2.0 m, suckers

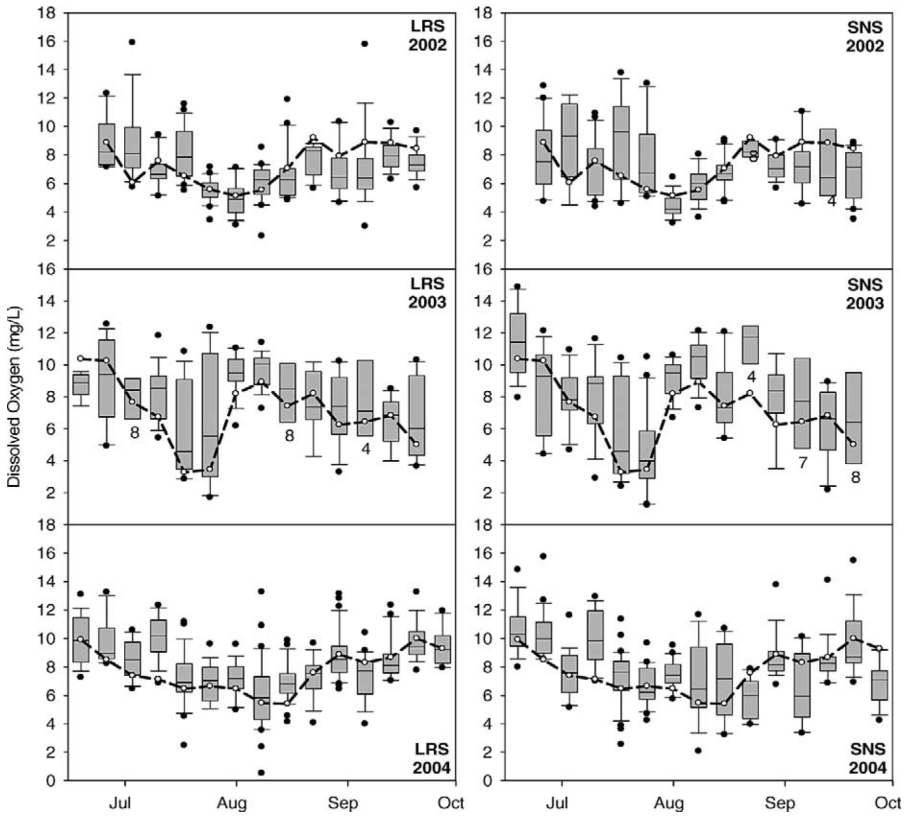

FIGURE 6.—Box plots of dissolved oxygen concentrations at Lost River sucker (LRS) and shortnose sucker (SNS) locations during each week of tracking in the study area of Upper Klamath Lake, 2002–2004. The ambient median dissolved oxygen concentration of the study area is represented by the dashed line. See Figure 5 for additional information.

seeking refuge in the relatively good water quality of Pelican Bay appeared to supersede staying in deep areas when water quality was poor. This movement may represent a trade-off between the risk of predation in shallow water versus occupying areas with low levels of DO.

The occupation of depths greater than 2.0 m may be explained by several factors. For example, Lost River and shortnose suckers are bottom-oriented species; as their diet consists of invertebrates, plankton, and detritus (Reiser et al. 2001; Moyle 2002), they could minimize exposure to avian predators and still forage for food in the deeper waters. In addition, cover (e.g., large woody debris) is sparse in the study area and depths greater than 2.0 m may provide concealment from avian predators (e.g., American white pelican *Pelecanus erythrorhynchos*; Findholt and Anderson 1995; Derby and Lovvorn 1997).

Water withdrawals from Upper Klamath Lake lowered lake elevation as the summer progressed (NRC 2004), reducing the amount of habitat available to suckers. Artificial lowering of Upper Klamath Lake may pose several problems for suckers. First, an increase in the amount of shallow areas in Upper Klamath Lake may place suckers at an increased risk of predation from American white pelicans, a known sucker predator (Scoppettone et al. 2006). For instance, from 2001 to 2005, Scoppettone et al. (2006) collected 5,193 anchor tags at known American white pelican nesting areas on Anaho Island in Pyramid Lake, Nevada. These tags were originally implanted in cui-ui *Chasmistes cujus* from 234 to 650 mm fork length, indicating pelicans are capable of consuming large quantities of adult suckers. Second, depending on proximity to a water quality refuge, suckers may be at risk if they become concentrated in deeper areas at night (i.e., trenches) and low DO events occur. These low DO events have been observed during reversals of prevailing wind patterns, which cause water circulation to stall and prolong oxygen-demanding processes (Wood et al. 2006).

