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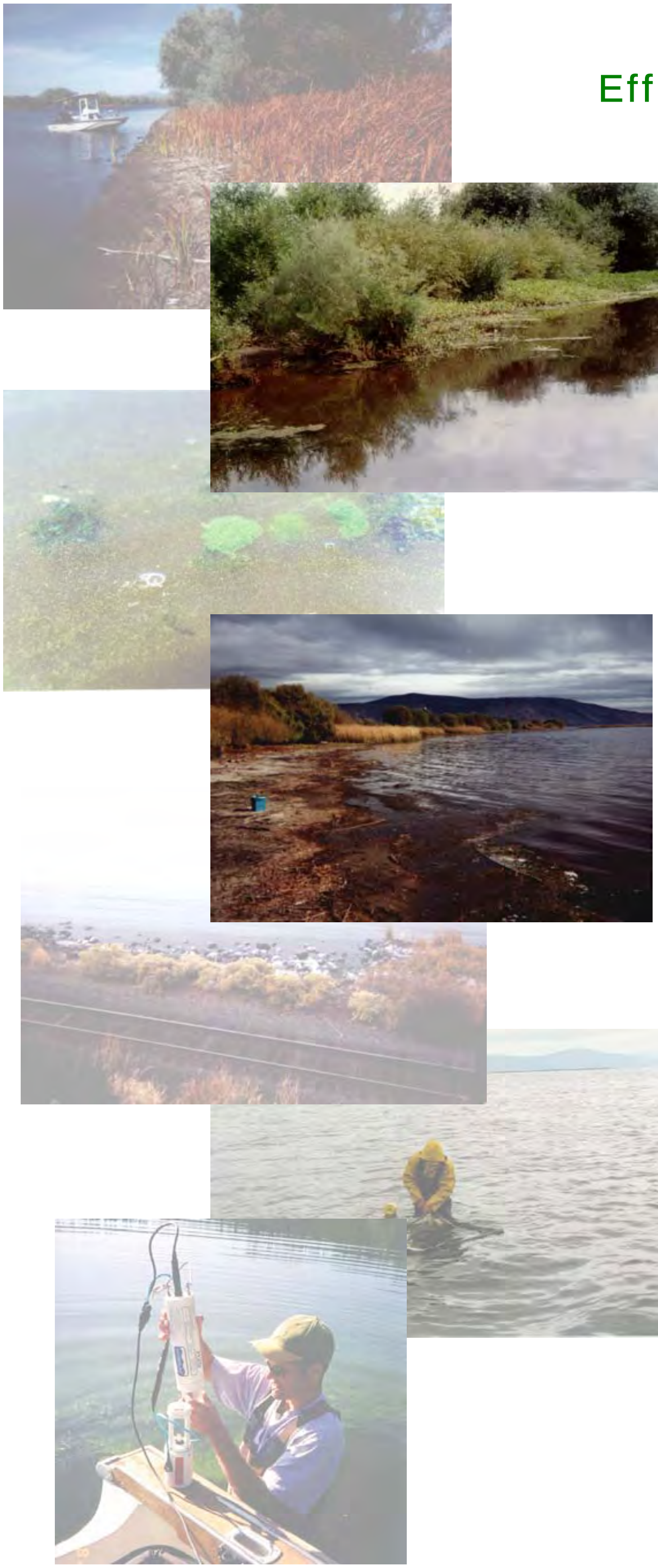

Effects of Water Quality and Lake Level on the Biology and Habitat of Selected Fish Species In Upper Klamath Lake

Prepared for:

Bureau of Indian Affairs
Portland, Oregon

Prepared by:

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March 12, 2001

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EXECUTIVE SUMMARY

Historically, the Klamath Tribes utilized many of the different fish species found in Upper Klamath Lake for subsistence and ceremonial purposes. Today, the abundance of many of these species has been severely reduced, with the numbers of two of the species, Lost River sucker (Deltistes luxatus), and shortnose sucker (Chasmistes brevirostris) so low that both have been listed by the U.S. Fish and Wildlife Service as endangered under the federal Endangered Species Act (ESA). Another sucker species, the Klamath largescale sucker (Catostomus snyderi), was previously listed as a "Category 2" species under the ESA, but was recently delisted. The Bureau of Indian Affairs (BIA), as trustee for the benefit of the Klamath Tribes, has been conducting studies for a number of years to determine the volumes of water in Upper Klamath Lake necessary to protect populations of key fish species resident in and migrating through the lake. As part of this work, in 1996, R2 Resource Consultants (R2) was contracted by the Bureau of Indian Affairs to conduct an analysis to assess the relationship of lake level elevations on existing physical habitat of fish, focusing on the above species. The results of that analysis (presented herein) consist of three major components; 1) synthesis of existing information on the biology of suckers, rainbow and redband trout, and chinook salmon as it pertains to fish habitat conditions in Upper Klamath Lake; 2) analysis of the direct effects of lake level on three important habitats (larval rearing habitat, adult spawning habitat, and depth utilization by adult suckers) of Lost River and shortnose suckers in Upper Klamath Lake; and 3) analysis of U.S. Bureau of Reclamation (USBR) radio telemetry data combined with USBR and Klamath Tribes water quality data to examine the effects of poor water quality on habitat utilization by adult suckers.

The assessment of water quality and physical habitat changes relative to lake level elevations was completed using a variety of methods and analytical techniques, of which all were founded on the completion of a detailed literature review. This review focused on data and information that described historical and current conditions of the fishery resources of the lake, and in particular, species-specific life history and habitat utilization information. R2 also completed several field surveys in Upper Klamath Lake commencing in 1992 with an initial field reconnaissance and extending through 1999 during which time the surveys included sampling of fish and measurements of selected physical habitat and water quality characteristics. The data compiled as part of the literature review were subsequently integrated with: 1) results of emergent vegetation mapping and marsh elevation data; 2) analysis of water depth – lake elevation information in selected springs known to be used by suckers for spawning; 3) analysis of depth utilization data for adult suckers as defined by USBR radio telemetry data; 4) analysis of water quality data (collected by the Klamath Tribes and USBR) linked with radio tagging information (collected by the USBR), to assess water quality related stress within the lake, and 5) results of field surveys, to allow an overall assessment of the relationship of lake level change on habitats of suckers in Upper Klamath Lake.

The results of our studies and analysis suggest that lake levels are ecologically linked on a physical basis to several and perhaps all of the life history stages of Lost River and shortnose suckers in Upper Klamath Lake. We have concluded that the availability of in-lake spawning habitats of Lost River and shortnose suckers within springs and shoreline areas is linked to lake levels. Likewise, the quantity and availability of emergent vegetation, which has been shown to be used by larval suckers, are related to lake levels. Our analysis of radio tagging data has identified a preferred water depth of adult suckers, the areal extent of which is related to lake levels. In addition, the results of our limited juvenile sucker sampling coupled with the preliminary results of a new USGS study, suggest that emergent vegetation also provides important habitats for juvenile suckers, which would thus be linked to lake levels.

Based on our findings, we recommend the following temporally distinct but ecologically linked lake levels as defined by one or more life history components for important fish species in Upper Klamath Lake:

- March 1 – May 31: lake levels of $4,143 ft (maximum habitats provided at 4,143.3 ft) – maximize in-lake spawning habitats for adult suckers
- June 1 – July 15: lake levels $4,142 ft (80% habitats provided at 4,142.8 ft) – maintain important emergent vegetation for larval and juvenile suckers; provide conditions that promote increased larval and juvenile survival
- July 16 – September 30: lake levels $4,141 ft (maximum habitat provided at 4,143.3 ft) maintain > 80 percent of preferred depth habitats of adult suckers and provide use of and access to refugia habitats by adult and habitat for juvenile suckers, and adult redband trout during periods of degraded water quality; provide conditions that promote increased adult survival during summer months.

1. INTRODUCTION

Historically, the Klamath Tribes utilized many of the different fish species found in Upper Klamath Lake for subsistence and ceremonial purposes. Today, the abundance of many of these species has been severely reduced, with the numbers of two of the species, Lost River sucker (*Deltistes luxatus*), and shortnose sucker (*Chasmistes brevirostris*) so low that both have been listed by the U.S. Fish and Wildlife Service (USFWS 1988) as endangered under the federal Endangered Species Act (ESA). Another sucker species, the Klamath largescale sucker (*Catostomus snyderi*), was previously listed as a “Category 2” species under the ESA, but was recently delisted. Adult migrations of suckers up the Sprague and Williamson rivers in the early spring once contained tens of thousands of fish. For the Klamath Tribes this migration both signified the end of winter and provided an important opportunity to replenish food supplies (Bienz and Ziller 1987; KRBFTF 1991).

Two salmonid species are also of interest and concern to the Klamath Tribes: redband trout (*Oncorhynchus mykiss*), which represents a unique race of rainbow trout, and chinook salmon (*O. tshawytscha*). The redband trout within Klamath and Agency lakes represents a unique adfluvial stock that reaches very large sizes, is resistant to the parasite *Ceratomyxa shasta*, and may be more tolerant of high pH and temperatures than most other rainbow trout stocks (KRBFTF 1991). Redband trout remain one of the species currently used by the Klamath Tribes. Chinook salmon are also considered very important to the Klamath Tribes (E. Miller, personal communication). Although currently extirpated, chinook salmon once occurred within many streams in the Upper Klamath Lake Basin and were utilized as food by the Tribes (Fortune et al. 1966; KRBFTF 1991).

The Bureau of Indian Affairs (BIA), as trustee for the benefit of the Klamath Tribes, has been conducting studies for a number of years to determine the volumes of water in Upper Klamath Lake necessary to protect populations of key fish species resident in and migrating through the lake. This work was commissioned as part of that effort to protect the treaty reserved fishing rights (treaty of 1864) of the Klamath Tribes.

Upper Klamath and Agency lakes have consistently experienced pH and dissolved oxygen (DO) levels during the summer in some locations that are acutely toxic to fish (KRBFTF 1991; R2 2001a, b; USGS 1996). These poor water quality conditions are related to large blooms of the blue-green alga *Aphanizomenon flos-aquae*, which result from high nutrient levels, and the shallow, well-mixed limnology of the two lakes. To evaluate possible measures that could be implemented to control these conditions, Drs. Eugene Welch and Michael Loftus, and Mr. Tom Burke have developed an integrated water quality model based on phosphorus (P) loadings to and within the lake (R2 2001b). The model did not assess the relationship of temporal changes in lake level elevations or water quality on the physical habitat of important fish species in Klamath Lake.

In 1996, R2 Resource Consultants (R2) was contracted to conduct an analysis to assess the relationship of lake level elevations on existing physical habitat of fish, focusing on the above species. This analysis was conducted to complement the other R2 studies (R2 2001a, b) by providing an assessment of lake level changes from a primarily physical rather than a chemical (water quality modeling) context, although this study also includes an assessment of water quality induced stress to fish and resulting effects on habitat utilization and fish production in the lake.

R2's analysis consisted of three major components. One component synthesized existing information on the biology of suckers, rainbow and redband trout, and chinook salmon as it pertains to fish habitat conditions in Upper Klamath Lake. Many of these studies are ongoing and most have occurred over the past ten years. A second component focused on direct effects of lake level on three important habitats of Lost River and shortnose suckers in Upper Klamath Lake: larval rearing habitat, adult spawning habitat, and depth utilization by adult suckers. The third major component was an analysis of U.S. Bureau of Reclamation (USBR) radio telemetry data combined with USBR and Klamath Tribes water quality data to examine the effects of poor water quality on habitat utilization by adult suckers.

The results presented herein were based on the best information and data available at the time of the analysis (March 2001). Ongoing studies may result in some modification and refinement to the overall conclusions presented in this report. The report is organized into the following major sections:

- Chapter 1, INTRODUCTION, presented above.
- Chapter 2, DESCRIPTION OF STUDY AREA, which describes and depicts relevant portions of the Upper Klamath Basin.
- Chapter 3, METHODS, which describes the data collection and analysis techniques that were used in the study.
- Chapter 4, review of THE BIOLOGY OF UPPER KLAMATH LAKE FISHES, which synthesizes information on the general life history, population status, history, and critical needs of various fish species.
- Chapter 5, EFFECTS OF LAKE LEVEL ON FISH HABITAT, which assesses how lake levels affect the abundance and quality of important habitats of fishes in the lakes.
- Chapter 6, EFFECTS OF POOR WATER QUALITY ON FISH AND FISH HABITAT UTILIZATION, which analyzes effects of water quality on fish and how this affects fish habitat utilization in Upper Klamath and Agency lakes.
- Chapter 7, CONCLUSIONS, which presents a concise summary of the major findings of this study, and presents R2's management recommendations resulting from the analysis.
- Chapter 8, REFERENCES, which lists the references cited in this report.

This report also contains several appendices including; APPENDIX A, Analysis of the Distribution and Stability of Existing Marsh Vegetation Bordering Upper Klamath and Agency Lakes (Chapin 1997a), APPENDIX B, Photographs Depicting Klamath Lake Fish Sampling Sites and Methods; APPENDIX C, Figures Supporting Chapter 6; APPENDIX D, GIS Plots of Defined Depth Intervals as a Function of Lake Level.

2. DESCRIPTION OF STUDY AREA

The study area considered by this report includes Upper Klamath and Agency lakes and their tributaries, the Sprague, Williamson, and Wood river basins (Figure 2-1). Only those portions of the tributaries utilized for spawning and/or rearing by Upper Klamath Lake fishes were examined. The Upper Klamath Lake watershed is located east of the Cascade Mountains in south central Oregon. Elevations range from approximately 4,000 to 9,000 ft above mean sea level (msl). Lower elevations within the watershed are semi-arid, with mean annual precipitation of 13.8 in./year, approximately 70 percent of which occurs as snow (Bond et al. 1968, Campbell et al. 1993). The natural aridity is enhanced by the abundance of pumice and ash soils, which drain quickly. Vegetation is accordingly adapted to low moisture levels, and is dominated by grassland habitats and forests of ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*P. contorta*).

Upper Klamath and Agency lakes are connected and are generally considered to be two parts of the same water body, with Upper Klamath Lake comprising 85 to 90 percent of the total surface area (Figure 2-2). Collectively, they form a large, shallow lake covering approximately 120 to 130 square miles (sq mi). Water level in Upper Klamath Lake is controlled at the Link River Dam by the USBR. Maximum lake level typically occurs in May or June and minimum lake level in October to November. Figures 2-3 and 2-4 show variation in lake level from 1990 to 1999. Surface area varies with lake elevation. At a minimum pool elevation of 4,137 ft msl, Upper Klamath and Agency lakes cover approximately 56,000 acres (R2 2001b). Corresponding size of Klamath and Agency lakes at full pool (4,143.3) is approximately 67,000 acres. Depths in both Upper Klamath and Agency lakes are shallow, with an average depth of approximately 7.1 ft during the mean summer pool elevation of 4,141.3 ft (R2 2001b). Both lakes have high nutrient levels that, combined with warm sunny days, shallow depths and frequent winds, leads to extensive growth of algae, particularly the blue-green alga *Aphanizomenon flos-aquae*. Both lakes are considered to be hypereutrophic (R2 2001b).

Although over 22,000 acres of wetland habitat have been converted to uplands since 1940 (Carlson 1993), both Agency and Upper Klamath lakes still contain large tracts of emergent wetland vegetation (Figure 2-2). Agency Lake has significant wetlands at the mouth of the Wood River and in isolated tracts along the northwestern and eastern shores, although these wetlands have been altered significantly by agricultural and diking activities with respect to flow, extent, and connectivity. The largest remaining wetland at 14,700 acres is at the north end of the lake in the Upper Klamath National Wildlife Refuge. Upper Klamath National Wildlife Refuge also forms most of the southwestern boundary of Agency Lake. Other significant wetland areas in Upper Klamath Lake are located in Shoalwater Bay, Squaw Point, Wocus Bay, and at Hanks Marsh (Gearheart et al. 1995).

The Williamson River is the largest tributary to Klamath Lake, with an average annual inflow of 762,500 acre-ft/year, or approximately 52 percent of the total inflow (R2 2001b). From Upper Klamath Lake, the Williamson River runs north to

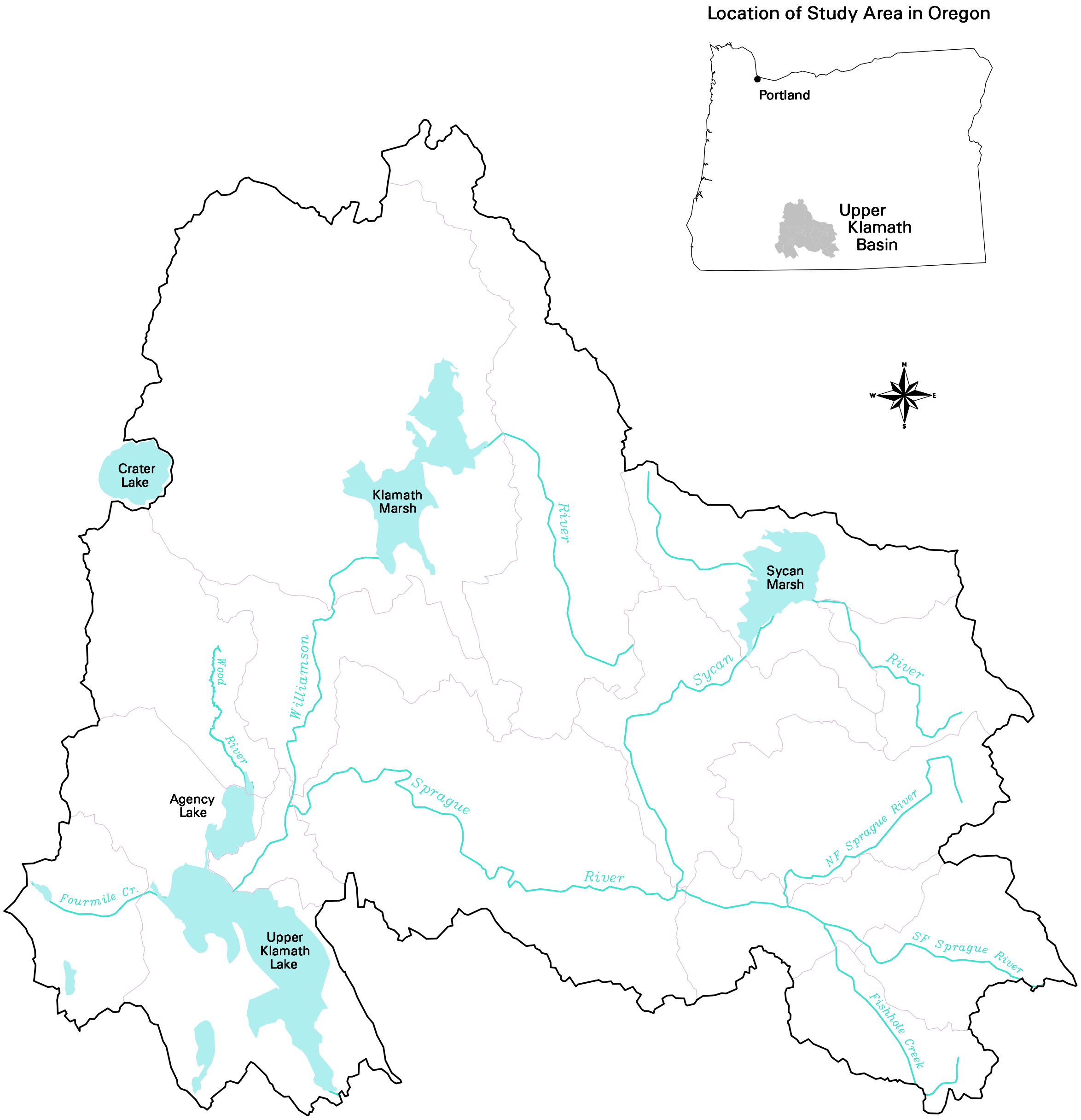


Figure 2-1. Upper Klamath Basin, Oregon.

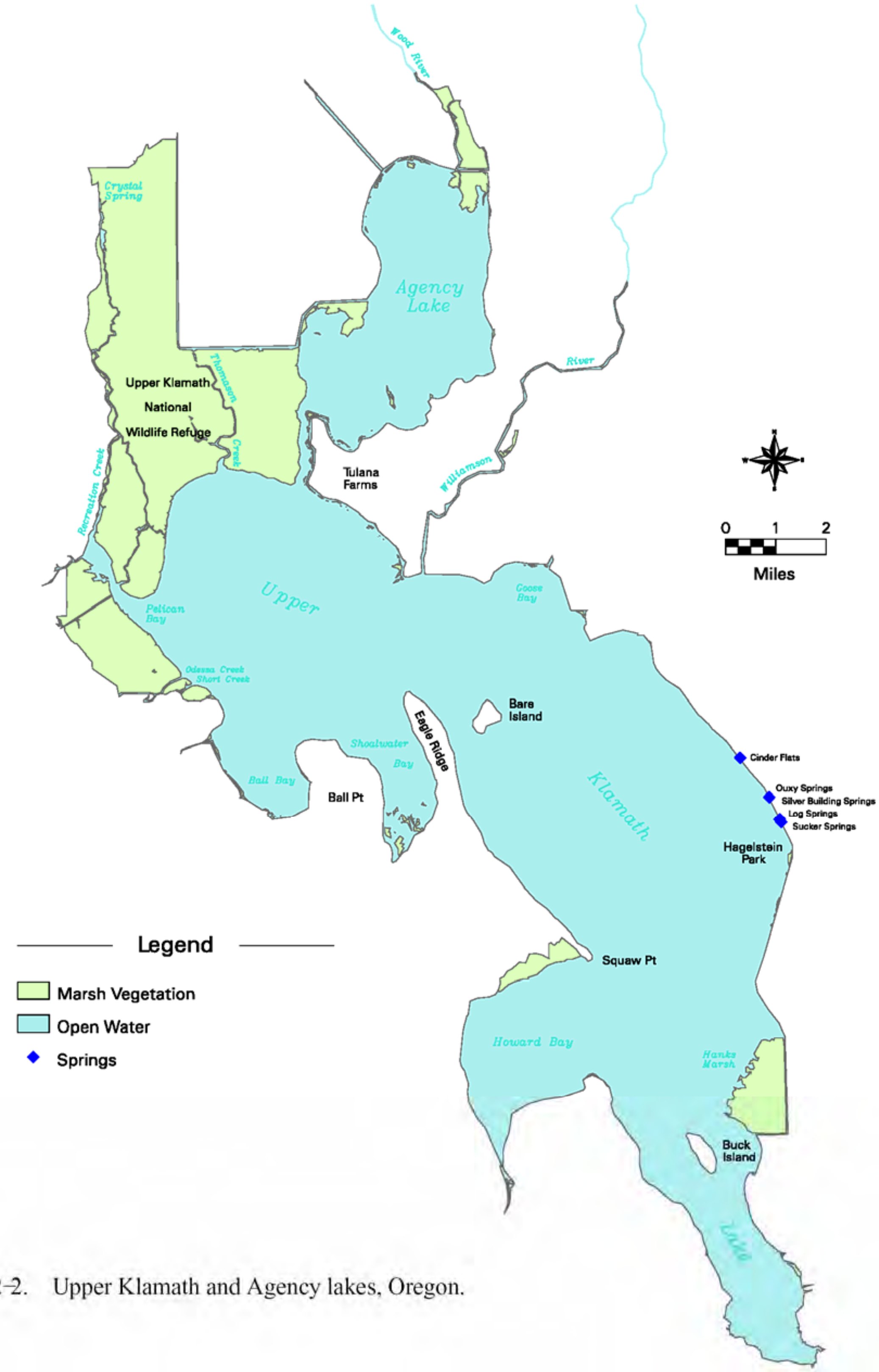


Figure 2-2. Upper Klamath and Agency lakes, Oregon.

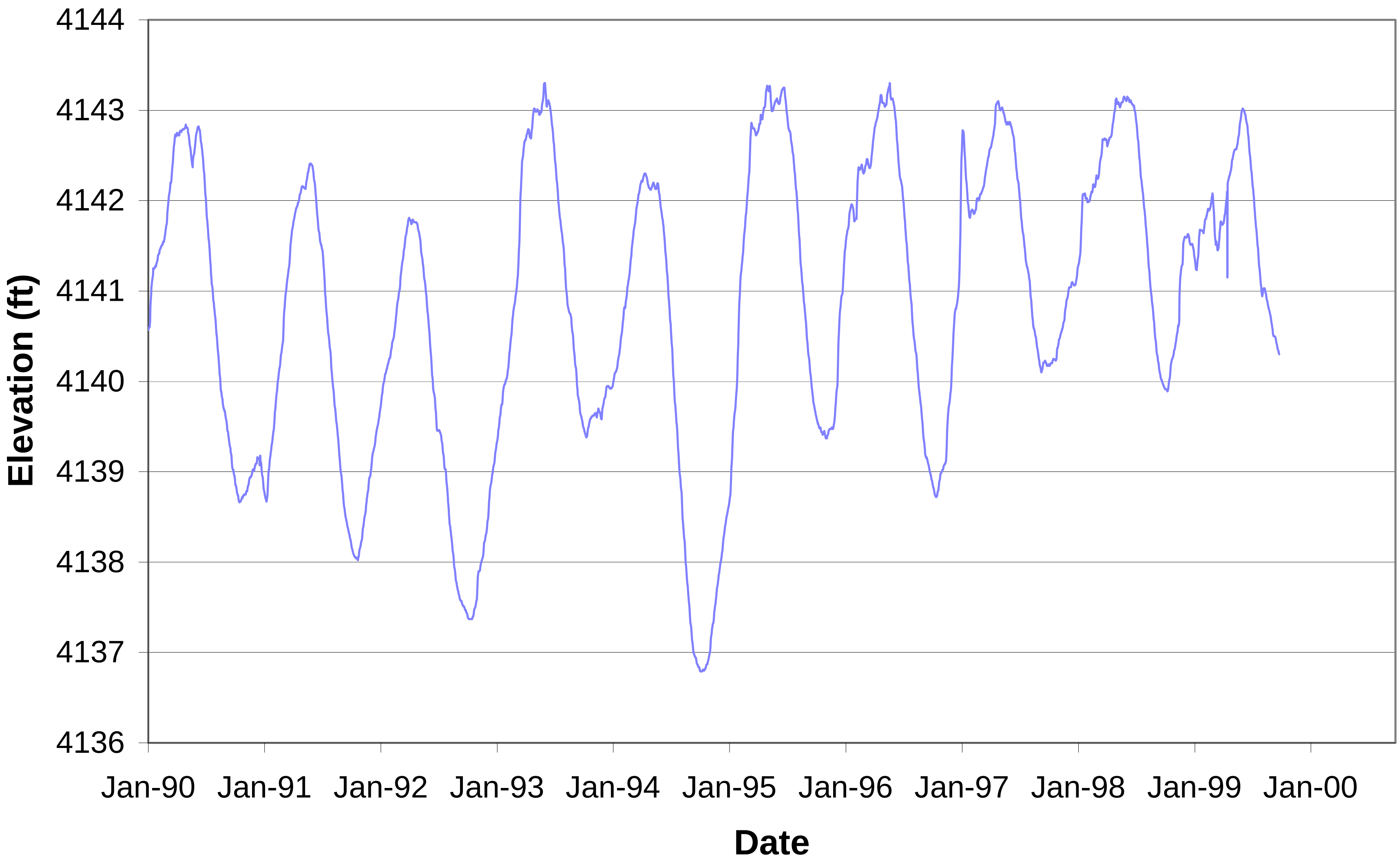


Figure 2-3. Lake level in Upper Klamath Lake from January 1990 to October 1999 (USBR datum).

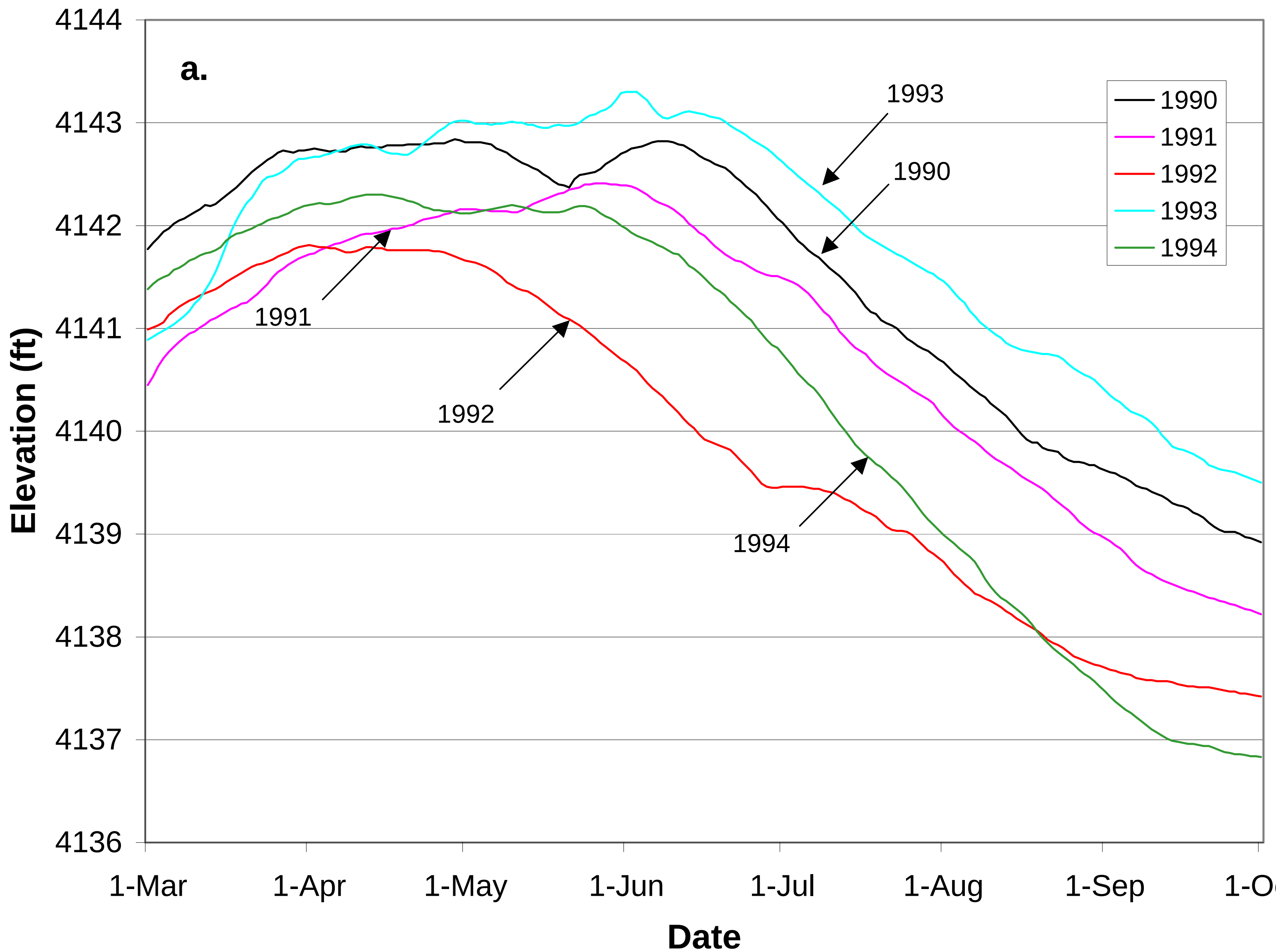


Figure 2-4a. Lake level in Upper Klamath Lake from March 1 to October 1 for years 1990 through 1994.

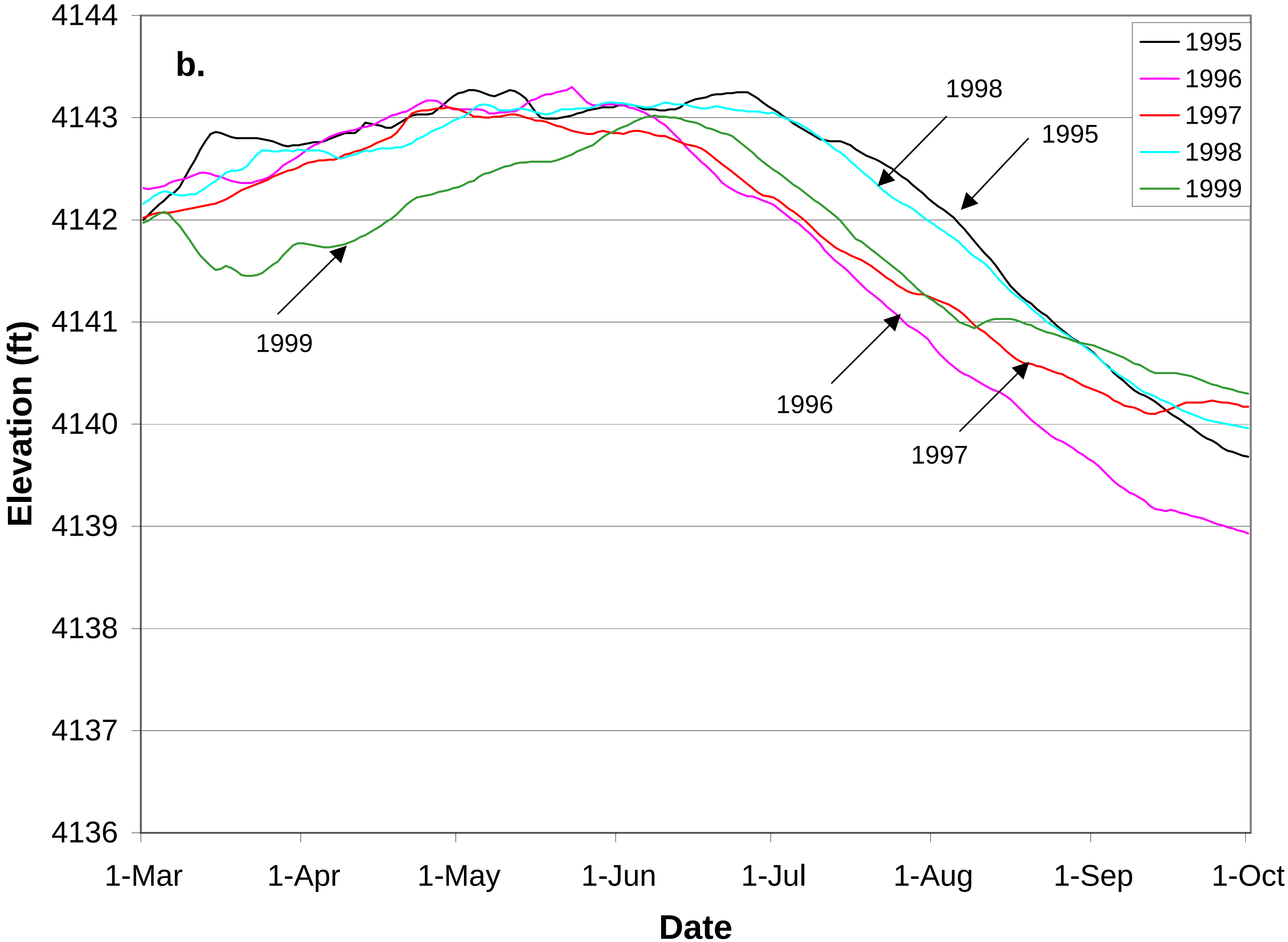


Figure 2-4b. Lake level in Upper Klamath Lake from March 1 to October 1 for years 1995 through 1999.

Klamath Marsh before turning east and south to its headwaters (Figure 2-1). The Williamson River is used for spawning by suckers that migrate from Upper Klamath Lake, and as a migration corridor for both suckers and adfluvial redband trout to spawning sites in upstream tributaries. These tributaries include the Sprague River and Spring Creek. The Sprague River, located approximately 10 miles upstream of Upper Klamath Lake, was historically an important spawning site for suckers from Upper Klamath Lake. Spring Creek is located approximately 15 miles upstream from the mouth of the Williamson River, and is together with the Williamson River upstream of the creek an important spawning site for adfluvial redband trout from Upper Klamath Lake (Figure 2-1).

The Wood River is the largest tributary to Agency Lake, and provides the second largest inflow overall to the Agency-Upper Klamath Lake complex. Average annual inflow of the Wood River is approximately 273,200 acre-ft/year, or about 19 percent of total inflow (R2 2001b). Larval suckers have been collected from the Wood River (Klamath Tribes 1996), and adult suckers (primarily shortnose and Klamath largescale suckers) have been captured near the mouth of the Wood River (R. Shively, USGS, personal communication). Presence of larval suckers, as well as adult suckers, indicates that some spawning by suckers occurs in this drainage.

The headwaters of the Wood River and its tributaries, Fort Creek and Crooked Creek, also support a significant spawning run of adfluvial redband trout (L. Dunsmoor, Klamath Tribes, personal communication).

The Upper Klamath Lake watershed contains a large number of active springs, which flow into tributaries of the drainage. The Williamson and Wood rivers and Spring Creek all originate at large artesian springs. In addition, numerous springs are present in or adjacent to Upper Klamath Lake including Harriman, Odessa, Sucker, Silver Building, Ouxy, Boulder, Barkley, and Log springs (Figure 2-2). Many of these springs are actively used by suckers for spawning during the spring. Recent surveys completed by Shively et al. (2000) documented Lost River and shortnose sucker spawning in Sucker Springs, Silver Building Springs, Ouxy Springs, and Cinder Flats. Shively et al. (2000) found only Lost River suckers within Boulder Springs. Springs in Upper Klamath Lake are also important because they provide inflows with high water quality during the spring and summer months. Consequently, they provide dilution flow that likely improves water quality conditions in areas proximal to the springs during periods of poor water quality in the lakes.

3. METHODS

The assessment of water quality and physical habitat changes relative to lake level elevations was completed using a variety of methods and analytical techniques, of which all were founded on the completion of a detailed literature review. This review focused on data and information which described historical and current conditions of the fishery resources of the lake, and in particular, species-specific life history and habitat utilization information. Those data were subsequently integrated with the results of emergent vegetation mapping and marsh elevation data to allow an assessment of the relationship of lake level change and physical habitat. Specific methods applicable to each of these study elements are described below.

3.1 LITERATURE REVIEW

Data used for this report were gathered through a review of available literature on the fisheries, hydrology, water quality, and habitat conditions present within Upper Klamath and Agency lakes, and for the Upper Klamath watershed in general. For this, over 50 sources of information were reviewed, which included published papers (in peer reviewed journals); unpublished manuscripts; state, federal, and tribal agency reports; and various data files. Primary sources of data and information included:

- Reports and manuscripts on sucker life history, genetics, toxicology, and environmental requirements from peer reviewed scientific journals (e.g., Transactions of the American Fisheries Society, Copeia, etc.). This focused on information on Lost River, shortnose, and Klamath largescale suckers, but applicable studies from other catostomid species, including cui-ui, razorback sucker, and white sucker were used, as needed, to provide insight into aspects of sucker ecology for which direct data on Upper Klamath Basin species were not available.
- Published government reports on water quality and fish in the Upper Klamath Basin; primary sources: U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), and Bureau of Reclamation (USBR).
- Unpublished reports on water quality, fish, and wetlands within the Upper Klamath Basin. Many of these reports were authored by the Klamath Tribes, Oregon State University researchers, USFWS, BIA, U.S. Environmental Protection Agency (USEPA), and the Oregon Department of Fish and Wildlife (ODFW), often as progress reports, or reconnaissance surveys.
- Data files (water quality, hydrology, etc.) from the USGS, USBR, the BIA, and the Klamath Tribes.

In addition to these data sources, direct interviews with state, federal, and tribal resource professionals familiar with the Upper Klamath Basin were conducted. These interviews were generally used to clarify uncertainty in written documents, or to obtain information not included in those documents. Information from those interviews is cited as personal communications in this report.

3.2 SITE RECONNAISSANCE AND FIELD SURVEYS

R2 completed several field surveys in the Upper Klamath Lake commencing in 1992 with an initial field reconnaissance and extending through 1999 (Figure 3-1 for specific sampling locations). The initial field reconnaissance (completed in 1992) involved a boat survey of the entire lake system and served to denote important locations of lake bathymetry and areas of known fish utilization. Subsequent surveys of specific tributaries (known to provide important fish habitat for Klamath and Agency lake fishes) were completed during the summer of 1996. The surveys were coordinated with personnel from the Klamath Tribes who provided site-specific information regarding fish species life history information and periodicity, and habitat utilization. During the second survey (1996), channel morphology and discharge information was collected from certain streams. Two known spawning sites (used by Lost River, shortnose and Klamath largescale suckers) in the lower Williamson River were also visited, as was the Wood River delta where it enters Agency Lake. R2 continued the surveys of the lake system over the period 1998–1999.

3.2.1 1998 Field Surveys

Three surveys were completed in 1998 (a relatively high lake level year), an initial reconnaissance survey completed on July 15 (lake level = 4142.62 ft) in which shoreline habitats were videotaped, a qualitative survey completed in late July, and a qualitative/semi-quantitative survey completed in August. The late July survey was completed over a three day period (July 29-31) and served to identify candidate areas for subsequent sampling in August. Visual surveys were completed via boat and included stops near Sucker and Ouxy springs, Goose Bay, the mouth of the Williamson River, Short Creek outlet, Odessa Creek outlet and near boat launch, Pelican Bay, and Harriman Springs. Qualitative dip net sampling was completed at several sites near Goose Bay to document general species composition. Site visits were also made via vehicle/foot to both Sucker and Ouxy springs, and to two other small springs locally known as "Silver Building" and "Log" springs. These springs are all located along the eastern shoreline of Upper Klamath Lake (Figure 2-2) and are known to be used by suckers for spawning during the spring. Representative photographs were taken and water temperature measurements collected at each of the sites.

The August 1998 surveys were completed during a two day period (August 20-21) and were focused on collection of fish species within shoreline habitats at ten locations within Upper Klamath Lake (Figure 3-1). These sites included:

- Mouth of the Williamson River,
- Goose Bay,
- 0.5 mi west of Goose Bay,
- Mouth of Short Creek (and portions within Short Creek),
- Mouth of Odessa Creek,
- Mid-section of Odessa Creek,
- Upper Odessa Creek (near boat launch),
- West-side shoreline of Upper Klamath Lake (about 0.5 mi northeast of Pelican Bay),
- Northwest corner of Klamath Lake (about 1.0 mi northeast of Pelican Bay),

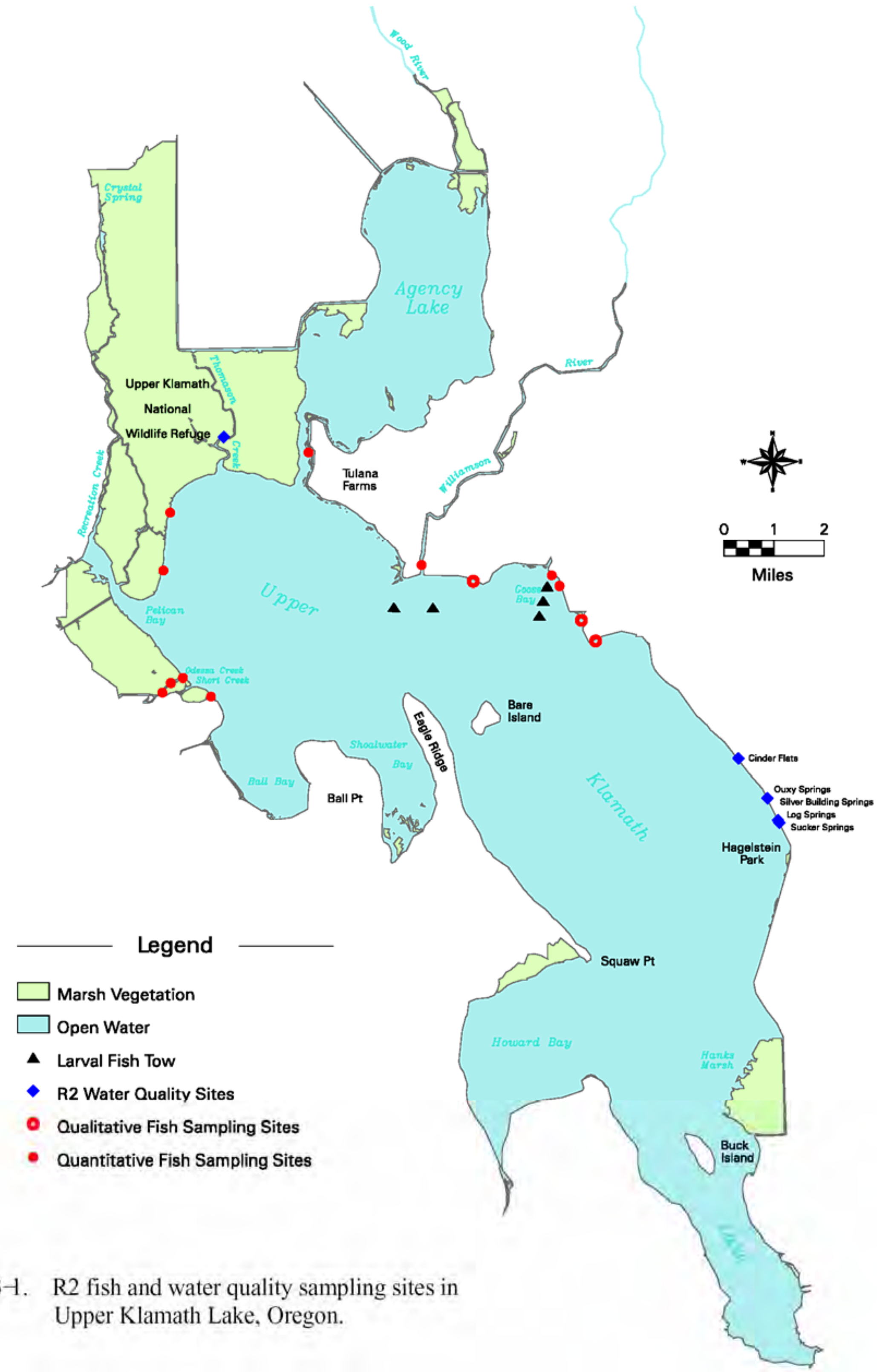


Figure 3-1. R2 fish and water quality sampling sites in Upper Klamath Lake, Oregon.

- East-side shoreline and midway within connecting channel between Upper Klamath Lake and Agency Lake (Figure 2-2).

The first three sites were surveyed on 20 August, the remaining sites on August 21. We used a beach seine (30 ft long; 5 ft high; 0.12 inch mesh) to capture fish at each of the ten locations (Figure 3-1). Each seine was deployed within an off-shore area in the deepest water possible and pulled towards the shoreline. Fish were removed from a 3 ft long by 5 ft high bag centered in the beach seine, transferred to plastic pails, anesthetized using MS-222 (tricaine methanesulfonate), identified to species, measured to the nearest mm (TL), allowed to recover, and released.