Evidence ratios suggested that there were no diel

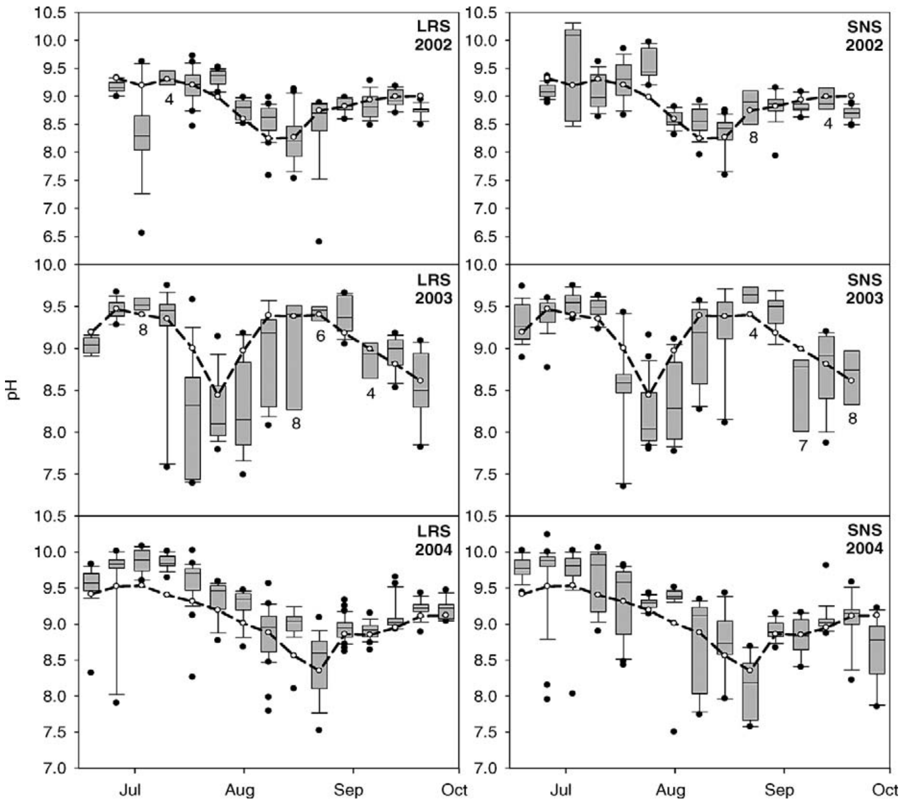

FIGURE 7.—Box plots of pH at Lost River sucker (LRS) and shortnose sucker (SNS) locations during each week of tracking in the study area of Upper Klamath Lake, 2002–2004. The ambient median pH of the study area is represented by the dashed line. See Figure 5 for additional information.

differences in depth or water quality at sucker locations. When evidence ratios implied that diel differences in depth or water quality did exist, differences were determined to be weak. For instance, there were only four instances when evidence ratios suggested that there were diel differences in depth or water quality at sucker locations, and the greatest was only 4.71 times more likely than no diel difference. These results suggest that individual suckers stay in areas of similar depth and are able to stay in areas with consistent water quality, despite diel variations in temperature, DO, and pH (Wood et al. 2006).

Poor water quality events, characterized by high pH and low DO, typically occur each year in Upper Klamath Lake as a result of the bloom dynamics of *A. flos-aquae* (Kann and Smith 1999). Suckers were distributed in Pelican Bay and offshore from Pelican Bay when the DO concentration in the study area was less than 4.0 mg/L during this study. Suckers appeared to respond quickly to deteriorating water quality. For instance, between July 15 and July 25, 2003, an individual shortnose sucker traveled 12.3 km from Bare Island to Pelican Bay as DO levels fell in the study area. Suckers used the well-oxygenated, cooler waters of Pelican Bay as a refuge from poor water quality through mid-August until water quality improved.