We also completed three pop net sets within the Goose Bay site during the August surveys. The nets were patterned after the design of Dunsmoor (unpublished) and consisted of a 10.8 ft^2 (1 m^2) buoyed frame fitted with 100 micron mesh nitex netting. The nets were anchored to a set of crossed steel plates. When deployed, the traps were submerged (in water depths 1-3 ft deep) via connectors attached from the buoyant frame to the steel plates. A trigger line was attached to shoreline vegetation distant to the traps to enable the remote release of the connectors. This would then allow the buoyant trap to surface thereby retaining any fish that were in the water column over the trap. Because in August, suckers would have already grown beyond the larval stage (the stage at which they are most vulnerable to pop netting), we used the survey to largely test the operation and performance of the pop nets.

Water temperature (EC), dissolved oxygen (mg/l), percent saturation, conductivity, and pH were measured using a Hydrolab7 MiniSonde Multiprobe at each survey site. Water depth and effective seine width (linear seine length) were measured with a survey rod at each site. A total of 10 beach seines were pulled during 20-21 August, including three in the Williamson River mouth/Goose Bay, and seven in Upper Klamath Lake.

The lake levels during the August 20-21,1998 surveys (4141.09 ft – 8/21/98) were about 1 ft lower than levels in July (4142.03 ft – 7/30/98) resulting in noticeable areas of exposed shoreline and emergent vegetation. We semi-quantitatively measured the extent of shoreline exposure at one representative area within Goose Bay by placing six transects perpendicular to the shoreline; the distance between transects was 50 ft. For each transect, a fiberglass tape was extended from the high lake level mark (observed on the upper shoreline) out to the waters edge (pool elevation of 4141.09 ft), and the length (nearest 1 ft) of exposed shoreline and emergent vegetation recorded. We also noted the range of useable wetted vegetation along each transect; i.e., the length of vegetation within the wetted portion of the transect that could be used as cover/habitat for fish.

3.2.2 1999 Field Surveys

In 1999, two surveys were conducted, the first on March 9 (lake elevation - 4141.87 ft), the second over June 2-3 (4142.91 ft – 6/2/99). The March survey consisted of a single night's snorkeling effort that was focused on observing adult suckers within Sucker Springs. The survey was conducted on the evening of March 9 and entailed entering Klamath Lake just north of Sucker Springs after dusk. The snorkelers (three fish biologists) made forays parallel to the shoreline and then perpendicular into the area influenced by Sucker Springs. Underwater lights were used to spot fish.

The June survey was conducted over a two day period in (June 2-3) and employed several gear types that were largely targeted toward larval and juvenile fishes. These included the use of pop nets, baited Gee minnow traps, beach seines, and twin bongo nets. The surveys focused on the Goose Bay area within the same general area we had sampled in 1998. We used pop nets on June 2 to evaluate whether larval fishes appeared to have a proclivity for using certain water depths in conjunction with emergent vegetation, as reported by Dunsmoor et al. (2000). Three sets were made consisting of: shallow (1.5 ft deep) with emergent vegetation; deep (2.5 ft deep) without emergent vegetation; and deep (2.5 ft deep) with emergent vegetation. Set times were greater than 3 hours. Eight baited minnow traps (using bread) were deployed in both shallow (1 to 1.5 ft deep) areas with cover (four traps), and in open water (> 2.5 ft deep) areas without cover (four traps). Traps were checked after two hours and redeployed over night. We also completed a series of three ichthyoplankton tows using a twin-conical bongo net, with each net consisting of a 19.6 inch (50cm) diameter circular frame fitted with a tapering 11.5 ft (3.5 m) long 100 micron nitex net leading to a cylindrical capture chamber. The bongo nets were pulled behind a 19 ft Boston Whaler at a speed of about 3-5 miles per hour (mph). Tows were made at varying distances (approximately 25 yds, 100 yds, and 250 yds) offshore but parallel to the Goose Bay study site; tow duration was five minutes. We also collected two shoreline seine hauls within a segment of shoreline about 200 ft west of the pop net locations. These samples were collected using the same procedures as employed in 1998. Water quality measurements (DO, pH, conductivity, temperature) were collected using the Hydrolab7 MiniSonde Multiprobe.

On June 3rd, we recovered all of the minnow traps and conducted a second set of pop net sampling, this time using four nets. The set included nets placed as follows: shallow (1.1 ft deep) with emergent vegetation; deep (2.6 ft) without emergent vegetation; deep (2.5 ft) with emergent vegetation; and shallow (1.3 ft) with emergent vegetation. Set times were all greater than two hours. We also made a series of four shoreline seine hauls from locations progressing easterly from the minnow and pop net sampling. A sub-sample of the larval fishes collected in those hauls was preserved in 70 percent ethanol for later identification; the samples were sent to the Klamath Tribes hatchery for verification of species and developmental stage. Two off-shore bongo net tows (5 minute duration/tow) were made within pelagic areas, one within a section west and one within a section east of the mouth of the Williamson River. These two locations were selected to see if there were any patterns in larval distribution within the lake, within the vicinity of one of the major larval recruitment sources (Williamson River). The tows were made parallel to shore and both were at approximately the same distances off-shore (> 250 yds).

3.3 MAPPING OF EMERGENT VEGETATION HABITATS IN UPPER KLAMATH AND AGENCY LAKES

The identification and mapping of emergent vegetation within Upper Klamath and Agency lakes were completed by Chapin (1997a). A complete description of methods and results of the vegetation mapping analysis are provided in Appendix A; the methods are summarized below.

Chapin (1997a) identified and delineated emergent vegetation from black and white aerial photographs of Upper Klamath and Agency lakes taken from June through August 1985 at a scale of 1:30,000. Emergent vegetation was classified into three categories, and non-emergent vegetation habitats into two categories as follows:

- Emergent vegetation with *low interspersion*: areas with emergent vegetation, but that contained few to no patches of open water
- Emergent vegetation with *moderate interspersion*: areas with emergent vegetation that contained scattered patches of open water (i.e., < 1:4 ratio of open water to vegetation)
- Emergent vegetation with *high interspersion*: areas with emergent vegetation that contained abundant patches of open water (i.e., > 1:4 ratio of open water to vegetation)
- Shrub vegetation dominated by willows (i.e., *Salix spp.*)
- Open water: open lake areas and continuous channels within delineated emergent vegetation

Interspersion was considered because larval and juvenile suckers have been found in greatest number in emergent vegetation that is in close proximity to open water (Coleman et al. 1989; KRBFTF 1991; Klamath Tribes 1996).

The analysis completed by Chapin (1997a) involved the preparation of acetate overlays of 7.5 minute topographic maps (Agency Lake, Crystal Spring, Howard Bay, Modoc Point, Pelican Bay, Shoalwater Bay, and Wocus quadrangles). Each overlay contained hand drawn polygons designating the appropriate class for all emergent vegetation within Agency and Upper Klamath lakes, and the Williamson and Sprague river deltas. Once completed, the polygons were digitized in ARC/INFO compatible format by EA Engineering, Science, and Technology. R2 subsequently utilized these digitized maps to analyze the location and interspersion of emergent vegetation in Upper Klamath and Agency lakes.

3.4 ANALYSIS OF MARSH INUNDATION VERSUS LAKE LEVEL

Two data sets were available to R2 to examine the relationship between marsh elevation and lake level. The first data set consisted of lake-wide bathymetry data collected by the USBR in 1996 and the GIS data layer of marsh vegetation created by Chapin and EA (Chapin 1997a). A second data set consisted of marsh and marsh edge elevations collected by the USBR in 1998. Because the scale of the bathymetry data near the lake shoreline was relatively coarse, the ability to model bottom elevation using these data was limited. Consequently, we did not use the bathymetry data set in the analysis. However, the lake-wide bathymetry data were used in the analysis of fish movement in relation to water depth; see Section 3.7.1 for methods used in that analysis.

The USBR marsh elevation data set consisted of a grid of sampling points collected in several of the larger marsh areas around the northern side of Upper Klamath Lake, including the marsh of the Wood River delta, Upper Klamath National Wildlife Refuge between Pelican Bay and Agency Lake, and the marsh area extending from Pelican Bay to Odessa Creek along the northwest shore of the lake. Within each marsh area, the sample points were generally equally spaced, although intervals between points in different marsh areas were substantially different. These data represent a systematic, unbiased sampling of surface elevations over extensive and separate marsh areas around the northern shoreline of Upper Klamath Lake. Consequently, they can be used to assess the percentage of marsh habitat inundated at specific lake levels.

The data set was sorted to separate sample points collected from the interior marsh area and those from the marsh edge. Sample points were typically labeled in the data set provided by the USBR as "marsh" and "edge." Overlaying the GPS coordinates of the sample points on the vegetation datalayer created by Chapin (1997a) and EA, confirmed the classification of sample locations as either "marsh" or "edge." "Edge" locations were along the interface between the general marsh areas and the lake or water courses (large streams and ditches); no edge locations were associated with patches of open water within the extensive interior marsh areas. In Upper Klamath Marsh, only data collected south of the main dike running east and west approximately 2.5 miles north of Upper Klamath Lake were used. Additional data north of this line bordered by upland and dike may not be as directly connected to lake level and were removed from the data set.

Elevation data for marsh and edge from each location and in all locations were ordered by elevation. From this ordered data set, a cumulative distribution of sample points versus lake level was determined and graphed. In the combined data set, the data were weighted by the relative distance between sample points in each marsh (i.e., Wood River, Upper Klamath Marsh). This weighting insured that more closely spaced sample points from smaller marshes would not be disproportionately represented in the combined data set. The percentage of weighted marsh sample points below a specified elevation can be considered a surrogate for the percentage of marsh area inundated at that elevation. The percentage of edge sample points can be considered a surrogate for the percentage of linear marsh-water interface inundated at a given elevation.

3.5 ANALYSIS OF LAKE LEVEL VERSUS SUCKER SPAWNING HABITAT

Lost River suckers are known to spawn at several spring and one non-spring location on the eastern shore of Upper Klamath Lake (Klamath Tribes 1991; Shively et al. 2000). Lake spawning locations include Sucker, Silver Building, Ouxy, and Boulder springs, and Cinder Flats, a non-spring spawning location. Data from the Klamath Tribes, USBR, and USGS were acquired to evaluate the effects of lake level on spawning habitat availability at these sites. Klamath Tribes information consisted of:

- elevation data for spawning area at Sucker Springs surveyed in 1991,
- elevation data for spawning area at Ouxy Springs surveyed in 1995,
- locations and elevations of spawning locations from Sucker Springs in 1995, and
- depths of individual spawning locations from Sucker Springs in 1995.

Of this information, only the 1991 Klamath Tribes data have been presented in a report (Klamath Tribes 1991). The other Klamath Tribes data were provided by Larry Dunsmoor and are cited in this report as "Klamath Tribes unpublished data." The Klamath Tribes data on spawning locations consisted of over 150 observations of "many" embryos or capture of larvae (using larval emergence traps) from a sample of 454 locations that were selected using a stratified systematic random sampling protocol. Depth and bottom elevation data were recorded for each observation. The USBR and USGS data consisted of ArcView GIS files of bathymetry for the general area around each spring or spawning site.

In the analysis conducted by R2, the area known to be utilized by spawning suckers at Sucker and Ouxy springs was delineated over the bathymetry. However, at the other sites, the area within the bathymetry coverage used for spawning was not confidently known. Consequently, we restricted the analysis to Sucker and Ouxy springs. At these two sites, areas within depth classes in 0.5 ft intervals were determined from the bathymetry contours. Within the delineated spawning area, the area within each depth class was then calculated using GIS. The analysis resulted in a quantification of spawning area by depth class, which was used in assessing the effects of lake level on available in-lake spawning area.

3.6 WATER QUALITY IMPACTS ON FISH

Water quality data sets were acquired from both the USBR and the Klamath Tribes from surveys and studies conducted in the 1990s. The Klamath Tribes' data set included vertical profile measurements of pH, dissolved oxygen (DO), temperature, and ammonia (integrated over water column) at eight locations (Figure 3-2) in Klamath Lake, collected approximately biweekly from May to November from 1990 to 1998 (Kann 1998). The USBR data sets were collected from 1993 to 1998 and included continuous monitoring of pH, DO, and temperature at selected locations that varied from year to year (Figure 3-2). USBR data were also available from profile stations at approximately 13 locations that had been monitored for various periods within the six years of record (Figure 3-2). In addition, the USBR conducted an extensive radio-tagging and telemetry study of adult suckers that included vertical profiles of pH, DO, and temperature from locations where tagged fish were detected. Data from all these studies were examined, summarized, and used to determine the water quality characteristics as experienced by Lost River and shortnose suckers in Klamath Lake.

3.6.1 General Assessment of Upper Klamath Lake Water Quality

The assessment of water quality conditions in Upper Klamath Lake focused on four parameters known to affect fish populations: pH, dissolved oxygen, water temperature, and un-ionized ammonia. To exemplify variation in lake water quality with respect to pH, dissolved oxygen, and water temperature, spatial and temporal patterns of each of these parameters were examined in 1992 and 1993. This comparison relied on data collected by the Klamath Tribes and the USBR from various locations in the lake. The comparison is not intended to show the relationship of water quality to lake level. Such a relationship is quite complex, involving a number of factors, and is addressed in R2 (2001b).

Because of a clear increase in the relative importance of un-ionized ammonia to fish stress since 1995, patterns of un-ionized ammonia were

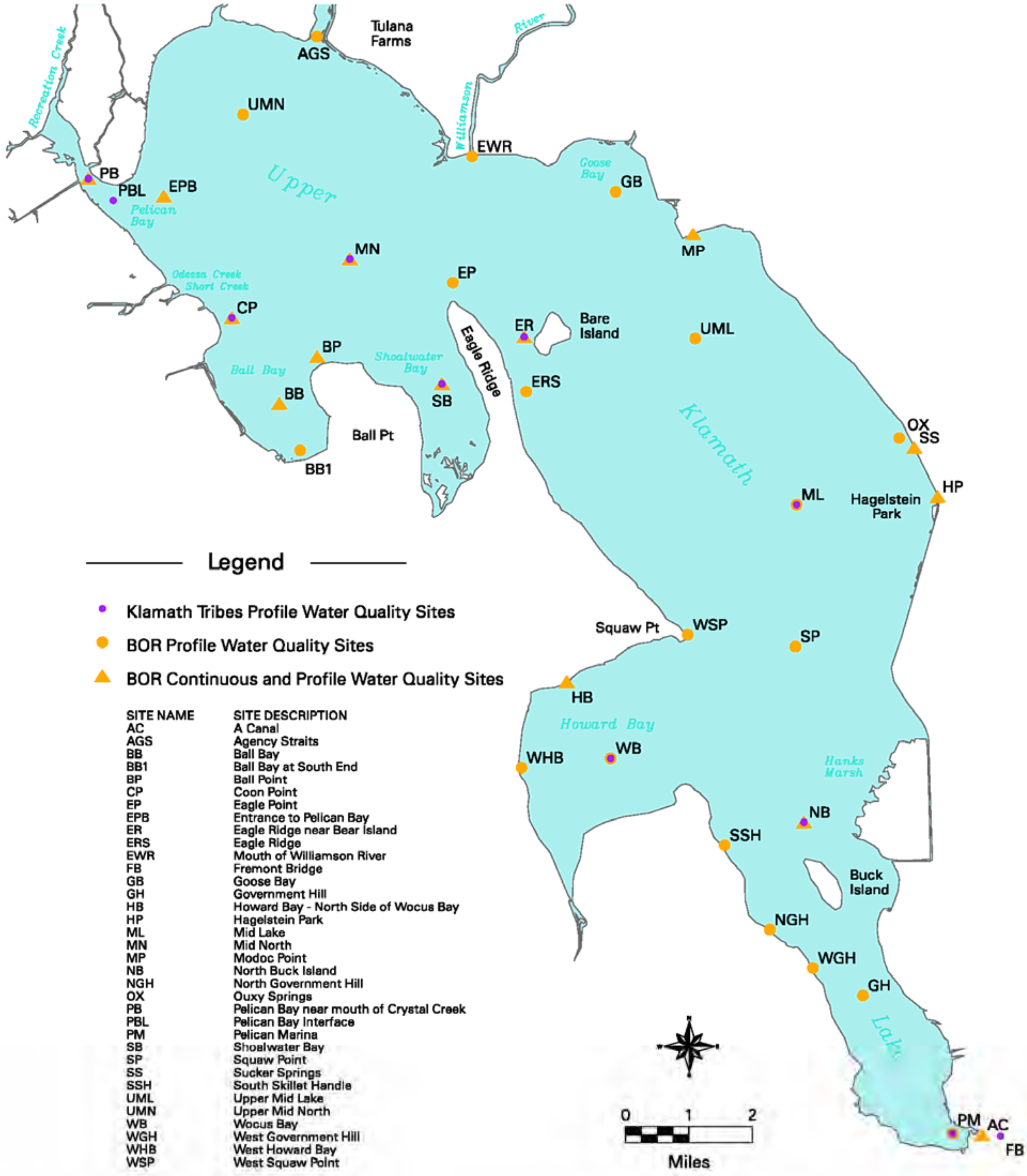


Figure 3-2. Klamath Tribes and Bureau of Reclamation water quality monitoring sites in Upper Klamath Lake, Oregon.

examined from a somewhat different approach than that of pH, DO, and temperature. This analysis focused on within and among year patterns in the exceedence of un-ionized ammonia above criteria values.

In this study, we examined the spatial and temporal pattern of un-ionized ammonia criteria exceedences by calculating the acute and chronic criteria concentrations for all data sets in the Upper Klamath Lake water quality data base (R2 2001a) that contained temperature and pH measurements coincidentally taken with integrated water column samples for total ammonia. Criteria values were calculated using the 1992 USEPA modifications to the 1984 Ammonia Criteria (USEPA 1985; USEPA 1992) equations for acute 1-hour and chronic 4-day criteria. Analysis of multiple-depth samples for ammonia in 1989 by the Klamath Tribes showed that the results of the depth-integrated water sample for ammonia could be assigned to all depths where pH and temperature were measured without substantial uncertainty (R2 2001a). This allowed the vertical profile of un-ionized ammonia to be evaluated at discrete depths at any of the sampling locations.

The acute and chronic un-ionized ammonia water quality criteria calculated for bottom waters sampled by the Klamath Tribes from 1990 through 1998 were compared to the ambient un-ionized ammonia concentrations in the depth strata most inhabited by suckers. This was done by computing the "acute ratio" (dividing the ambient concentration by the acute criteria concentration) for each location and date. This acute ratio was used to determine the degree and extent to which the ambient un-ionized ammonia concentrations might contribute to sucker species stress and potential mortalities in Upper Klamath Lake.

3.6.2 Spatial and Temporal Evaluation of Water Quality

Water quality data sets received from the USBR and the Klamath Tribes were used to generate weekly bottom water quality contours of Upper Klamath Lake with Arc-View Spatial Analyst (v2.0). Bottom water quality measurements of DO and pH were used to reflect the habitat used by suckers. The bottom water quality data set included all of the USBR fixed-station profile, telemetry profile, and Klamath Tribe profile bottom data. The daylight average values from the USBR continuous measurement stations were also included in the bottom water quality data set when the water quality probes were within 1 meter of the lake bottom (Section 3.6). Weekly contour maps were generated from July through September. While there are limitations in the accuracy of the interpolated contours due to both constraints of the data set and the capabilities of the Arc-View Spatial Analyst software (i.e., effects of bathymetric depth variation are not incorporated into the analysis), the maps generated provide a general characterization of the extent of poor water quality regions in the lake. These maps were later combined with bathymetric depth coverages of Upper Klamath Lake and overlaid with fish telemetry locations to help interpret fish movement in response to changes in week-to-week water quality patterns.

3.7 FISH MOVEMENT

The radio telemetry data used in this analysis were collected and compiled by the USBR (Peck 2000).

From 1993-1999 adult shortnose and Lost River suckers were caught and tagged at several locations in the Upper Klamath Lake Basin. These fish were then monitored throughout the year. During winter, monthly surveys were conducted by airplane to locate individual fish. During spring, summer, and fall, weekly monitoring was conducted by airplane and boat. At those times, attempts were made to collect fish depth and water quality profile data for each fish observation. Our analysis included observations and data from 1993-1998 that had been confirmed in Upper Klamath Lake via boat observations.

3.7.1 Sucker Depth Frequency Distribution

The USBR database contained a depth measurement for every sucker location detected and confirmed by boat. These data were analyzed to determine if sucker depth utilization changed seasonally and with lake level. We selected the May through June period to represent spring conditions during which water quality has not generally become degraded (although pH values rise above 9 in June) and lake levels are generally high. From 1993 to 1998, the lake levels from May-June, ranged from above 4,143 ft (in all years but 1994) to 4,141 ft in June of 1994 (Figure 2-4). We selected the July through September period to represent the period when low DO in deeper waters and high pH conditions in near surface waters tend to occur. During these summer periods, lake elevations have ranged from 4,143 ft in July, 1995 to 4,136.9 ft near the end of September, 1994. Thus, this summer portion of the radio-tagging data record encompasses nearly the entire range of possible lake water surface elevations.

3.7.2 Sucker Depth Habitat Utilization

Depth frequency distributions of radio-tagged adult Lost River and shortnose suckers were determined for the entire period of the USBR study and for each species in each year of study. However, radio-tagged adults were not uniformly distributed throughout Upper Klamath Lake. Our analysis of the USBR radio-tagged sucker locations (confirmed by boat observations) indicated that more than 90 percent were located north of an east-west line drawn just south of Bare Island. Figure 3-3 shows the array of locations in the lake where adult shortnose or Lost River suckers were detected between April and December, 1993 through 1998. It is evident from the figure that few fish were found south of the demarkation line and that heavier concentrations of observed fish locations occurred in Ball Bay, off Coon Point and off the mouth of Pelican Bay.

The depth frequency analysis was thus restricted to the observations in the northern area of Upper Klamath Lake. The frequency distributions were used to distinguish depth categories most frequently used by adult suckers (Utilization Depths) from those categories infrequently occupied (used by less than 5 percent of the population) (Avoided Depths). We used Upper Klamath Lake bathymetry to determine the area (hectares) and percentages of the lake bottom area in the same depth categories, at progressively lower lake surface elevations. The areas of utilization, avoidance, and dry lake bed were then expressed as a percentage of full-pool bottom area at declining lake surface elevations to determine the percentage of habitat lost to adult suckers at declining lake levels. The results were evaluated with respect to the importance of adequate lake-bottom habitat for adult suckers.

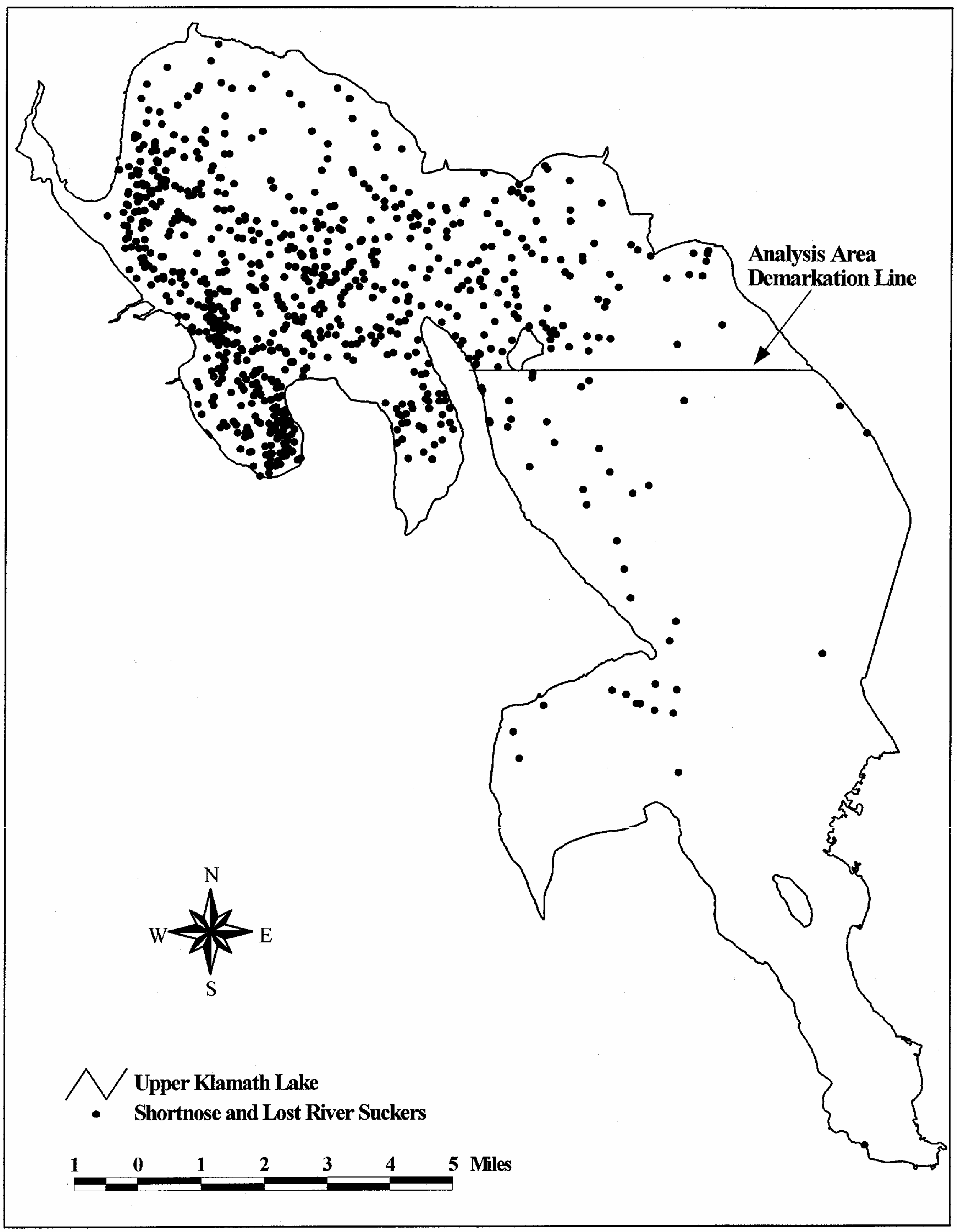


Figure 3-3. The distribution of radio-tagged adult shortnose and Lost River suckers in Upper Klamath Lake, 1993 through 1998, between April and December of each year (Lake level elevation range from 4,143 to 4,136.9 ft msl).

3.7.3 Sucker Depth Preference

An adult sucker depth preference analysis was performed using data collected near the lowest lake elevation of record in the USBR study (4,136.9 ft msl). This subset of the USBR data (90 observations) was selected because the fall period of 1994 presented little water quality stress to suckers, and deeper waters of the lake were at their lowest percentage relative to their availability at full pool lake elevation. The depth preference analysis compared the percentage of adult suckers found in 3-ft incremental depth intervals to the percentage of area of the lake bottom available in the same depth increments. A preference ratio calculation was used to determine which depth category was used by suckers relative to its availability in the lake, north of Bare Island. The ratio of percent fish use to percent lake bottom available in each category indicated preference for a particular depth category (ratio > 1.0) or avoidance of a depth category (ratio much less than 1.0). A ratio value of 1.0 indicates that the fish use of a depth category is equivalent to its availability and therefore no preference or avoidance is shown.

3.7.4 Fish Movement in Response to Water Quality Conditions

The fish locations and bottom water quality data (0.2 meters above the lake bottom) were used to characterize the water quality regime adult suckers actually experienced on a weekly basis each year. An avoidance analysis of stressful water quality conditions was conducted using a comparison of stress index values calculated for bottom waters at fixed monitoring locations with stress index values at fish locations from May through September periods in 1993 through 1998. The stress index values from both sources of data were then categorized into four groups (no stress, low stress, moderate stress, and high stress) and compared using analysis of variance (ANOVA) techniques (or Kolmogorov-Smirnov [KS] distribution statistics). The distribution of stress from the fixed monitoring locations was considered the expected values the fish would encounter in the absence of any avoidance response. Therefore, a finding that fish actually experience substantially less stress than forecast from the fixed monitoring station, would indicate the ability of adult suckers to sense and move away from water quality imposed stress.

Fish movement away from poor water quality was also examined by overlaying fish locations on GIS generated water quality maps (Section 3.6.2).

3.7.5 Water Quality Stress Index

The sublethal stress index used in analyses and evaluations in this report is the same as presented and used in R2 (2001a). The method development and supporting literature-based stress threshold values are fully explained in that document and will not be repeated here in detail**.** However, we provide brief descriptions of the stress indices used in this report to facilitate reader understanding.

3.7.5.1 Combined Stress Index

The development of the stress index and support for the low and high stress threshold values used for sucker species and rainbow trout are found in R2 (2001a). In this report, the same stress criteria and equations were used to calculate stress index values of water quality from the USBR radio telemetry study. The stress criteria are shown in Table 3-1 for pH, DO, temperature and un-ionized ammonia.

A combined stress index was developed to permit the quantification of stress from the four individual water quality parameters as a single index value. This was done by transforming the individual water quality values from their measurement units into a scale ranging from zero (no stress) to one (high stress). This was completed for each parameter by defining a unique logistical function for a species criterion, such that the low-stress criteria are given an assigned value of 0.01, and the high-stress criteria are assigned a value of 0.99. An equation of the form noted below was used with regression techniques to generate parameter-specific stress equations.

$$S = 1/(1+e^{(a+bx)}) \qquad \textbf{(EQ-1)}$$

Where

S = relative stress defined as a fractional value between 0 and 1

a and b = regression parameters unique to specific high- and low-stress criterion for a species and water quality parameter

x = the ambient water quality value measured in the lakes

A Combined Stress Index (S_c) was calculated in the same manner as fractional, and competing sources of fish mortalities are combined as described in Ricker (1975) and Kjelson et al. (1987). This is realistic, because the logistical transformation normalized all the parameters to a fractional scale between 0 and 1. By using an

Table 3-1. Low- and high-stress threshold concentrations or conditions for Klamath Lake Lost River and shortnose sucker species.

Parameter	Species	Low Stress Threshold	High Stress Threshold
pH	sucker species	9.0	9.75
Dissolved Oxygen	sucker species	6.0 mg/L	4.0 mg/L
Temperature	sucker species	25 ^oC	28 ^oC
Un-ionized Ammonia	sucker species	USEPA chronic AWQC criteria*	USEPA acute AWQC criteria

* Temperature and pH-dependent, (USEPA 1987, 1992), See R2 2001a, Appendix Table A for values.

analogous process of combining sources of competing stress, it can be shown that combined stress arising from the four water quality parameters can be calculated as:

$S_C = 1-[(1-S_{pH})(1- S_{DO})(1- S_T)(1- S_{UNH3})]$ ***(EQ-2)***

Where

S_C = combined stress from the 4 variables

S_{pH}, S_{DO}, S_T, and S_{UNH3} = stress attributable to the individual parameters: pH, DO, temperature, and un-ionized ammonia, respectively

If individual stressors are combined in this way, the combined stress variable (S_C) also has a range from 0 to 1. If one or more of the four stressors contribute high stress (value ≈ 1), S_C will approximate a value of 1. If all four parameters contribute very little or no stress (values ≈ 0), S_C will approximate a value of 0.

3.7.5.2 Stress Sum Index

Assuming that stress from different water quality parameters is, at least, additive, the individual stress index values from the co-occurring conditions of ambient pH, DO, temperature and un-ionized ammonia can also be added together to form a " Stress Sum Index" value. This "Stress Sum Index" (S_S) may more accurately portray the total water-quality imposed stress when more than one of the co-occurring stressors have individual stress values close to 1.0. S_S is calculated as:

$S_S = \Sigma(S_{pH}, S_{DO}, S_T, S_{UNH3})$ ***(EQ-3)***

Where,

S_S = Summation of stress from the 4 variables

S_{pH}, S_{DO}, S_T, and S_{UNH3} = stress attributable to the individual parameters: pH, DO, temperature, and un-ionized ammonia, respectively

The range of this stress summation index is from 0 to a maximum of 4.0, if data for 4 individual stressors are available. For the USBR radio telemetry study, un-ionized ammonia data were not collected and therefore, the maximum value for the index was 3.0. We used S_S in this report to facilitate comparisons of relative total stress pertinent to the water quality analysis associated with the radio telemetry data in Chapter 6.

4. BIOLOGY AND LIFE HISTORY REQUIREMENTS OF UPPER KLAMATH LAKE FISHES

As previously noted, Klamath and Agency lakes and their tributaries contain a variety of fish species (Table 4-1). Of these species, five are of special interest because of their current or historic importance to the Klamath Tribes. These species are: Lost River sucker, shortnose sucker, Klamath largescale sucker, rainbow (redband) trout, and chinook salmon (Table 4-2). The Lost River and shortnose suckers are currently listed as endangered under the ESA (USFWS 1988). Klamath largescale suckers were previously listed as a Category 2 species under ESA, but have recently been delisted. Because of concerns over their small and declining population levels, the recreational and subsistence fisheries for these sucker species were closed in 1987 (USFWS 1993). Redband trout consisting of both adfluvial and fluvial stocks were historically abundant in the Upper Klamath Lake Basin, and remain the focus of a large fishery by both Tribal members and the general public. Chinook salmon were likewise historically abundant in the Upper Klamath Basin, but were extirpated from the watershed due to downstream dams on the lower Klamath River (no fish passage facilities were included in the lower dams). Chinook salmon remain of interest to the Klamath Tribes because of proposals to reintroduce this species into the basin.

The discussion below synthesizes information on the life history requirements of these five fish species, with particular emphasis on suckers and on physical habitat features that may be influenced by different lake levels. Additional information concerning the biology and life history requirements of various Upper Klamath Lake fishes can be found in Bienz and Ziller (1987), Buettner and Scoppettone (1990), Logan and Markle (1993), USFWS (1993), Perkins et al. (2000a), Coleman et al. (1989), USFWS (1988), Simon et al. (2000b), and Cooperman and Markle (2000).

4.1 LOST RIVER SUCKERS

4.1.1 Distribution and Abundance

Lost River suckers are native to the Lost River and Upper Klamath basins including Upper and Lower Klamath lakes, Tule Lake, and Sheepy Lake in Oregon and California (Moyle 1976). Within Upper Klamath Lake, the Lost River sucker is native to the Williamson, Sprague, and Wood rivers, and Crooked, Seven Mile, Four Mile, Odessa, and Crystal creeks (Golden 1969; USFWS 1993). Presently, the Lost River sucker is present in Upper Klamath Lake and its tributaries (Buettner and Scoppettone 1990), the Lost River including Tule Lake (USFWS 1993), and down the Klamath River to Iron Gate Reservoir (Desjardins and Markle 2000).

Bienz and Ziller (1987) produced total adult population estimates in the Williamson and Sprague rivers of Lost River suckers of 23,123 (11,858, to 86,712 95% CI) and 11,861 (8,478 to 19,763 95% CI) fish during 1984 and 1985, respectively. Historical estimates indicate much higher population levels. For example, the snag

Table 4-1. Fish Species Present in Upper Klamath and Agency Lakes, Oregon.

Family	Species
Petromyzontidae-Lampreys	Klamath lamprey *(Lampetra similis)*
	Pacific lamprey *(L. tridentata)*
	*Pit-Klamath brook lamprey *(L. lethophaga)*
Acipenseridae-Sturgeons	*White sturgeon *(Acipenser transmontanus)*
Salmonidae-Trouts	*Chinook salmon (*Oncorhynchus tshawytscha*)
	Brown trout *(Salmo trutta)*
	Eastern brook trout *(Salvelinus fontinalis)*
	Rainbow Redband trout *(Oncorhynchus mykiss/newberri)*
Cyprinidae-Minnows	Blue chub *(Gila coerulea)*
	Fathead minnow *(Pimephales promelas)*
	Speckled dace *(Rhinichthys osculus)*
	Tui chub *(Gila bicolor)*
Catostomidae-Suckers	Klamath largescale sucker *(Catostomus snyderi)*
	Lost River sucker *(Deltistes luxatus)*
	Shortnose sucker *(Chasmistes brevirostris)*
Ictaluridae-Catfishes	Brown bullhead *(Ameiurus nebulosus)*
Centrarchidae-Sunfishes	Largemouth bass *(Micropterus salmoides)*
	Pumpkinseed *(Lepomis gibbosus)*
Percidae-Perch	Yellow perch *(Perca flavescens)*
Cottidae-Sculpins	Klamath Lake sculpin *(Cottus princeps)*
	Marbled sculpin *(Cottus klamathensis)*
	Slender sculpin *(Cottus tenuis)*

* May have been historically present but not currently a component of the Klamath Lake fish fauna

Table 4-2. Life stage periodicity for fish species of interest, Upper Klamath River basin, Oregon.

Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
REDBAND TROUT[1]	Adult	X	X	X	X	X	X	X	X	X	X	X	X
	Spawning	X	X	X	X	X	X						X
	Incubation	X	X	X	X	X	X						X
	Fry		X	X	X	X	X	X	X				
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
	Migration												
SPRING CHINOOK	Adult				X	X	X	X	X	X			
	Spawning								X	X			
	Incubation	X							X	X	X	X	X
	Fry	X	X	X	X	X							
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
	Migration			X	X	X	X	X					
FALL CHINOOK	Adult									X	X	X	
	Spawning										X	X	
	Incubation	X	X	X							X	X	X
	Fry		X	X	X	X	X	X					
	Juvenile												
	Migration					X	X	X					
LOST RIVER SUCKER	Adult	X	X	X	X	X	X	X	X	X	X	X	X
	Spawning		X	X	X	X	X						
	Incubation		X	X	X	X	X						
	Larval				X	X	X	X					
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
	Migration	X	X	X	X	X	X						
SHORTNOSE SUCKER	Adult	X	X	X	X	X	X	X	X	X	X	X	X
	Spawning				X	X	X						
	Incubation				X	X	X						
	Larval				X	X	X	X					
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
	Migration	X	X	X	X	X	X						
KLAMATH LARGE SCALE SUCKERS	Adult	X	X	X	X	X	X	X	X	X	X	X	X
	Spawning			X	X	X							
	Incubation			X	X	X	X						
	Larval			X	X	X	X	X					
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
	Migration												

[1]Includes both resident and adfluvial populations

fishery for Upper Klamath Lake adults declined from a 1968 figure of approximately 10,000 to only 687 in 1985 (USFWS 1993). This fishery was subsequently closed to all harvest. Buettner and Scoppettone (1990) found that most of the Lost River suckers collected during a fish kill in 1986 were > 19 years old, indicating that the age-structure of the mid 1980s population was heavily weighted towards large, older fish. Comparisons of 1986 and 1988 age structures indicated that little recruitment to the adult population occurred from 1970 through 1976.

Populations and age-structure of adult Lost River suckers have been variable since 1986. Buettner and Scoppettone (1990) found an influx of younger fish sampled from the 1988 spawning run, corresponding to the 1977 and 1978 year classes. Another, larger recruitment of reproductive adults occurred in 1995 (likely from the 1991 year class), with a third recruitment beginning to appear in 1998 from the 1993 year class (Perkins et al. 2000a). After 1995, however, a series of fish kills related to poor water quality during mid- to late summer have resulted in a sharp decline in the numbers of adults returning to spawn in years following fish kills with a total decrease of 84 percent for Lost River suckers between 1995 and 1998 (Buettner 1998; Perkins et al. 2000a). The decline continued into 1999 (Markle et al. 2000).

Comparisons of larval and juvenile fish abundance among years are available for years since 1995 for larvae, and since 1991 for juveniles After trying several types of gear and sampling methods, Doug Markle, David Simon, and their associates from Oregon State University (OSU) have established a systematic sampling protocol that provides a relative estimate (as catch per unit effort [CPUE]) of larval abundance and early, mid-, and late summer juvenile abundance (i.e., age 0 fish) (Simon et al. [2000a] for a synthesis of data through 1999). Presumably due to difficulties in identifying larvae and early juveniles to species, Simon et al. (2000a) combine population data on Lost River and shortnose suckers for these early life stages. Their results indicate that larval numbers were highest in 1999, relatively high in 1996 and 1997, but low in 1998. Early summer juvenile numbers were high in 1996 and 1999 and low in 1991, 1992, 1994, and 1998. Juveniles surviving to late summer-early fall were highest in 1999; relatively high in 1991 and 1995; and relatively low in other years. The year class of 1992, a year of very low summer lake levels and poor water quality, was judged by Simon et al. (2000a) to be a complete failure, although data from adult populations are needed to confirm that little to no recruitment occurred in 1997. The results of the OSU group indicate that survivorship of larvae to juveniles is extremely variable from year to year.

Although separate data for early juveniles (i.e., beach seine data) of Lost River and shortnose suckers were combined in the summary of results presented in Simon et al. (2000a), beach seine data through 1997 are separated by species in an earlier report (Simon et al. 1998). Beach seines from 1991, 1993, and 1995 to 1997 all caught much fewer Lost River suckers compared to shortnose suckers, although cast net and otter trawl catches of older juveniles for the two species were relatively similar. The differences between species found in the beach seine data suggest that Lost River and shortnose early juveniles may utilize different habitats or that the larger Lost

River sucker juveniles can better avoid beach seine nets.

4.1.2 Life History

Most Lost River suckers are adfluvial and reside primarily in Upper Klamath Lake. Most Lost River sucker spawning occurs in tributary streams but some spawn in springs located along the shoreline of Upper Klamath Lake (Scoppettone and Vinyard 1991). Spawning migrations into the Williamson and Sprague rivers begin as early as January and continue into mid-June in some years (Buettner and Scoppettone 1990; Klamath Tribes 1996; Perkins et al. 2000a) (Table 4-2). Most spawning occurs during a five-week period starting during the first three weeks in April, with peak spawning varying among years from mid-April to early May. Data suggest that there may be two runs of Lost River suckers, an early run that spawns in the upper Sprague River and a later run that spawns in the lower Sprague River and Williamson River.

Although Buettner and Scoppettone (1990) did not detect adult Lost River suckers migrating through the Sprague River fish ladder in 1987 or 1988, monitoring efforts in the past 10 years have consistently documented substantial use of the ladder by both upstream and downstream migrating suckers (L. Dunsmoor, Klamath Tribes, personal communication). Telemetry data have indicated that adult fish remain in spawning streams for only 6 to 16 days. Adults are known to travel as much as 11 mi (18 km) up the Williamson River and over 70 mi (113 km) up the Sprague River systems during spawning (Klamath Tribes 1996).

Adult Lost River suckers also spawn in numerous springs along the eastern shore of Upper Klamath Lake between Modoc Point and Hagelstein Park (Sucker, Silver Building, Ouxy, and Boulder springs) and one non-spring site (Cinder Flats) (Shively et al. 2000). Spawning activities at springs have been reported from February to early June with the peak spawning period from mid-March to mid-April (Klamath Tribes 1991; Perkins et al. 2000a; Shively et al. 2000; USFWS 1993). Spawning was reported from Harriman Springs in the northwest corner of the lake, but the last known usage of that spawning location by Lost River suckers was in 1974 (Andreasen 1975). Logan and Markle (1993) reported capture of sucker larvae from the Wood River and Crooked Creek in 1991, which indicates that spawning was occurring in these streams. These larvae may or may not have been Lost River suckers, since Logan and Markle did not identify which species was spawning. Recapture data from Shively et al. (2000) indicate that some Lost River suckers have a strong fidelity to shoreline spawning locations, which strongly suggests that there is a stock of lake spawning Lost River suckers that is distinct from a river spawning stock (Perkins et al. 2000a; Shively et al. 2000).

The Lost River sucker is the largest of the three sucker species inhabiting Upper Klamath Lake (Buettner and Scoppettone 1990). Buettner and Scoppettone (1990) conducted extensive studies of spawning in this species. They estimated Lost River suckers to be up to 43 years of age, with adults becoming sexually mature between 6 and 14 years of age, with the majority maturing at age 9. Analysis from a strong 1991 year class indicated that sexual maturity can be earlier, with male Lost River suckers becoming sexually mature at age 4 and females at age 7 (Perkins et al. 2000a). Lost River suckers are iteroparous (i.e., reproduce more than once), but may not spawn every year (Perkins et al. 2000a). Perkins et al. (2000a) estimated that fecundity (the number of eggs) ranges from 44,000 to 236,000 eggs per female, which is generally higher than the fecundity recorded for shortnose or Klamath largescale suckers.

Presently, larval Lost River suckers spawned low in the river system spend little time in the tributary systems after emergence. They move downstream towards lacustrine habitat at night shortly after swim-up in May or June (Bienz and Ziller 1987; Buettner and Scoppettone 1990, Klamath Tribes 1996). Buettner and Scoppettone (1990) found that emigration began by May 1 in 1987 and 1988, with over 90 percent of all larvae emigrating between 5 May and 5 June. Larvae and juvenile Lost River suckers were collected in the lower 6 mi (10 km) of Williamson River and in Upper Klamath Lake. Emigrants averaged 10 to 13 mm total length (TL). Buettner and Scoppettone (1990) reported that larval and juvenile Lost River suckers were frequently found with shortnose suckers, usually in schools of 5 to 30 fish.

In a more recent study, Markle et al. (2000) found that there were two peaks of larval abundance in 1999, one around the end of May and one in the middle of June. The first peak was somewhat delayed from a spawning peak in mid-April, but the second larval peak corresponded well with a May spawning peak. There was also a third spawning peak that corresponded to low, but steady, larval production through early July. Although late larval production is low, it may be disproportionately more important to the size of the year class, as median hatch date of juvenile survivors in September is often early June (Simon et al. 2000b)

Investigators at OSU have recently developed a method of aging larval and juvenile suckers using daily increments in otoliths, with lapilli the preferred otolith structure used for aging (Hoff et al. 1997; Logan 1998). Being able to age larval and juvenile suckers provides a powerful tool for relating the survivorship of year 0 fish to patterns of hatch date, growth rate, migration, distribution, and a variety of environmental variables.

The range of hatch dates determined from lapilli were found to correspond reasonably well with the timing of spawning found by a number of investigators (Andreasen 1975; Buettner and Scoppettone 1990; Golden 1969; Klamath Tribes 1996). Logan (1998) found that hatch dates of October surviving fish from 1991 to 1995 were later in years with highest October juvenile CPUE (1991 and 1993). Although this could be a result of selective survivorship favoring later born fish, Simon et al. (2000b) noted that in 1995, a year when mean hatch was earlier, spawning was also earlier.

Growth rate of young-of-the-year varies considerably from year-to-year in Lost River suckers, but there is only a weak correlation of CPUE and growth rate (Logan 1998). Growth rate of later hatched fish are significantly higher than that of earlier hatched fish, which may be due to lower water temperatures experienced by the earlier fish (Simon et al. 2000b). Regression analysis of growth rate versus a variety of environmental variables over time intervals during the 1994 and 1995 growing seasons showed a consistent relationship between growth rate and water temperature, but no consistent relationship with other variables (lake level, DO, un-ionized ammonia) (Simon et al. 2000b). In a similar analysis conducted from data collected in 1997, however, larval growth was found to be negatively correlated with pH and un-ionized ammonia, with un-ionized ammonia having the largest effect (Terwilliger et al. 2000). Un-ionized ammonia concentrations in Upper Klamath Lake were much higher in 1997 compared to 1994 and 1995. Because the toxic un-ionized ammonia component of total ammonia increases with pH, it is likely that these two factors interact to reduce growth in larval suckers.

Based on otolith increment analysis, larvae appear to be between 25 and 32 days old when they first reach the mouth of the Williamson River from the spawning areas (Logan 1998). Larvae appear to enter the lake from the Williamson River quickly after entering the flexion stage of larval development (Cooperman and Markle 2000).

4.1.3 Food Habits

Lost River sucker larvae, like all other larval fishes, need to feed before total absorption of their egg yolk, which occurs about when flexion begins and larvae are entering Upper Klamath Lake from the Williamson River (Klamath Tribes 1996; Cooperman and Markle 2000). Investigations by both OSU (Cooperman and Markle 2000) and Klamath Tribes (1996; L. Dunsmoor, unpublished data) biologists have consistently shown that larvae collected in the lower Williamson River have empty guts, indicating they must begin feeding soon or they will die. Biologists from the Klamath Tribes (1996) hypothesize that larval suckers subsist mainly on zooplankton and that larval survival is dependent on the timing of zooplankton blooms and the movement of larvae into emergent vegetation. Because there is little emergent vegetation in the lower Williamson River, larvae do not have nursery habitat and more abundant food sources available to them until they reach Upper Klamath Lake.

Buettner and Scoppettone (1990) found that, volumetrically, the diets of juvenile Lost River suckers were dominated by benthic detritus and algae. Animal matter was numerically dominated by *Chydorus*, a benthic zooplankton, and volumetrically by chironomids (Buettner and Scoppettone 1990). The most thorough information available on food habits of adult Lost River suckers is from Clear Lake Reservoir (Parker et al. 2000). Lost River suckers are primarily benthivorous, in contrast to the mostly planktivorous shortnose suckers. Chironomid larvae were the most common benthic invertebrates consumed by Lost River suckers, with only minor amounts of other invertebrates. Detritus comprised 35 to 57 percent of gut volume, much of which might be ingested with the chironomid larvae.

4.1.4 Habitat Requirements

Migration into the spawning tributaries appears to begin when water temperatures average 8 to 10°C (Buettner and Scoppettone 1990) and peaks when water temperatures are 10 to 15°C (Perkins et al. 2000a). For lake spawning suckers, Sucker Springs provides a constant water temperature of 15°C during spawning. Spawning took place when discharge averaged 1059 cubic ft/sec (cfs) (30 m^3/s) in the Williamson River and 530 cfs (15

m^3/s) in the Sprague River (Buettner and Scoppettone 1990). Lost River suckers spawn near the bottom, dispersing their eggs over larger gravel, cobble and boulder substrates (Buettner and Scoppettone 1990; USFWS 1993). However, USFWS (1993) indicates that spawning preference is more flow related than substrate related. River spawning habitat consists of water depths ranging from 0.36 to 2.3 ft/s (11 to 70 cm/s), mean water column velocities ranging from 0.60 to 4.0 ft/s (18 to 125 cm/s), and focal velocities of 0.2 to 2.9 ft/s (6 to 85 cm/s) (Buettner and Scoppettone 1990). Spring spawning habitat has only been examined in detail at Sucker Springs. Research by the Tribes in 1995 (Klamath Tribes, unpublished data) showed that greater than 95 percent of spawning locations (i.e., where embryos were observed) were in depths greater than 1 ft (30 cm), with approximately 50 percent in depths greater than 2.3 ft (70 cm).

After migration from the spawning areas, adult Lost River suckers congregate in the northern end of Upper Klamath Lake (Buettner and Scoppettone 1990; Peck 2000). The northern portion of Upper Klamath Lake may have limited areas of better water quality conditions during the spring and summer months than the rest of the lake (R2 2001b; USGS 1996). In part, this is because the northern portion of the lake receives over 90 percent of the lake's inflow, 14 percent coming from springs and 79 percent arriving in the form of stream flow (Buettner and Scoppettone 1990). In 1986 Bienz and Ziller (1987) observed over 100 large suckers in Pelican Bay, a well-oxygenated area that is fed by cold water springs. The authors hypothesized that these fish were attempting to avoid the low DO and high pH levels in other areas of the lake by congregating in the bay, where DO levels were at least 6 mg/l during sampling. Similarly, Coleman et al. (1988) found higher water quality conditions in Pelican Bay than in the rest of Upper Klamath Lake; mean summer temperatures there were 16.2°C and DO levels were 12.1 mg/l compared to mean temperatures and mean DO for other lake sites of 19.2°C and 9.2 mg/l. Use of freshwater inflow areas have been pronounced during fish kill events (USBR 1996). During a 1995 fish kill, small groups of "unhealthy" Lost River and shortnose suckers were seen in Pelican Bay, Harriman Springs, Williamson River, Odessa Creek, and Short Creek (USBR 1996). During the kills of 1996 and 1997, many dead adult suckers were found in places like Pelican Bay, and virtually all of the living adults seen in these areas were obviously near death; no significant use of these areas as refuges was documented during these kills (L. Dunsmoor, Klamath Tribes, personal communication). Fish using these areas may undergo cold water shock, as temperature differences of up to 10°C between the upper lake and inflow areas have been recorded (USBR 1996). Interestingly, none of the radio tagged adult shortnose or Lost River suckers were observed in Pelican Bay during the six-year period, 1993 to 1998, of the USBR radio tagging study (Figure 3-3).

As noted above, larval Lost River suckers move downstream to lacustrine habitats in Upper Klamath Lake and the lower Williamson River immediately after swim-up during daytime observations (Buettner and Scoppettone 1990). Ninety percent of the swim-up and metalarvae were found in water depths less than 1.6 ft (50 cm) (Buettner and Scoppettone 1990). Most of these larvae were in water of zero velocity and found over sand, mud, and concrete substrates. Many of the larvae maintain position along the margins of Upper Klamath Lake and the lower Williamson River, inhabiting near surface waters in narrow bands of emergent vegetation and pockets of open water surrounded by emergent vegetation (Coleman et al. 1989; Klamath Tribes 1996).

Results of several studies have shown the importance of the open water/emergent vegetation interface for larval suckers. Pop net sampling for larvae in the lower Williamson River and Goose Bay has shown significantly higher usage of emergent vegetation areas then nonvegetated sites (Klamath Tribes 1995). Cooperman and Markle (2000) found almost all larvae in shoreline areas of Upper Klamath Lake near the Williamson River and at Goose Bay to be associated with emergent or submergent habitat. Studies by Dunsmoor (1993) and the Klamath Tribes (1995) indicated that emergent vegetation-like structures significantly reduce predation on larval suckers in a laboratory setting. Vegetation also likely provides shelter from turbulent flows and waves within Upper Klamath and Agency lakes. Evidence shows that while migrating to lacustrine habitats, young suckers move to shallow shoreline areas of the river during the day (USFWS 1993).

Buettner and Scoppettone (1990) found that juvenile Lost River suckers were frequently found along shoreline areas of Upper Klamath Lake in areas with gentle slopes and water depths less than 4.3 ft (130 cm). These juvenile suckers were found primarily in areas devoid of cover, over sand and mud substrates, but in relatively close proximity to macrophytic vegetation. Juvenile suckers were rarely found within dense beds of *Scirpus* vegetation, which lines much of the available shoreline. Coleman et al. (1989) similarly noted that juvenile suckers up to 100 mm Total Length (TL) were seldom seen within beds of aquatic vegetation in Upper Klamath Lake and Agency Lake. Data from Simon et al. (2000b) indicate that juvenile suckers tend to be caught more on cobble or gravel substrates than sand or finer substrates. They suggest that this substrate preference may explain why juveniles are seldom caught in marsh vegetation, which is typically associated with fine textured substrates.

Determining the habitat preference of juvenile suckers, however, depends in part on the type of gear used. As larval and juvenile suckers develop, their increasingly greater swimming ability enables them to avoid gear typically used to capture younger fish. Consequently, OSU investigators have established a sampling regime for young-of-the-year fish that progresses from larval trawls, to beach seines, to cast nets, and finally to otter trawls (summarized in Simon et al. 2000a, 2000b). Because abundance of young juveniles are determined using beach seines and cast nets which cannot be deployed in emergent vegetation, their sampling regime excludes emergent habitat. As a result of these sampling logistics, the extent to which juvenile suckers use emergent habitats has received little attention until recently.

R2 (as noted in this report) captured juvenile suckers in shoreline emergent vegetation habitats in 3 of 7 locations sampled by seining during August 20-21, 1998. Sampling of these habitats by seines was problematic due to snagging of nets on debris and vegetation, and the tendency for the bottom of the nets to slide up and over the vegetation thereby allowing fish to escape. Thus, gear type and sampling efficiency likely does factor into whether juvenile suckers are captured within emergent vegetation. Indeed, juveniles were captured in late July in marshes near Goose Bay using dip nets (Klamath Tribes 1996).

The USGS has recently initiated a study to evaluate juvenile sucker utilization of emergent vegetation habitats. Sampling was completed using 0.25 in. mesh trap nets rather than seines. Preliminary results indicate that juvenile suckers do use emergent vegetation, including both shoreline areas as well as off-shore *Scirpus* habitat islands (R. Shively, USGS, personal communication). Sampling to date has been limited primarily to areas northwest of Goose Bay and near Tulana Farms, and an area southeast of Modoc Point. Shively reported that capture of juvenile suckers in emergent vegetation continued up into September, but that fewer numbers were found in the later samplings. He hypothesized that declining water levels either decreased suitability of emergent vegetative habitats, decreased effectiveness of their trap nets, or both, resulting in decreased catches later in the sample period. In preliminary match-pair sets of traps placed within marsh and open water areas, Shively (R. Shively, USGS, personal communication) indicated they have found as many or more juveniles in marsh areas as in open water habitats. This pattern was apparent until mid-August, after which numbers of juvenile decreased in the vegetated areas.

There is little evidence that juvenile suckers move offshore later in the summer, as there is no consistent pattern of increased catches in offshore otter trawls as nearshore cast net catches decline (Simon et al. 2000b). However, substantial numbers of age 0 shortnose and Lost River suckers were captured offshore in Clear Lake and Gerber Reservoir in late summer of 1993 (M. Buettner, personal communications). The OSU data indicate that juveniles have moved out of the northern one-third area of Upper Klamath Lake by October, including areas off the marshy shoreline of Upper Klamath Marsh. While the highest concentrations of larval and young juvenile fish are found from the mouth of the Williamson River south to Hagelstein Park, the highest numbers of juveniles in fall are found in three areas: the southern end of the lake south of Buck Island, the eastern shoreline from Modoc Point to Hagelstein Park, and the Shoalwater Bay/Ball Bay area. It is important to note, however, that these juvenile sucker distributions are based on a sampling regime that specifically excluded emergent vegetation.

4.2 SHORTNOSE SUCKERS

4.2.1 Distribution and Abundance

The shortnose sucker is native to Upper Klamath Lake and its tributaries and the Lost River system (Moyle 1976; Scoppettone and Vinyard 1991; USFWS 1993). Shortnose suckers may have gained access to the Lost River through a series of irrigation canals constructed by the USBR (Moyle 1976). However, their presence in Clear Lake, which has been closed to upstream migration since Clear Lake Dam was built in 1910, provides evidence that this species is native to the Lost River system (USFWS 1993). Currently, shortnose suckers are found from Upper Klamath Lake, its tributaries, the Klamath River downstream to Iron Gate Reservoir, and Clear

Lake, Gerber Reservoir, and Lost River and Tule Lake in the Lost River system (USFWS 1993).

In the 1980s, population levels of the shortnose sucker were found to be critically low (Bienz and Ziller 1987; USFWS 1988). Bienz and Ziller (1987) estimated the spawning population of shortnose suckers in 1984 to be 2,650 fish (95% CI of 1,026 to 10,461). In 1985, a population estimate was not made due to low numbers of recaptured fish. Catch per unit effort indices were used to assess the population of shortnose suckers in 1984 through 1986. Statistics indicate a decline of 44 percent (17.6 and 9.9 shortnose suckers per trip) between the 1984 and 1985 electrofishing efforts, and a decline of 67 percent (9.9 and 3.3 shortnose suckers per trip) between the 1985 and 1986 indices (Bienz and Ziller 1987). In 1986, the fish kill in Upper Klamath Lake during mid-August only 7 shortnose suckers were collected (Buettner and Scoppettone 1990).

Abundance of shortnose suckers spawning in the Williamson and Sprague rivers was much lower than that of Lost River suckers in 1984 and 1985, but from 1995 through 1999 it has been higher (Perkins et al. 2000a; Markle et al. 2000). However, shortnose suckers have experienced even larger declines than Lost River suckers since 1995, with an estimated total decrease in the spawning population of 95 percent from 1995 to 1998 (Perkins et al. 2000a). Abundance of shortnose suckers were slightly lower in 1999 compared to 1998 (Markle et al. 2000).

Age structure of shortnose suckers collected from 1986 to 1988 was weighted toward older fish, as with Lost River suckers (Buettner and Scoppettone 1990). However, unlike what data for Lost River suckers showed, there did not appear to be a greater influx of younger shortnose suckers into the Williamson and Sprague rivers spawning populations in 1988 compared to 1985 and 1986 (Buettner and Scoppettone 1990). Similar to Lost River suckers, there was substantial recruitment of adults into the population in 1995 and 1998, probably corresponding to strong year classes in 1991 and 1993 (Perkins et al. 2000a).

As discussed in Section 4.1.1, early juveniles of shortnose suckers were much more abundant than those of Lost River suckers in beach seines from 1991, 1993, and 1995 to 1997 (Simon et al. 1998). These differences suggest that early juvenile shortnose and Lost River suckers may have different patterns of habitat use. In later summer and fall, when data are reported separately for each species, numbers of juveniles are usually similar between the two species, with some exceptions (Simon et al. 2000b). For example, in fall 1994 numbers of shortnose sucker juveniles were relatively low, compared to relatively high numbers of Lost River sucker juveniles; in fall 1996, their relative abundance was just the opposite.

4.2.2 Life History

Like the Lost River sucker, shortnose suckers are generally adfluvial and, thus, migrate to tributary areas to spawn and then move downstream quickly, spending most of their time in Upper Klamath Lake (Coleman et al. 1989; Buettner and Scoppettone 1990). Spawning migrations begin in February and continue through May (Bienz and Ziller 1987; Buettner and Scoppettone 1990) (Table 4-2). Buettner and Scoppettone (1990) found that spawning peaked from April 15 to May

15. Both the Williamson and Sprague rivers are used for spawning. Visual observations indicate spawning shortnose suckers move at least 12 mi (20 km) upstream of Upper Klamath Lake (Buettner and Scoppettone 1990). Some reports have stated that very few spawning fish enter the Sprague River Dam fish ladder, (Bienz and Ziller 1987; Buettner and Scoppettone 1990). However, L. Dunsmoor (Klamath Tribes, personal communication) stated that migration of shortnose suckers through the fish ladder to upstream spawning locations is greater than these reports indicate. In addition to the fluvial habitats, shortnose suckers have been observed spawning at Sucker, Ouxy, and Silver Building springs and at Cinder Flats along the eastern shore of Upper Klamath Lake; numbers of shortnose suckers were much lower than the number of spawning Lost River suckers at these locations (Shively et al. 2000; USFWS 1993).

Demographic studies indicate that shortnose suckers can live for at least 25 years. Collections within Upper Klamath Lake found individuals in 12 age classes ranging from 4 to 27 years old (Scoppettone 1988; Buettner and Scoppettone 1990). Most of these fish began spawning at age 6 and 7; however, Perkins et al. (2000a) found that both male and female shortnose suckers were recruited into the adult populations by age 4+. Summarizing data from a variety of sources, Perkins et al. (2000a) estimated fecundity of shortnose suckers to range from 18,000 to 72,000 eggs per female. This represents a much lower figure than that of the Lost River sucker, and may be related to the shortnose sucker's smaller body size, which rarely exceeds 52 cm fork length (FL) in Upper Klamath Lake (Scoppettone and Vinyard 1991).

Patterns of larval emigration from spawning sites to Upper Klamath and Agency lakes are similar to those for Lost River suckers, with which they are often found (NBS 1996). Emigration from spawning sites begins soon after hatching, and leads to rapid downstream movement (USFWS 1993). Buettner and Scoppettone (1990) found that larval emigration began by May 1 in 1987 and May 11 in 1988, with most of the emigration taking place over a six-week period. Peak migration occurred at night between 0200 and 0600 hrs. Larvae ranged from 11 to 13 mm TL.

4.2.3 Food Habits

Limited data on food habits of juvenile shortnose suckers indicates a dietary overlap with the Lost River sucker. As a consequence, information on juvenile diets for Lost River sucker noted above likely apply to shortnose sucker as well. A benthic omnivorous diet consisting of cladocerans, detritus, chironomids, *Chydorus*, and algae has been reported for the juvenile shortnose sucker (Buettner and Scoppettone 1990).

Parker et al. (2000) reports that adult shortnose suckers from Clear Lake Reservoir feed primarily on zooplankton. Cladocerans were the most common and abundant invertebrates found in the guts of adult shortnose suckers, with copepods, ostracods, and chironomid larvae also found in smaller but variable amounts. Detritus composed a much smaller percentage of gut volume in shortnose suckers, ranging from 7 to 37 percent, than in Lost River suckers. The terminal mouth morphology of shortnose suckers, which is unique among western catostomids, is clearly related to its largely planktivorous diet.

4.2.4 Habitat Requirements

The spawning activity of shortnose suckers peaked from April 15 to May 15 in 1987 and 1988 when mean daily water temperatures ranged from 9 to 15ºC in the Williamson River and 9 to 17ºC in the Sprague River (Buettner and Scoppettone 1990). Similar shortnose sucker spawning times were found by Beak (1987) in Copco Reservoir where shortnose suckers gathered in a staging area in the upper reservoir by the first two weeks in April 1987. As noted above, shortnose suckers also utilize spring spawning areas in Upper Klamath Lake (Shively et al. 2000). Spawning in the Williamson and Sprague rivers occurred in mean water velocities ranging from 0.6 to 4.1 ft/s (18 to 125 cm/s) and focal velocities from 0.3 to 2.4 ft/s (9 to 88 cm/s). Spawning took place in shallow riffle areas 0.4 to 2.3 ft (11 to 70 cm) deep over gravel and cobble substrates (Buettner and Scoppettone 1990). Coleman et al. (1989) suggest that shortnose suckers select slightly smaller substrates for spawning than the Lost River sucker. Like the Lost River sucker, shortnose suckers appear to select flow related variables rather than substrate when choosing spawning sites (USFWS 1993). Beak (1987) observed shortnose sucker spawning after fluctuations in discharge began in the lower Klamath River, and concluded that discharge did not play a key factor in timing of shortnose sucker spawning activity. Water depth is used for cover, but cover does not appear to limit spawning. Coleman et al. (1989) found that fish would spawn during the night in areas with poor cover. Following spawning, shortnose suckers migrate downstream to lacustrine habitats (USFWS 1993).

As with Lost River suckers, several studies suggest that the northern portion of Upper Klamath Lake is important for juvenile and adult fish during the spring and summer months. First, radio-tagged fish were predominantly found in the northern portion of the lake. For example, two radio-tagged fish were tracked to the Thomason Creek area in the northern part of Upper Klamath Lake by Buettner and Scoppettone (1990); and more extensive telemetry data collected by the USBR from 1993 through 1999 show almost all the radio-tagged fish occurring in the northern portion of Upper Klamath Lake (Peck 2000). Second, netting studies consistently found greater numbers of shortnose suckers in the northern portion of the lake (Markle and Simon 1994), where large numbers of larvae were seen near the edge of aquatic vegetation. The USBR (1996) reports that suckers were restricted to the upper two-thirds of Upper Klamath Lake during 1993-1995 radio-tagging studies. No suckers were reported below Howard Bay, with most of the fish using off-shore areas 3.3 to 29.5 ft (1-9 m) in depth. Bienz and Ziller (1987) captured 15 shortnose suckers between July 2 and August 28 in nets placed in Upper Klamath Lake and Agency Lake. No captures in this study were made in the southern portion of Upper Klamath Lake. Extensive sampling of the southern portion of the lake by the USBR in 1998 resulted in capture of few adults (M. Buettner, USBR, personal communication).

Larval and juvenile shortnose suckers were found together with Lost River suckers in Upper Klamath and Agency lakes and the lower Williamson River (Buettner and Scoppettone 1990). However, identification problems make larval and juvenile habitat associations difficult (L. Dunsmoor, Klamath Tribes, personal communication).

4.3 KLAMATH LARGESCALE SUCKER

4.3.1 Distribution and Abundance

The Klamath largescale sucker resides in both fluvial and lacustrine habitats (adfluvial populations), attaining its largest size in lakes (Coleman et al. 1989; Buettner and Scoppettone 1990). Historical distribution of Klamath largescale sucker includes the entire Williamson/Sprague watersheds. Populations of Klamath largescale suckers reside in the upper Sprague and Williamson rivers, Agency and Upper Klamath lakes, and J.C. Boyle and Gerber reservoirs (Bienz and Ziller 1987). Within the Upper Klamath Basin, this species is widely distributed (Bienz and Ziller 1987).

Adfluvial Klamath largescale sucker populations in the Williamson and Sprague rivers were estimated to be 8,698 (95% CI 4,932 to 16, 786) and 6,986 (95% CI 4,426 to 11,393) fish in 1984 and 1985, respectively (Bienz and Ziller 1987). The authors stated that "the status of the Klamath largescale population in the Klamath watershed is good when compared to the Lost River or shortnose sucker." A decrease of approximately 20 percent in the number of fish passing the Sprague River fish ladder was noticed over the course of their study from 1984 to 1985. However, year to year variation is evident. For example, Buettner and Scoppettone (1990) reported that 527 adult Klamath largescale suckers were captured at the Sprague River fish ladder in 1987, while 164 were captured in 1988.

4.3.2 Life History

Adult fish begin entering the Sprague River by early March and late April, peaking in numbers in late March (Table 4-2). This is approximately 20 to 40 days earlier than the spawning migration period for shortnose and Lost River suckers (Buettner and Scoppettone 1990). Telemetry data from three adult Klamath largescale suckers indicate that fish may migrate as far as 79 mi (128 km) upstream of the Sprague River fish dam and spend from 10 to 28 days in the Sprague River before returning to Upper Klamath Lake (Coleman et al. 1989; Buettner and Scoppettone 1990).

Ages of 66 Klamath largescale suckers ranged from 4 to 31 years old (Buettner and Scoppettone 1990). The authors concluded that male Klamath largescale suckers become sexually mature at 4 to 7 years of age, while females mature at 5 to 7 years. Unlike Lost River and shortnose suckers, the presence of younger spawning fish in 1988 indicated relatively recent recruitment in Klamath largescale suckers (Buettner and Scoppettone 1990). However, Buettner and Scoppettone (1990) concluded that smaller fish entering the Sprague River fish ladder were of fluvial origin, and noted that the presence of both adfluvial and fluvial forms of Klamath largescale suckers may confound their age and growth data. They also observed fecundity numbers ranging from 13,500 to 120,000 eggs per female.

Klamath largescale suckers emigrate at a variety of ages from swim-up larvae to early juveniles (Buettner and Scoppettone 1990). The ability to distinguish shortnose suckers and Klamath largescale suckers is currently unreliable for larval/early juvenile stages (L. Dunsmoor, Klamath Tribes, personal communication). Buettner and Scoppettone (1990) found that like Lost River and shortnose larvae, Klamath largescale larvae migrate mainly at dark, with a bimodal migration peaking at 2100 to 2300 hrs and again from 0300 to 0500 hrs. In 1987 larval emigration began on April 21, with a majority taking place over a period of five weeks starting on May 7 and running to June 15. Larvae were not captured in 1988 until May 5. However, because of difficulty in identifying larval suckers to species, these data on Klamath largescale larval migration should be considered cautiously. Emigration had ceased in both years by the middle of July.

4.3.3 Food Habits

Like the two other species of suckers, Klamath largescale suckers are benthic oriented omnivorous feeders, consuming primarily zooplankton and detritus in largest quantities (Buettner and Scoppettone 1990). As a consequence, information on juvenile diets for Lost River sucker likely apply to Klamath largescale sucker as well.

4.3.4 Habitat Requirements

Adult migration into the Sprague River fish ladder by Klamath largescale suckers begins when mean daily temperature in the Sprague River reach 6 to 8ºC (Coleman et al. 1989; Buettner and Scoppettone 1990). The only known spawning area is a spring emerging from the side and bottom of a pond with an outlet to the Sprague River known as Kirk Springs (Buettner and Scoppettone 1990). Here, Klamath largescale spawning activity was observed in a pond-like location in water of zero velocity, depths of 2.4 to 3.4 ft (73 to 104 cm), temperatures of 12 to 13ºC, and substrate dominated by sand and gravel. Water depths greater than 2.9 ft (0.9 m) were used as cover during the day (Coleman et al. 1989).

Klamath largescale larvae and juveniles were found in the upper reaches of Sprague and Williamson rivers, lower Williamson River, and Upper Klamath and Agency lakes (Buettner and Scoppettone 1990). However, identification problems make larval and juvenile habitat associations difficult. Fry and juveniles in rivers were found over gravel and cobble substrates with sites having depths and water velocities similar to those of sites used by Lost River and shortnose suckers (Buettner and Scoppettone 1990). Klamath largescale sucker tolerances to water quality parameters are reportedly similar to those of the shortnose sucker (Castleberry and Cech 1992).

4.4 RAINBOW/REDBAND TROUT

4.4.1 Distribution and Abundance

Rainbow trout are widely distributed throughout the Klamath Basin including Agency and Upper Klamath lakes (Logan and Markle 1993). Native rainbows of Upper Klamath Lake are unique in terms of their morphology, life history, allozyme variation, and disease resistance (ODFW 1995) and have been classified as redband trout (*O. m. newberri*) by Behnke (1992). For the remainder of this report, native rainbow trout will be referred to as redband trout.

Currens (1992, cited in Logan and Markle 1993) has found both “lake form” (adfluvial) and “stream form” (fluvial) redband trout in the Upper Klamath Lake Basin. According to Ken Currens (cited in Logan and Markle 1993), steelhead (anadromous rainbow trout) were native to Upper

Klamath Lake suggesting that both forms of resident redband trout have a common ancestor with steelhead. Steelhead are known to have migrated at least as far as Klamath Falls before the construction of Copco Dam in 1917 (ODFW 1995). In addition to native redband trout, hatchery rainbow trout have been stocked in the Upper Klamath Lake Basin since 1922 (Logan and Markle 1993). Nine different populations of redband trout were identified by ODFW (1995) in Klamath Lake. Redband trout are listed as a "sensitive" species in Oregon and federal Category 2 candidate species (ODFW 1995).

Status of the four different gene conservation units in/around Klamath Lake is presented in ODFW (1995). The Klamath Lake population in the lower Williamson River appears to be in a stable to increasing condition at present time. Wood and lower Sprague rivers are witnessing depressed redband populations, which have been correlated to habitat degradation caused by overgrazing and irrigation withdrawals. Similar problems are influencing redband trout populations in the upper Williamson River and upper Sprague River gene conservation groups.

4.4.2 Life History

Of the nine different populations of redband trout in the Klamath Lake gene conservation unit, one is fluvial, three are resident, four are adfluvial, and one is resident/adfluvial in nature. Other populations in the Jenny Creek, upper Williamson River, and upper Sprague River gene conservation groups are dominated by the resident life history (ODFW 1995). Despite the proximity of these different populations of redband trout in the basin, little gene flow appears to take place between them (ODFW 1995). The steelhead life history, probably introduced to Upper Klamath Lake when the Modoc Basin was opened to the Pacific Ocean, is no longer present in the Upper Klamath Basin (ODFW 1995).

4.4.3 Food Habits

Rainbow trout are generally considered opportunistic carnivores, consuming a vast array of food items (Raleigh et al. 1984). Macroinvertebrate drift, varying with availability, comprises the greatest majority of the summer prey items, while benthic aquatic invertebrates dominate winter diets of rainbow trout (Raleigh et al. 1984).

4.4.4 Habitat Requirements

In the Upper Klamath Lake System, the redband trout life history allows them to take advantage of highly productive rearing areas in lakes and marshes while migrating to small streams and rivers to spawn (Table 4-2) (ODFW 1995). The adfluvial population of redband trout in Upper Klamath Lake can access riverine habitats in the Williamson, Wood, and Sprague river basins.

Human intervention has caused the loss of some of the components of the lake/marsh/stream ecosystem that the redband trout utilize. The use of diking, channeling, and draining marshlands for agricultural pursuits have created a void in the habitat of the redband trout (ODFW 1995). Loss of these systems interrupts the migratory nature that is so important in the redband trout life history.

Optimal adult spawning habitat consists of riffle and run habitats for spawning, interspersed with areas of deep, slow water and abundant instream cover for holding and resting. Female rainbow trout select redd sites near the head of a riffle composed of gravel substrates (Raleigh et al. 1984). Water temperatures vary from 4 to 9ºC during the spawning process, with preferred water velocities from 1.3 to 2.9 ft/s (40 to 90 cm/s) (Bjornn and Reiser 1991).

Bisson et al. (1982) found that fry inhabit riffles associated with large woody debris. A shift in habitat occurs as fry age, with individuals moving into deeper and swifter water (Bisson et al. 1982; Everest and Chapman 1972). Bisson et al. (1988) found age-1 steelhead in a variety of velocities, tending to display a preference for pools with swift thalwegs. Juvenile rainbow trout can spend up to two summers in a stream and two summers in a lake before they become sexually mature (Greeley 1933).

Rainbow trout lacustrine habitat is characterized by clear, cold, oligotrophic lakes (Raleigh et al. 1984). The redband trout in Upper Klamath Lake have adapted to a naturally eutrophic system that has more recently become hypereutrophic. Raleigh et al. (1984) reported optimal DO levels to be $7 mg/L at water temperatures #15ºF and $9 mg/L at temperatures > 15ºF. Redband trout typically retreat to spring-fed areas like Pelican Bay when water quality in Upper Klamath Lake becomes poor.

4.5 CHINOOK SALMON

4.5.1 Distribution

Chinook salmon are not currently present within Upper Klamath or Agency lakes or their tributaries. However, historic reports indicate that the species was present before the construction of impassable dams downstream of the lakes (Fortune et al. 1966; Logan and Markle 1993). Although there is uncertainty about the life history of this extirpated chinook stock, populations of chinook salmon did exist in the Upper Klamath Basin.

4.5.2 Life History

Like all Pacific salmon species, chinook salmon are anadromous and semelparous. Within this life history pattern, chinook salmon vary in regards to ocean migration, estuarine and oceanic residence, ocean migration, and freshwater return timing. Two behavioral forms are present among chinook salmon stocks (Table 4-2). “Stream-type” individuals typically spend more than one year in freshwater residency as juveniles before migrating to the ocean, returning to spawn in the spring or summer (Healey 1991). “Ocean-type” chinook salmon normally spend less than three months in freshwater before migrating to the ocean as juveniles and returning to freshwater to spawn in the fall as adults. Nehlsen et al. (1991) reported both a spring-summer and fall chinook stock within the Klamath River.

4.5.3 Food Habits

Mature chinook salmon, like all Pacific salmon, cease all feeding activities when they begin their freshwater residency stage before spawning. Larval and adult insects are the dominant foods of juvenile chinook salmon during their freshwater residency (Kjelson et al. 1982; Becker 1973), suggesting that juvenile fish feed within the water column on invertebrate drift. A similar opportunistic feeding strategy is employed by smolts when they begin their estuarine residency period, targeting chironomid larvae, pupae, and adults even when other prey items are available in greater densities (Sheffler et al. 1992; Kjelson et al. 1982). As chinook grow, they tend to shift their diet towards the larger prey items, which inhabit deeper waters of the estuary, eventually selecting for larval and juvenile fishes (Healey 1991). The majority of ocean feeding studies are composed of larger chinook salmon captured in the commercial fishery (Healey 1991). Spring and summer months appear to be the most active feeding times of the year, with the bulk of the food consumed off the coast south of Washington from April through June. July and August appears to be the months of heaviest feeding of chinook salmon off the southwest coast of British Columbia. The periodicity of feeding activities for these two regions has been related to the dietary differences between the chinook salmon that reside there (Healey 1991). Chinook feeding north of Washington target herring (*Clupeidae spp*.) and sand lance (*Ammodytes hexapterus*) while prey items are dominated by anchovies (*Engraulis mordax*) and rockfishes (*Scorpaenidae spp*.) south of Washington.

4.5.4 Habitat Requirements

Upon completion of spawning, all mature adult chinook salmon die. Because of this relatively short period of freshwater residency, habitat requirements of adult Pacific salmon in this section are limited to spawning and holding cover aspects.

Chinook spawn over a range of water temperatures varying from 6 to 14ºC (Bjornn and Reiser 1991; Raleigh et al. 1986). Chapman et al. (1986) found chinook spawning in the Columbia River from water's edge down to 22 ft (6.7 m) below the water's surface, while Bjornn and Reiser (1991) listed preferred depths $0.75 ft (≥0.23 m). Raleigh et al. (1986) state that depth plays a minor role in determination of chinook spawning success, except during extremely low water conditions that may desiccate the redd, stating that minimal depths $0.66 ft (≥0.2 m) and base flows ≥50 percent of the annual mean daily flow should provide sufficient spawning waters. Owing to their body size, spawning chinook salmon prefer larger gravel and cobble substrates ranging from 0.75 to 4.0 in. (1.9 to 10 cm) (Raleigh et al. 1986). Chapman et al. (1986) found 32 to 35 percent of their redd substrate samples were retained in a sieve size of 3.0 in. (7.62 cm), with 5 percent of the material being made up of fines < 0.28 in. (< 0.7 cm); they noted that the larger particles $4.0 in. (> 10 cm) were often found in the bottom of the egg pocket. Raleigh et al. (1986) hypothesized that gravels of 6.0 in. (15.2 cm) in diameter were approaching the upper end of usefulness for chinook salmon.

Water velocity has been proposed as the most important variable in selection of spawning areas by chinook salmon; Raleigh et al. (1986), listed an optimal range of 1.0 to 3.0 ft/s (30 to 91 cm/s). Chapman et al. (1986) found water velocities along spawning transects (measured 0.66-0.8 in. [20-25 cm] above the substrate) to be well over 1.0 ft/s (30 cm/s).

Instream cover is important to adult chinook that may enter freshwater systems up to several months before they spawn (Bjornn and Reiser 1991). Features such as submerged rootwads, logs, boulders and deep water habitats like pools and glides can provide resting areas and refugia both before and during the spawning process.

Immature chinook salmon represent the most diverse group of salmon with respect to lengths of freshwater residence. Taylor and Larkin (1986) found both "stream-type" and "ocean-type" juveniles within the Fraser River Basin. Stream-type individuals tended to stay in freshwater throughout their first summer and winter, with smoltification then taking place as yearlings. Ocean-type fry spend only a few weeks to months in freshwater, migrating to the ocean sometime during their first spring or summer.

Incubation temperature regimes for chinook vary from a low of 5°C to a high of 14°C (Bjornn and Reiser 1991). Chinook eggs require 882 to 991 temperature units on average before hatching (1 temperature unit = 0.55°C above freezing for 24 h) (Beauchamp et al. 1983). Chinook fry emergence is initiated in March and usually complete by late April (Lister and Walker 1966; Lister and Genoe 1970). Lister and Genoe (1970) reported that newly emergent chinook fry averaged 43 mm fork length.

After hatching, chinook prefer quiet, shallow water with substrates varying from silt to rubble as large as 8 in. (20.3 cm) (Everest and Chapman 1972). As fish grow, habitat selection shifts to faster and deeper waters. Roper et al. (1994) and Stein et al. (1972), found similar affinity of chinook juveniles for deep water habitats in streams in Oregon. Stein et al. (1972) indicated a preference by chinook juveniles for backwater eddies, while Roper et al. (1994) found age-0 chinook heavily concentrated in pool habitats.

Age-0 chinook salmon choose cover over uncovered sections in an artificial stream channel (Brusven et al. 1986). Results from this study and Lister and Genoe (1970) indicate an importance for undercut banks during summer residency in freshwater. Hillman et al. (1987) confirmed age-0 chinook salmon preference for undercut banks, while residing in velocities less than 0.7 ft/s (21 cm) and depths of 0.65-2.7 ft (20-81 cm). Like Everest and Chapman (1972), Hillman et al. (1987) and Lister and Genoe (1970) noticed a shift in habitat use from slow shallow water to faster, deeper water with an increase in age.

Within ocean-type chinook, migration of age-0 fish to saltwater can begin immediately after emergence from spawning gravels, or can occur several months later. The initiation of migration to the ocean may be triggered by environmental cues such as streamflow reductions and temperature increases (Stein et al. 1972). Healey (1991) indicated that movement downstream to the ocean is not controlled entirely by passive displacement from water velocities, but under an "active behavior" of juvenile chinook salmon.

Levy and Northcote (1982) found that chinook fry displayed the longest period of residency in tidal channels of three salmon species. Age-0 chinook were present in the Fraser River estuary for at least one month, in which time they grew to fork lengths of almost 7 cm. The authors felt that a short freshwater residency combined with extended stays in the estuary may benefit chinook by reducing competition with other salmonids in rivers and streams.

5. EFFECTS OF LAKE LEVEL ON FISH HABITAT

Several studies have noted an association between fishes in Upper Klamath Lake and emergent vegetation (plants rooted in water with stems emerging above the water surface). Vincent (1968) reported that rainbow trout were captured almost exclusively from stations in northern Upper Klamath Lake along emergent vegetation during his summer collections. Sampling by the Klamath Tribes (1995) has shown a significantly greater density of larvae in emergent vegetation than in adjacent unvegetated habitat. During annual sampling in 1993, OSU investigators found sucker larvae to be primarily associated with submerged and emergent vegetation (Markle and Simon 1994). Cooperman and Markle (2000) found 94 percent of captured sucker larvae associated with either emergent (90 percent) or woody (4 percent) vegetation rather than non-vegetated habitat. Although juvenile use of emergent vegetation is less well documented, Klamath Tribes biologists have found juveniles present in emergent vegetation in late July (Klamath Tribes 1996), and recent investigations by the USGS (Rip Shively, USGS, personal communication) indicate that juveniles utilize emergent vegetation in significant numbers at least into early September (provided access to emergent vegetation is still available as lake levels decline).

Collectively, these studies suggest that emergent vegetation habitats are important to Upper Klamath Lake fishes. This is especially true for larval and juvenile life stages of Lost River and shortnose suckers. Emergent vegetation likely provides shelter from predators and/or turbulent flows from waves (Klamath Tribes 1991, 1995), serves as food sources (Klamath Tribes 1995), and may provide localized improvements in water quality. Given the importance of emergent vegetation habitats, the recovery program for the endangered Lost River and shortnose suckers emphasizes the restoration and maintenance of emergent vegetation habitat (USFWS 1993; KBWUPA 1993; USBR 1996; Matthews and Barnard 1996).

The extent of emergent vegetation and wetlands habitat within the margins of the lake has been substantially reduced due to past management activities in the basin. Draining, diking, and conversion to agricultural lands have all dramatically reduced the amount of remaining emergent vegetation. Carlson (1993) found that approximately 22,000 acres of the original emergent vegetation along Agency and Upper Klamath lakes were eliminated during the period of 1940 to 1989. Unfortunately, much of this emergent vegetation loss occurred in the delta of the Williamson River (Carlson 1993), an area that was of major importance to larval suckers emigrating downstream from spawning areas in the Williamson and Sprague rivers (Klamath Tribes 1996).

The historic loss of emergent vegetation and its functional role of providing habitat markedly increases the value and importance of remaining emergent vegetation, particularly in the area near the Williamson River delta. However, the availability of these remaining habitats for Upper Klamath Lake fishes is, at times, limited by current water management of Agency and Upper Klamath lakes by the USBR. As USBR releases water from Upper Klamath Lake to meet irrigation and downstream flow needs, lake levels are reduced. This reduction in lake level dewaters many areas containing emergent vegetation, which eliminates their availability to fish (Klamath Tribes 1991, 1995).

To evaluate the effects of varying lake level elevations on physical habitat (as defined in part by combinations of water depth and emergent vegetation) available to Upper Klamath Lake fishes, R2 considered three questions:

- What is the spatial distribution of emergent vegetation habitats in Agency and Upper Klamath lakes?
- What is the importance of emergent vegetation habitat to fishes in Upper Klamath and Agency lakes?
- What is the relationship of lake level to the availability and quality of emergent vegetation habitat in Upper Klamath and Agency lakes?

Dunsmoor et al. (2000) determined the quantity of emergent vegetation habitat available to larval and juvenile suckers in shoreline areas of the lower Williamson River and of Upper Klamath Lake near the mouth of the Williamson River and in Goose Bay. Their analysis utilized transects into shoreline marsh areas that determined the outside edge and elevational profile of the marsh surface. From these data, they were able to quantify the volume and percent of habitat available to larval suckers as a function of lake level.

R2 conducted a separate analysis, reported herein, using a different data set to address the question of how marsh habitat availability changes in response to lake level. R2's analysis does not duplicate Dunsmoor et al.'s (2000) study, but rather complements it by examining elevations in other marsh areas around Upper Klamath Lake.

5.1 DISTRIBUTION AND RELATIVE VALUE OF EMERGENT VEGETATION HABITAT IN AGENCY AND UPPER KLAMATH LAKES

5.1.1 Distribution of Emergent Vegetation Habitat

As can be seen in Figure 5-1, the majority of emergent vegetation in Upper Klamath Lake is located in the northern portion of the lake. Additional emergent vegetation areas of significant size were located in the northern portion of Howard Bay, on the eastern shore of Upper Klamath Lake opposite Howard Bay, at the Wood River delta in Agency Lake, and along the southwestern shore of Agency Lake. Small emergent vegetation areas were also identified in scattered sites located in Shoalwater Bay, along the eastern shore of Upper Klamath Lake (e.g., Goose Bay), and along northwestern and southeastern shores of Agency Lake. Only minor amounts of emergent vegetation habitats were located along the lower reaches or delta areas of the Williamson River despite the historic occurrence of large expanses of emergent vegetation in this area (Carlson 1993). By contrast, although the mouth and delta of the Wood River have also experienced extensive conversion of emergent vegetation to agricultural lands, there is still a significant amount of emergent vegetation remaining in this area (Carlson 1993; Chapin 1997a). It should be noted, however, that existing marshes may differ substantially from those occurring historically. Changes in flow patterns, connectivity between

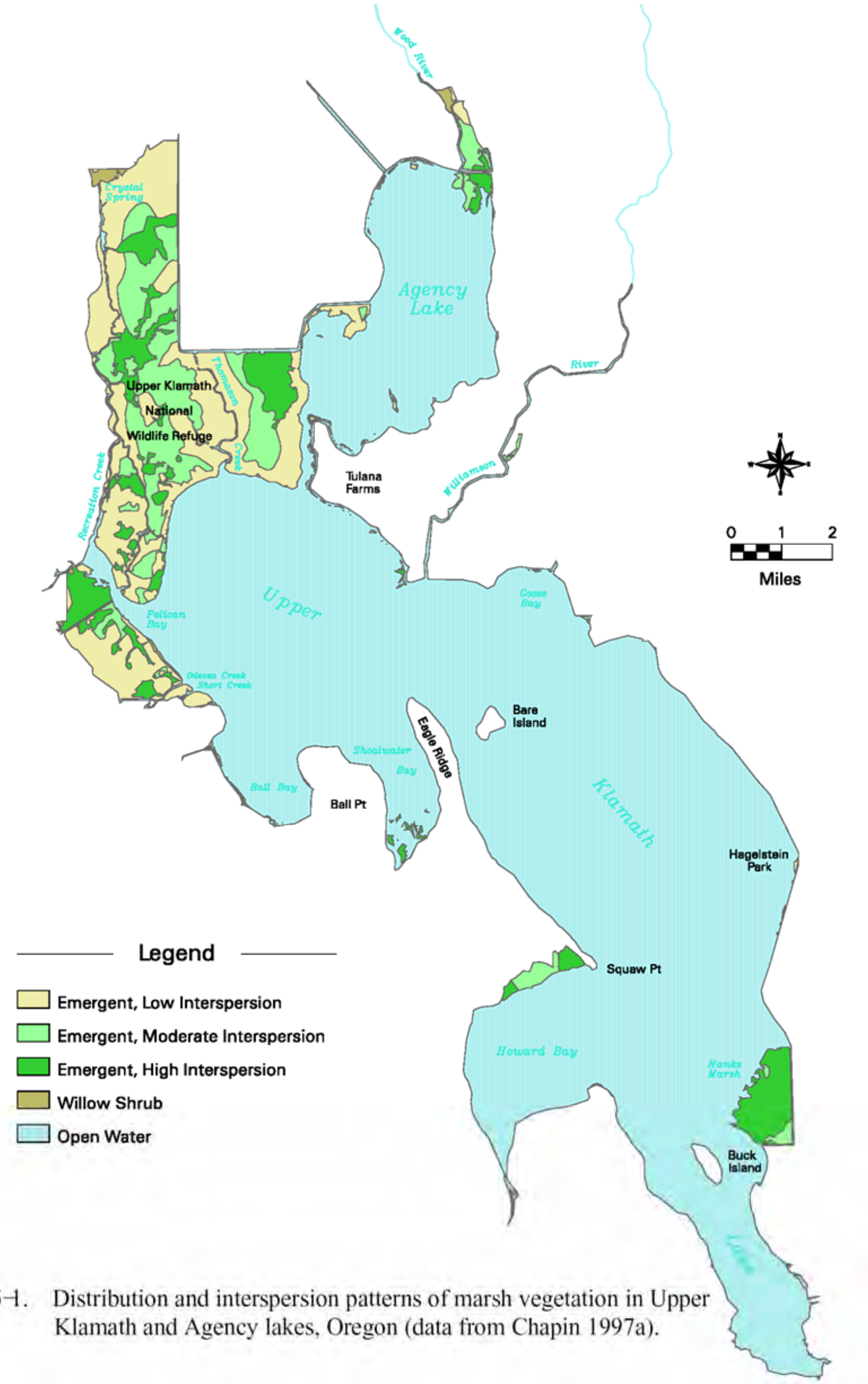


Figure 5-1. Distribution and interspersion patterns of marsh vegetation in Upper Klamath and Agency lakes, Oregon (data from Chapin 1997a).

marsh and open water, and water quality may have occurred and could affect their use by fish.

Most of the emergent vegetation mapped in the northern portion of the lake by Chapin (1997a) was in extensive, largely contiguous areas. There were also many smaller emergent vegetation areas that were disconnected from the shoreline and were essentially islands. These islands are likely relicts of older marsh edges that have been eliminated by diking. Extensive emergent vegetation in the northern portion of the lake contained stream channels (e.g., Wood River, Crystal, Recreation, Thomason, and Odessa creeks, etc.) that transport freshwater into the lake. These streams provide low pH, freshwater inflows to the adjoining emergent vegetation, and likely enhance the habitat value of these areas for fish. Suckers historically spawned in many of these streams (Golden 1969; USFWS 1993), and still do spawn in the Wood River system, which suggests that these marsh areas were previously much more important to Upper Klamath Lake sucker populations.