Although poor water quality events occurred each summer, shortnose suckers were primarily within Pelican Bay during 2003. In contrast, Lost River suckers were located off the mouth of or within Pelican Bay each year of the study. Terwilliger et al. (2003) revealed that nighttime DO levels less than 4.0 mg/L for juvenile Lost River suckers and less than 1.0 mg/L for juvenile shortnose suckers caused enough stress to reduce growth at temperatures greater than 22°C and suggested shortnose suckers may be more tolerant of low DO conditions. The median lethal DO concentrations were consistently lower for juvenile shortnose suckers (range, 1.14–1.34 mg/L over 24–96 h) than for juvenile Lost River suckers (range, 1.58–1.62 mg/L over 24–96 h) in laboratory studies (Saiki et al. 1999). Assuming adult suckers exhibit similar tolerance to DO conditions, results of this study concur with Terwilliger

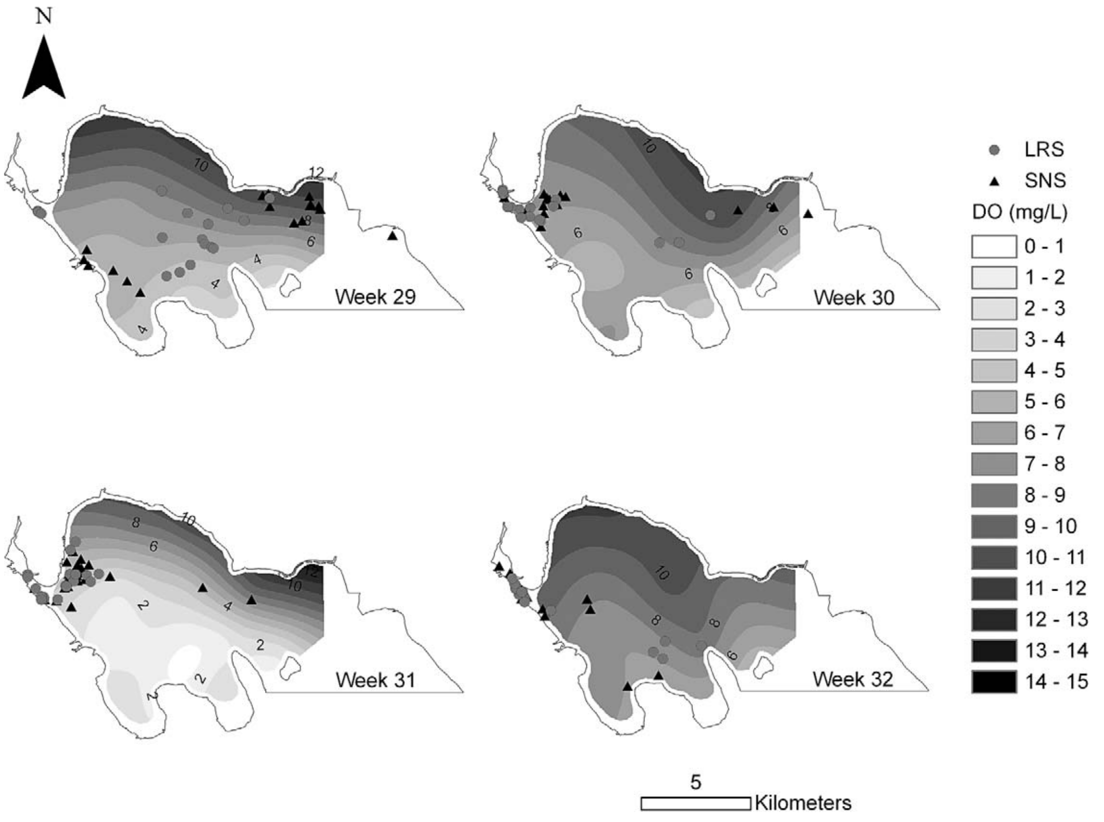

FIGURE 8.—Distributions of Lost River suckers (LRS) and shortnose suckers (SNS) during weeks 29–32, 2003, in relation to the dissolved oxygen (DO) concentrations (mg/L) in the study area of Upper Klamath Lake. The DO gradients were created using interpolations from water quality monitoring stations (Wood et al. 2006).

et al. (2003) and Saiki et al. (1999) that shortnose suckers may be more tolerant of low DO conditions than are Lost River suckers.