5.1.2 Relative Value of Emergent Vegetation Habitats

The emergent vegetation present in Upper Klamath Lake is considered to provide habitat for several species of sucker larvae, and to an unknown degree juvenile suckers (R2 data presented in Section 5.1.5, R. Shively, USGS, personal communication). However, the value of emergent vegetation as rearing or shelter habitat likely varies with the accessibility of each emergent vegetation parcel. Value of emergent vegetation to larval and juvenile fish may also depend on water quality differences between marsh and open water areas. For example, Forbes et al. (1998) found lower pH but higher DO in Hanks Marsh compared to an open water site near Bare Island.

Historically, streams divaricated through delta areas and may have transported larvae to interior marsh areas during high flows in spring when larvae emigrate to the lake (Matthews and Barnard 1996). Consequently, interior marsh areas may have been more important to sucker larvae than recent studies have shown. The depth of water covering emergent vegetation also likely affects the value of such habitats for fish. For example, the Klamath Tribes (1995) found that depth strongly influenced predation rates of fathead minnows on sucker larvae.

Since open water/vegetation edges may be particularly important to larval suckers, as well as other fish, the degree of water and vegetation interspersion is likely to be one indicator of marsh value as fish habitat. Habitat quality related to interspersion is largely a characteristic of individual wetland stands, while quality related to depth of inundation is directly linked to lake levels. In our analysis, we determined both the amount of emergent vegetation having various degrees of interspersion and the proportion of marsh and marsh edge inundated at different lake levels.

5.1.2.1 Interspersion

Chapin’s (1997a) division of emergent vegetation into different classes permitted a qualitative assessment of the value (in terms of accessibility and usability by fish) of different emergent vegetation in Agency and Upper Klamath lakes. Emergent vegetation with low interspersion was comprised of uniform blocks of vegetation with low "edge" habitat; i.e., the interface between plants and open water was limited. Although the edge habitat in emergent vegetation with low interspersion is likely used by fish, R2 considered it the least valuable (of the three interspersion classes) because of the limited amounts of open water areas within the interior segments of this habitat type. By contrast, in emergent vegetation with high interspersion, open water channels or spaces comprised at least 25 percent of the emergent vegetation area. Because such emergent vegetation has a significant amount of edge habitat, it was considered the most valuable fish habitat. Emergent vegetation with moderate interspersion contained open spaces, but it comprised less then 25 percent of the total surface area. Emergent vegetation with moderate interspersion was therefore considered to be of a habitat value intermediate to the high and low interspersion classes. Willow-shrub habitats were also considered as providing habitat for fish. However, such areas were relatively rare and were often closely associated with upland habitats that would often not be accessible to fish (Figure 5-1).

Of the total acres of emergent vegetation delineated, 48 percent were low interspersion, 29 percent were moderate interspersion, and 24 percent were high interspersion (Chapin 1997a) (Table 5-1). Most emergent vegetation in the middle to southern portions of the lake was composed primarily of emergent vegetation in the moderate to high interspersion classes. By contrast, vegetation within the northern portion contained significant amounts of low interspersion emergent vegetation, with moderate and high interspersion emergent vegetation present primarily in interior areas (Figure 5-1). Examination of aerial photographs from 1952, however, indicated that much of the low interspersion marsh in the northern portions of the marsh previously had high interspersion (Chapin 1997a). Thus, habitat quality of these marshes for suckers and other fish was likely higher in the past.

Based upon this qualitative analysis, most emergent vegetation in the southern and middle portions of the lake has interspersion levels that would render them as good habitat for fish (Figure 5-1). However, much of this emergent vegetation is located in areas where fish sampling during the summer months have found few suckers and trout (Vincent 1968). Consequently, although the

Table 5-1. Total acres and percentage total of emergent vegetation by interspersion level for Upper Klamath Lake, Oregon.

Total Acres	Emergent Vegetation						Non-Emergent Vegetation
	Low Interspersion		Moderate Interspersion		High Interspersion		Willow/Shrub
	Acres	%	Acres	%	Acres	%	Acres
Lake-Wide							
16,523	7,763	47.7	4,652	28.6	3,856	23.7	252

structure of this emergent vegetation appears good, water quality, proximity to larval influx areas, internal water circulation patterns, or other factors appear to be limiting present use of these areas by suckers and trout. It is also possible that fish utilize these areas, but that the sampling locations and frequencies have simply been too sparse and infrequent to detect habitat use; problems related to gear type efficiency may also have influenced sample results. In contrast, although the northern portion of the lake contained a lower percentage of high quality emergent vegetation habitats, the total acreage available was much greater than for the rest of the lake. The abundant emergent vegetation acreage having moderate and high interspersion, as well as the presence of freshwater inflows through many of these areas, indicates significant potential as habitat for fish. Areas within the northern area with the greatest proportion of high interspersion emergent vegetation included the eastern shore of Pelican Bay, and the interior portions of emergent vegetation located in the extreme northwestern portion of Upper Klamath Lake (Figure 5-1).

5.1.2.2 Inundation of Emergent Vegetation

The depth of water within emergent vegetation habitat is directly related to the nearshore lake bottom profile and lake water level. For example, shallow nearshore areas with low slope can be completely inundated or dewatered by small changes in water surface elevation. When such areas are present, even slight variations in lake levels can have a dramatic effect on lake-wide and area specific amounts of emergent vegetation habitat available to fish.

Analysis of the USBR marsh elevation data indicates that almost all interior marsh and marsh edge interior are inundated at a lake surface elevation of 4,141 ft (USBR datum) (Figure 5-2). As lake level drops, progressively less interior marsh habitat is inundated. Approximately 50 percent of the existing interior marsh habitat sampled in the north end of the lake is exposed at a 4,140 ft lake surface elevation. At a lake surface elevation of 4,139.5 ft, approximately half of the marsh edge is no longer inundated (i.e., it is dewatered). Nearly all interior marsh habitat is no longer inundated at 4,139.0 ft. At a lake level of 4,138.0 ft, virtually all of the marsh edge is above the lake surface.

Buettner and Scoppettone (1990) found that about 85 percent of larval suckers were found in water depths between 0.33 and 1.64 ft (10 and 50 cm). A depth of 1 ft is the approximate mid-point of this depth range and represents a conservative estimate of marsh water depth used by larval suckers. To determine the availability of interior marsh and marsh edge habitat to fish, then, lake surface elevations 1 ft above the marsh surface can reasonably be used to determine how availability of interior marsh and marsh edge habitat changes with lake surface elevation (Figure 5-3). Thus, at a lake surface elevation of 4,142.0 ft, > 90 percent of existing marsh interior and marsh edge habitat is available to larval suckers. At a lake surface elevation of 4,141.0 ft approximately 50 percent of the interior marsh habitat is lost to larval suckers and about 30 percent of marsh edge habitat is unavailable. When lake level drops to 4,140.0 ft, nearly all of the interior marsh habitat becomes unavailable to

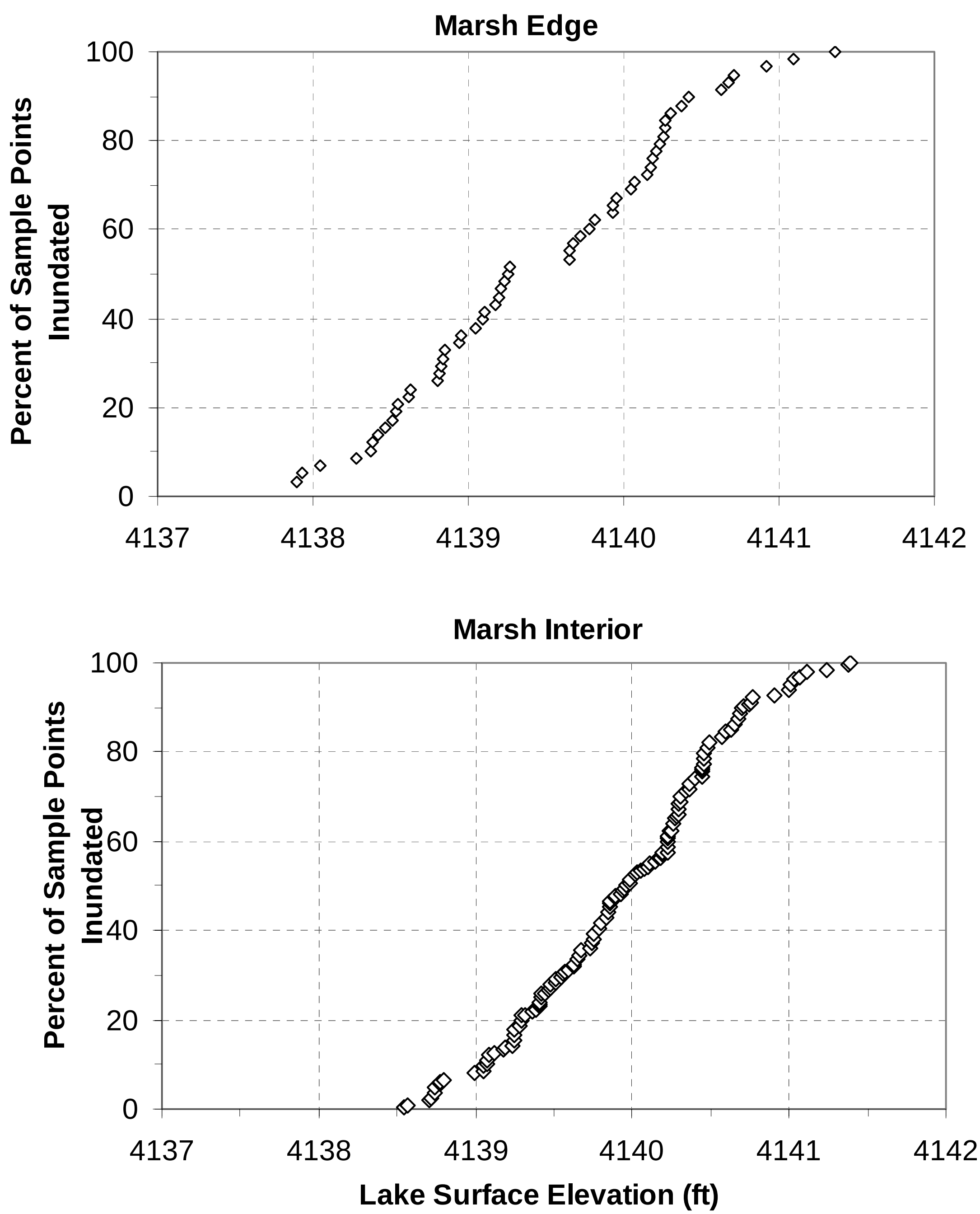


Figure 5-2. Cumulative percent of marsh interior (bottom) and marsh edge (top) sample points (weighted by distance between samples) that are inundated at progressively higher lake surface elevations (USBR data for northern Upper Klamath Lake and Agency Lake marsh areas).

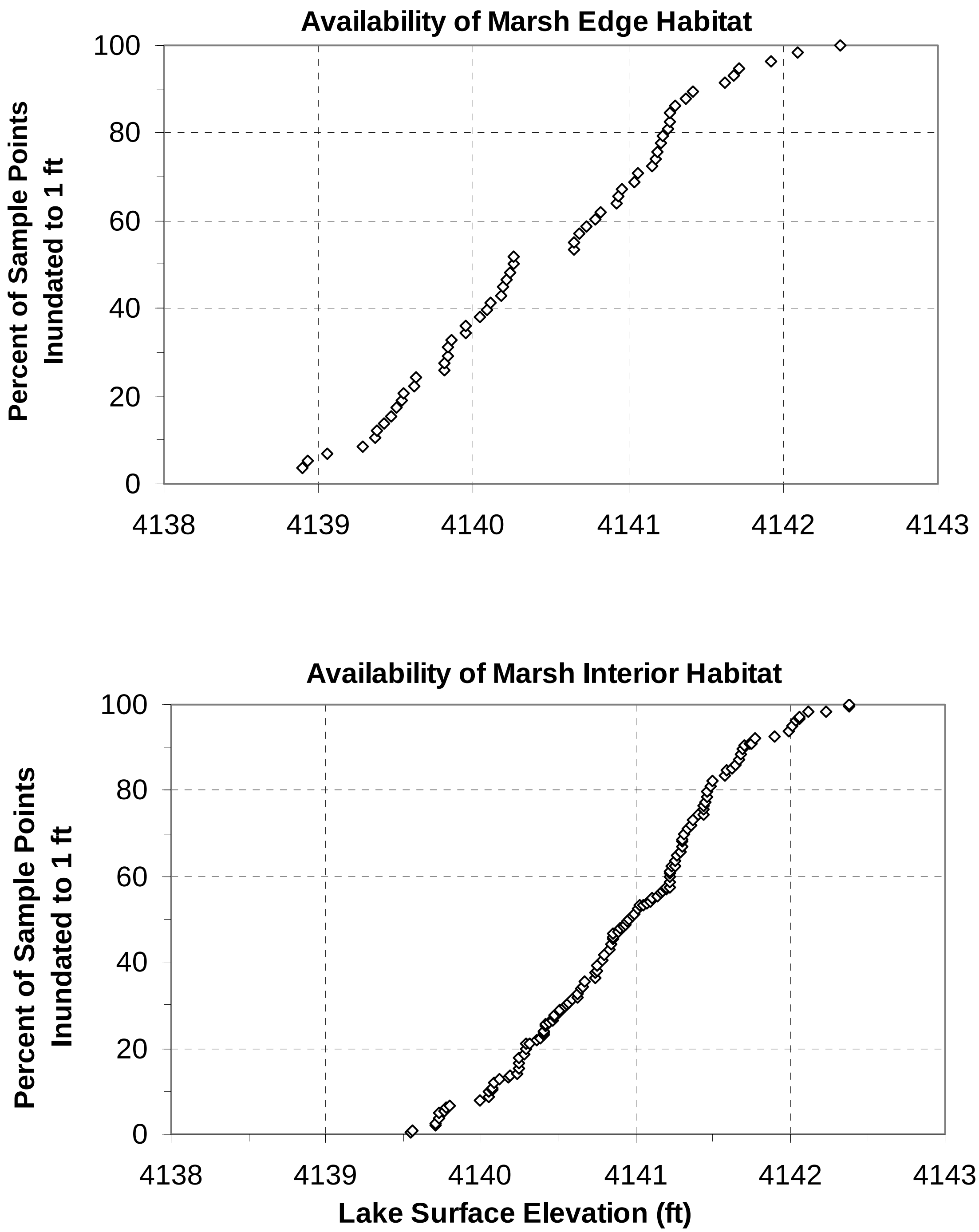


Figure 5-3. Cumulative percent of marsh interior (bottom) and marsh edge (top) sample points (weighted by distance between samples) that are inundated to a depth of 1 ft at progressively higher lake surface elevations (USBR data for northern Upper Klamath Lake and Agency Lake marsh areas).

larvae. By 4,139.0 ft, almost all marsh edge habitat is unavailable, which means that larval fish no longer have access to emergent vegetation because it is effectively disconnected from the water.

5.1.3 Extrapolation of Analysis to Other Marsh Areas in Upper Klamath Lake

Sucker larvae tend to be found in highest numbers along the eastern shore of Upper Klamath Lake south of the Williamson River (Simon et al. 2000b), probably due to the effect of currents on the relatively weak-swimming young fish. As they mature into juveniles, suckers are still found along the eastern shore of the lake but become increasingly dispersed late in the season (Simon et al. 2000b). The marshes from which the USBR elevation data were collected, however, are along the northern shore of the lake and not the primary marsh areas presently known to be used by larval or juvenile suckers. This raises the question of whether the relationship of lake level to habitat availability in these marshes is also representative of marshes along the eastern shore.

Emergent plant species are known to have specific hydroperiods, which refers to depth, duration, and frequency of inundation (Mitsch and Gosselink 1986). As water depth increases, plants face increasing difficulty in getting oxygen to their root systems, and some plant species are better adapted at dealing with this physiological problem than others. If water levels fluctuate, plants must cope with the highest water levels during the growing season; the lower elevation limit of their distribution along a shoreline water depth gradient reflects the annual high water levels to which they are exposed. The lower limit of distribution of a given species is likely to be similar across Upper Klamath Lake in response to that species ability to tolerate depth and duration of inundation. Since the species composition of emergent vegetation of Upper Klamath Lake within the marshes along the northern shore is similar to that along the eastern shore (e.g., *Scirpus acutus*, *Typha latifolia*, *Sparganium eurycarpum*), the relationship of lake level to the elevation of emergent plant species would be expected to be similar between the northern and eastern shores of the lake.

The difference in size and elevation gradient between the marshes in the northern portion of the lake and those elsewhere in the lake could also affect the extrapolation of this analysis. The extensive northern marshes are essentially flat, with little to no elevation gradient, with only a small proportion of these marshes higher than 4,141 ft elevation. In contrast, the narrow (# 30 ft wide) emergent vegetation zone along the eastern shore of the lake has a sharper elevation gradient as the shore grades into upland. Therefore, the area of emergent vegetation at higher lake surface elevations (i.e., near 4,143 ft) relative to the entire emergent zone will be much greater along the narrow eastern emergent zone than across the extensive, flat northern marshes. For this reason, the proportion of interior marsh habitat availability in the northern marshes is not likely to be representative of emergent vegetation habitat availability in the narrow, eastern emergent zone.

The availability of emergent edge habitat (i.e., the interface between emergent habitat and open water, or the lower end of the elevation gradient of emergent vegetation), however, would not be affected by marsh size or width. The amount of available emergent edge habitat is a measure of accessibility to marsh habitat; as lake levels decline below the emergent-water edge, the emergent habitat is no longer connected to open water. Because the lower edge of emergent habitat is at approximately the same elevation along the northern and eastern shorelines (Section 5.1.4), the availability of emergent edge habitat at a given lake level, then, should be similar between the northern and eastern emergent vegetation.

5.1.4 Consistency with Previous Studies of Emergent Vegetation Habitat

The results of R2's analysis of the USBR marsh elevation data are in general agreement with the trends observed by Dunsmoor et al. (2000) and Chapin (1997b). R2 independently reviewed the work of Dunsmoor et al. (2000) who surveyed the depth and distribution of emergent vegetation in the lower Williamson River and along the shoreline west and east of the Williamson River mouth in Upper Klamath Lake (Figure 5-4). Dunsmoor et al. (2000) found that the mean elevation of the outermost edge of vegetation varied from 4,138.8 to 4,140.2 ft in their two lakeshore study areas (Goose Bay and Tulana Farms). An analysis of aerial photographs from a variety of dates and locations around the lake, showed that open areas within marshes were largely exposed when lake level dropped to an elevation of 4,140.0 ft (Chapin 1997b)

These three sources of data (this R2 report; Dunsmoor et al. [2000], and Chapin [1997b]) combined are strong evidence that when lake level falls lower than 4,140 to 4,139 ft, that very little emergent vegetation (interior and edge) throughout the lake is inundated. Consequently, availability of emergent habitat to larval and juvenile suckers largely disappears at a lake surface elevation 1 ft higher than this range of inundation, or 4,141 to 4,140 ft. That is, emergent habitat is largely unavailable at a lake surface elevation below 4,141 ft. At lake surface elevation of 4,140 ft and below, little emergent habitat is accessible to young suckers, because the marsh edge is too shallow (< 1 ft depth) to be effective as habitat.

Dunsmoor et al. (2000) also determined the volume of emergent habitat that would be present at various lake surface elevations up to full pool (4,143.3 ft) by using the bottom elevation profile and the length of habitat present in their study area. They found that the volume of habitat along the lake shoreline in the Tulana Farms and Goose Bay areas (as a proportion of habitat volume at full pool) was diminished by about 50 percent at a lake surface elevation of 4,142.0 ft (Figure 5-5). Less than 5 percent of emergent habitat volume along the lake was present at a lake level of 4,140.0 ft. The results of Dunsmoor et al.'s (2000) analysis of habitat volume suggest lower habitat availability (assuming habitat volume is similar to habitat availability) with respect to lake level than do R2's results for availability of interior marsh habitat. For example, there is a loss of half of the emergent habitat volume at an elevation of 4,142.0 ft in Dunsmoor et al.'s analysis, versus a loss of half of habitat availability at a 4,141.0 ft elevation in R2's analysis of USBR data. But this difference is essentially due to the difference in width and elevation gradient between the northern marshes and narrow, shoreline emergent zone discussed above (Section 5.1.3). Thus, Dunsmoor et al.’s (2000) is likely to be more representative of emergent habitat presently used by larval and juvenile suckers than is the R2 analysis of USBR data presented herein.

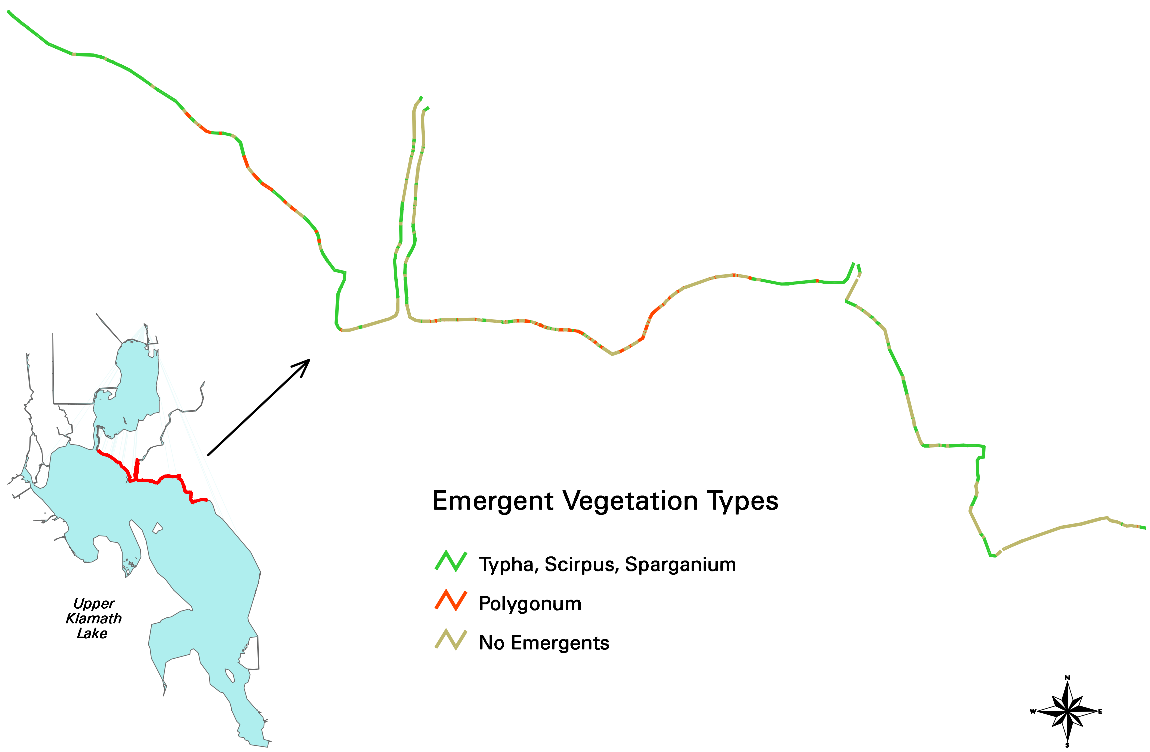


Figure 5-4. Distribution of shoreline marsh vegetation near the mouth of the Williamson River, Upper Klamath Lake, Oregon (data from Dunsmoor et al. 2000).

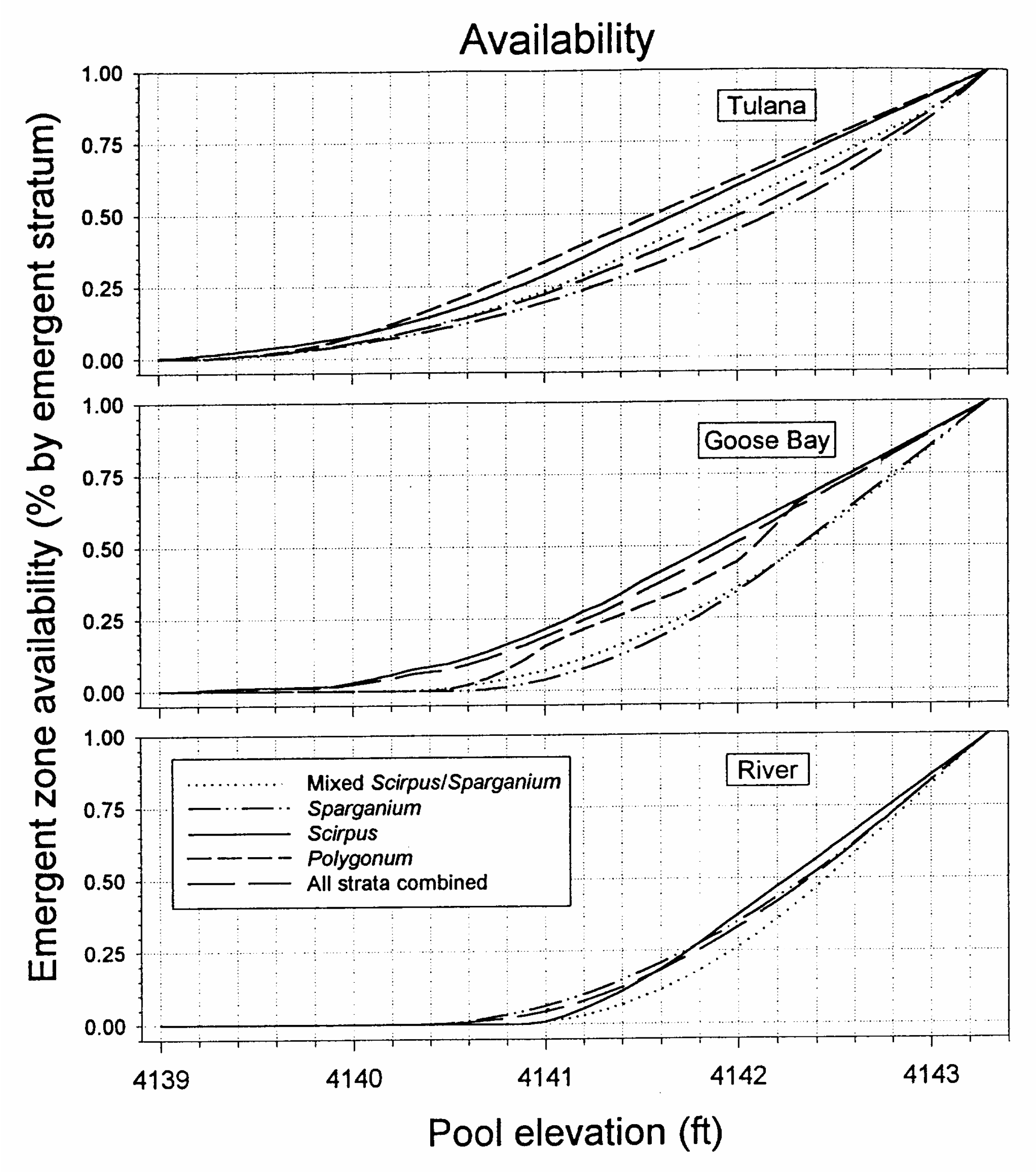


Figure 5-5. Availability of emergent zone habitats to larval and juvenile suckers expressed as percent of total volume of emergent vegetation type that is inundated at a specified pool elevation (data from Dunsmoor et al. 2000).

Future restoration of emergent habitat in the Williamson River delta area, however, could change the configuration of the eastern shore. If relatively steep banked dikes that currently characterize the delta shoreline area are removed, the shoreline could eventually resemble the northern marsh, with extensive marsh areas adjacent to the lake. In that case, the analysis of R2 may better represent the effects of lake level on emergent habitat availability to larval and juvenile suckers. The restored marsh areas will likely be different from their pre-diking condition due to subsidence of the old marsh surface, but nonetheless there should be relatively flat marsh areas along the lake shoreline, like that present now at the edge of the northern marshes. Consequently, the relationship between emergent vegetation habitat availability and lake level should be similar to that of Figure 5-3 rather than Figure 5-5.

5.1.5 Potential Effects of Higher Water Levels on Emergent Vegetation Habitat

Although lake levels above 4,142.0 ft through most of the growing season should provide adequate opportunity for access and utilization of emergent vegetation habitat by juvenile suckers, long term effects of lake level on the structure and extent of emergent vegetation also need to be considered. In some marsh systems, particularly marshes in the prairie pothole areas of midwestern North America, periodic drawdowns are known to be important for seedling germination and colonization by emergent plant species, such as cattails and bulrushes (Kadlec 1962, Van der Valk and Davis 1980). The prairie pothole model of marsh vegetation dynamics is widely cited, and it might be argued that lower levels in Upper Klamath Lake should also occur periodically to allow expansion of emergent vegetation along its shoreline to maintain and even increase the amount of rearing habitat available to larval and juvenile suckers.

Drawdowns in prairie pothole marsh systems are attempts to mimic natural climatic precipitation cycles in relative small drainage basins. In these cycles, emergent vegetation is converted to open water as a result of a high water period, and natural low water periods or artificial drawdowns, which periodically result in exposed sediments, are a mechanism to reestablish emergent vegetation. Relatively low water levels in the next one to two years are needed in these prairie pothole marshes for emergent vegetation to develop before high water levels in the next climatic cycle result in reduction of emergent vegetation (Weller 1978).

For drawdowns to be effective, reflooding of exposed substrates must be minimal for one to two years after the drawdown (Millar 1973; Harris and Marshall 1963). Reflooding to greater depths (3 ft or more) in subsequent years results in opening up of emergent vegetation stands and replacement with open water, setting the stage for another drawdown. In Upper Klamath Lake, water levels are maintained for water storage and are therefore raised to a maximum every year when possible (4,143.3 ft). Annual amplitude in lake level is currently at least 3 ft in most years and has been greater than 6 ft in some years. Because emergent vegetation generally can not persist below 3 ft water depth (Chapin 1997a; Squires and Van der Valk 1992; Millar 1973), the emergent vegetation around Upper Klamath Lake occurs down to 4,139-4,140 ft, as shown by the studies of Chapin (1997b) and Dunsmoor et al. (2000). Drawdowns in Upper Klamath Lake that expose sediments (i.e., below 4,140 ft), thus, occur regularly but reflooding to depths > 3 ft typically occur within the next year, eliminating most emergent wetland plants that germinated in the exposed sediments. In other words, the relatively high annual amplitude of Upper Klamath Lake that is required for water management purposes negates any benefits a drawdown might have. Because the water regime of Upper Klamath Lake is not compatible with a cyclic pattern of emergent vegetation establishment like that occurring in prairie potholes, drawdowns are not likely to be effective in maintaining or increasing emergent vegetation along the lake shoreline.

In contrast to a cyclic pattern of emergent vegetation development, flooding, and reestablishment, emergent vegetation around Upper Klamath Lake appears to be relatively stable, at least on the time scale of decades (Chapin 1997a). The consistent maximum water levels of about the same level (i.e., 4,143.3 ft) likely controls both the upper and lower end of the emergent vegetation zone distribution, for reasons discussed just above. Thus, maintenance of higher levels in Upper Klamath Lake later in the summer to improve access of juvenile suckers to emergent vegetation habitat should not reduce the development or extent of emergent vegetation along its shoreline.

5.1.6 Nearshore Fish Survey Results

5.1.6.1 1998 Field Surveys

During the reconnaissance survey in July 1998, we observed large spans of *Scirpus* and *Sparganium*, and some *Polygonum sp.* that under the existing lake level (4142.03) were inundated and connected to the lake. We dipnetted a few locations within Goose Bay and a site just west and captured a few chubs and fathead minnows. Many off-shore island stands of *Sparganium* and *Scirpus* were evident along the northern portion of the lake extending west from Goose Bay past the mouth of the Williamson River and Agency Straits. Like the shoreline vegetation, these islanded areas were inundated at the 4142 ft lake elevation. We also visited a number of inlet streams and springs to Upper Klamath Lake including Short Creek, Odessa Creek, Pelican Bay, Harriman springs, and Ouxy, Log, Silver Building, and Sucker springs. We stopped at Cinder Flats, located just north of Ouxy springs. Spot temperature measurements taken at a number of these locations documented a wide range of temperatures including sources of relatively cool water provided by many of the springs (Table 5-2). As previously noted, several areas in Upper Klamath Lake associated with these spring-fed locations are used for in-lake spawning by suckers, likely a function of proper water depth, substrate and water temperature combinations (Klamath Tribes 1991; Shively et al. 2000). Water temperatures within Pelican Bay were relatively cool compared to temperatures in Upper Klamath Lake (> 22^{o}C). Suckers have been observed moving into the Pelican Bay area during fish kill events (Perkins et al. 2000b), most likely in response to poor water quality conditions in the lake. However, the suckers that do find their way to this area generally do not survive (L. Dunsmoor, Klamath Tribes, personal communication), perhaps because of their already debilitated condition upon arrival, in combination with the sharp thermal change. The prevailing cool and clear waters of Pelican Bay likely render

Table 5-2. Water temperatures measured at selected springs and inlet streams to Upper Klamath Lake, July and August 1998.

Location (Date)	Time	Water Temperature ºC
Short Creek – Outlet (7/30/98)	1020 hrs	25
Short Creek – 10 ft distal from spring (8/21/98)	0945 hrs	15
Short Creek – within springs (8/21/98)	0945 hrs	8
Odessa Creek – near outlet (7/30/98)	1100 hrs	20
Odessa Creek – near outlet (8/21/98)	1225 hrs	22
Odessa Creek – above boat ramp (8/21/98)	1048 hrs	12
Odessa Creek – 150 ft below wood pilings (8/21/98)	1130 hrs	13.5
Pelican Bay – middle (7/30/98)	1150 hrs	18
Pelican Bay – middle (8/21/98)	1320 hrs	18 – surface 14.5 – 0.5 ft
Harriman Spring (7/30/98)	1230 hrs	8
Ouxy Springs at Railroad Bridge (7/30/98)	1610 hrs	17
Ouxy Springs at mouth (7/30/98)	1610 hrs	17
Klamath Lake – 10 ft distal to Ouxy Springs outlet (7/30/98)	1610 hrs	28 – surface 20 – bottom
Silver Building Springs – source (7/30/98)	1635 hrs	17
Silver Building Springs – mouth (7/30/98)	1640 hrs	20
Log Springs – along shore (7/30/98)	1645 hrs	19
Log Springs – 5 ft distal from shore (7/30/98)	1645 hrs	22
Sucker Springs – (7/30/98)	1700 hrs	15.5
Sucker Springs – 15 ft distal from shore (7/30/98)	1710 hrs	17

it as important refugia habitat for redband trout, as water temperatures in the lake increase during the summer months. We observed one large redband trout in about 4 ft of water about mid-way in Pelican Bay.

Results of our August 1998 seining at 10 locations within and tributary to Upper Klamath Lake are presented in Table 5-3. The sampling was conducted along shoreline areas of the lake or inlet streams. We estimated an effective sampling width of the seine of 20 ft. Emergent vegetation was prevalent at many of the sites, making sampling difficult and in some cases, likely ineffective. Overall, a total of 2,001 fish were captured in two survey days (Table 5-3). Blue and tui chubs dominated the total catch (72% of total), while fathead minnows (19% total catch) and yellow perch (6% total catch) also represented substantial portions of the total catch. A total of 43 juvenile (age 0) Lost River suckers (2% total catch) were captured during the survey, of which 31 were captured in the outlet of Short Creek, 8 from the east-side of Agency Straits, 3 near Goose Bay, and 1 at the northwest corner of Upper Klamath Lake (Table 5-3). These fish averaged 62 mm standard length and ranged from 45 to 80 mm. Simon et al. (2000a) reported the highest catches of suckers in beach seines during the 1999 surveys at locations near the mouth of the Williamson River, in Goose Bay, and near Hagelstein Park. Catch rates during the 1999 surveys were much higher than in 1998. The size range of suckers we found (45 to 80 mm) was higher than those reported by Simon et al. (2000b); ranges of Lost River and shortnose as captured in August 1999 were 40 to 58 mm, and 25 to 56 mm, respectively. Simon et al. (2000a, 2000b) reported that age 0 suckers were abundant on small particle, rocky substrates such as gravel and cobble. Our limited sampling suggests that juvenile suckers also utilize emergent vegetation as habitat; all of the suckers we captured were found within seine pulls through aquatic/emergent vegetation. As previously noted, the USGS initiated a study in 2000 that is evaluating age 0 sucker use of shoreline and near-shore marsh and emergent vegetation habitats. Their initial surveys have found suckers using both types of habitats, including *Scirpus* islands (R. Shively, USGS, personal communication); further surveys will be conducted in 2001. These results suggest that suckers continue their association with emergent vegetation well past the larval stage.

Results of our shoreline mapping at the one Goose Bay location indicated that the lengths of shoreline at each of six transects that contained emergent vegetation that were exposed at the 4141 ft lake level ranged from 18 ft to 21 ft. Based on transect spacing widths of 50 ft, the overall areal loss of emergent vegetation translates into about 4,900 ft^2 or 70 percent of the total area (6,900 ft^2) that would be inundated under a high lake level (4143 ft). This finding comports well with that of Dunsmoor et al. (2000), which found that only 25 percent of potential emergent habitat volume remains at a lake level of 4,140 ft (Figure 5-5). If, as we believe, juvenile (age 0) suckers likewise use this emergent vegetation, its loss due to declining lake levels over the summer period may relegate these fish to open water locations that lack cover and habitat complexity, and thereby rendering them more vulnerable to predation.

Dissolved oxygen concentrations ranged from 5 mg/l at the outlet of Odessa Creek to 11 mg/l at

Table 5-3. Total number and percent of seine catch August 20 and 21, 1998 by site and species for Upper Klamath Lake, Oregon.

	Blue/Tui Chub		Lost River Sucker		Pumpkinseed		Slender Sculpin		Yellow Perch		Fathead Minnow		Total
Location	#	%	#	%	#	%	#	%	#	%	#	%	#
Williamson River near mouth/Left Bank	861	99.7					1	0.1	2	0.2			864
Goose Bay	273	92.9			2	0.7	1	0.3	18	6.1			294
0.5 Mi. East of Goose Bay			3	0.8							380	99.2	383
Outlet of Short Creek	196	59.2	31	9.4					104	31.4			331
Upper Odessa Creek	5	50.0			1	10.0	2	20.0	2	20.0			10
Mid-section of Odessa Creek	2	100.0											2
Odessa Creek Outlet													0
West-side Shoreline of Klamath Lake	12	80.0			1	6.7	2	13.3					15
Northwest Corner of Klamath Lake	8	53.3	1	6.7	4	26.7	2	13.3					15
East-side of Agency Straits	79	90.8	8	9.2									87
Total Fish Captured	1436	72	43	2	8	.5	8	.5	126	6	380	19	2001

the site 0.5 mi. east of Goose Bay (Table 5-4). The highest pH values were at the sites within Upper Klamath Lake (Goose Bay, 0.5 mi. east of Goose Bay), although the overall range of values was relatively low (7.4 to 8.4). We completed one set of water quality measurements (DO and temperature only) in the Upper Klamath National Wildlife Refuge within Thomason Creek located about 0.5 mi. above its confluence with Upper Klamath Lake. Dissolved oxygen ranged from 3.5 mg/l at the surface to 1.2 mg/l about 6.5 ft deep. These low DO concentrations would not be conducive to fish production, indeed would be lethal to redband trout as well as both sucker species (Table 6-1). If such conditions exist within the inner sections of the adjoining marshes, we would not expect much use of those areas by any fish species.

On March 1999, we revisited several locations along the eastern shore of Upper Klamath Lake including Ouxy and Sucker springs, and Cinder Flats. Water temperatures within Ouxy and Sucker springs were 17^{o}C and 15^{o}C, respectively, contrasted with lake temperatures of 7^{o}C. Although Lost River suckers generally begin to stage for spawning at this time, we did not observe any suckers during a night-time snorkeling survey within Sucker Springs. We did observe one adult (approximately 14 in.) redband trout within the zone of spring influence near Sucker Springs.

5.1.6.2 1999 Field Surveys

The fish sampling in 1999 was conducted earlier in the year (June) than the 1998 studies and focused primarily on sampling for larvae. Water quality conditions during the two day survey were conducive to fish, with DOs of 8.7 (6/2/00) to 8.4 (6/3/00), and pH of 8.3 (6/2/00) to 8.0 (6/3/00).

The results of two days of pop net sampling are depicted in Table 5-5, which lists the water depths and cover associations of each net. For the June 2 sampling, the highest number (53) of larval fishes was captured in the net located in a water depth of 1.5 ft that was located within emergent vegetation. No fish were captured in either of the other net sets. On June 3rd, we captured few (2) larval fishes and those were equally distributed between nets within emergent vegetation and in open water. However, there were substantial wind-waves during the sampling period and therefore fish distribution was more likely a function of wind-current rather than volitional positioning.

Two seine hauls completed just west of Goose Bay captured 0 fish in haul number one and a total of 5 juvenile and 11 larval fishes in haul two (Table 5-6). The minnow trapping proved to be largely ineffective in sampling either juvenile or larval fishes; only 3 fish (2 blue chub, 1 fathead minnow) were captured in 8 traps set overnight.

Results of the three ichthyoplankton tows on June 2nd at varying distances from shore collected the highest numbers of larvel fishes from the two tows that were about 100 yds (50 larval fish) and 25 yds (35 larval fish) from shore; 5 larval fish were captured in the tow 250 yds from shore (Table 5-7). This suggests some tendency for larval fish to be more closely associated with near-shore/shoreline areas than open-water habitats.

Four seine pulls on June 3rd resulted in the capture of from 0 to 17 juvenile fish (total 29 fish), and from 0 to 100 larval fish (Table 5-6). The majority of juvenile fish were blue chub (25; 86%), followed by fathead minnow (3; 10%), and sculpin (1; 3%). We preserved a sub-sample of 24 larval fishes in formalin to allow species

Table 5-4. Water quality characteristics at sites sampled during August 20-21, 1998 fish surveys in Upper Klamath Lake.

Site – Location	Water Temp. (C)	D.O. (mg/l)	O2 Saturation (%)	Conductivity (mS/sec)	pH	Secchi (ft)
Williamson River near mouth/Left Bank	20.1	8.5	109.1	0.1042	7.9	2.5
Goose Bay	21.0	8.9	115.8	0.1061	8.1	2.8
0.5 Mi. East of Goose Bay	22.2	11.0	147.3	0.1053	8.4	2.8
Outlet of Short Creek	13.0	5.1	60.6	0.1102	7.8	1.5
Upper Odessa Creek	12.0	7.3	80.2	0.0953	7.7	4.0
Mid - section of Odessa Creek	13.5	6.9	76.2	0.0917	7.7	4.0
Odessa Creek Outlet	22.0	5.0	65.8	0.1191	7.7	4.0
West-side Shoreline of Klamath Lake	23.4	8.3	113.0	0.1067	7.7	2.0
Northwest Corner of Klamath Lake	24.0	7.9	108.0	0.1054	7.7	2.0
East-side of Agency Straits	21.6	6.0	77.0	0.1126	7.4	3.3
Rt. Fork of USFWS Refuge Canal - Surface	22.2	3.5	-	-	-	-
Rt. Fork of USFWS Refuge Canal - 1 m deep	-	1.9	-	-	-	-
Rt. Fork of USFWS Refuge Canal - 2 m deep	17.6	1.2	-	-	-	-

Table 5-5. Date, depth (ft), cover, water temperature (°C), soak time (sec), and number of larval fish captured during reconnaissance-level pop-net surveys conducted in Goose Bay, Klamath Lake, Oregon, 1999.

Date	Depth (ft)	Cover	Water Temp. (°C)	Soak Time (min.)	Number Captured
2 June	1.5	Emerg. Veg.	16.5	205	53
2 June	2.5	Open Water	16.5	195	0
2 June	2.5	Emerg. Veg.	16.5	190	0
3 June	1.1	Emerg. Veg.	15.5	195	0
3 June	2.6	Open Water	15.5	225	2
3 June	2.5	Emerg. Veg.	15.5	210	2
3 June	1.3	Emerg. Veg.	15.5	190	2

Table 5-6. Date, depth (ft), cover, water temperature (°C), number of juveniles, and number of larval fish captured during reconnaissance-level seine net surveys conducted in Goose Bay, Klamath Lake, Oregon, 1999.

Date	Depth (ft)	Cover *	Water Temp. (°C)	No. Juveniles Captured	No. Larvae Captured
2 June	1-3	Mixed	16.5	0	0
2 June	1-3	Mixed	16.5	5	11
3 June	1-3	Mixed	15.5	0	50
3 June	1-3	Mixed	15.5	7	0
3 June	1-3	Mixed	15.5	17	100
3 June	1-3	Mixed	15.5	5	10

* - mixed represents conditions of open water mixed with emergent vegetation

Table 5-7. Date, depth (ft), cover, water temperature (°C), soak time (sec), and number of larval fish captured during reconnaissance-level bongo-net surveys conducted in Goose Bay, Klamath Lake, Oregon, 1999.

Date	Depth (ft)	Location	Water Temp. (°C)	Tow Time (min.)	Number Captured
2 June	3	250 yds offshore	16.5	5	5
2 June	3	100 yds offshore	16.5	5	50
2 June	3	25 yds offshore	16.5	5	35
3 June	3	West of mouth of Williamson River	15.5	5	0
3 June	3	East of mouth of Williamson River	15.5	5	15

identification. The samples were analyzed by L. Dunsmoor, Klamath Tribes; results of laboratory analysis indicated that the samples contained 6 flexion meso-larvae (sucker), 1 post-flexion meso-larvae (sucker), 6 meta-larvae (sucker), and 11 meta-larvae (fathead minnow). This subsample indicates that over half (54%) of the larval fish were suckers. The suckers were likely to be either shortnose or Lost River species.

Results of the two ichthyoplankton tows made on June 3rd at locations west and east of the mouth of the Williamson River are shown in Table 5-7. A total of 15 larvae were collected in the sample east of the mouth, and 0 larvae in the sample from the west. Although only two samples, the data are indicative of a larval distribution pattern that is influenced by wind and wind-driven currents in the lake. Prevailing winds from the northwest (as were occurring during the field sampling) would tend to generate a wind-current in the same direction, with larvae entering the lake via the mouth of the Williamson being transported in currents that would tend to distribute them in an easterly direction. On calm days, however, the distribution of larval would likely be more uniformly divided in both a westerly and easterly direction.

5.2 SUCKER SPAWNING HABITAT

Along the eastern shore of Upper Klamath Lake, suckers spawn at several locations where springs discharge directly into the lake and at one non-spring location (Figure 2-2) (Shively et al. 2000). As previously noted, the lake spawning locations include Sucker, Silver Building, Ouxy, and Boulder springs, and Cinder Flats, a non-spring spawning location. Lost River suckers comprise most of the spawners at these sites, with only small numbers of shortnose suckers found at the spring sites during spawning periods. Recapture of tagged fish suggests that spring spawning Lost River suckers are a distinct population from the adfluvial, river spawning population.