Pelican Bay appears to be a key refugium for suckers during poor water quality events. Although Pelican Bay provides suitable water quality, other refugia are accessible to suckers in the study area. For instance, the Williamson River provides about 50% of the freshwater inflow to Upper Klamath Lake (NRC 2004). The Williamson River is readily accessible to suckers throughout the summer, but they do not often use the river environment as a refugium. This prompts the question why suckers use Pelican Bay and not the Williamson River as a refuge during poor water quality events. This pattern may be explained by several factors. First, suckers may expend more energy in lotic than in lentic habitats, which potentially reduces condition. Second, circulation in Upper Klamath Lake is driven predominately by wind currents (Wood et al. 2006). Prevailing wind currents drive circulation in a clockwise direction in the study area. Assuming suckers follow these currents, Pelican Bay would provide the nearest refuge area.

Between July 22 and September 30, 2003, 108 dead suckers were collected from Upper Klamath Lake and dead and distressed fish were seen in Pelican Bay (B. S. Hayes, USGS, personal communication). The first observations of dead suckers in Upper Klamath Lake corresponded to the beginning of a low DO event. In late July, 2003, the median DO concentration approached 3.0 mg/L throughout the majority of the study area. Although DO conditions improved after August 2, 2003, suckers continued to die in Upper Klamath Lake suggesting secondary stressors may have been a factor in fish deaths.

Poor water quality may directly cause stress, and fish under stressful conditions may experience disease outbreaks (Wedemeyer et al. 1990). Upper Klamath Lake typically experiences poor water quality each summer resulting from *A. flos-aquae* blooms. Poor water quality poses a source of stress to suckers, placing them in a compromised state of health. In 2003, a year with extremely poor water quality, moribund and dead suckers were collected in Pelican Bay. Examination of these suckers revealed a prevalence of columnaris (J. S. Foott, U.S. Fish and Wildlife Service, personal communication), a bacterial disease that was associated with fish die-off events during 1995–1997 (Perkins et al. 2000). Wedemeyer et al. (1990) similarly noted that high densities of salmonids may lead to myxobacterial gill disease outbreaks. Despite the good water quality in Pelican Bay, crowding of suckers may have increased already stressful conditions for both Lost River and shortnose suckers. Crowded conditions may have compromised fish health by reducing immune function (Maule et al. 1989), thus causing mortality.

Management efforts may be enhanced by future studies that elucidate the life history differences between Lost River and shortnose suckers at all life stages to extend the results of this study. Findings of this study also expanded upon previous investigations to provide important information on adult sucker distribution and habitat associations in response to poor water quality events. Pelican Bay appears to act as a key refugium during periods of poor water quality within the study area and efforts to maintain the quality of its habitat may be beneficial for suckers. Furthermore, conservation of suckers may benefit from restoring connectivity to other water quality refugia in Upper Klamath Lake. The National Research Council (NRC 2004) noted refuge and spawning areas, such as Barkley Springs in southeastern Upper Klamath Lake, were once used by suckers, but connectivity has since been cut off. In 2003, a particularly severe crash of *A. flos-aquae* led to poor water quality and subsequent partial fish kill. Poor water quality in 2002 and 2004 was evident though no dead fish were observed. Future Klamath River basin sucker conservation would benefit from research aimed at identifying the underlying mechanistic drivers that may be interacting to promote fish die-off events and potentially threatening the future persistence of these endemic sucker species.

Acknowledgments

R. Anderson, G. Balmert, P. Barry, D. Bennetts, G. Blackwood, T. Blankenburg, B. Bozarth, K. Buelow, D. Gambetta, B. Hayes, H. Hendrixson, B. Herring, E. Janney, M. Johnson, S. Kincaid, A. Scott, B. Swigle, D. Taylor, S. Thompson, J. Whisler, and S. VanderKooi assisted with field work. B. Greer, S. Kincaid, and B. Swigle provided ArcGIS assistance. M. Lindenberg provided assistance with the preparation of water quality data. G. Blackwood oversaw database management. The U.S. Fish and Wildlife Service assisted with aerial surveys. This manuscript was improved by comments from S. Burdick, N. Hendrix, C. Jennings, S. VanderKooi, and three anonymous reviewers. This project was funded by the U.S. Bureau of Reclamation Interagency Agreement 06AA204053 and the U.S. Geological Survey. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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