Although a detailed characterization of spring spawning habitat has not been reported to date, there are some data available on spawning depth and substrates at spring spawning sites. Sucker and Ouxy springs are the only sites for which information is complete enough to estimate spawning area depth.

The Klamath Tribes (1991) surveyed elevations of sucker spawning habitat at Sucker Springs and found that the spawning area would be completely covered with water at a lake surface elevation of 4,141.46 ft. More detailed bathymetry data of Sucker Springs was collected by the USBR and Klamath Tribes in 1995. An independent set of bathymetry data were collected by the USGS in 1999 for Ouxy and Silver Building springs and for Cinder Flats. The Klamath Tribes conducted additional studies of spawning location and depth at Ouxy Springs in 1995. Using an ArcView GIS, R2 combined the mapping of actual spawning locations at Sucker and Ouxy springs conducted by the Klamath Tribes in 1995, with the bathymetry data collected by the Klamath Tribes, USBR, and USGS (using the GIS bathymetry data compiled by Kurzke [2000]). The R2 GIS analysis showed that nearly all of the spawning area at Sucker Springs would be inundated (i.e., wetted) at a lake surface elevation of 4,141.5 ft (Figure 5-6), very similar to the 1991 survey data of the Klamath Tribes. At Ouxy Springs, the USGS data showed an area of gravel and rocks that was identified as a "preferred spawning area."

This area corresponded closely to the spawning area at Ouxy Springs delineated by the Klamath Tribes (Klamath Tribes, unpublished data). Using the “preferred spawning area” delineated in the USGS bathymetry data, R2’s GIS analysis showed that a lake surface elevation of 4,142.5 ft would also inundate all of the sucker spawning area at Ouxy Springs.

Data collected by the Klamath Tribes in 1995 indicate that spawning depths at Sucker Springs ranged from 0.5 to 3.7 ft (15 to 113 cm) (Klamath Tribes, unpublished data). At Sucker Springs, for which there is the most detailed data, a comparison of the elevation of 1995 spawning locations to spawning area in different elevation categories showed no strong trend in the utilization of the documented spawning area with respect to bottom elevations (Figure 5-6). However, the proportion of spawning locations (as determined by the presence of many embryos or captured larvae) was nearly two times the proportion of spawning area within the lowest bottom elevation category of 4,139.0 to 4,139.5 ft.

To evaluate the effect of lake level on spawning habitat availability, a depth of 2 ft (0.6 m) was used as a conservative approximation of preferred spawning depth. We considered this depth conservative because over 60 percent of spawning locations at Sucker Springs were found at depths greater than 2 ft (Figure 5-7) (Klamath Tribes, unpublished data). Adequate spawning depth in these lake spawning areas is likely related to a number of factors. For example, deeper spawning depth provides more protection of eggs and embryos from the turbulent water due to wave action. Protection from predators may also influence the selection of spawning locations by adult suckers. At Sucker Springs, observations suggest that spawning suckers avoid areas with clear water during the day and spawn at sites with clear water primarily at night, suggesting their choice of spawning locations is influenced by active predator avoidance behavior.

Figure 5-8 shows the amount of preferred spawning area (expressed as percent of spawning area inundated to a depth of 2 ft) versus lake surface elevation for Sucker and Ouxy springs. At Sucker Springs it is evident that available spawning area declines sharply as lake level drops below full pool (4,143.3 ft). At a lake elevation of 4141.5 ft, there is approximately 5 percent of the utilized spawning area that remains at a preferred depth of 2 ft. At Ouxy Springs, more than 30 percent of the utilized spawning area is at a depth less than 2 ft when the lake is at full pool. Thus, a substantial portion of the utilized spawning area is judged to be at less than the preferred depth even when lake levels are at a maximum. As lake levels decline, available spawning area with a 2 ft depth at Ouxy Springs declines more or less linearly until there is essentially no spawning area of 2 ft depth available below a lake elevation of 4141.5 ft.

5.3 ADULT SUCKER DEPTH UTILIZATION

This section examines the relationship between water depths utilized by adult shortnose and Lost River suckers and Upper Klamath Lake surface elevations using radio telemetry data collected by the USBR from 1993 to 1999. Three analyses are presented. First, the results of a depth frequency analysis for these two species are presented and used to establish their depth utilization patterns

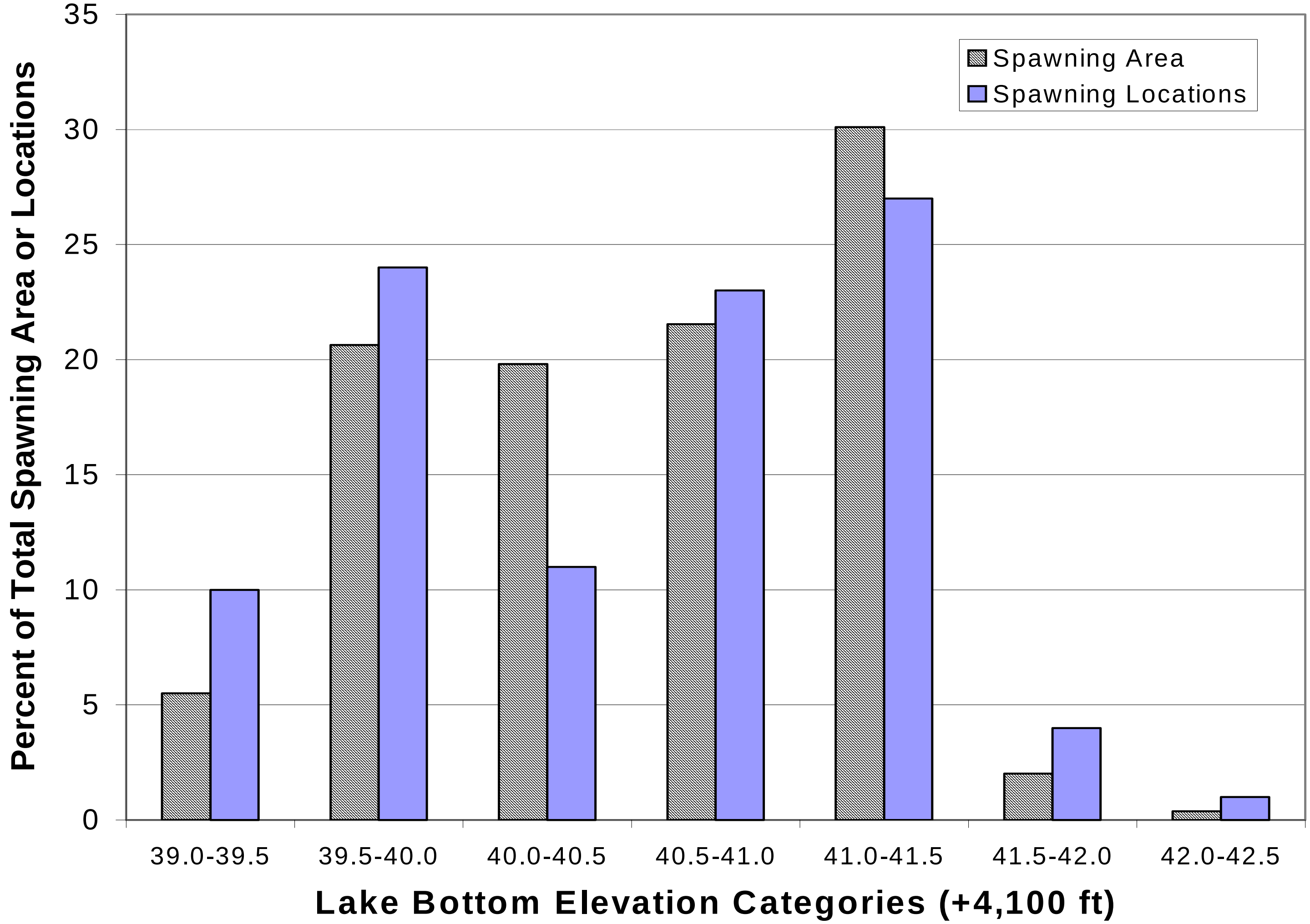


Figure 5-6. Percent of total spawning area and locations (sites of many observed embryos and of emerging larvae during March-April 1995) in different bottom elevation categories at Sucker Springs, Upper Klamath Lake, Oregon (spawning area from USBR/Klamath Tribes 1999 bathymetry data; spawning locations from Klamath Tribes, unpublished data).

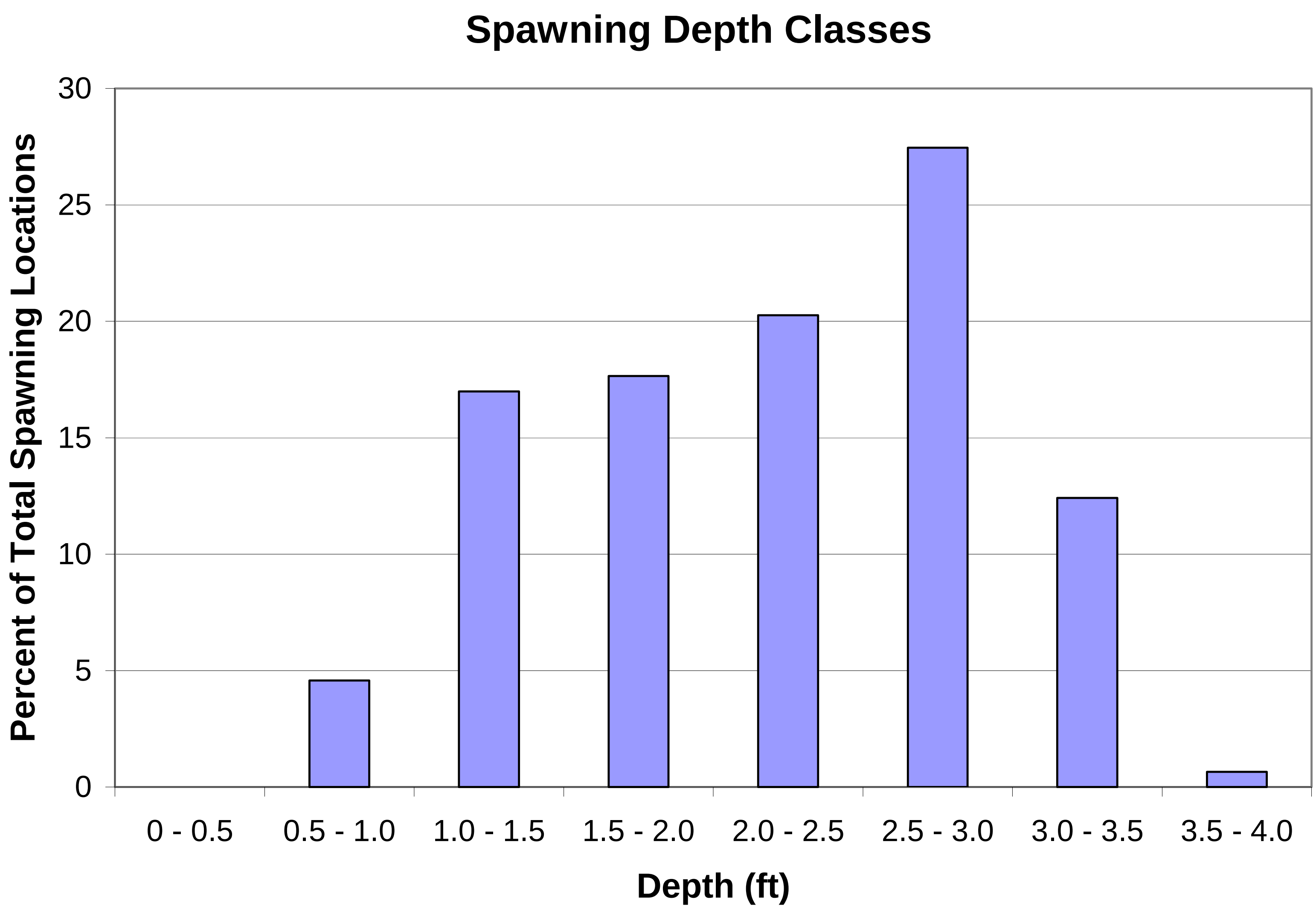


Figure 5-7. Percent of spawning locations (sites of many observed embryos and of emerging larvae during March-April 1995) in different depth categories at Sucker Springs, Upper Klamath Lake, Oregon (Klamath Tribes, unpublished data).

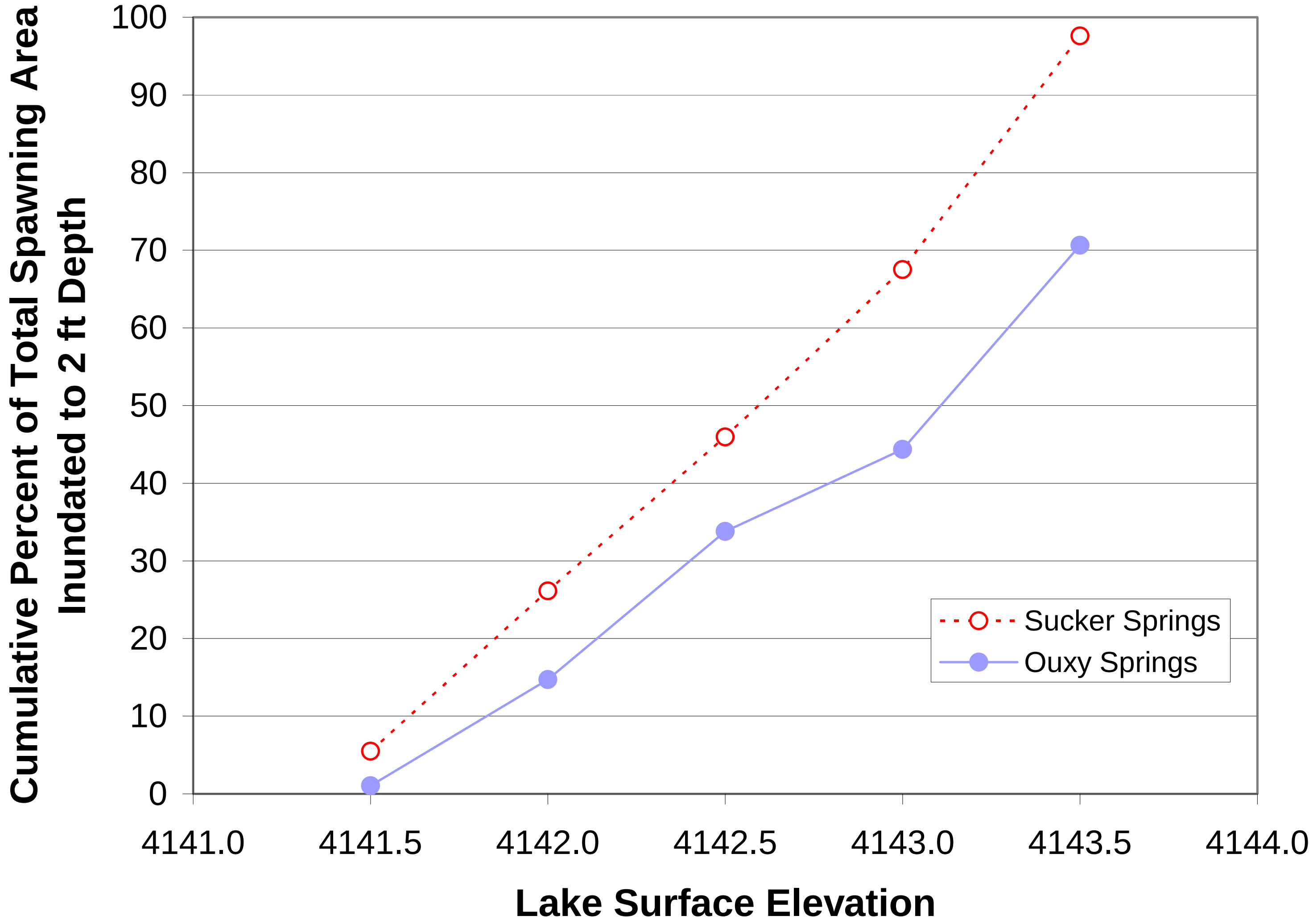


Figure 5-8. Cumulative percent of total spawning area inundated to 2 ft depth at Sucker and Ouxy springs, Upper Klamath Lake, Oregon (Klamath Tribes, USBR, and USGS bathymetry data).

from July through September, during the period when poor water quality conditions generally prevail in some portions of the lake. As poor water quality may restrict access to depths fish would otherwise prefer, this analysis demonstrates depth utilization rather than preferred depth use. Second, the period between September and October 1994, a period when water quality conditions improved but lake levels were relatively low, provided an opportunity to evaluate sucker depth preferences, absent the confounding influence of potential avoidance of poor water quality. The results of that analysis confirmed the patterns of depth utilization defined for July through September. In the third analysis, USBR Upper Klamath Lake bathymetry data were used to determine the area of the lake that can be utilized or avoided by fish at decreasing lake surface elevations. The relationship between the utilized and avoided areas in the lake and declining surface elevations represents how and the extent to which adult sucker depth habitat for these endangered species is affected by lake level management decisions.

5.3.1 Sucker Depth Frequency Distributions

The depths at all sucker locations confirmed by boat telemetry in the July through September portion of the radio-tagging study were subjected to frequency distribution analyses using 3 ft depth increments from 0 ft to greater than 15 ft water depths. The results are shown in Figure 5-9 and indicate that the depths occupied by both species shifted from deeper waters in the spring (9 to12 ft) to slightly shallower waters in summer (6-9 ft). The lower panels in Figure 5-9 suggest that, in the spring, Lost River sucker adults are more concentrated in the 9-12 ft depth range than are adult shortnose suckers. In the summer months the depth distribution utilized by adults of the two sucker species were essentially identical. Such shifts in depth utilization between seasons may be attributable to avoidance of low dissolved oxygen (DO) in deeper waters, inshore movements toward areas of better water quality, or simply the decrease in lake elevation that occurs in summer months.

Results of the radio-tagging analysis indicated that the two sucker species were similarly distributed spatially, although some differences are evident in their spring distribution. This finding is similar to that reported for a sucker telemetry study in Tule Lake (Buettner 2000) where Lost River and shortnose suckers intermingled and showed similar movement patterns during a three year monitoring period. We therefore used the combined species distribution as depicted in the upper panel of Figure 5-9 to delineate depths utilized and depths avoided. A depth utilization range from 3 to 15 ft (0.9 to 4.8 m) included more than 95 percent of all observations. One percent of those daytime observations were in water of 3 ft (0.9 m) or shallower for both species, and only 3 percent of Lost River and 4 percent of shortnose sucker observations were found in water depths greater than 15 ft (4.8 m). These two depth ranges (0 to 3 ft and greater than 15 ft) are evidently avoided by these species.

The shallower depth range avoided by suckers would not likely afford large fish suitable cover, and the conditions associated with those depths would likely be more turbulent due to wind-driven wave action. Light penetration and turbulence may also affect the abundance of food organisms.

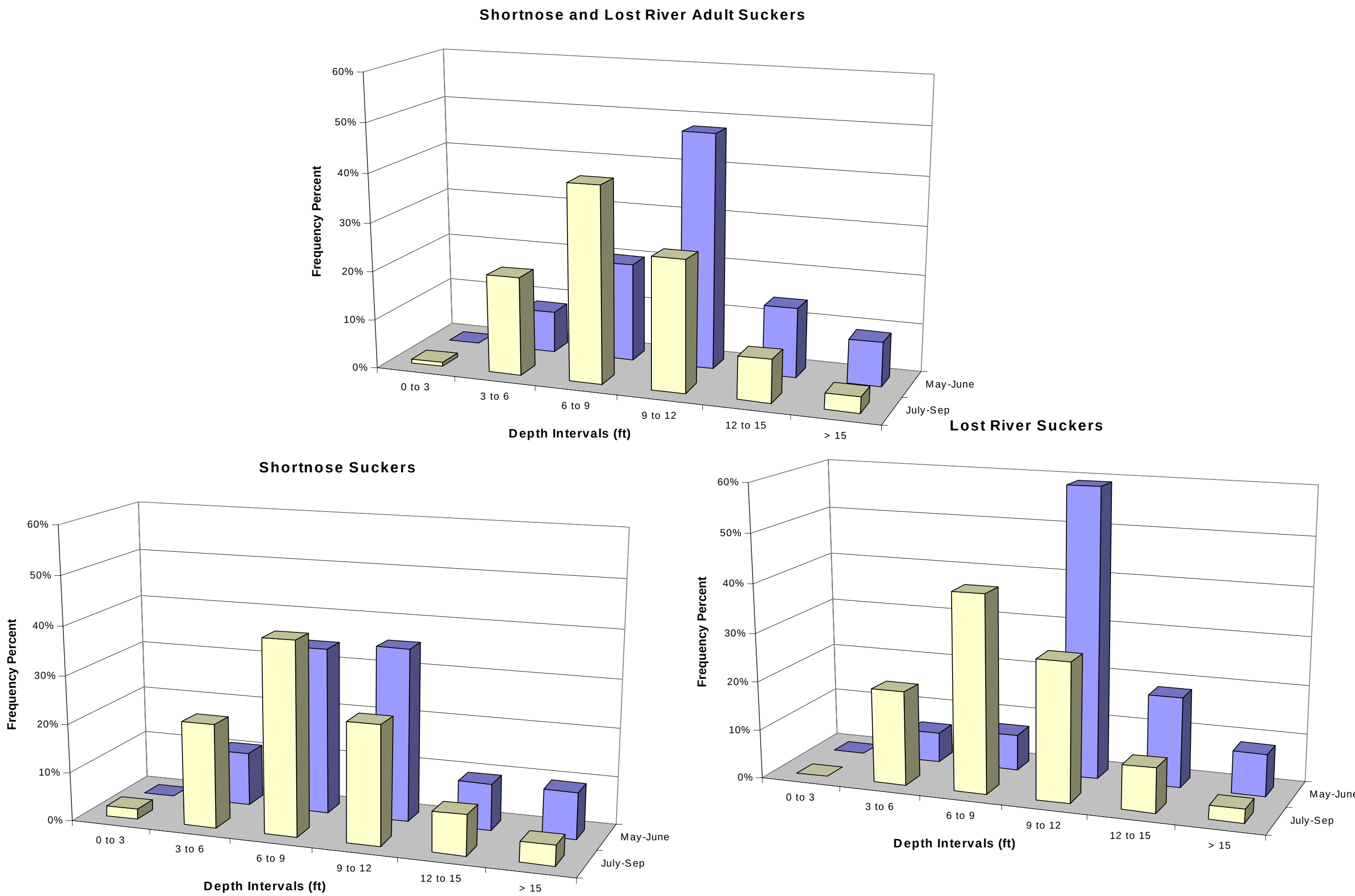


Figure 5-9. Shortnose and Lost River adult sucker depth frequency distributions in spring and summer months, 1993-1998 (Lake elevation range from 4,143.2 to 4,136.9 ft msl) (shortnose sucker May-June N = 69, July-September N = 186; Lost River sucker May-June N = 65, July-September N = 242; combined adult sucker May-June N = 134, July-September N = 428.

Algal blooms near the surface cause greater elevations of pH in surface waters that may stimulate adult sucker avoidance. Buettner (2000) reported that both sucker species in Tule Lake were rarely found in waters shallower than 2.6 ft (0.8 m), with the fish becoming concentrated in the deepest areas 4.9 ft (1.5 m) in summer months where water quality was better than elsewhere in the lake.

The deeper waters of Upper Klamath Lake (> 15 ft) may not be hospitable to suckers due to the more frequent occurrence of low off-bottom DO concentrations in summer months. Neither algal oxygen production nor atmospheric reaeration can improve low DO in deeper waters of the lake during calm periods, unless there is substantial vertical mixing. Low DO in deeper waters may also affect food organism abundance. Water depth sensors built into 8 radio tags deployed in the USBR radio telemetry study (5 in Lost River suckers and 3 in shortnose suckers) confirmed that adults of both species are bottom oriented. None of the 96 measured fish depths showed that the sensors were more than 1 ft above the bottom depth where these fish were located when water quality profiles were recorded. Therefore, bottom substrates and conditions may also play a role in sucker depth habitat selection or avoidance. Although little is known regarding adult sucker preferred bottom types in Upper Klamath Lake, Buettner (2000) noted that adult suckers concentrated in deeper areas over predominantly inorganic, clay sediments and were rarely found over shallower, softer, organic rich peat sediments elsewhere in Tule Lake.

5.3.2 Sucker Depth Preference

In 1994, lake elevations fell below 4,137 ft by the end of September and into October. This period of minimal lake elevations provides the best basis to estimate actual sucker species depth preferences and confirm the inference that adult suckers avoid water depths less than 3 ft (0.9 m). This is so because water quality conditions improve in the fall, removing the confounding influence on fish distributions due to poor water quality avoidance. Also, the relative areas of deeper water are at a minimum relative to the more expansive areas of shallow waters (Section 5.3.3), challenging adult suckers to find and remain in deeper waters if that is their preference. The USBR radio tag depth data for September through October 1994 were therefore analyzed to provide a measure of preference or avoidance of various depth intervals.

The 90 observations made in these two months occurred while lake surface elevations ranged between 4,136.79 and 4,137.22 ft msl and were associated with temperature and pH measurement near the lake bottom that would not cause stress to fish. The pH ranged from 7.32 to 9.01 and water temperatures ranged from 9.1 to 20.8°C, DO ranged from 3.8 to 11.2 mg/L. Ten percent of the 90 observations were associated with DO concentrations that would indicate moderate to high stress and occurred in a depth range from > 3 to 12 ft (> 0.9 to 3.7 m). Fish encountering these lower DO concentrations were not however, excluded from the analysis and any bias due to poor DO water quality is thought to be minimal.

The data were subjected to the same frequency analysis used for the summer time data, with results expressed as percent frequency in 6 depth intervals. The frequency of the percentage area in northern Upper Klamath Lake was calculated for the same depth intervals for a lake elevation of 4,137 ft and the results of both analyses depicted in Figure 5-10. By comparing the percentages of bottom area with the percentages of fish use in each water depth category, it is evident that the frequency of use is not equal to the percentage of bottom area available in most depth intervals. Only 1.1 percent of the fish were found in the 0 to 3 ft depth range, representing 42 percent of the bottom area available at a lake elevation of 4,137 ft. More than 90 percent of the fish use occurs in 54 percent of the available bottom area in the 3 to 9 ft depth range, and a slightly higher percentage use than percent available bottom area occurs in the three deeper depth categories.

These results were then converted to fish preference values by taking the ratio of fish use to available bottom area in each depth category as shown in Figure 5-11. A ratio of 1.0 indicates that fish neither prefer nor avoid a particular depth range. Preference for a depth range is indicated by a value greater than 1.0 and avoidance of a depth range results in a ratio value of less than 1.0. The results, shown in the figure, indicate that adult suckers show a strong preference for the 6 to 9 ft depth range, as 4.4 times as many fish were observed in 7.7 percent of the lake area in this depth interval than would occur if there were no preference. In contrast, strong avoidance of water depths less than 3 ft is evident, even though water quality had improved in shallower waters relative to the summer month. Moderate preference is shown for the other depth categories.

5.3.3 Sucker Depth Habitat Utilization

The same depth intervals used to determine the depth utilization frequency were applied to the Upper Klamath Lake bathymetry data to determine the bottom surface area in each water depth interval over a range of lake surface elevations. These results are shown in Figure 5-12 and Table 5-8 as the number of hectares in each depth category. The figure and table show that as surface lake elevation declines from full pool (4,143.3 ft) to a minimal pool elevation of 4,136 ft, the areas of the lake bottom within various depth intervals change substantially over the range of elevations examined. From full pool to a lake surface elevation of 4,142 ft, there is a sharp reduction in the 9-12 ft depth category. However, the 6-9 ft depth area that is preferred by suckers (Figure 5-11) changes little between full pool and 4,142 ft. The loss of area in this interval is compensated by area gains from deeper depth intervals as lake level falls. From 4,142 ft to 4,138 ft elevation, the 6-9 ft and 9-12 ft depth area diminish substantially, while the 3-6 ft interval area remains fairly constant and the 0-3 ft interval area increases to more than half the full-pool area. Between 4,138 ft and 4,136 ft elevation, the final depth interval utilized by suckers (3-6 ft) also declines substantially. Over the full range of lake elevations examined, the wetted area diminishes from 10,677 hectares at full pool to 6,631 hectares at a lake elevation of 4,136 ft above the demarkation line. On a percentage basis, the lost wetted area of 4,046 hectares represents 38 percent of the full pool area.

The lake elevation-dependent losses of sucker utilization area is more simply illustrated in Figure 5-13 and displayed in Table 5-9. In this figure and table, the areas in depth intervals utilized by suckers have been summed for each 1-ft increment of surface elevation and expressed as a percentage of the full pool area. The areas in depth intervals avoided by suckers are also expressed as a percentage of full pool area, as is the "dry" area that increases as lake levels decline. It is evident that both the sucker utilization area (depth range of 3 to 15 ft) and the area of preferred depth (6 to 9 ft) remain at a high and constant percentage of the full pool area (above 90 percent) until the surface elevation falls below 4,142 ft and then declines rapidly and linearly below 4,141 ft. When lake surface elevation drops to 4,136 ft, there is a major reduction in the area of both utilized and preferred depth ranges compared to their areas at a lake elevation of 4,142 ft. Less than 25 percent of the area of utilized depth and less than 7 percent of the area of preferred depth that is present at 4,142 ft

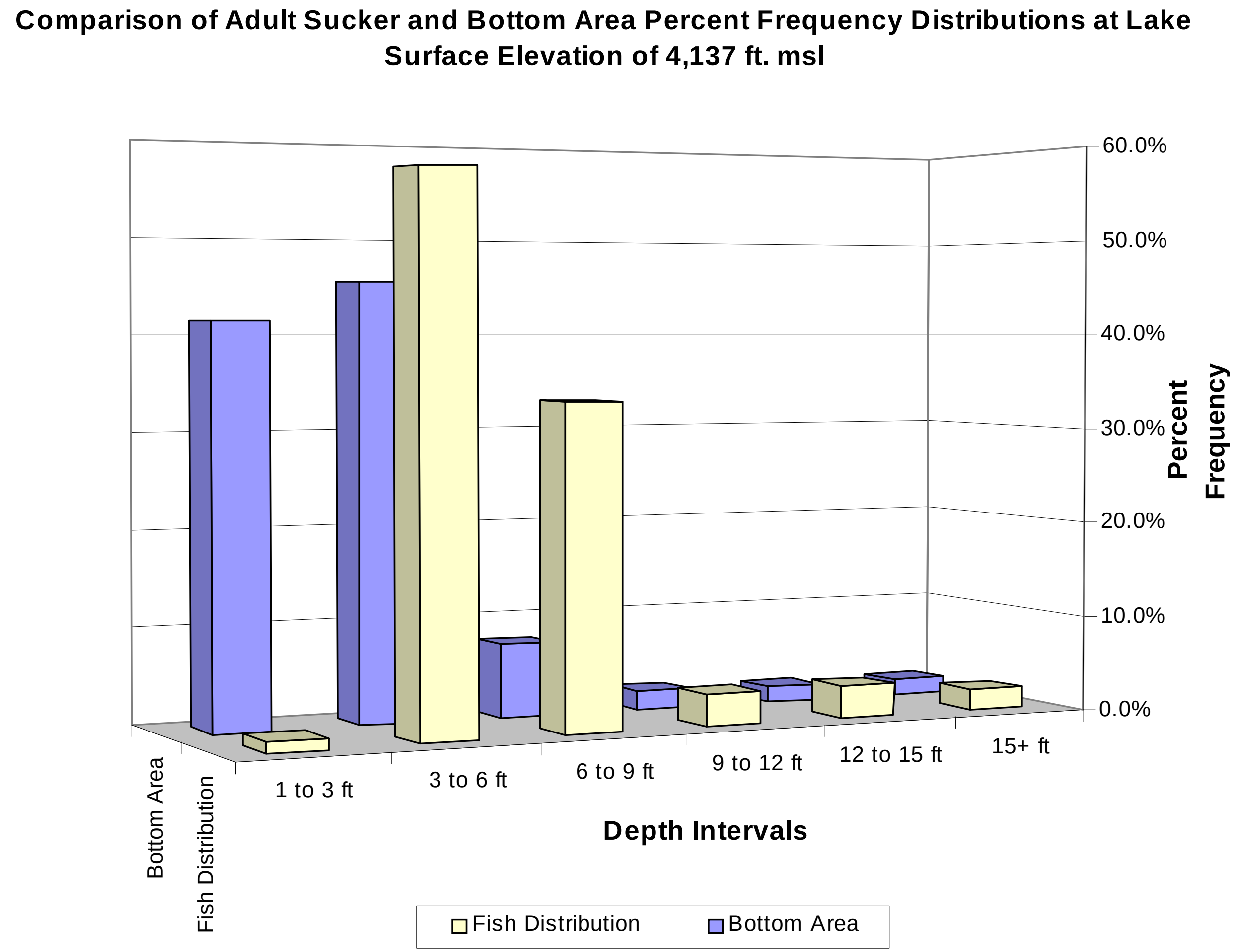


Figure 5-10. Comparison of the percentage frequency distribution of radio-tagged adult Lost River and shortnose suckers with the frequency distribution of percent bottom areas in discrete water depth intervals for the area north of Bare Island, at a mean lake surface elevation of 4,137 ft msl.

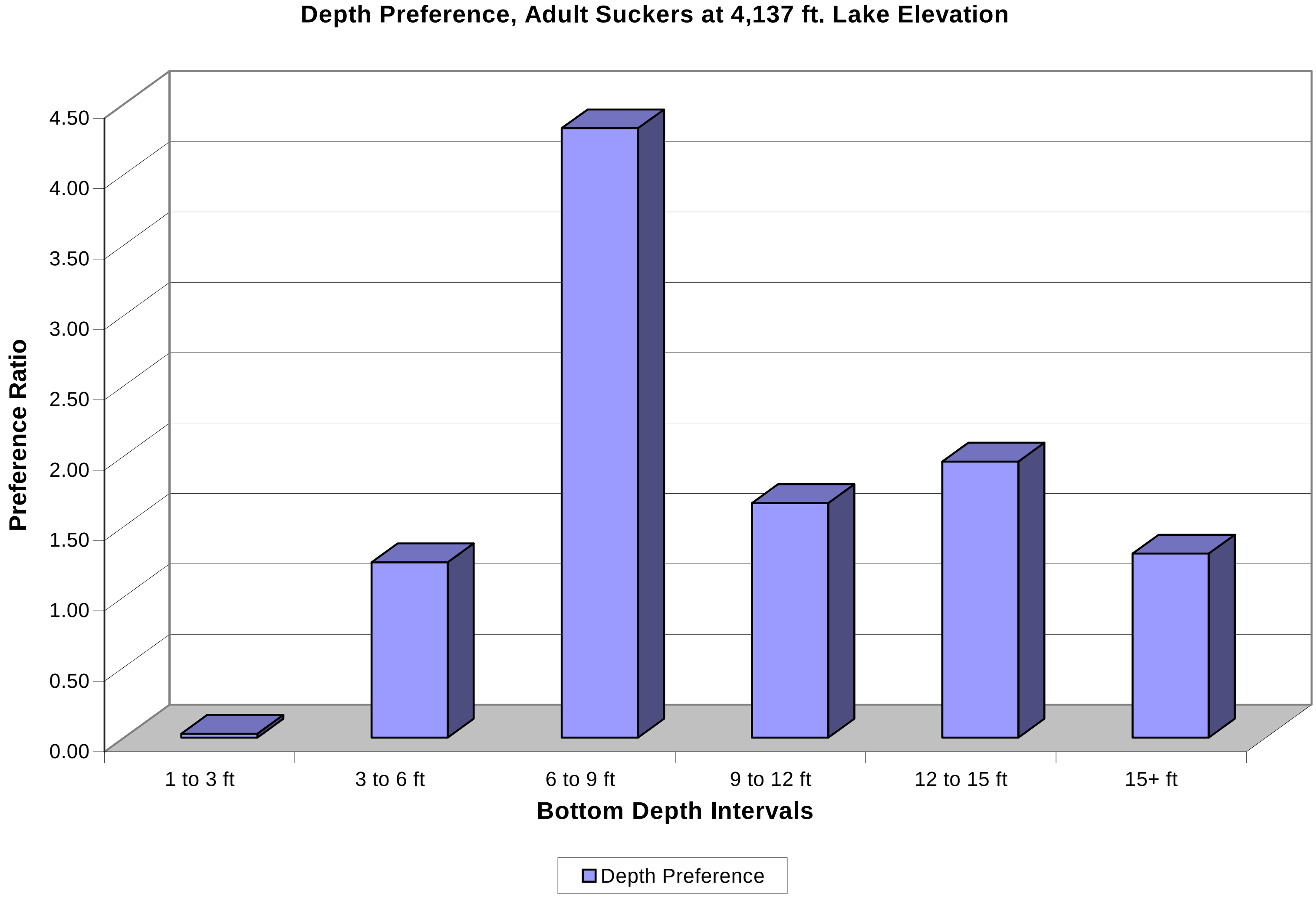


Figure 5-11. Apparent depth preference ratios for radio-tagged adult Lost River and shortnose suckers at mean lake surface elevation of 4,137 ft msl in consecutive water column depth intervals.

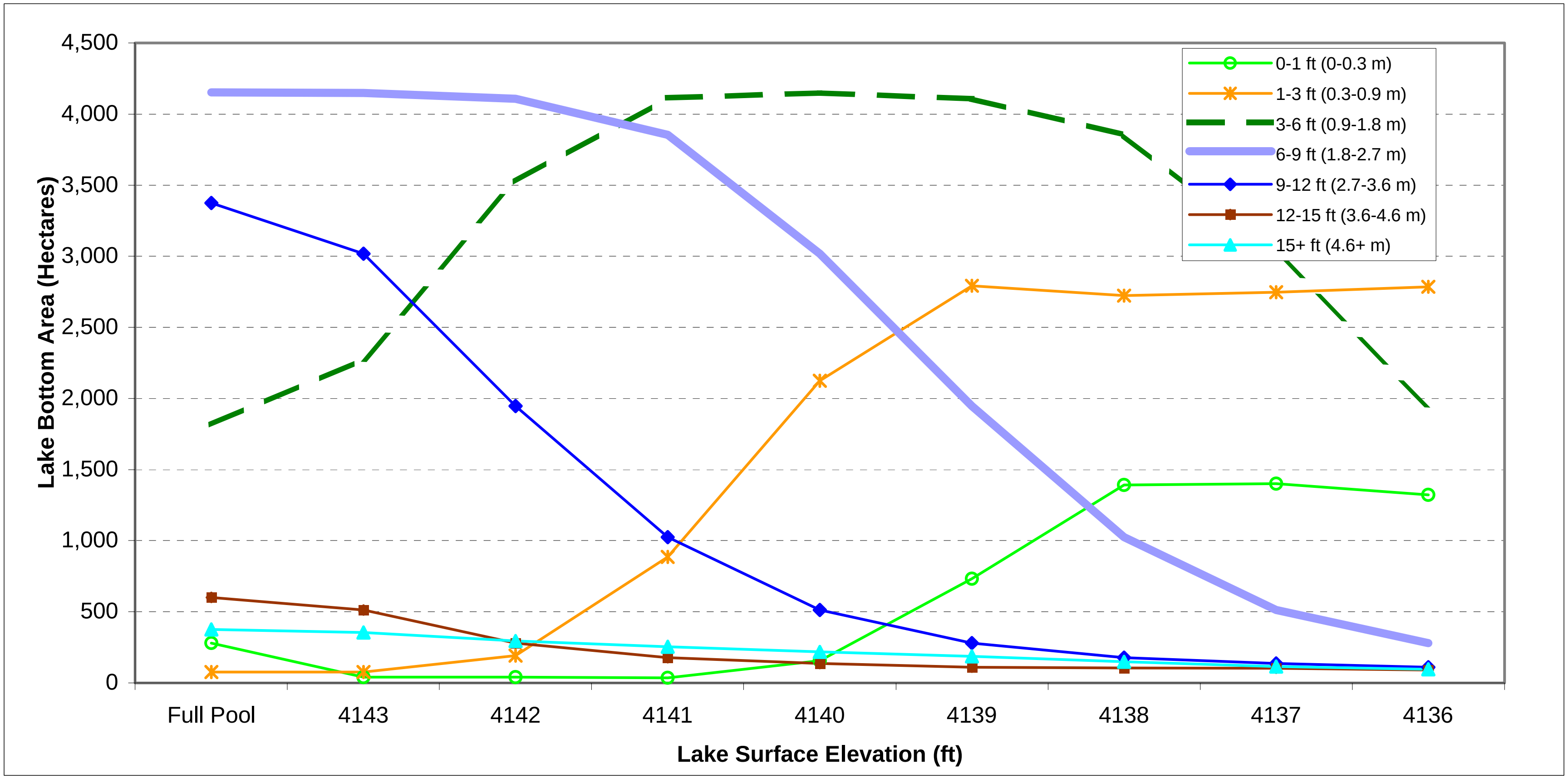


Figure 5-12. Upper Klamath Lake bottom areas in various water depth intervals at declining lake surface level elevations for the area north of Bare Island, based on Bureau of Reclamation Upper Klamath Lake bathymetry.

Table 5-8. Upper Klamath Lake bottom areas (hectares) in selected depth intervals at different lake surface level elevations for the area north of Bare Island. Data based on Bureau of Reclamation bathymetry.

Depth Range	Lake Elevation (ft msl)								
	Full Pool	**4143**	**4142**	**4141**	**4140**	**4139**	**4138**	**4137**	**4136**
Dry Area	0.0	249.8	290.8	330.7	367.2	521.9	1254.4	2645.6	4046.5
0-1 ft	279.7	41.0	39.9	36.5	154.7	732.5	1391.1	1400.9	1322.5
1-3 ft	76.2	76.4	191.3	887.2	2123.6	2792.1	2723.4	2747.4	2784.2
3-6 ft	1815.8	2278.4	3524.6	4114.5	4148.4	4106.6	3852.4	3016.6	1948.2
6-9 ft	4153.7	4148.4	4106.6	3852.4	3016.6	1948.2	1024.7	512.6	280.6
9-12 ft	3375.5	3016.6	1948.2	1024.7	512.6	280.6	178.1	136.4	109.3
12-15 ft	600.9	512.6	280.6	178.1	136.4	109.3	105.6	103.8	90.9
15+ ft	375.5	354.3	295.5	253.3	218.0	186.2	147.7	114.2	95.3
Total Area (w/o dry bed)	10677.4	10427.6	10386.6	10346.8	10310.2	10155.5	9423.0	8031.9	6630.9

Table 5-9. Percentage of full pool area that is dry, avoided, utilized, and preferred by Lost River and shortnose suckers at different lake surface elevations for the area north of Bare Island.

Depth Interval	Lake Elevation (ft msl)								
	Full Pool	**4143**	**4142**	**4141**	**4140**	**4139**	**4138**	**4137**	**4136**
Avoided (0-3 and 15+ ft)	7%	4%	5%	11%	23%	35%	40%	40%	39%
Utilization (3-15 ft)	93%	93%	92%	86%	73%	60%	48%	35%	23%
Preferred (6-9 ft)	39%	39%	38%	36%	28%	18%	10%	5%	3%
Dry Area	0%	2%	3%	3%	3%	5%	12%	25%	38%

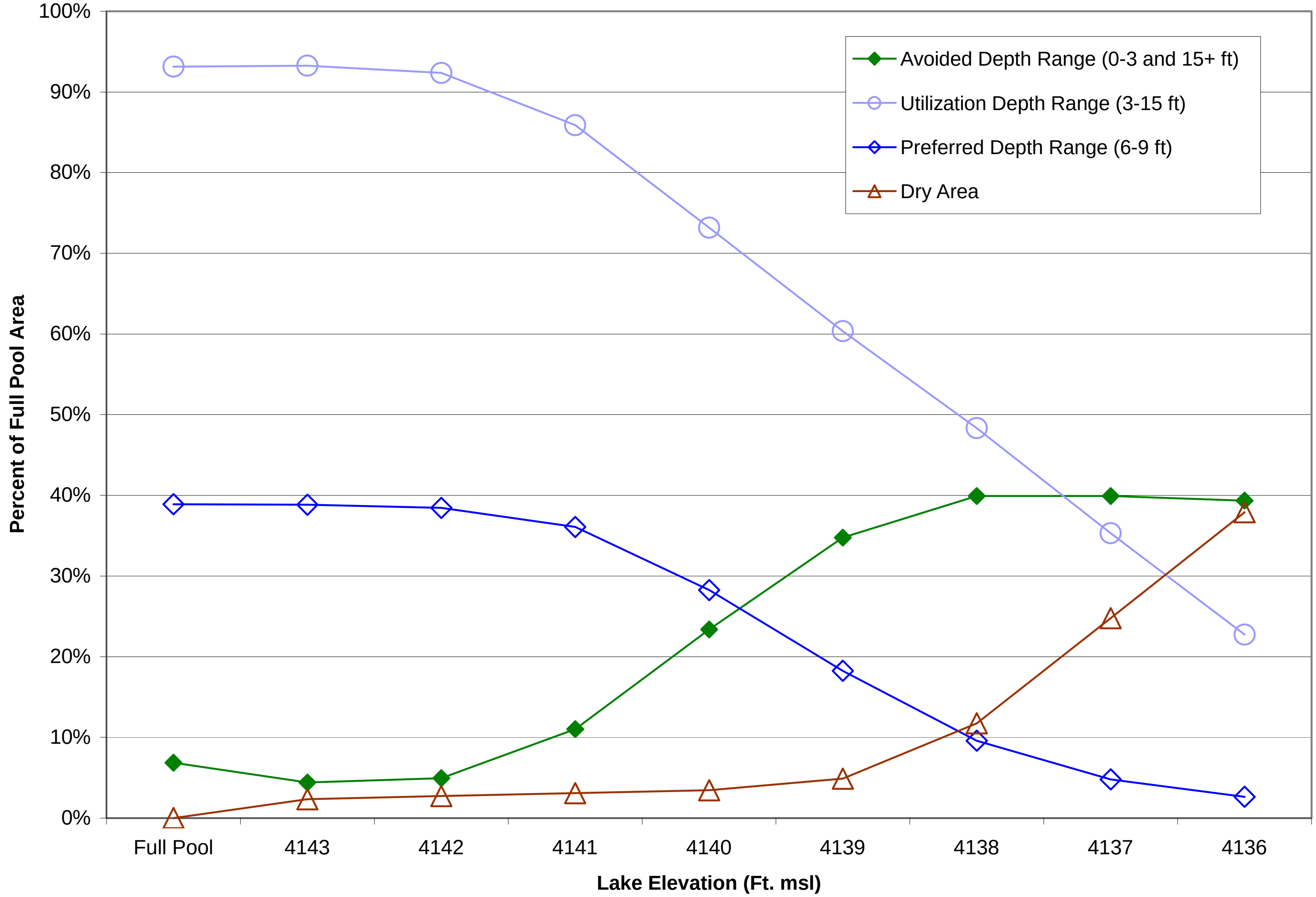


Figure 5-13. Percentage of full pool area avoided, utilized, and preferred by Lost River and shortnose sucker adults for area north of Bare Island (based on Bureau of Reclamation Upper Klamath Lake bathymetry).

6. EFFECTS OF POOR WATER QUALITY ON FISH AND FISH HABITAT UTILIZATION

This section addresses the general question of how fish habitat utilization of Upper Klamath Lake is affected by reduced water quality during summer months. The species considered are those discussed in Chapter 4, with a focus on Lost River and shortnose suckers and redband trout. A thorough analysis of the existing water quality conditions in Upper Klamath Lake, and the mechanisms responsible for reduced water quality is presented in R2 (2001b). The stress experienced by fish as a result of poor water quality is presented in R2 (2001a). In this section we summarize portions of that document where relevant and relate this information to how fish utilize different habitats within Upper Klamath Lake. We first define the lethal and sub-lethal stress inducing concentrations of four water quality parameters known to influence fish health in Upper Klamath Lake (Section 6.1) and then describe Upper Klamath Lake water quality conditions (for different years) relative to these four parameters (Section 6.2). In the remaining two sections, we provide a spatial and temporal water quality analysis based on USBR radio tagging data of suckers (Section 6.3), and then discuss patterns of fish habitat utilization during periods of poor water quality, again based on USBR radio tagging data (Section 6.4).

6.1 LETHAL AND SUBLETHAL EFFECTS OF POOR WATER QUALITY ON UPPER KLAMATH LAKE SUCKERS

This section focuses on four water quality parameters that at certain concentrations or levels, are known to induce stress to fish. These parameters are pH, un-ionized ammonia, temperature, and dissolved oxygen (DO).

6.1.1 Lethal Stress

Lethal levels of water quality induced stress to larval and juvenile suckers have been quantified by Saiki et al. (1999). They determined upper median lethal concentrations (LC_{50}) of pH, un-ionized ammonia, temperature, and DO for Lost River and shortnose sucker larvae and juveniles using 96 hour long acute toxicity tests (Table 6-1).

The LC_{50} for pH was similar for the two species and for both larval and juvenile life stages. For DO and temperature, the LC_{50} was similar between species but life stages differed in sensitivity. Larvae were more sensitive than juveniles to low DO, but juveniles were more sensitive to temperature than were larvae. Sensitivity to un-ionized ammonia differed both between species and between lifestages, with Lost River sucker larvae being the most sensitive and shortnose sucker juveniles being the least sensitive.

Meyer et al. (2000) examined chronic toxicity to DO, pH, and un-ionized ammonia, with test durations extending from 14 to 30 days. Their results were generally consistent with the results from the 96 hour tests of Saiki et al. (1999). Meyer et al. (2000) found that the 30 day LC_{50} for un-ionized ammonia and 14 day LC_{50} for DO were similar to 96 hour values, primarily because most mortality occurred in the first 24 hours. In the Meyer et al. (2000) study, pH did not exceed 10.0, and significant pH induced mortality did not occur.

Table 6-1. Upper median lethal concentrations (96 hr) for pH, un-ionized ammonia (NH3), temperature, and dissolved oxygen (DO) to larval and juvenile Lost River (LR) and shortnose (SN) suckers (from Saiki et al. 1999).

Species and Lifestage	Mean LC_{50} Values (95% confidence intervals)			
	pH	NH3 (mg/L)	Temperature (°C)	DO (mg/L)
LR larvae	10.35 (10.26-10.45)	0.48 (0.44-0.52)	31.69 (31.47-31.91)	2.10 (2.07-2.13)
LR juvenile	10.30 (9.94-10.67)	0.78 (0.70-0.86)	30.51 (29.99-31.04)	1.62 (1.41-1.86)
SN larvae	10.38 (10.31-10.46)	1.06 (0.73-1.53)	31.82 (31.75-31.90)	2.09 (1.90-2.29)
SN juvenile	10.39 (10.22-10.56)	0.53 (0.34-0.82)	30.35 (29.44-31.28)	1.34 (1.15-1.55)

It should be noted that in both the Saiki et al. (1999) and Meyer et al. (2000) studies, effects of poor water quality were tested for one parameter at a time, with levels of other water quality parameters held at non-stressful levels. Since sublethal or lethal levels of water quality for two or more parameters may occur simultaneously under ambient conditions and does in Upper Klamath Lake, the LC_{50} in studies such as these are not necessarily transferable to ambient conditions.

Martin and Saiki (1999) examined the effects of ambient water quality on caged Lost River suckers in Upper Klamath Lake. Their study was conducted in the summer of 1995, which was a year when water quality in Upper Klamath Lake was not as low as in some recent years, but levels of pH and DO at times exceeded the 96 hour LC_{50} for Lost River juvenile suckers found by Saiki et al. (1999). Martin and Saiki (1999) found that DO was the water quality parameter most strongly associated with juvenile Lost River sucker mortality, with high mortality (> 90 percent) at DO levels of #1.05 mg/L, and relatively low mortality (< 10 percent) at DO concentrations $1.58 mg/L. Although pH also exceeded lethal limits, the time of exposure was either too short, or other factors were ameliorating the effects.

Using stepwise logistical regression, Martin and Saiki (1999) also looked at the interaction of two or more water quality parameters. Significant interactions (in order of decreasing relative importance) included:

DO * pH,
DO * pH * NH_3,
DO *NH_3,
pH * temperature,
DO * pH * NH_3,
DO * pH * NH_3, * temperature, and
NH_3 * temperature.

6.1.2 Sublethal Stress

In addition to the effects of lethal stress on Lost River juvenile suckers, Meyer et al. (2000) examined the effects of sublethal stress. They used several different endpoints of sublethal stress, including growth, whole-body ion count, swimming performance, and gill histopathology. The former three endpoints all show functional impairment, whereas structural changes in gills are not necessarily associated with impaired function. For the three functional endpoints, Lost River juvenile suckers generally did not show sublethal responses to low DO concentrations, elevated pH, or elevated un-ionized ammonia concentrations. There were, however, significant changes in gill structure in response to un-ionized ammonia concentrations 3.5 times lower than levels at which significant mortality and growth effects occurred. No effects of pH < 10.0 on gill structure were found, and effects of sublethal DO on gill structure were not examined due to technical problems.

Meyer et al.'s (2000) study suggested that an adverse functional effect of pH, DO, and un-ionized ammonia did not occur until lethal levels were approached, but that potentially important structural changes in gills did occur at un-ionized ammonia concentrations well below lethal levels. There are, however, several factors that limit the applicability of Meyer et al.'s (2000) data to actual conditions in Upper Klamath Lake. Fish in their study were fed to satiation, which may not be the case among larval and juvenile suckers in the lake that may be stressed. Also, fish were exposed to relatively constant levels of each parameter, with only one parameter tested at a time, which, as noted above, is not likely to occur under natural conditions.

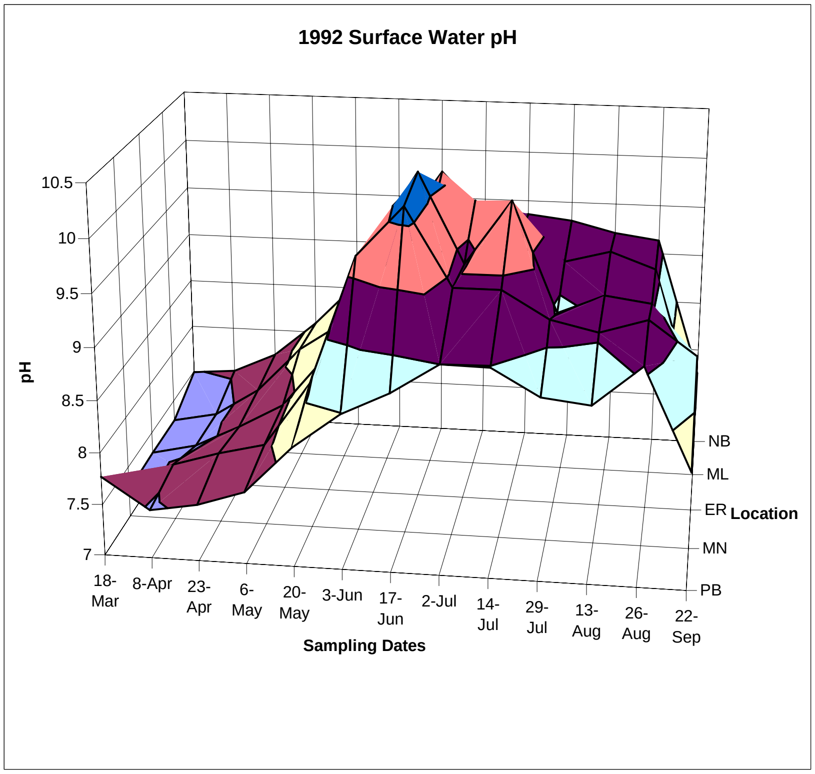
6.2 WATER QUALITY CONDITIONS IN UPPER KLAMATH LAKE

The water quality conditions in Upper Klamath and Agency lakes have been extensively studied (Coleman et al. 1988; Kann 1993a, Kann 1993b, Kann 1998; Gearheart et al. 1995) and most recently evaluated in conjunction with a water quality model for total phosphorus loading to the system (R2 2001b). In that report and elsewhere, the mechanisms associated with the hyper-eutrophic conditions of Klamath Lake have been described and discussed in detail. To illustrate temporal and spatial patterns in lake water quality, we discuss data from two years, 1992 and 1993 for pH, dissolved oxygen, and temperature. For ammonia, a more detailed characterization is provided because of a distinct change in patterns of un-ionized ammonia levels during the 1990 to 1998 period.

6.2.1 pH

The pH is a measure of the concentration of H^+ ions in water (specifically the logarithm of $1/[H^+]$). Very low pH values indicate high concentrations of H^+ ions, or acid conditions. High pH values (e.g., > 9.0) by contrast, are associated with strong OH^- ion concentrations, or basic conditions. Fish are susceptible to negative impacts from pH when either very acid or very basic conditions exist. The photosynthetic activity of the algal blooms raise the pH of lake waters in the period from May through October (Wood et al. 1996) and is directly related to algal biomass (Kann and Smith 1999). The range of pH considered to be harmless to freshwater aquatic life is from pH 6.5 to 9.0 (USEPA 1987). The algal blooms in Upper Klamath Lake raise pH beyond this range.

Examples of the seasonal and spatial pattern of pH level in surface waters of Upper Klamath Lake water quality data collected by the Klamath Tribes are shown in Figure 6-1. This figure contrasts pH conditions in 1992 and 1993. Data for pH are



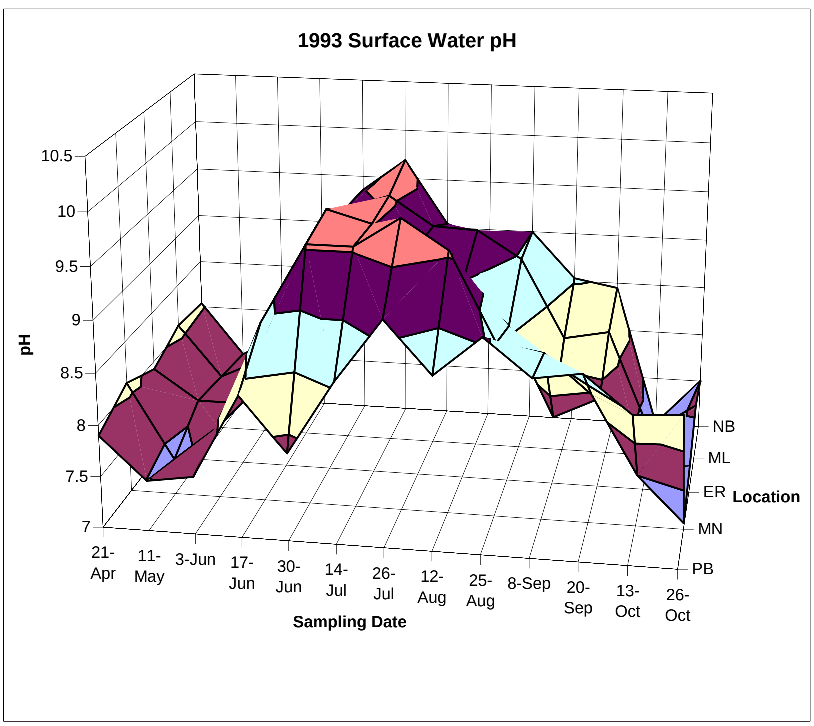


Figure 6-1. Spatial and temporal pH in a low lake elevation (1992) and high lake elevation (1993) year (PB = Pelican Bay; MN = Mid North; ER = Eagle Ridge; ML = Mid-Lake; NB = North Buck Island). Shading indicates intervals of 0.5 pH units.

shown for an array of sampling locations in Upper Klamath Lake ranging from Pelican Bay (PB) in the northwest corner of the lake to just north of Buck Island (NB) in the southern portion of the lake (Figure 3-1 for sampling locations). In 1992, surface water pH values reached and exceeded 9.0 from late May through the end of August and exceeded pH values of 10.0 in late June in the central portions of the lake. In 1993, a pH of 9.0 was not exceeded until after mid-June and did not persist throughout the lake after mid-August. Maximum pH values in excess of 9.5 were reached or exceeded in at least one location until mid-August. In both years, Pelican Bay shows lower pH levels (better water quality) than any other location sampled.

Kann and Smith (1993) showed that coincident measures of chlorophyll *a* and pH were directly correlated, most strongly in afternoon measurements. Values of pH > 9, in excess of generally acceptable water quality criteria, were exceeded in more than 80 percent of the data when afternoon chlorophyll *a* concentrations were greater than 50 µg/L. Wood et al. (1996), in summarizing data from 1990 through 1995, found that the lake-wide, May-October median Klamath Lake chlorophyll *a* levels ranged between 52 and 99 µg/L. Consequently, high pH values are a predominant feature of current lake water quality and occur most frequently where and when algal concentrations are high. Continuous monitoring of pH at several locations in the lakes has shown that pH declines at night, when photosynthesis is absent and when respiratory and atmospheric carbon dioxide enter the waters. This cycle results in a diurnal oscillation in pH levels that can exceed 2 pH units. Kann (1993b), however, presented continuous monitoring data that shows that pH levels may exceed 9.0 for more than a week at a time and values greater than 10 are exceeded during peak bloom periods.

Wood et al. (1996) summarized pH data collected between 1990 and 1995 by the Klamath Tribes at 12 locations in Upper Klamath and Agency lakes. The water column profile records show that pH values in excess of 9.5 were typical of surface waters in June and July in most years. In many profiles of pH, values greater than 9.5 occurred throughout the water column and persisted for several weeks. Thus, fish inhabiting these areas would experience exposures to high pH levels for extended periods.

6.2.2 Dissolved Oxygen

Algal photosynthesis causes DO supersaturation during daylight hours, but respiration by algae and other microbes depresses oxygen levels at night. Conditions of DO supersaturation have been associated with sublethal effects on several fish species including largemouth bass (Stewart et al. 1967) and rainbow trout (Caldwell and Hinshaw 1995). There is, however, no direct evidence that DO supersaturation causes adverse lethal or sublethal effects on sucker species found in Klamath Lake. Therefore, this evaluation will focus on the occurrence of depressed, sub-saturation oxygen concentrations that are known to adversely affect sucker species and rainbow trout.

R2 (2001b) pointed out that oxygen demand of bottom sediments plays an important role in phosphorus recycling and is heightened by the decay of algal biomass following each year's algal bloom. Wood et al. (1996) found that oxygen levels below 4 mg/L occurred most frequently between July and November at depths greater than

2 meters. They selected a criterion of 4 mg/L based on published water quality criteria (USEPA 1987). They summarized oxygen profile data collected by the Klamath Tribes that showed day-time depressions below 4 mg/L within a meter or two of the bottom more frequently in deeper sections of the lake. The highest frequency of dissolved oxygen concentrations depressed below 4 mg/L occurred in August and September in deeper waters, and no values less than 4 mg/L were found at any lake location in June (Wood et al. 1996).

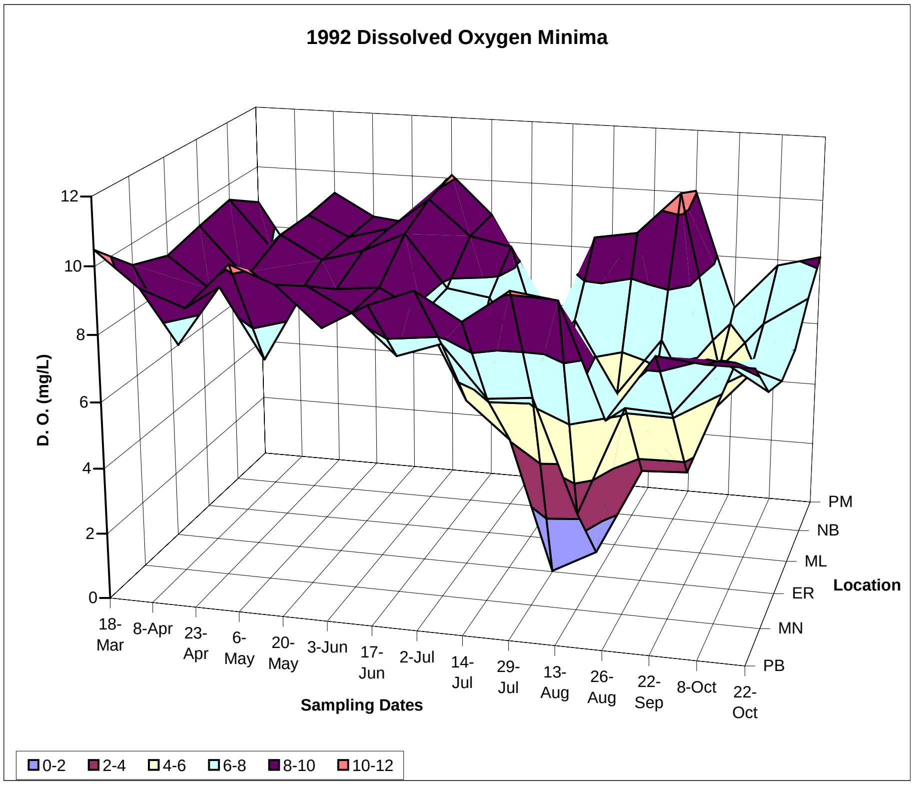
Examples of the seasonal and spatial pattern of DO in Upper Klamath Lake are presented in Figure 6-2. As with Figure 6-1, these graphs are based on Klamath Tribes data and show DO in 1992 and 1993 at a variety of locations (Figure 3-1) in Upper Klamath Lake. These data show that DO minima equal to or less than 4 mg/L were encountered at the deepest location off Eagle Ridge (ER) in both years. These low concentrations persisted at this location for 5 consecutive weeks in 1992 and for 3 consecutive weeks in 1993. In 1992, the only other measurement below 4.0 mg/L occurred in mid-August at the mid-north (MN) sampling location. The single value below 4 mg/L measured in June, 1993, in Pelican Bay (PB) may be an anomalous measurement or may represent oxygen demand from organic material from upstream marshlands.

6.2.3 Temperature

Water temperatures in Upper Klamath and Agency lakes typically rise above 10°C in May and 20°C by mid- to late June. Median temperatures in open lake waters may reach 23°C in late July (Wood et al. 1996). Temperatures approaching 30°C may occur in shallow water bays on calm, sunny days.

Although lake water temperatures do not reach lethal limits for sufficient duration to directly affect mortality among sucker species of concern, they may surpass optimum temperatures for salmonid species during summer months. USEPA (1987) lists 18°C for salmon species and 19°C as the maximum weekly average temperature (MWAT) upper limit for optimum growth, and 23 to 24°C as the short-term maximum temperature for survival for Pacific Coast salmonid species. Data summarized by Wood et al. (1996) show that median lake temperatures routinely exceed the MWAT limits from late-June through mid-September. Median temperatures greater than 23°C for two consecutive weeks were found in late-July or early-August in two of the five years of data they reviewed.

R2 (2001b) noted that high temperatures can lead to more stressful conditions associated with other water quality parameters. For instance, higher water temperatures may accelerate algal growth and, hence, promote high pH conditions in the lake (Kann 1998). Wood et al. (1996) also found that warmer spring periods were associated with earlier and higher chlorophyll levels in the lake. They found that early warming resulted in bloom initiation in May, while in cool years blooms were delayed until late June. Higher temperatures in the summer and fall accelerate microbial decay of organic material settling to the bottom of the lake as well as lowering oxygen solubility. Both conditions can cause more extreme low oxygen levels in deeper, near bottom lake waters. Higher



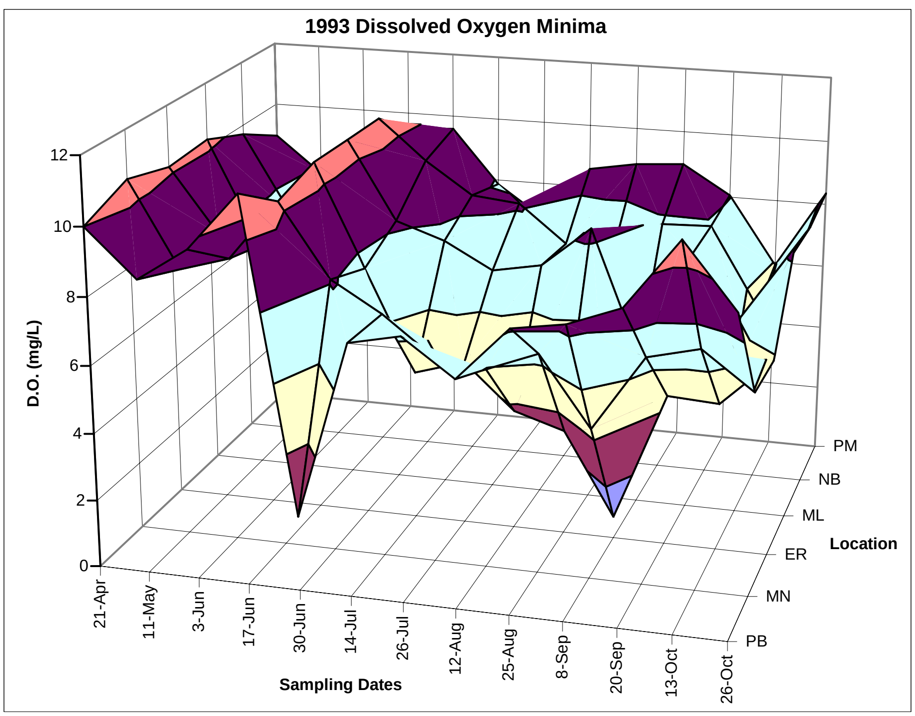


Figure 6-2. Dissolved oxygen (mg/L) concentrations in near-bottom waters of Upper Klamath Lake in 1992 and 1993 (Figure 5-1 for key to locations).

water temperatures also increase fish metabolism and, therefore, their oxygen requirements (Fry 1947). Higher water temperatures also increase the proportion of un-ionized ammonia, but decrease the sensitivity of fish to un-ionized ammonia toxicity (USEPA 1985). Higher temperatures are also associated with increased pathogen and parasite growth rates (Snieszko 1974).

6.2.4 Ammonia Toxicity

Un-ionized ammonia is known to be toxic to fish at levels encountered in Upper Klamath Lake samples (Monda and Saiki 1993, 1994). Ammonia is a by-product of the decay of organic material, including the algal biomass produced in the lake (R2 2001b). The portion of total ammonia that is in the toxic, un-ionized form is determined by the pH and temperature of water and can affect both acute and chronic toxicity to fish depending on the level and duration of exposure (USEPA 1985). The water quality criteria for ammonia must be calculated based on the ambient temperature and pH of the water sampled. These criteria are especially sensitive to changes in pH in that much larger fractions of ammonia are in the un-ionized form as pH rises above 8.0. Fish, however, are more sensitive to ammonia in the un-ionized form at lower temperatures. The process of determining if ammonia criteria are exceeded is therefore somewhat complex. In addition, toxicity of un-ionized ammonia exposure depends on both the life stage and sensitivity of the different fish species exposed. Stress and potential toxicity associated with ionized ammonia ($NH4^+$) has been recognized, but is essentially integrated into the USEPA un-ionized ammonia criteria (1992) by virtue of the fact that toxicity from both ammonia fractions in test results that USEPA used to establish water quality criteria were assigned to the un-ionized ammonia concentration.

Wood et al. (1996) summarized the exceedences of chronic un-ionized ammonia criteria for fresh water aquatic life, when cold water fish species are present, and found that exceedences ranged from a frequency of 2 to 8 percent in samples analyzed between 1990 and 1994 from Upper Klamath and Agency lakes. These criteria were presumably selected to identify the onset of adverse effects on fish attributable to un-ionized ammonia. In accordance with the ammonia criteria guidelines (USEPA 1985), they did not consider nearly 40 percent of the samples in which the pH was greater than 9.0 and therefore underestimated the frequency with which potentially toxic, un-ionized ammonia concentrations might be encountered by Klamath Lake fish species (R2 2001b).

To examine the spatial and temporal pattern of un-ionized ammonia criteria exceedences, R2 calculated the acute and chronic criteria concentrations for all data sets in the Upper Klamath Lake water quality data base (R2 2001a) that contained temperature and pH measurements coincidentally taken with integrated water column samples for total ammonia (Section 3.6.1). Using the "acute ratio" (dividing the ambient concentration by the acute criteria concentration), R2 determined the degree and extent to which the ambient un-ionized ammonia concentrations might contribute to sucker species stress and potential mortalities in Upper Klamath Lake.

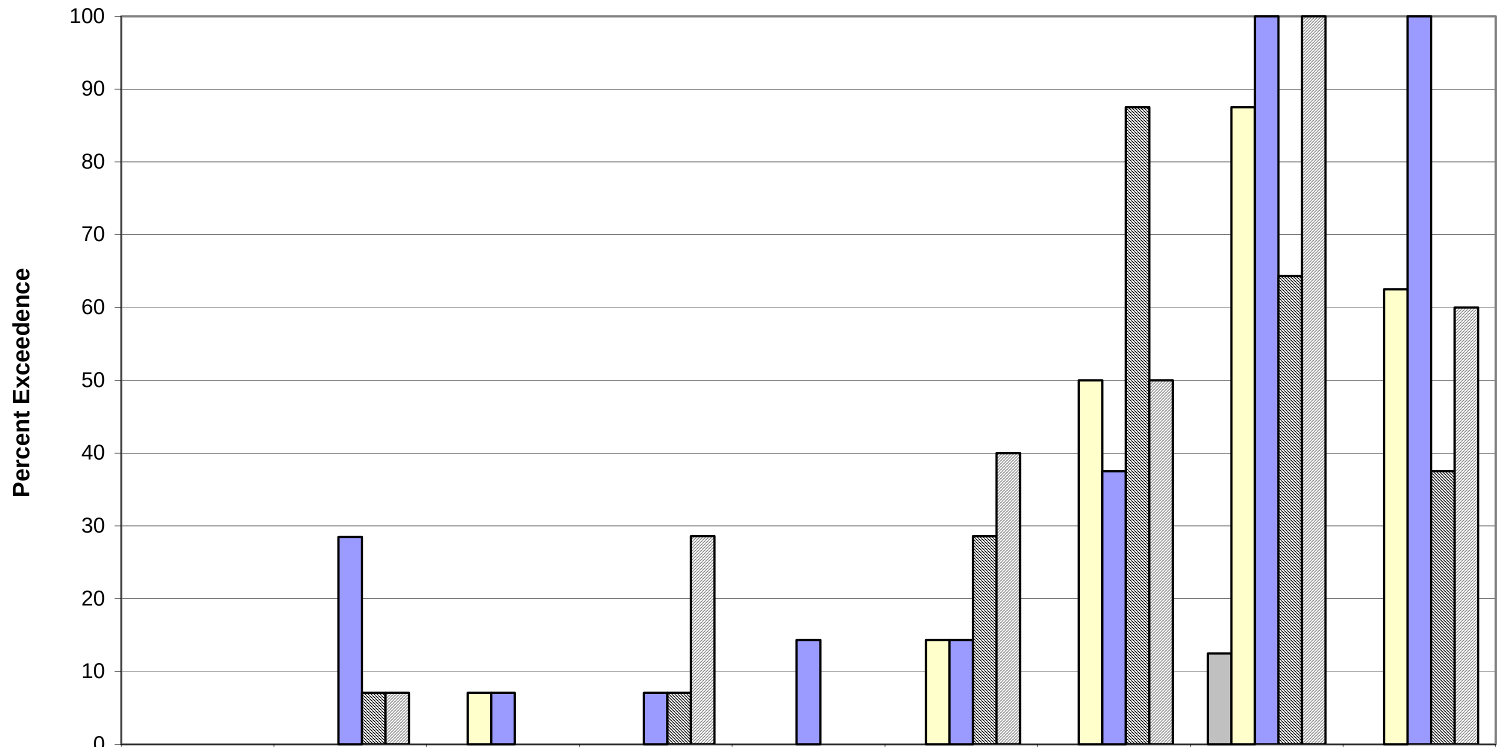
Graphs of the acute ratio at each location sampled by the Klamath Tribes for each year (1990 –1998) are shown in Appendix C, with data tables of the actual ratio values. When the acute ratio value for a location/date exceeds 1.0, the USEPA acute criteria for un-ionized ammonia are exceeded. Because the USEPA chronic un-ionized ammonia criteria are 23% of the acute un-ionized ammonia, when the acute ratio exceeds 0.23 in these figures for a particular location/date, the USEPA chronic criteria for un-ionized ammonia are exceeded. In these figures, the shaded histograms represent locations south of the east-west demarkation line at Bare Island described in section 5.3 as the boundary for 90 percent adult sucker habitat use. These southern sampling locations included ML, NB, WB, and PM (Figure 3-1). In the northern area of the lake, where > 90 percent of adult Lost River and shortnose suckers reside, line-patterned histograms are used to distinguish these areas (ER, MN, SB and CP in 1997 and1998 only). A variable "Y-axis" scale is used in these figures to facilitate location comparisons within each year and a data table is provided to distinguish low acute ratio values from dates and locations where un-ionized ammonia values were unavailable.

Appendix Figures C-1 through C-9 show that exceedences of acute un-ionized ammonia criteria were rarely characteristic of Upper Klamath Lake bottom waters from 1990 through 1996. Single acute criteria exceedences occurred in bottom waters at ER in July of 1991, PM in September 1993, and ML in 1996. In 1997 and 1998 acute exceedences were most prevalent in July, nearly absent in August, but reoccurred in September of both years. Chronic criteria exceedences on bottom waters occurred where and when acute exceedences were present and at other times and locations shown in the figures where the acute ratio exceeded a value of 0.23. Inspection of the figures shows that chronic exceedences in bottom waters in the northern portion of the lake were more prevalent or equal to those at the more southern 4 locations from 1990 through 1996. Beginning in 1995, chronic exceedences became much more prevalent and occurred on consecutive sampling dates in the northern lake area. The severity of these chronic conditions expanded lake-wide and appears to be consistently present at nearly all locations sampled from mid- to late-June and through July of each year.

The percent exceedences of USEPA chronic criteria for un-ionized ammonia in bottom waters of Upper Klamath Lake are shown in Figure 6-3 for all sampled lake locations. Figure 6-4 shows the un-ionized, percent exceedences of USEPA chronic criteria for bottom water locations north of Bare Island. The period shown in both figures is for May through September in each year of the Klamath Tribes' water quality data set (1990 through 1998).

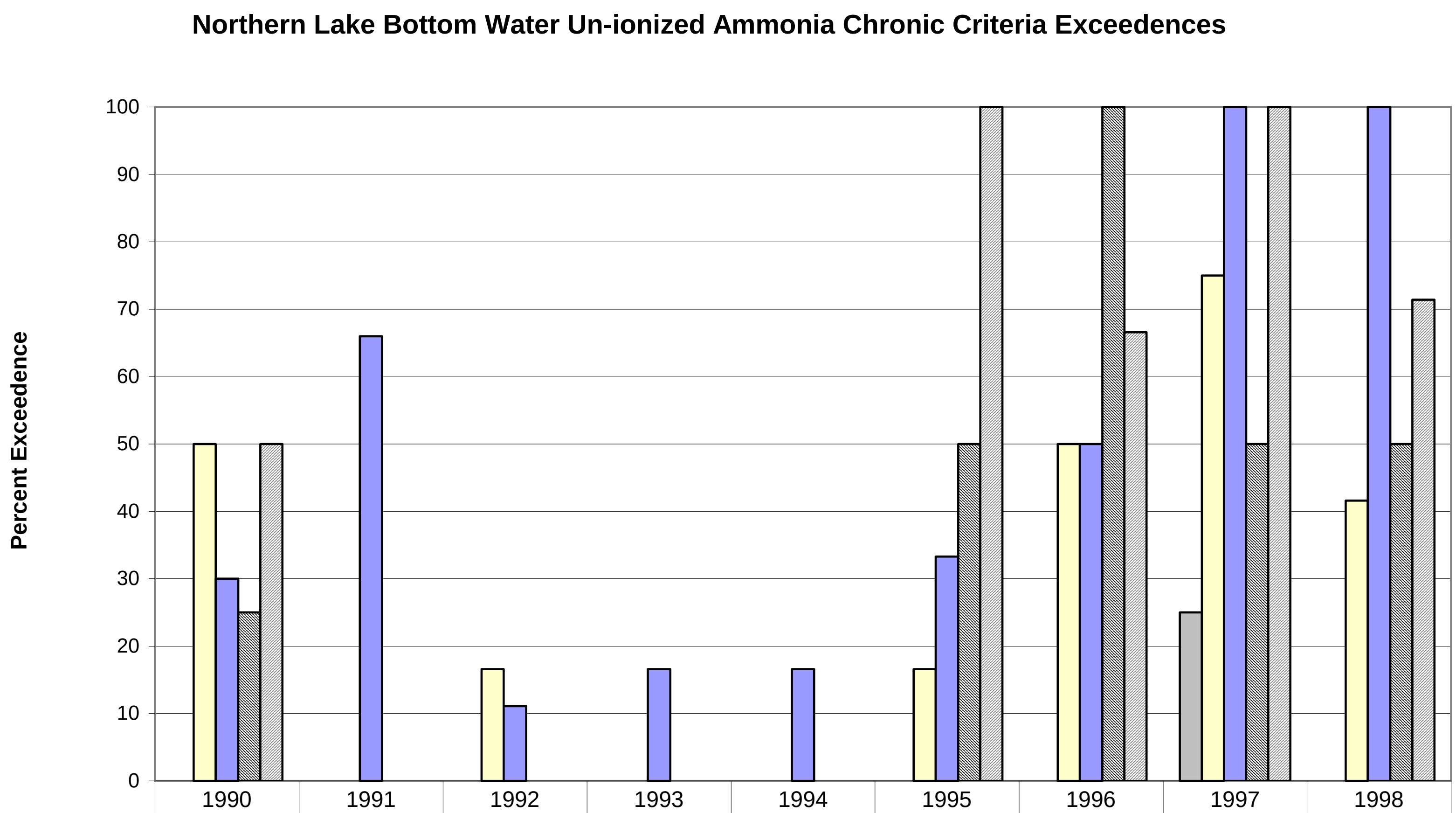
No data are shown for the whole-lake chronic criteria exceedence in 1990 because southern lake sampling occurred in only 2 of 10 surveys that year. Chronic exceedences in the northern locations are shown, as at least two of the three northern sampling locations were sampled in all 10 surveys in 1990. The pattern of exceedences in both figures shows that substantial increases in un-ionized ammonia exceedences began in 1995 and persisted through 1998. The northern section of the lake appears to have equal or greater percent exceedence in nearly all months of record when compared to the lake as a whole. For those months in which chronic exceedences occur at 100 percent of the locations sampled, the data suggest that suckers can experience, at least,

Whole Lake Bottom Water Un-ionized Ammonia Chronic Criteria Exceedence



	1990	1991	1992	1993	1994	1995	1996	1997	1998
May		0	0	0	0	0	0	12.5	0
June		0	7.1	0	0	14.3	50	87.5	62.5
July		28.5	7.1	7.1	14.3	14.3	37.5	100	100
August		7.1	0	7.1	0	28.6	87.5	64.3	37.5
September		7.1	0	28.6	0	40	50	100	60

Figure 6-3. Percentages of all bottom water un-ionized ammonia chronic criteria exceedences at locations sampled from May through September 1991-1998 in Upper Klamath Lake.



	1990	1991	1992	1993	1994	1995	1996	1997	1998
May		0	0	0	0	0	0	25	0
June	50	0	16.6	0	0	16.6	50	75	41.6
July	30	66	11.1	16.6	16.6	33.3	50	100	100
August	25	0	0	0	0	50	100	50	50
September	50	0	0	0	0	100	66.6	100	71.4

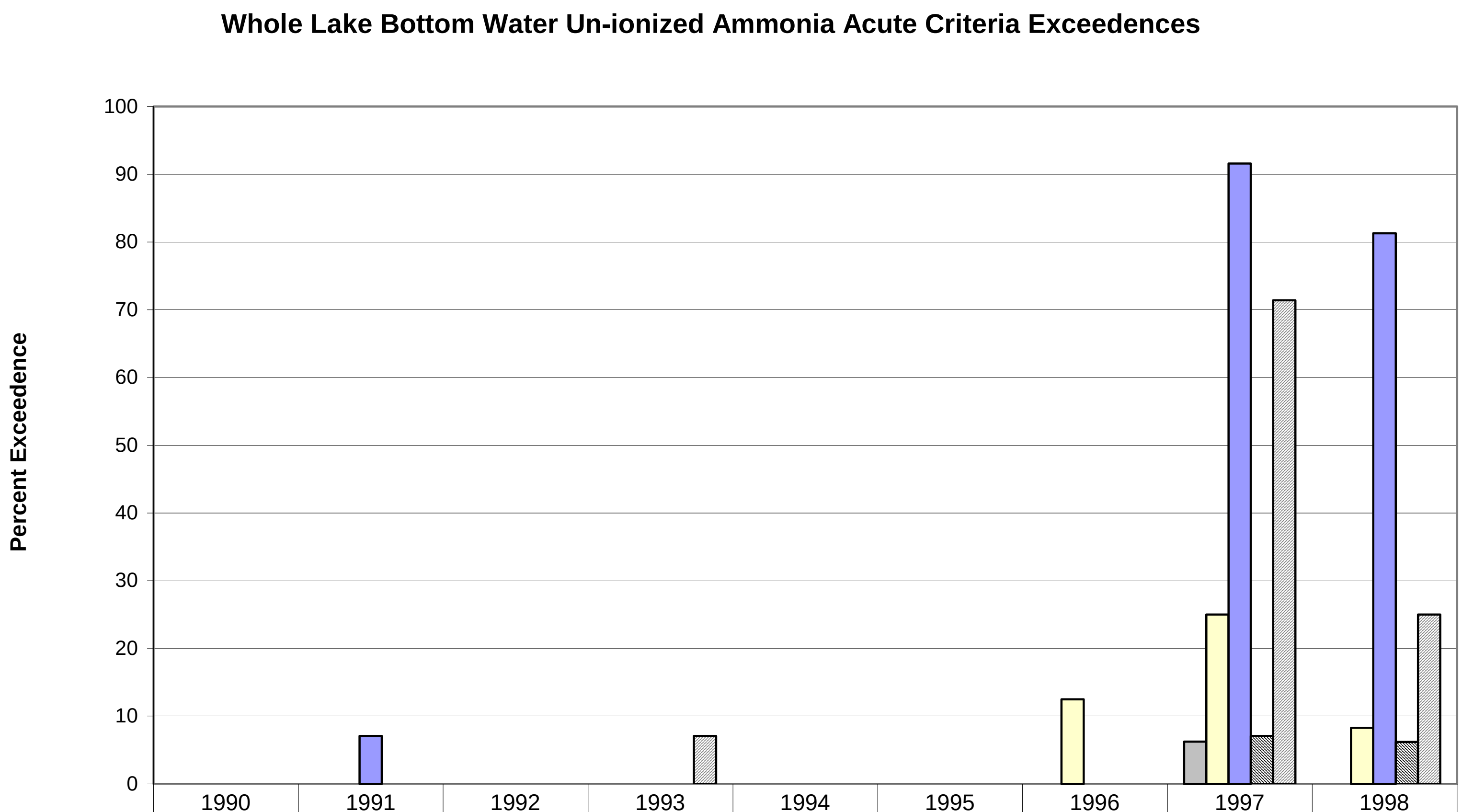
Figure 6-4. Percentages of bottom water un-ionized ammonia chronic criteria exceedences at locations sampled north of Bare Island from May through September, 1990-1998 in Upper Klamath Lake.

sublethal effects and stress from ammonia exposure.

Percentages of bottom water samples exceeding the USEPA acute criteria for un-ionized ammonia are shown for the whole lake (Figure 6-5) and for the northern section (Figure 6-6) for 1990 through 1998. Acute exceedences for the whole lake in 1990 are omitted from Figure 6-3 for reasons described above. However, no acute exceedences occurred in the May or September sampling at southern locations in that year. The figures show that acute exceedences of un-ionized ammonia criteria rarely occurred, during the sampling period, at any lake location until 1997. Although the percent of bottom water exceedences was prevalent in the northern lake section in July of 1997 and 1998, acute exceedences are shown to be more persistent and wide spread in the whole lake figure (Figure 6-5). This indicates that more severe conditions of ammonia exposure occurred in the southern portion of the lake in those years.

When and where these acute exceedences occurred in the latter two years of the Klamath Tribes water quality data are shown in Appendix C (Figures C-1 through C-9). Figures C-8 and C-9 show that often the acute exceedences were 2 to 10 times the USEPA acute criteria concentration in 1997 and 1998, which would exceed LC_{50} concentrations of un-ionized ammonia measured for larval and juvenile Lost River and shortnose suckers (Monda and Saiki 1993, 1994; Bellerud and Saiki 1995; Saiki et al. 1999; Meyer et al. 2000). These high concentrations of un-ionized ammonia are therefore sufficient to cause mortality among younger suckers and adults, provided adults are equally sensitive to ambient ammonia concentrations. Perkins et al. (2000b) attributed the adult sucker mortalities that occurred in Klamath Lake in the August-September/October months of 1995 through 1997 primarily to hypoxia following the decline and decay of the annual algal blooms. They also noted that stressful conditions due to un-ionized ammonia and high pH preceded the period of peak mortalities. With respect to un-ionized ammonia concentrations in the northern portion of Klamath Lake, the results presented here are consistent with their evaluation.

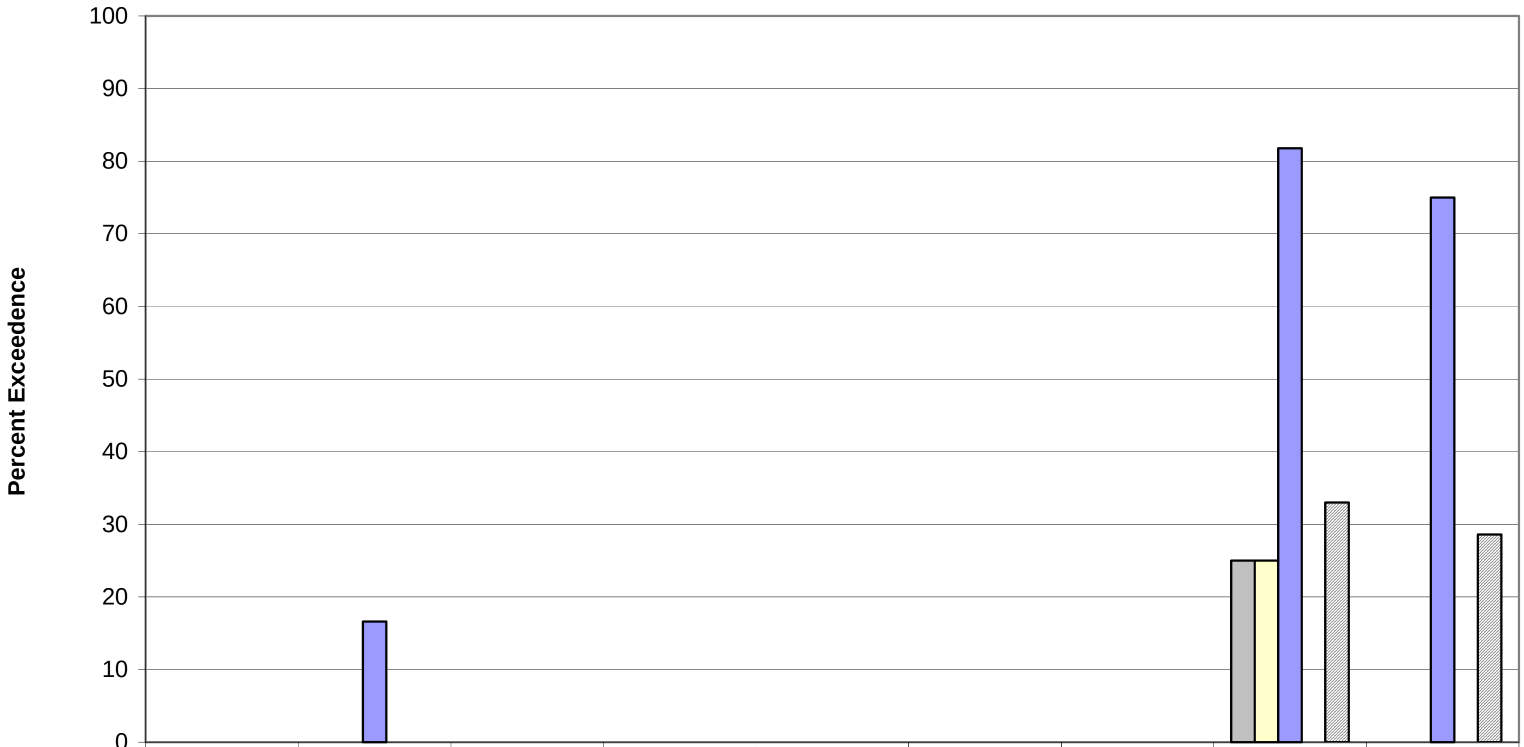
The chronic toxicity study of Meyer et al. (2000) found that un-ionized ammonia concentrations 3.5 times below lethal concentrations were associated with gill lamellae thickening in Lost River sucker larvae following 30 days of chronic exposure testing. Such thickening nearly doubled the diffusion distance necessary for oxygen to enter the fishes blood stream, which would effectively increase the ambient DO level needed to satisfy respiratory metabolic requirements. If such a response is typical of other sucker life stages, the ambient exposures to high levels of un-ionized ammonia in 1997 and 1998 could have contributed to later hypoxic mortalities at DO concentrations that would otherwise not be lethal. Inspection of the un-ionized ammonia concentrations in the Klamath Tribes water quality database shows that concentrations in excess of the gill effect threshold of 200 µg/L occurred in 43 percent of the bottom water samples in 1997 and in 24 percent of the bottom water samples in 1998. In 1997, these high concentrations of un-ionized ammonia persisted for 3 to 4 consecutive, biweekly samplings in the June/July period at all sampling locations, except CP (Coon Point). In 1998, no more than two consecutive sampling periods in the northern portion of the lake showed



	1990	1991	1992	1993	1994	1995	1996	1997	1998
May		0	0	0	0	0	0	6.25	0
June		0	0	0	0	0	12.5	25	8.3
July		7.1	0	0	0	0	0	91.6	81.3
August		0	0	0	0	0	0	7.1	6.2
September		0	0	7.1	0	0	0	71.4	25

Figure 6-5. Percentages of all bottom water un-ionized ammonia acute criteria exceedences at locations sampled from May through September, 1991-1998 in Upper Klamath Lake.

Northern Lake Bottom Water Un-ionized Ammonia Acute Criteria Exceedences



	1990	1991	1992	1993	1994	1995	1996	1997	1998
May	0	0	0	0	0	0	0	25	0
June	0	0	0	0	0	0	0	25	0
July	0	16.6	0	0	0	0	0	81.8	75
August	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	33	28.6

Figure 6-6. Percentages of bottom water un-ionized ammonia acute criteria exceedences at locations sampled north of Bare Island from May through September, 1990-1998 in Upper Klamath Lake.

un-ionized ammonia concentrations in excess of 200 µg/L, while high concentrations persisted for three consecutive sampling periods at ML, NB and WB in the southern lake area. These observations may partially explain the basis for the fish kill in 1997 and its absence in 1998.

6.3 SPATIAL AND TEMPORAL WATER QUALITY ANALYSIS

This section summarizes and evaluates the water quality parameters measured in conjunction with the USBR radio telemetry studies of adult Lost River and shortnose sucker in Upper Klamath Lake. The data used in this section are from the USBR fixed-location monitoring stations and profile measurements taken at locations where radio-tagged adult suckers were found and confirmed by boat telemetry. We consider the USBR profile water quality data as the best available for characterizing conditions actually experienced by adult suckers, because they were collected where and when a fish was physically located. We only considered measurements made within 3.28 ft (1 m) of the lake bottom as representative of adult sucker habitat, since radio-tagging data indicated that adults of both species were never located more than 1 ft above the lake bottom (Section 5.3). As described in Section 5.3, more than 90 percent of the confirmed sucker telemetry sightings occurred in the northern portion of the lake, north of the east-west line shown in Figure 3-3. Where available and applicable, USBR data from May through September in years 1993 through 1998 from this northern lake area were used in our analysis.

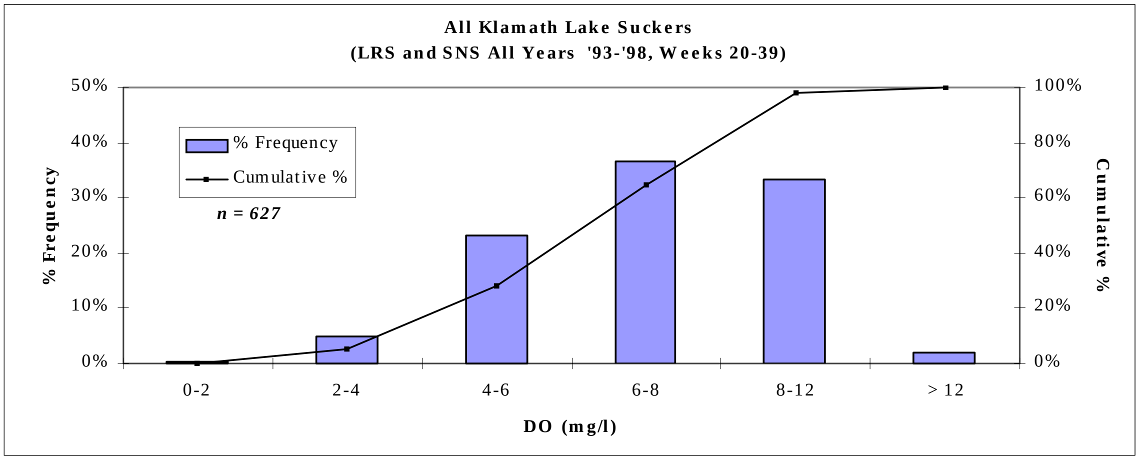
6.3.1 Water Quality Characteristics of Adult Sucker Habitat

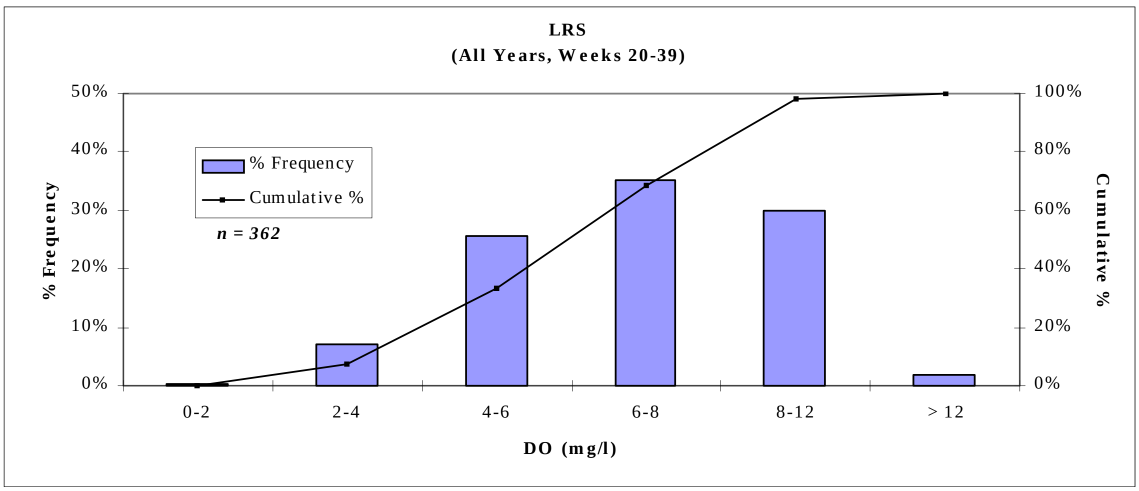
The USBR radio-telemetry study of adult sucker locations and movements documented the DO, pH and temperature for the majority of confirmed sucker sightings from May through September in each year. An overview of the results for each parameter is presented below. The USBR did not measure un-ionized ammonia as part of the study and hence, we were not able to evaluate the frequency with which different concentrations of un-ionized ammonia were encountered by suckers.

6.3.1.1 Dissolved Oxygen (DO) Regime

From 1993 through 1998, bottom water DO measurements are available for 627 times and locations in Upper Klamath Lake where either Lost River or shortnose sucker adults were detected and confirmed by radio telemetry. Of these, 362 sightings were Lost River and 265 were shortnose sucker adults. These data are shown in Figure 6-7. The frequency distributions of the observations for the two species are similar, indicating their use of areas in the lake with similar oxygen concentration. We therefore combined species histograms, which were later used to evaluate stress (Section 6.3.2). Table 6-2 shows the percentages of observations in each DO concentration interval for each sucker species and the two species combined for the period of record. The frequency distribution in the table also shows the percentages of bottom water DO in each category from data collected at the USBR fixed monitoring stations for the same period in the northern section of the lake.

These data (Table 6-2) show that 33.2 percent of Lost River and 21.9 percent of shortnose adult





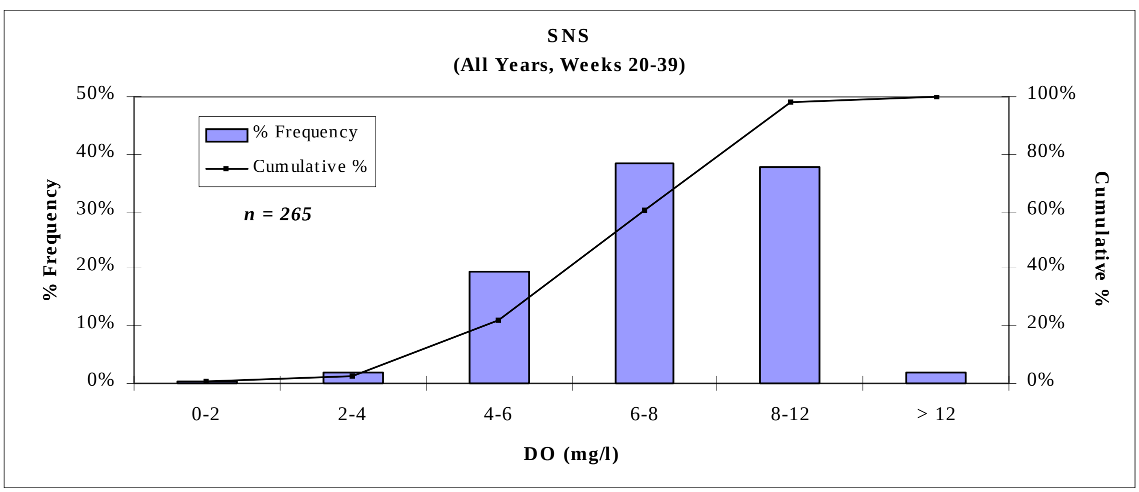


Figure 6-7. Percent frequency and cumulative percent distributions of adult Lost River and shortnose sucker exposures to bottom-water dissolved oxygen concentration intervals in Upper Klamath Lake, north of Bare Island, May through September, 1993-1998.

Table 6-2. Percentages of radio-tagged suckers encountering various dissolved oxygen (DO) concentrations in Upper Klamath Lake and percentages of bottom water DO at USBR monitoring stations from May through September, 1993-1998.

	Bottom-Water Dissolved Oxygen Concentration Ranges (mg/L)						
Species/Station	**0 - 2**	**2 - 4**	**4 – 6**	**6 - 8**	**8 – 12**	**> 12**	**Number of Observations.**
Lost River	0.3%	7.2%	25.7%	35.1%	29.8%	1.9%	362
Shortnose	0.4%	1.9%	19.6%	38.5%	37.7%	1.9%	265
Combined Sp.	0.3%	4.9%	23.1%	36.5%	33.2%	1.9%	627
USBR Fixed Locations	6%	8%	17%	35%	33%	1%	631

observations occur in bottom waters with DO concentration of < 6 mg/L, when the May through September period is considered as a whole. When the July through September period is considered, the percentages increase to 40.6 and 28.6 percent for the two species, respectively. However, since the telemetry data were collected during daylight hours, they may not represent the maximum DO stress experience, because DO concentrations generally decline during nighttime hours. Both the frequency and severity of low DO stress to adult suckers would therefore likely be underestimated by these daytime measurements.

The data in Table 6-2 also show that Lost River sucker adults are more than 3 times as prevalent in water of <4.0 mg/L DO than are adult shortnose suckers. This may be, in part, a consequence of Lost River suckers use of deeper waters than shortnose suckers in spring months (Figure 5-9), but may also reflect species tolerance difference to low DO; the Lost River suckers being somewhat more tolerant than the shortnose sucker.

The frequencies of exposure of adult suckers to DO conditions in each year of the USBR study are shown in Appendix Figures (C-10 to C-13). The data generally indicate that Lost River sucker adults experienced less than 6 mg/L DO exposure in 18.8 percent to 42.9 percent of the annual measurements between May and September. Similarly, the range experienced by shortnose sucker adults was from 11.1 percent to 40.0 percent. Depending on the actual duration of exposure to these lower DO concentrations, these fish would experience varying degrees of stress. Only 2 of the 627 fish observations occurred in the 0-2 mg/L range, and one of these fish was classified as dead in the week following the encounter. The other survived the low DO encounter and survived at least through the following year.

The comparison of the combined sucker species frequencies in each DO category with those from the fixed location monitoring stations indicates that the frequencies are essentially equivalent at DO concentrations above 6.0 mg/L. It thus appears that adult suckers are successful at avoiding areas of DO less than 2 mg/L (6 percent at fixed locations vs 0.3 percent at fish locations). They appear to be moderately successful at avoiding DO concentrations in the 2-4 mg/L range (8 percent at fixed locations vs 4.9 percent at fish locations). However, the data show that a greater percentage of the fish were located in the 4-6 mg/L range than would be expected from the fixed location percentage (17 percent at fixed locations vs 23.1 percent of fish locations). This suggests that adult suckers are insensitive to conditions of sublethal stress, have acclimated to this DO range, or that the incidences of DO in the 4-6 mg/L range are so extensive spatially, that fish can not find areas of higher DO levels. We examine this in more detail in the evaluation of water quality related stress to adult suckers in Section 6.3.2.

6.3.1.2 Adult Sucker pH Regime

The USBR radio-telemetry data contained 618 measurements of bottom water pH at confirmed fish locations in the northern portion of Upper Klamath Lake between May and September 1993-1998. Of these, 355 were for adult Lost River sucker locations and 263 were for shortnose sucker locations. These data are shown in Figure 6-8 as percentage frequencies over the range of pH values characteristic of the lake-bottom waters in spring and summer months. The figure shows the percentage distribution in pH categories for each species and for the combined species. As for DO, the histogram arrays for the two species were similar, reflecting their common habitat range in the lake. We therefore used the combined species frequency distribution to represent the best estimate of the pH regime experienced by adult suckers examining stress experienced by these fish (Section 6.1.2). Table 6-3 shows the percentages of observations in each pH category interval for each species and for the two species combined for the period of record.

Table 6-3. Percentages of radio-tagged suckers encountering various pH levels in Upper Klamath Lake and percentages of bottom water pH at USBR monitoring stations from May through September, 1993-1998.

	Bottom-Water pH Level Intervals						
Species/Station	**<7.5**	**7.5-8.5**	**8.5-9.0**	**9.0-9.5**	**9.5-10.0**	**>10.0**	**Number of Observations**
Lost River	3.7%	22.3%	23.1%	34.4%	15.5%	1.1%	355
Shortnose	0.4%	20.2%	19.8%	39.2%	19.8%	.8%	263
Combined Sp.	2.3%	21.4%	21.7%	36.4%	17.3%	1.0%	618
USBR Fixed Locations	6%	32%	24%	30%	7%	1%	631

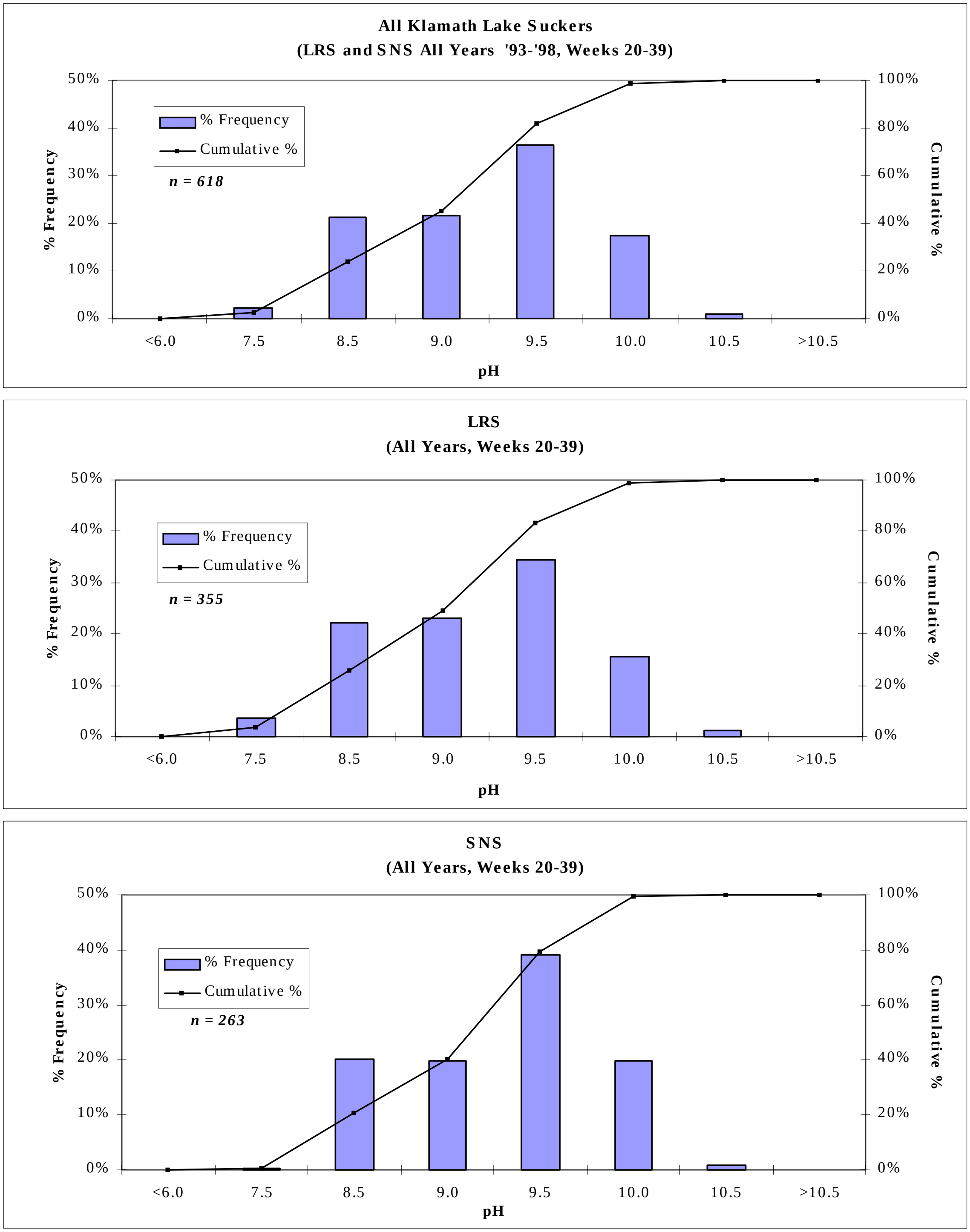


Figure 6-8. Percent frequency and cumulative percent distributions of adult Lost River and shortnose sucker exposures to pH level categories in Upper Klamath Lake bottom-waters, north of Bare Island, May through September 1993-1998.

These data show that 51.0 percent of the Lost River sucker and 59.8 percent of the shortnose sucker observations occurred in bottom waters where pH was greater than 9.0 in the May through September period. These exposures to stressful levels of pH increase to 53.8 and 65.4 percent in the July through September period for the two species, respectively. As for DO, these bottom-water measurements were collected during daylight hours, when pH would be higher than during nighttime hours. Thus, in contrast to DO, the pH values likely represent the high range fish might experience relative to a 24-hour average exposure.

The frequencies of exposure to pH conditions in the northern region of Upper Klamath Lake for individual years of the USBR study are shown in Appendix C Figures C-14 through C-17. These data show that the range of exposures to pH higher than 9.0 was between 34.0 and 86.9 percent for Lost River sucker adults, and between 33.3 and 83.9 percent for shortnose sucker adults for the May through September period. The actual degree of stress the adult suckers would experience at these pH levels would depend on the duration of exposure. Only about 1 percent of the observations for each species occurred in the pH range above 10.0. These exposures are in the range of LC_{50} levels measured for larvae and juveniles of both species (Meyer et al. 2000; Saiki et al. 1999). All these exposures to potentially lethal pH levels occurred in 1994 and represented 3.8 percent and 5.6 percent of the total number of observations in that year for Lost River and shortnose sucker adults, respectively. However, 1995 was the year with the highest percentages of pH levels above 9.0 for both species, reaching 83.9 percent of the shortnose and 86.9 percent of the Lost River adult sucker observations from May through September, and 93.8 percent for both species when only the July through September period is considered.

Table 6-3 also allows the comparison of the combined sucker species frequency in each pH interval category with frequencies in the same categories from the fixed location monitoring stations sampled by USBR. Above a pH of 9.0, 54.7 percent of the combined species observations occurred while only 38 percent of the fixed station monitoring values fell within this range. Thus adult suckers may either not sense, or can not avoid these higher pH levels as such conditions may be pervasive in the summer months where adult suckers find higher DO waters. It also appears that fewer than expected adult sucker observations occurred in waters with pH levels below 8.5 (23.7 percent of combined sucker species observations versus 38 percent of measurements at fixed location). However, these lower pH waters are often associated with lower DO levels, which may deter their use by adult suckers (lower DO is associated with lower pH in areas where carbon dioxide is high due to microbial respiration and reduced photosynthesis). We examine these findings further in the combined water quality stress results (Section 6.3.2).

6.3.1.3 Temperature Regime

Temperature was also measured at each confirmed fish location during the 1993-1998 USBR radio-telemetry study. These data are summarized below in the same manner as for DO and pH. Figure 6-9 shows the frequency distributions of bottom water temperature observations for the

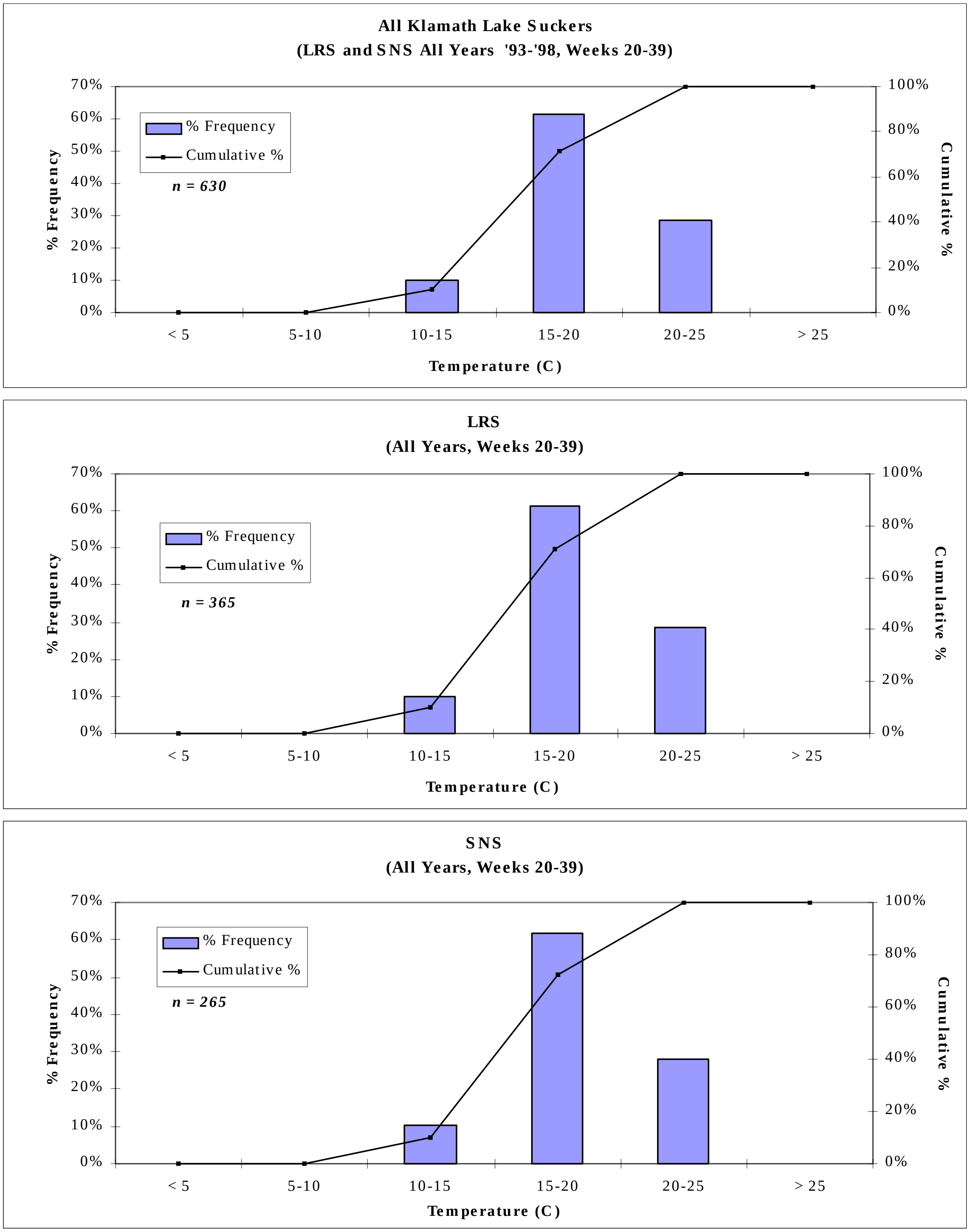


Figure 6-9. Percent frequency and cumulative percent distributions of adult Lost River and shortnose sucker exposures to bottom-water temperatures in Upper Klamath Lake, north of Bare Island, May through September, 1993-1998.

individual sucker species and species combined for the May through September period for the years of study. The figure shows that the two species temperature regimes are essentially identical, as would be expected for species cohabiting the northern part of the lake.

Table 6-4 shows the percentages in bottom-water temperature categories for distribution of the two sucker species individually, their combined distribution, and the USBR fixed location monitoring stations occupied during the same period. The table shows that no bottom-water temperatures exceeded 25°C where fish were located during the 6 years of study.

For the entire period of record, the fish observation temperature range was from 10.6°C to 24.6°C, while for the fixed monitoring locations 6 observations (1 percent) were below 10.0°C and 1 observation was greater than 25°C in the lake bottom waters. As none of the observed fish location temperatures exceeded 25°C, no direct stress due to temperature would be expected for adult suckers in the northern part of Upper Klamath Lake. It has been noted that higher summer temperatures can indirectly contribute to stressful conditions for fish because of elevated oxygen demand of decaying organic material, as well as higher respiratory requirements of suckers (R2 2001a).

Higher summer month temperatures can also result in an increase in the portion of ammonia present as (potentially toxic) un-ionized ammonia in the lake water. As noted above, the USBR study did not include the measurement of ammonia, but, as described in Section 6.2.4 and R2 (2001a), measurements of un-ionized ammonia from the Klamath Tribes water quality database were shown to be pervasively high in the northern lake region, especially from 1995 through 1998. Nevertheless, based on our above analysis, we did not consider temperature of bottom waters in the assessment of direct, water quality combined stress to adult suckers in Section 6.3.2.

6.3.2 Water Quality Induced Stress of Adult Suckers

The potential sublethal stress levels experienced by sucker species and redband rainbow trout have been described and evaluated using a combined

Table 6-4. Percentages of radio-tagged suckers encountering various bottom water temperature ranges and percentages of bottom water temperature at USBR monitoring stations from May through September, 1993-1998.

	Bottom-Water Temperature (°C) Intervals					
Species/Station	**<10**	**10-15**	**15-20**	**20-25**	**>25**	**Number of Observations**
Lost River	0%	10.1%	61.1%	28.8%	0%	365
Shortnose	0%	10.2%	61.9%	27.9%	0%	265
Combined Sp.	0%	10.2%	61.4%	28.4%	0%	630
USBR Fixed Locations	1%	15%	52%	32%	0%	631

stress index based on Klamath Tribes' water quality monitoring data from 1990 through 1998 (R2 2001a). In that document, combined stress based on ambient levels of pH, DO, temperature and un-ionized ammonia for individual depths at each monitored site was calculated and averaged over selected depths to provide a stress index value for each station. This provided a quantification of general levels of stress that fish could experience at any location and date sampled among the seven monitoring stations usually occupied in the Klamath Tribes' study throughout Upper Klamath Lake. From this evaluation of individual and combined sublethal stress, it is evident that water quality in Upper Klamath Lake was stressful to both suckers and trout for much of the summer during the 1990 through 1998 study period. However, it appears that the source of stress over the study period changed, with pH and DO being the major sources of stress from 1990 through 1995, but un-ionized ammonia becoming a large source of stress in 1996 through 1998. Cumulative stress (cumulative sum of the product of number of days times the average stress value between sampling intervals) was highest in 1995 and 1997 and was associated with moderate to large fish kills. The depth averaging process used in the assessment of stress in the supplement to this report cited as R2 (2001a) however, may not have captured the true extremes of combined stress that fish inhabiting discrete depths would experience.

In this section, we use the same combined stress index approach (R2 2001a) to summarize stress experienced by adult Lost River and shortnose suckers. However, this analysis is based on pH and DO measured in bottom waters where fish were located by radio-telemetry as part of the USBR radio-tagging study (1993-1998). As noted in Section 6.3.1.3, the ambient temperatures in bottom waters where adult suckers were located never exceeded 25ºC. Thus, temperature at fish locations would not directly contribute to the combined stress index values and we omitted it from the index calculations in this section. The USBR study did not include the measurement of un-ionized ammonia, so the combined stress index values presented in this section are only for DO and pH.

The results of the combined DO/pH stress index presented here complement those in R2 (2001a) and more specifically characterize levels of water quality DO/pH related stress that adult suckers have experienced, rather than stress conditions that have occurred more broadly, lake-wide. As before, we limited the assessment to the northern portion of the lake where more than 90 percent of adult suckers were found.

6.3.2.1 Average Combined Stress

The combined stress for the ambient DO and pH bottom water data for each fish observation was calculated and sorted into annual data groupings by successive week number. All combined DO/pH stress index values for individual weeks beginning in mid-May (week 20) to October (week 40) were averaged to characterize the conditions experienced by adult suckers in the northern portion of Upper Klamath Lake. These results are shown in Figures 6-10 and 6-11. The figure panels show the time-series of average stress for each year of the USBR study. While there are weeks where no fish were found, the data show the seasonal nature of stress encountered by adult suckers. The DO/pH combined stress for all

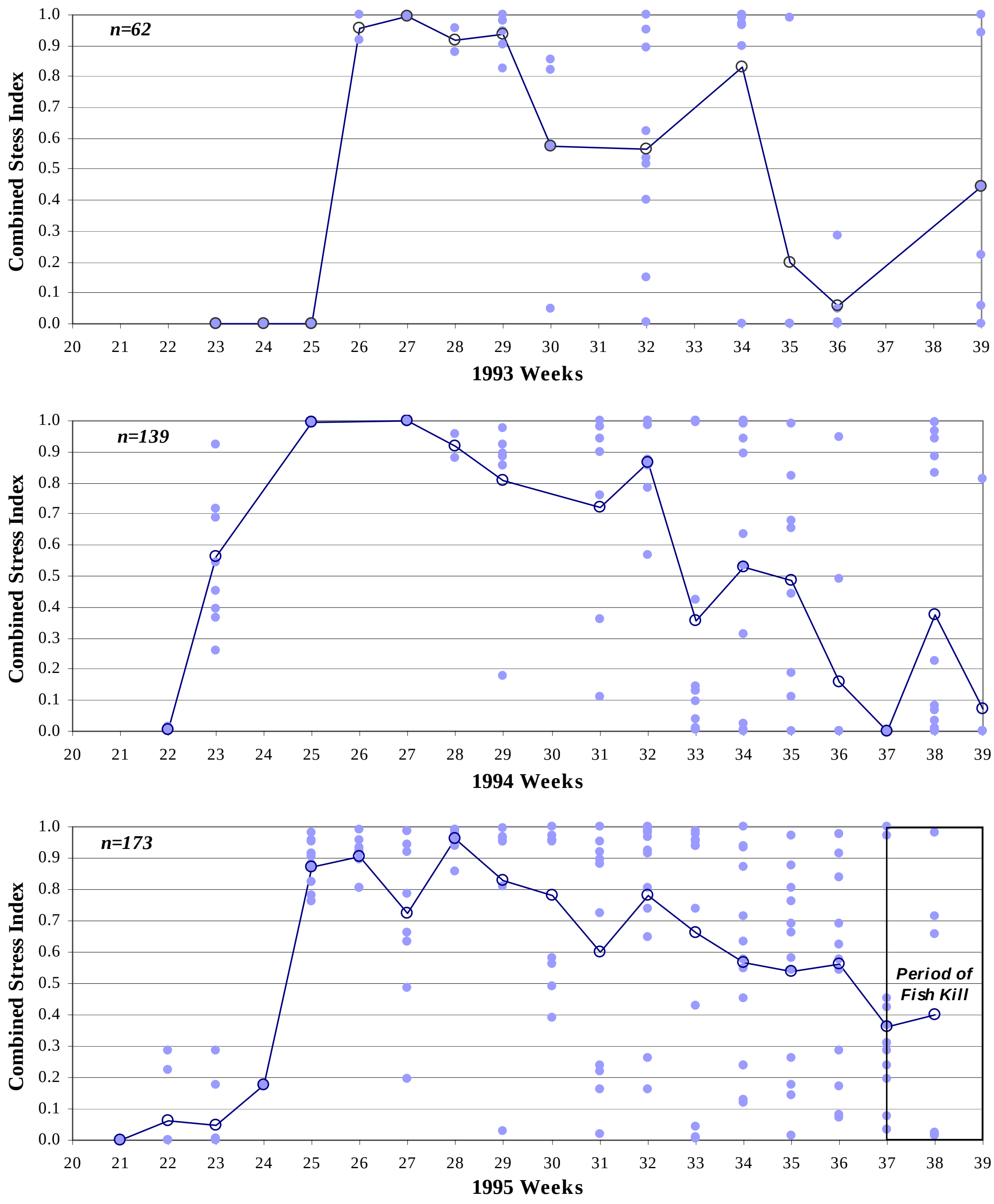


Figure 6-10. Combined DO/pH stress index values in bottom waters of northern Upper Klamath Lake for adult Lost River and shortnose sucker adults from mid-May through September 1993-1995. Connected lines represent average values.

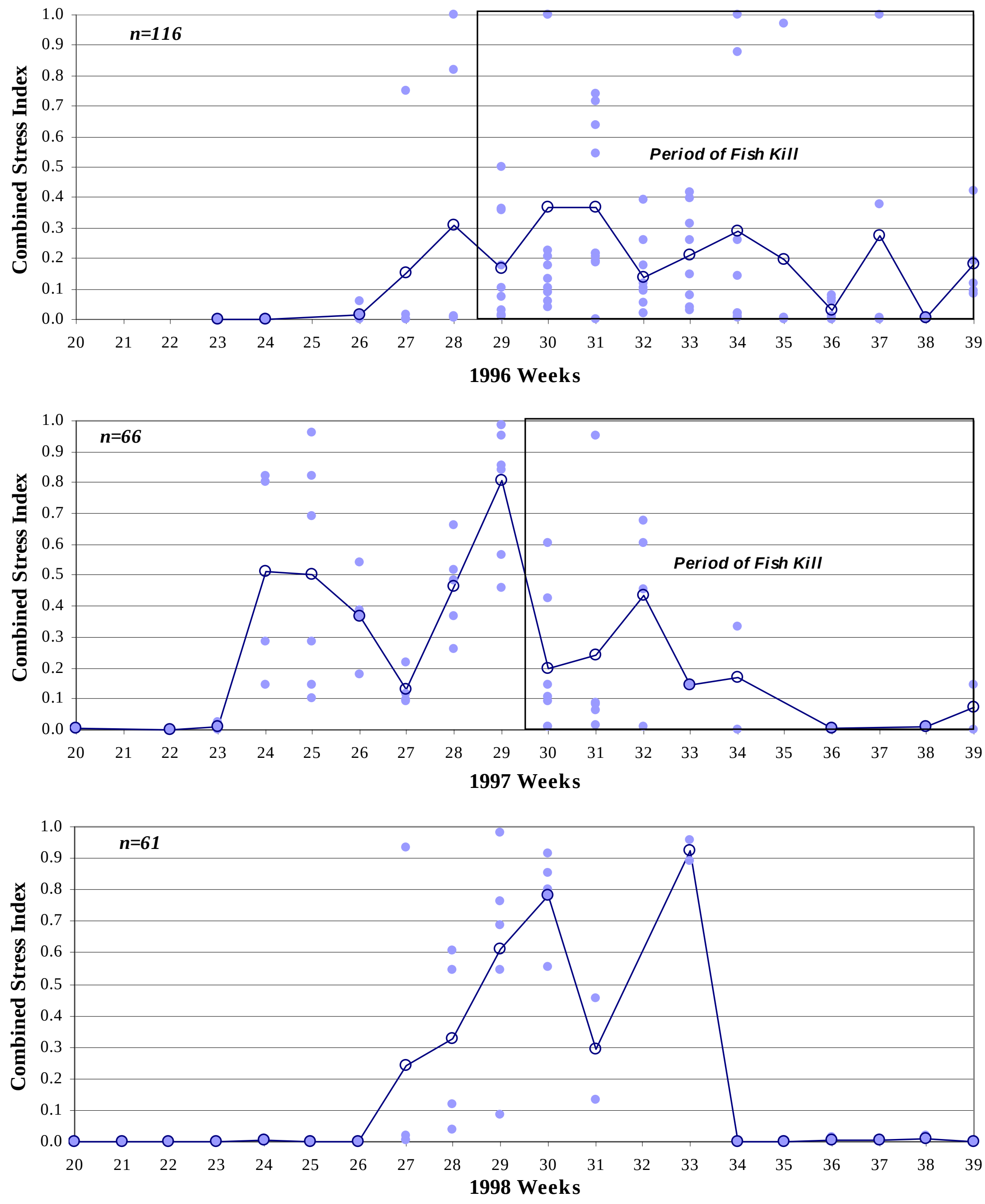


Figure 6-11. Combined DO/pH stress index values in bottom waters of northern Upper Klamath Lake for adult Lost River and shortnose sucker adults from mid-May through September 1996-1998. Connected lines represent average values. (Note: zero stress value represents fish observations)

the adult suckers located in each week, from mid-spring though early fall are shown to convey the weekly ranges of stress encountered by individual fish.

The annual patterns of DO/pH combined stress from 1993 through 1995 show stress beginning to increase in early to mid-June, reaching a maximum in late June, and remaining high through most of July. Stress levels tend to decline through August and September. This seasonal trend for average stress experienced by individual adult suckers is due to the increasing numbers of individuals found in lower stress areas after mid-July.

This annual pattern of DO/pH stress appears to change in 1996 through 1998, with average stress levels rarely exceeding 0.5 until late July and few values exceeding 0.9, on average, in any weekly period. While this at first appears to be inconsistent with the occurrence of known fish kills in 1995, 1996 and 1997, in those years un-ionized ammonia was also high and would therefore also be stressful (Section 6.2.4). Stress to adult suckers from un-ionized ammonia is not included in the DO/pH combined stress shown in these figures as ammonia data were not collected.

6.3.2.2 Combined DO/pH Avoidance

To investigate whether or not adult suckers demonstrate an ability to sense and avoid stressful conditions associated with poor water quality, we made comparisons between the combined DO/pH stress at fish locations, and conditions at fixed monitoring locations in each year of the USBR study. Bottom water DO and pH data were compiled from the 3 to 12 fixed-location monitoring sites. Data were limited to weekly to bi-weekly fixed-location water quality profiles made in the same weeks that water quality profiles for radio telemetry located adult suckers were made. The combined DO/pH stress index values for the fixed and fish locations were grouped into four categories ranging from “zero” stress to “high” stress for each year of study. These comparisons are shown in Figure 6-12 in the four categories in each year.

The statistical significance of these paired comparisons was tested using one-way ANOVA procedures on the percentage data, after applying an arc-sin, square-root transformation to better meet the assumptions of normality for the test. The test results show that only the high stress comparison between fish and fixed monitoring locations were statistically significant at $\alpha = 0.05$ and $p < 0.05$ with respect to the occurrence of combined stress values equal to 1.0. This leads to the inference that adult suckers are only successful at avoiding conditions at the maximum combined DO/pH stress level. This level of combined DO/pH stress is only achievable when one parameter exceeds the high stress criteria or both parameters exceed values approaching 0.9 simultaneously. Such combined stress values indicate that the combined stress has exceeded the adaptive capacity of adult suckers to adjust to the prevailing conditions, sublethal maximum stress levels have been exceeded, and that severe stress levels, possibly lethal conditions, exist due to exposure to combined DO/pH conditions.

The results of the ANOVA also suggest that adult suckers experience low to moderate stress in proportion to these occurrences in the northern portion of the lake and do not seek out or tend to congregate in areas of good, zero-stress water

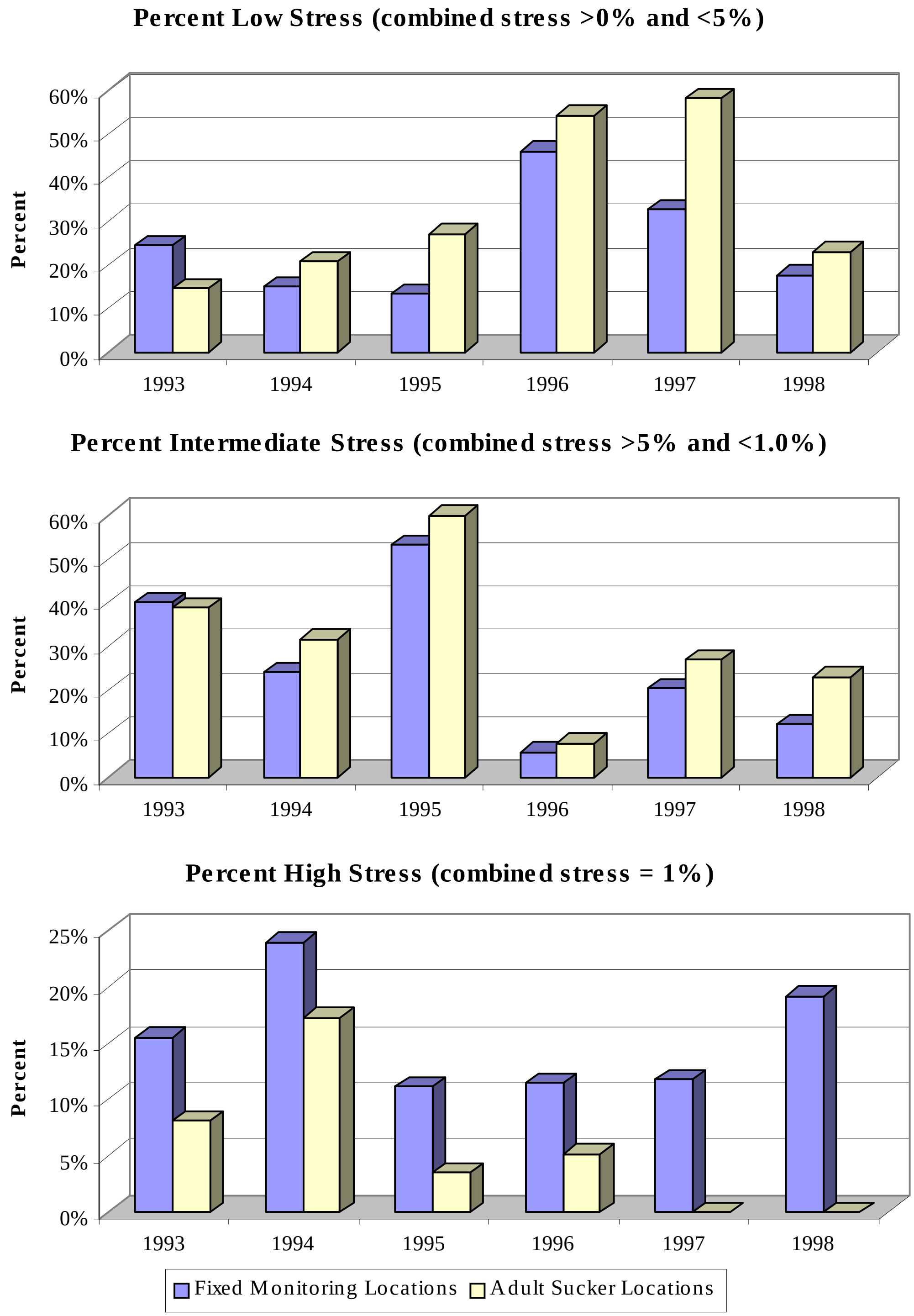


Figure 6-12. Comparison of percentages of combined DO/pH stress index values between fixed monitoring and adult sucker locations in northern Upper Klamath Lake from mid-spring through September 1993-1998.

quality. Alternatively the areas of poor water quality may be so wide spread it is not possible for fish to find and/or remain in areas of better water quality. Therefore, except for the most extreme conditions of stress, the monitoring data collected at various lake locations represent stress conditions as experienced by fish in those areas.

6.3.2.3 Bottom-Water Stress Sum Index

The Klamath Tribes' water-quality monitoring program included three stations in the northern portion of Upper Klamath Lake that were part of previous stress evaluations (R2 2001a). Temperature, pH, DO and un-ionized ammonia measurements in bottom waters from the Klamath Tribes study were evaluated and presented as the sum or total of the stress index values calculated for each parameter. Temperature of bottom waters did not contribute to sucker stress and was excluded from the summations. The other three parameters each ranged between 0 and 1.0, so a maximum range for the sublethal stress sum index could be 0 to 3.0 if all three were coincidentally at their maximum value. This calculation of a total sublethal stress differs from the combined stress index in R2 (2001a) and the combined DO/pH stress discussed above, both of which have a maximum of 1.0.

The total bottom-water stress from pH, DO and un-ionized ammonia at the Klamath Tribes' Shoalwater Bay (SB), Mid-North (MN) and Eagle Ridge (ER) stations are shown for the years 1990-1998 in Figures 6-13, 6-14, and 6-15. The sum of the individual stressors is shown for the sampling dates in each year beginning in May and ending in November, when data were available. The horizontal panels in each figure characterize the pattern and sources of multiple co-occurring stressors on sequential sampling dates within a year. The Y-axis is scaled to 2.0 in all the figures to facilitate station and year comparisons, as that is the maximum of any of the stress totals for the three stressors found in this analysis.

From 1990 to 1992 the predominant seasonal pattern was: pH stress commencing in June, followed by either co-occurring or exclusive stress from DO (Figure 6-13). Un-ionized ammonia stress was the least prevalent and usually occurred at significant levels later in the year, with the exception of an early July, 1991 event at ER. Total stress in 1992 was almost exclusively from pH and DO in a sequential pattern, but maximum sublethal DO stress level occurred for three and four successive weeks at SB and ER, respectively.

DO was a more prominent source of bottom-water sublethal stress from 1993 through 1995, especially at ER, followed by SB in 1993 and 1995 and at MN in 1994 (Figure 6-14). In 1994, concurrent pH and DO stress increased the total stress to near or in excess of 1.6, a value nearly matched in 1995 at ER in mid-August. This was coincident with the reappearance of un-ionized ammonia stress that had been absent from the data set since July of 1991 at ER.

The total bottom-water stress in 1996 through 1998 is shown in Figure 6-15. The predominant feature in these figures is the frequent and consecutive occurrence of high, sublethal un-ionized ammonia stress. The onset of un-ionized ammonia stress as early as mid-June is also not found elsewhere in the data record. The concurrent stressors of ammonia and pH or ammonia and DO elevate the total stress to above 1.6 and as high as 2.0 at ER for two consecutive sampling periods in 1997 and 1998. Only slightly lower values occurred at MN and SB in October of 1996 and July/August of 1997 and 1998. While not convincingly evident in 1995, the presence of un-ionized ammonia stress in 1996 and 1997 could have contributed to the fish kills in August and September of those years.

A common and general feature of Figures 6-13 through 6-15 is that the occurrence of total stress values of 1.0 or more, when individual stressor values are added, occurs with regularity in all years and at all three monitoring locations in northern Upper Klamath Lake. In the first six years of the data set, values of 1.0 total stress most frequently occurred in bottom waters at ER, followed by SB and MN. Station MN in 1993 and 1995 is the only location where there were no total stress values greater than 1.0 in the May through September period.

From 1996 through 1998, with the increase of un-ionized ammonia stress in addition to stress from pH and DO, the average incidence of total stress values equal to or greater than 1.0 is 5.3 per sampling location. In contrast, the average per sampling locations for the first 6 years (1990 – 1995) is 3.3. This suggests that there was a 60 percent increase in the incidence of total stress levels of 1.0 or greater in the last three years of the data set. This increased incidence is coincident with and largely attributable to the documented increases of un-ionized ammonia in the northern portion of Upper Klamath Lake.

6.4 FISH HABITAT UTILIZATION DURING PERIODS OF POOR WATER QUALITY

This section presents and describes examples of adult sucker movements and distributions during periods of reduced water quality and receding lake levels over the summer months. The analysis is then discussed in the context of refugia availability and use when the species is excluded from using the main body of Upper Klamath Lake.

6.4.1 Adult Sucker Movement and Distribution

We selected two years (1994 and 1996) for discussion based on completeness of data records and representation of lake levels; 1994 was a low lake level year and 1996 was 2 ft higher than 1994 through the summer (Figures 2-4a and 2-4b). In the figures that follow, USBR water quality measurements of DO at fixed monitoring locations and from confirmed fish locations in each successive week were used to generate concentration contours of DO in bottom waters of the lake. These are shown as weekly sequences of overlays of DO concentration contours and fish locations on bathymetry depth gradients. Because the DO data were collected on several different days in the week, during daylight hours, they represent the general patterns of DO in the northern part of the lake with which the specific locations and movements of adult suckers can be compared. The bathymetry represented on the individual figures is the actual elevation ascribed to the individual weeks to the nearest 1-ft lake level increment. The fish locations are shown with a symbol and a tail. The symbol represents the location of a fish in the current week, and the tail is a line originating at the fish's location in the previously known location, usually in the previous week. Figures 6-16 and 6-17 depict weekly movement patterns of adult suckers for 1996 commencing in the first week of July (week 27) and extending into the third week of August (week 34). Figures 6-18 through 6-20 depict a similar series for 1994 from week 27 to week 39, early in October.

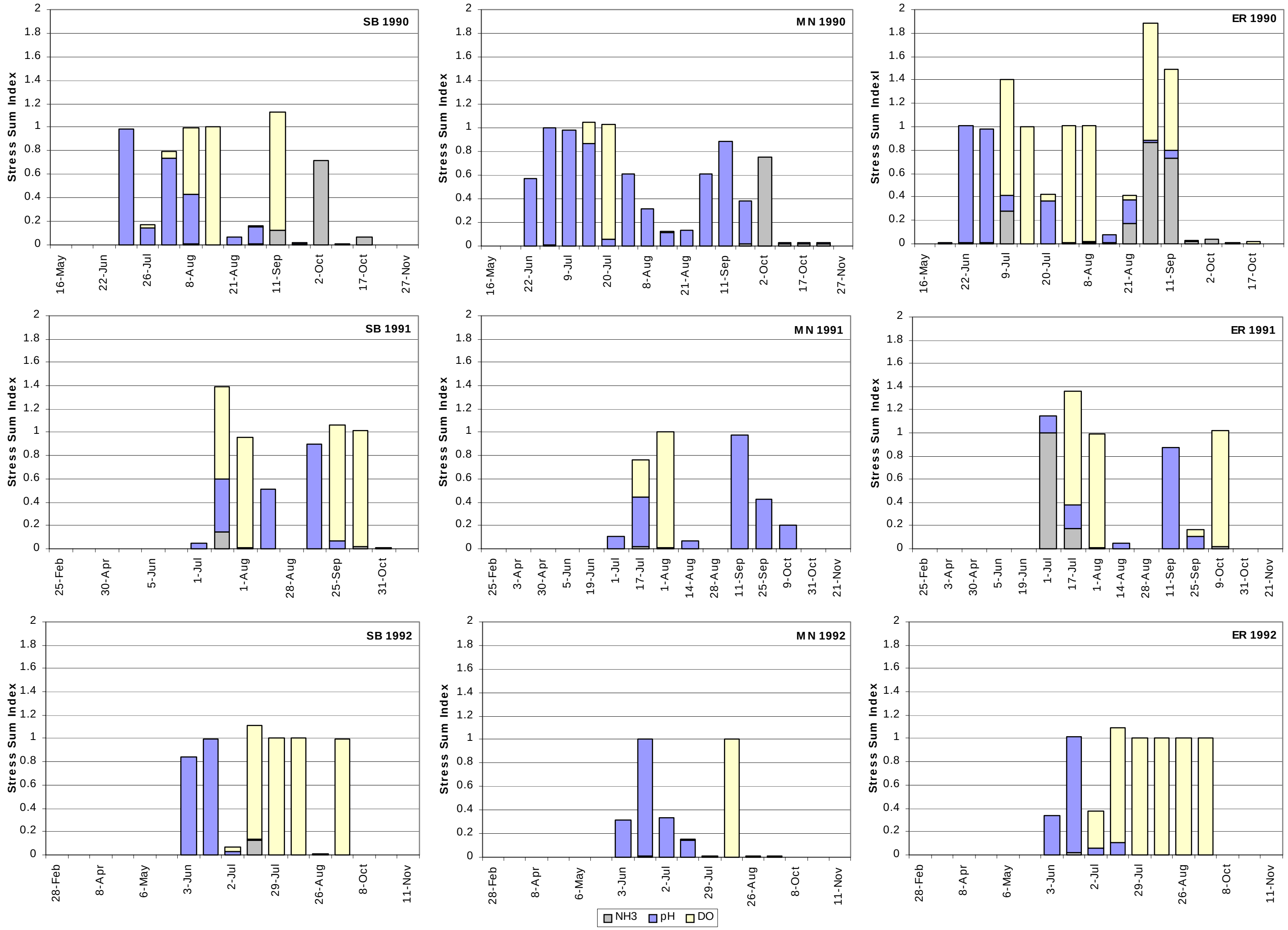


Figure 6-13. The annual patterns of individual and concurrent stressors quantified using the stress sum index in the bottom-water at three locations in northern Upper Klamath Lake for the years 1990-1992, based on Klamath Tribes' water quality data.

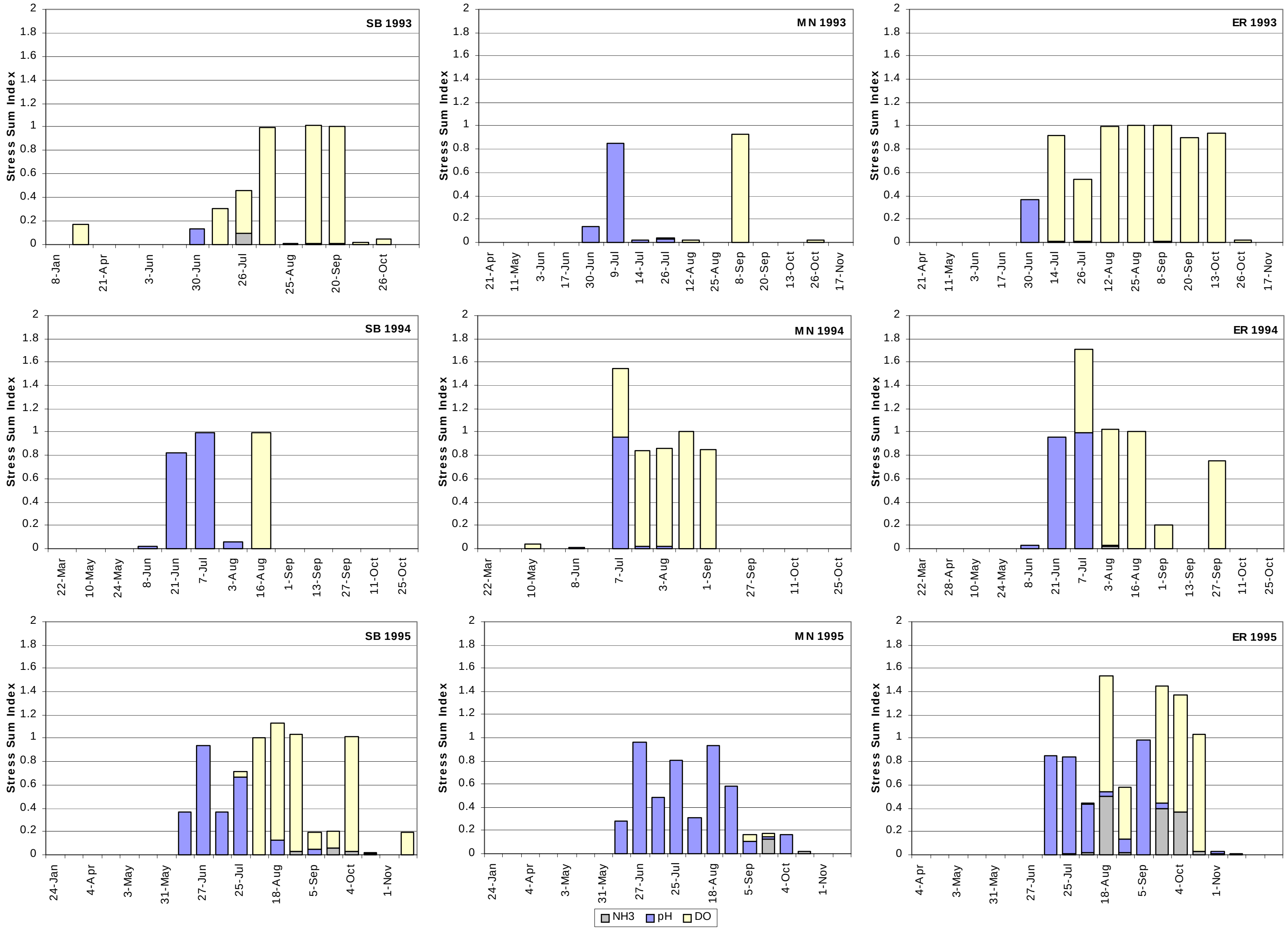


Figure 6-14. The annual pattern of individual and concurrent stressors quantified using the stress sum index in bottom water at three locations in northern Upper Klamath Lake for the years 1993-1995, based on Klamath Tribes' water quality data.

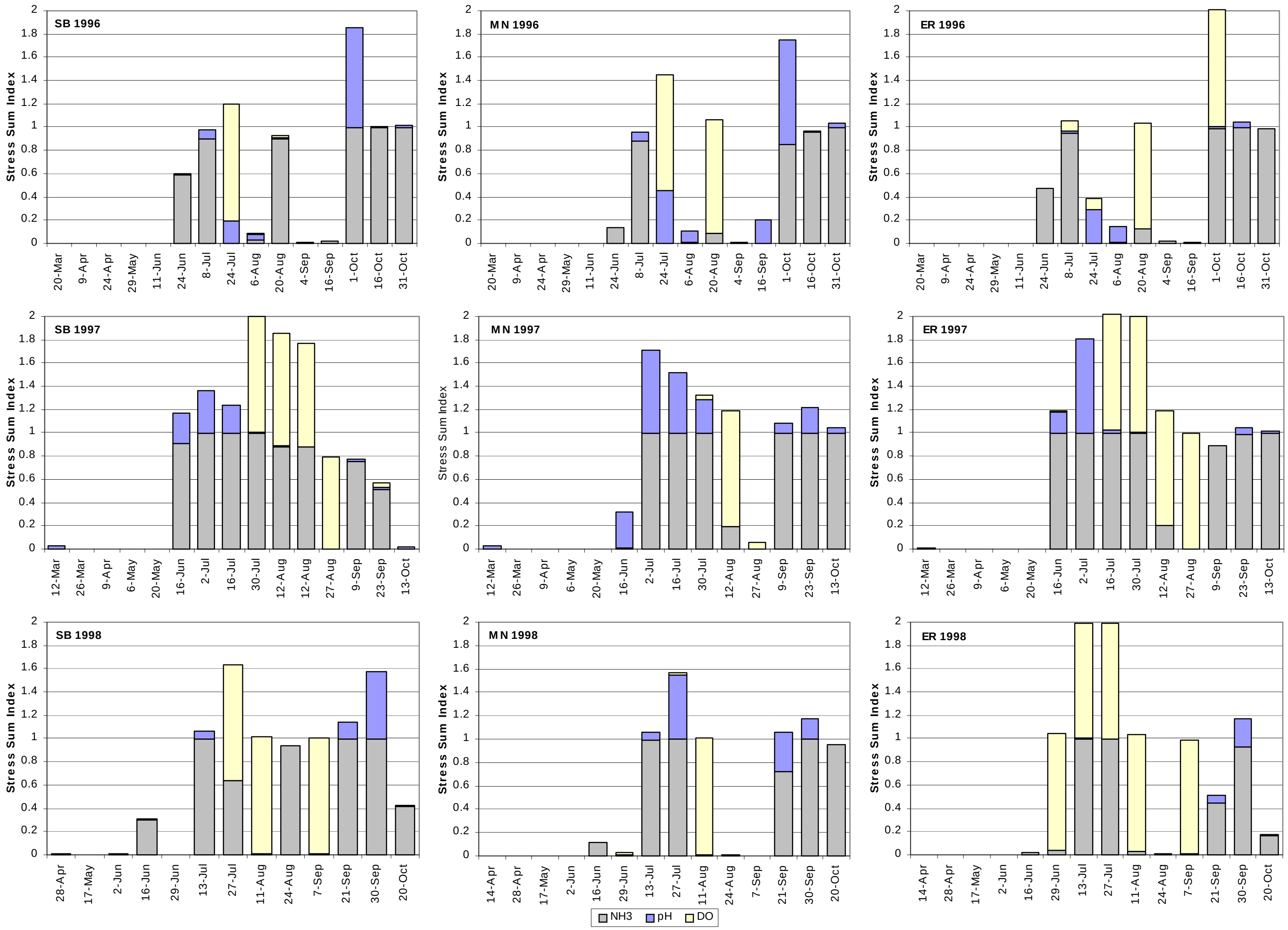


Figure 6-15. The annual pattern of individual and concurrent stressors quantified using the stress sum index in the bottom water at three locations in northern Upper Klamath Lake for the years 1996-1998, based on Klamath Tribes' water quality data.

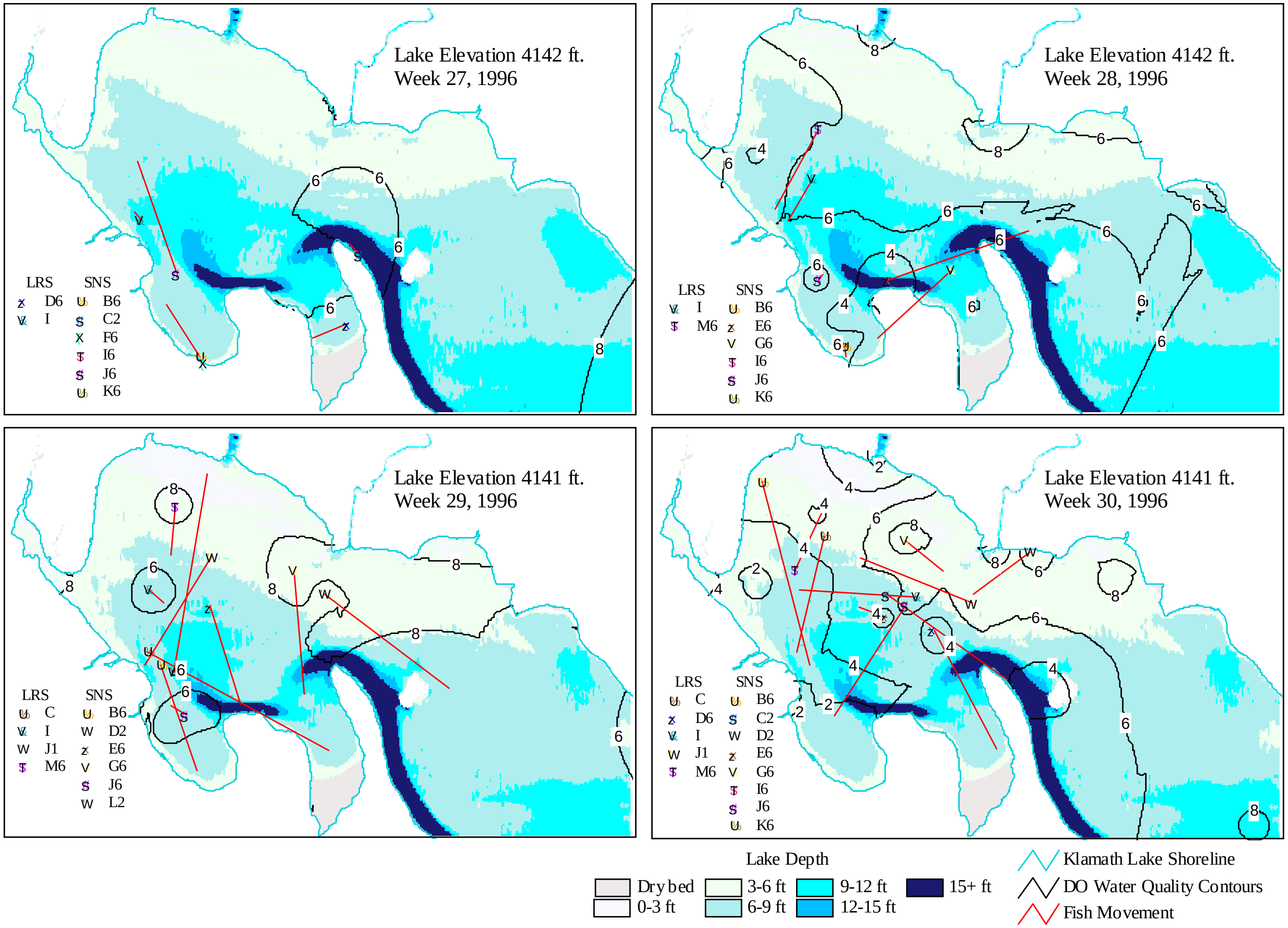


Figure 6-16. Adult sucker distribution and movements in response to changing water quality (DO) and lake elevation, July – August 1996, weeks 27-30.

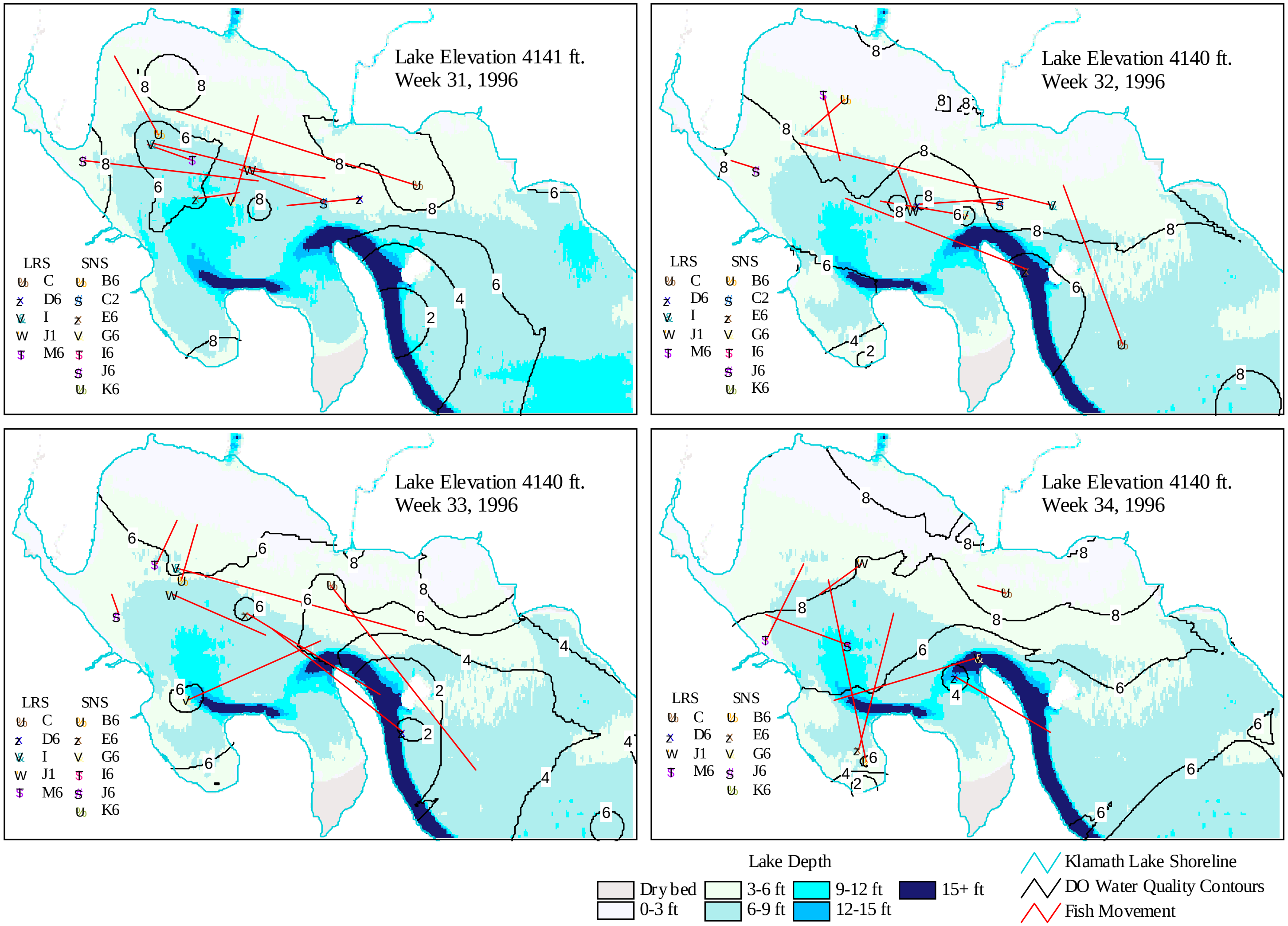


Figure 6-17. Adult sucker distribution and movements in response to changing water quality (DO) and lake elevation, July – August 1996, weeks 31-34.

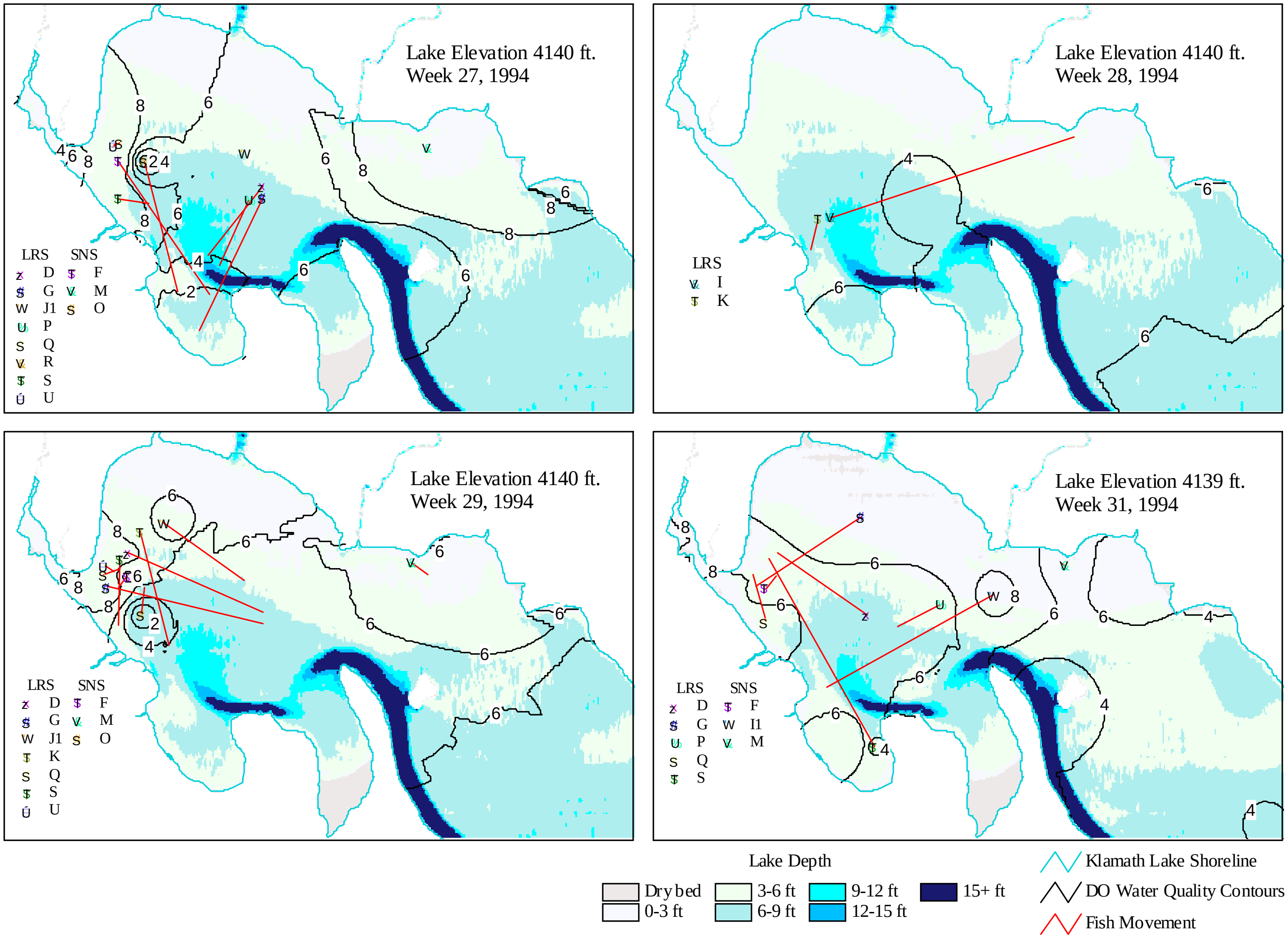


Figure 6-18. Adult sucker distribution and movements in response to changing water quality (DO) and lake elevation, July – September 1994, weeks 27-31.

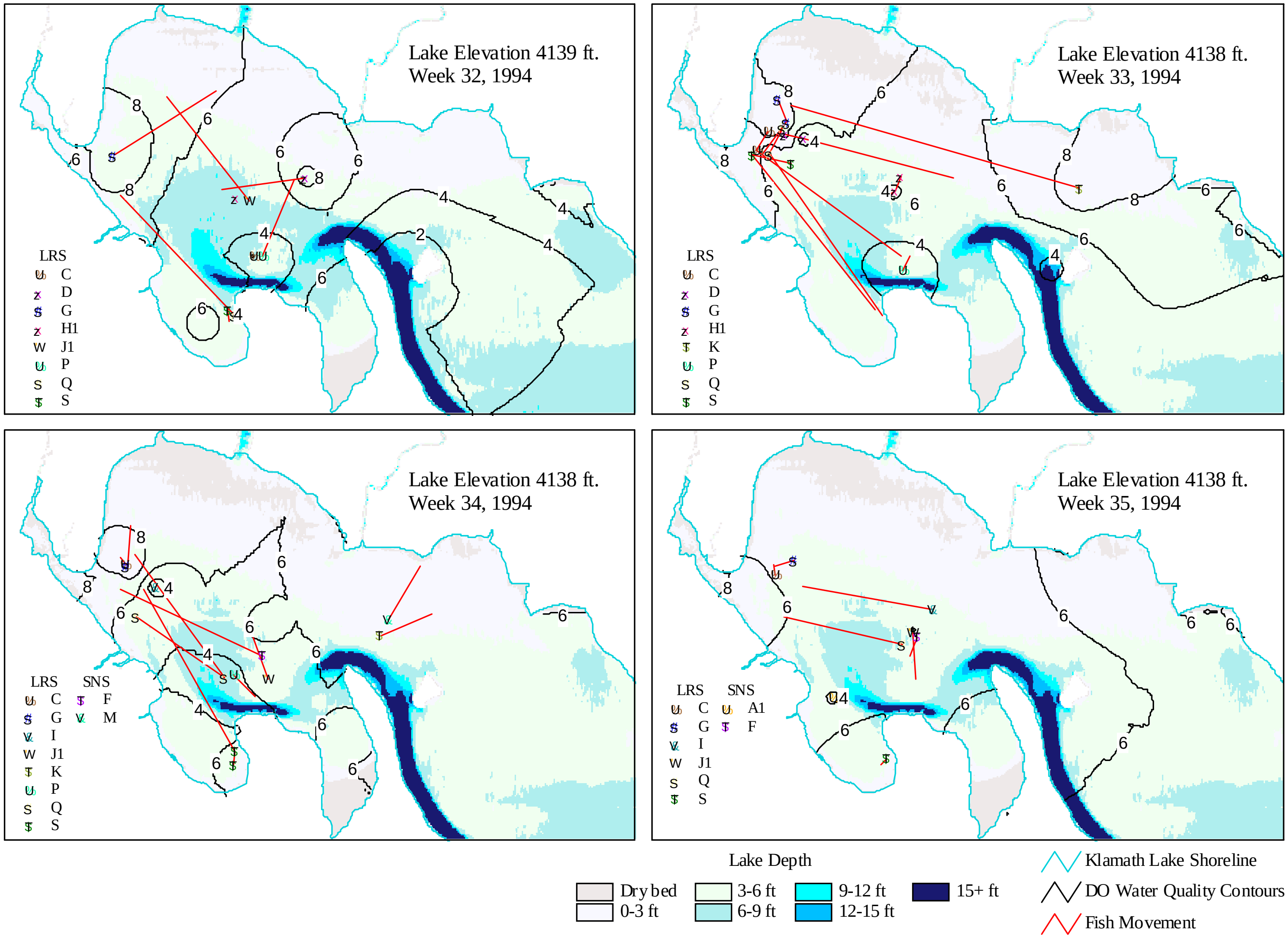


Figure 6-19. Adult sucker distribution and movements in response to changing water quality (DO) and lake elevation, July – September 1994, weeks 32-35.

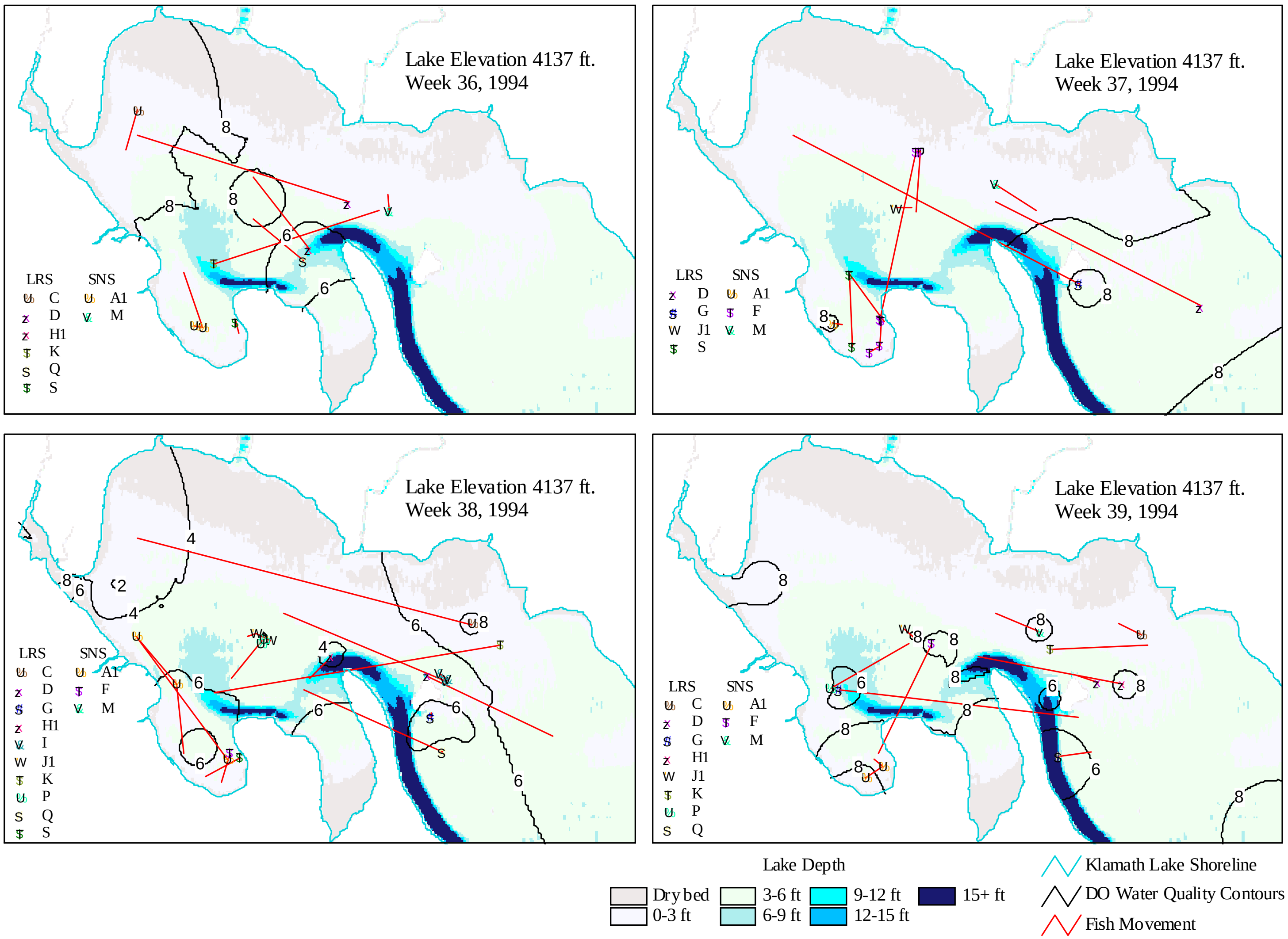


Figure 6-20. Adult sucker distribution and movements in response to changing water quality (DO) and lake elevation, July – September 1994, weeks 36-39.

The figures illustrate directed fish movements in relation to changing bottom-water concentrations of DO in the northern section of Upper Klamath Lake. While adult suckers may move in response to other stimuli (food supply, cover, etc.), the movements of the tagged fish shows several distinct instances where fish move from areas of declining DO and usually find improved DO conditions on a week to week basis.

In 1996, weeks 28, 30 and 33 illustrate this point. In week 28 (Figure 6-16), one fish moved to lower DO, while the other 5 either did not move from their previous location (2 fish) or moved to area of higher DO (3 fish). In week 30, 4 fish exited the western areas of the lake where DO had declined below 4 mg/L and found areas of higher DO. Three others also moved from lower to higher DO area, but 4 fish moved to areas of the same or lower DO. In week 33 (Figure 6-17), one fish moved to lower DO, while 8 fish found the areas of the same or higher DO.

In week 27 of 1994, the fish are seen to have exited the Ball Bay area (Figure 6-18) where DO dropped below 4 mg/L, and in week 29 all but one of the fish located in that week have congregated in the area of higher DO off the mouth of Pelican Bay. In week 31, the fish dispersed away from the Pelican Bay when DO declined in that area. In week 33 (Figure 6-19), fish again congregated off shore of Pelican Bay, but dispersed again the following week (week 34), probably in response to the declining lake level to below 4,138 ft. By week 38 (Figure 6-20), more than half the fish were found east of Eagle Ridge, apparently displaced east ward when lake level fell below 4,137 ft.

In several sequences of the foregoing results, it is evident that fish move away from their preferred depth habitat and, perhaps, their normal feeding range, into shallower waters to find higher DO levels (e.g., 1994 – weeks 31, 33, 38, 39; 1996 – weeks 29, 30, 31). The tails on the fish symbols shown in the figures signify the minimum distance fish move on a week to week basis and underestimate the actual distance traveled by an unknown amount. It must be noted that the movement of fish initiated by an avoidance response to low DO, pH, or other water quality parameters, or in response to declining lake level represents an expenditure of energy that would otherwise be unnecessary. This energy expenditure therefore constitutes an additional source of physical and physiological stress to the adult suckers in Upper Klamath Lake. It is also clear that receding lake levels below 4,138 ft restrict access to areas near Pelican Bay, where adult suckers apparently find refuge from poor DO water quality conditions that characterize the northern area of the lake in summer months. It is also evident that receding lake levels at and below 4,137 ft forced adult suckers eastward and away from their preferred habitat range in the northern lake area.

6.4.2 Review of Other Information on Fish Habitat Refugia During Periods of Low Water Quality

Since suckers, redband trout, and other fish in Upper Klamath Lake regularly face high levels of physiological stress resulting from poor water quality in summer months, habitats that maintain higher water quality have high importance to fish as refugia. Refugia habitat for juvenile fish may differ from those of adults. In this section, we summarize information on possible refugia habitat and how fish distribution is known to change during periods of water quality induced stress.

In Upper Klamath and Agency lake, areas with freshwater inflow have generally been considered to have higher water quality than most other areas during and after algal blooms in Upper Klamath Lake (Bienz and Ziller 1987, Buettner and Scoppettone 1990, Vincent 1968). Pelican Bay in the northwestern corner of the lake and the areas offshore of the Williamson and Wood rivers are the most evident areas of freshwater inflow. There are also numerous springs along the eastern shore of Upper Klamath Lake, Bare Island, and perhaps elsewhere that provide isolated areas of freshwater input during the summer months (USBR 1996).

Marsh areas are another possible refugia from poor water quality. Forbes et al. (1998) examined water quality in Hanks Marsh from 1992 through 1994 and found strong differences in some water quality parameters between marsh and open water areas. They noted that *Aphanizomenon flos-aquae* was largely absent from interior marsh areas during summer months and that waters in the marsh are not well mixed with lake water as lake level declines. They attributed the lack of blue-green algae to humic substances present in the marsh sediments and water. They found that pH was much lower in the interior marsh area, but did not examine levels of un-ionized ammonia or DO. Their results indicate that interior marsh areas may offer some refugia to fish when high pH conditions associated with algal blooms are present in the lake.

It is well-known that redband trout retreat to the northern portion of Upper Klamath Lake, especially Pelican Bay, during summer months (Buettner and Scoppettone 1990, Vincent 1968). The waters in and around Pelican Bay are likely the primary refugia for redband trout due to relatively low water temperatures, lower pH, and higher DO levels resulting from inflow from several spring-fed streams and wetlands.

The extent to which suckers utilize the higher water quality in Pelican Bay during periods of poor water quality in the lake is not certain. There is no evidence from the USBR radio tagging study that adult suckers enter Pelican Bay. From time to time they apparently congregate near the mouth of Pelican Bay (Figure 6-8, weeks 27, 29, and 33). In a preliminary study of fish distribution in Upper Klamath Lake in 1964 by Vincent (1968), almost all suckers were caught near areas of incoming water. Buettner and Scoppettone (1990) observed numerous Lost River suckers in Pelican Bay during August 1986, and many dead or dying Lost River and shortnose suckers were found in clear water areas in and near Pelican Bay in September and October 1995 and August 1997 during fish die-offs (Buettner 1997, 1998). These observations indicate that when suckers are stressed to the point of mortality, they are seeking out much higher water quality in this area. By using these areas, however, they are possibly further stressed by cold-water shock (USBR 1996).

Available information is inconsistent on whether or not juvenile suckers seek out refugia during summer and fall months when water quality tends to be lower. Buettner and Scoppettone (1990) found that over a wide range of habitat conditions sampled, juvenile suckers were found in areas with pH below 9.0 and with DO between 4.5 and 12.9 mg/L, although a chi-square analysis showed no significant difference between habitat available and that used. Since their study was conducted in 1988, when water quality was relatively moderate, stress to juveniles was not likely as high as in years with major fish-kills. They also found that juveniles tend to move to offshore areas in September. Simon et al. (1995) also reported that there was a tendency to find juvenile suckers in areas with pH < 9.0 and in areas with DO > 8.0 mg/L, but they conducted no statistical tests to determine whether or not there was a significant association of juvenile sucker distribution and water quality. The USBR (1996) summarized data from 661 cast net and beach seining samples in 1995, most juvenile suckers were found at DO levels between 6 and 15 mg/L, and from over 100 sample sites with DO < 6 mg/L, only one had juvenile suckers. In surveys for larval and juvenile suckers conducted by the USBR during June 1995, large numbers of larval suckers were observed in clear water areas along shorelines near Barkley Springs, and juveniles were captured in this area during July and August in both 1994 and 1995 (USBR 1996). The USBR (1996) also cited Larry Dunsmoor, Klamath Tribes fisheries biologist, as having collected juvenile suckers in Odessa Creek during the summer. We collected juvenile suckers in Short Creek during our 1998 sampling (Table 5-3). These observations certainly indicate that areas of higher water quality are used by juvenile and larval suckers, but it is unknown whether or not these areas are sought out by young-of-the-year suckers.

Sampling from 1990 through 1998 by investigators (Simon et al. 2000b for summary and synthesis) indicated that juvenile suckers were more selective of substrates than of water quality (however, neither fish nor water quality were sampled in marsh or emergent vegetation). They found that in summer, juveniles tend to be found more on coarse substrates, such as gravel and cobble, as opposed to fine textured substrates, which Vincent (1968) also reported. Levels of DO tended to be higher over coarser substrates than over fines, but pH was found to be lower over fines than over coarser substrates. Juveniles were generally not found offshore of marsh areas, where water quality is often higher, and were found in highest abundance along the eastern shore. In late summer and fall, they found much higher numbers of juveniles in the southern portions of the lake, with juvenile suckers almost lacking in the northern 1/3. This is in strong contrast to the movements of adult suckers in the northern part of the lake during mid- to late summer, as shown by the USBR telemetry data in this report and in Peck (2000). Simon et al. (2000b) did not find juveniles to move offshore in late summer or fall, as Buettner and Scoppettone (1990) did.

The apparent existing pattern of having more juvenile suckers found in the southern portion of the lake during the late summer and fall may in part be explained by the loss of emergent vegetation as lake levels typically recede over this period. Using 4142 ft as a level that would preserve the majority of emergent vegetation, Figure 2-4 shows that the lake levels for essentially all of the years evaluated (1993-1999) begin to dip below this level in early August and continue to decline through the end of September. Given that the majority of marsh and emergent vegetation areas are located in the northern portions of the lake, it is possible that as these habitat features become non-functional/ unavailable due to lake level reductions, juvenile suckers passively (via lake circulation) and/or actively emigrate from these areas and become more widely distributed in the southern portions of the lake. In addition, emergent vegetation habitats have largely been unsampled in most of the research and monitoring that has targeted juvenile suckers to date. Recent findings by USGS (detailed in Section 4.1.4) and R2 suggest that use of these habitats by juvenile suckers may be substantial. Maintaining lake elevations high enough to allow use by juvenile suckers, combined with inclusion of emergent habitats in future research and monitoring efforts, could well lead to a revision of our understanding of juvenile sucker distribution in the northern portion of Upper Klamath Lake.

Conditions that lead to fish die-offs may not affect juvenile suckers as severely as adults, as larger fish were disproportionately represented among dead fish compared to fish previously marked (Buettner 1998) or measured (Perkins et al. 2000b). Other explanations for fewer small, dead fish include greater predation of dying and scavenging of dead fish by birds (which would tend to select smaller fish), the absence of juvenile fish in the area of the fish kills, and the ability of juvenile fish to avoid poor water quality by inhabiting shallower, more in-shore waters. The tendency of juveniles to be more shoreline oriented, as opposed to the more offshore oriented adults, may expose them to less stressful conditions.

In summary, it is evident that clear waters in Pelican Bay and associated tributaries are important refugia for redband trout and may be utilized by adult suckers in periods of high water quality induced stress. The northern portion of the lake appears to be more heavily utilized by adult suckers during periods of lower water quality in summer. It is uncertain whether or not juvenile suckers actively avoid areas of poor water quality. Because juvenile suckers tend to stay relatively close to shore where water quality may be somewhat better, they may avoid water quality induced stress more readily than adults.

Our temporal and spatial analysis of radio tagging data documented the movement of fish from areas of declining DO to areas of improved DO conditions. However, in doing so, some fish were forced to move away from preferred depths, an action that likely translates into an expenditure of energy that occurs during already stressful conditions.

7. CONCLUSIONS

Notwithstanding the effects on water quality as described in R2 (2001b), the results of our studies and analysis suggest that lake levels are ecologically linked on a physical basis to several and perhaps all of the life history stages of Lost River and shortnose suckers in Upper Klamath Lake. We have concluded that the availability of in-lake spawning habitats of Lost River and shortnose suckers within springs and shoreline areas is linked to lake levels. Likewise, the quantity and availability of emergent vegetation, which has been shown to be used by larval suckers, are related to lake levels. Our analysis of radio tagging data has identified a preferred water depth of adult suckers, the areal extent of which is related to lake levels. In addition, the results of our limited juvenile sucker sampling coupled with the preliminary results of a new USGS study, suggest that emergent vegetation also provides important habitats for juvenile suckers, which would thus be linked to lake levels. In this section, we summarize the results of our analysis and conclusions pertaining to each of these life history components (Sections 7.1 to 7.4), and then in Section 7.5 render a set of recommendations relative to lake level management of Upper Klamath Lake.

7.1 ADULT SPAWNING HABITAT AND LAKE LEVEL

Numerous studies indicate that an important sub-population of Lost River and perhaps shortnose suckers spawn in springs along the eastern shore of Upper Klamath Lake (Klamath Tribes 1991, Shively et al. 2000). Availability of preferred spawning habitat at both Sucker and Ouxy springs declines with depth from the full-pool elevation of 4,143.3 ft (Figure 5-8) (with preferred spawning habitat having a depth of at least 2 ft). At other sucker spawning sites along the eastern shore of Upper Klamath Lake (Silver Building and Boulder springs, Cinder Flats), data are insufficient to determine how spawning habitat availability changes with lake surface. At a lake surface elevation of 4,142.0 ft, less than 30 percent of preferred spawning habitat remains at Sucker Springs and less than 15 percent remains at Ouxy Springs.

Maintaining higher lake levels during spawning periods would ensure the potential of these unique habitats could be realized. Assuring a greater diversity of spawning habitats for sucker species would also be accomplished.

Suckers are known to spawn in Sucker Springs from late February to early June (Section 4.1.2). Perkins et al. (2000a) reported that peak spawning at spring sites was generally from mid-March to mid-April, however Shively et al. (2000) found the bulk of spawning at all sites was from early-April to mid-May in 1999. Since there appears to be some year-to-year variability in the timing of migration at spring sites in Upper Klamath Lake, mid-March to mid-May is a reasonable time frame for specifying lake levels adequate for maintaining habitat availability to spawning suckers.

Based on available information on depth and timing of sucker spawning, water surface elevations in Upper Klamath Lake should be preferably at full-pool of 4,143.3 ft, from early March through May in order to maximize preferred spawning habitat for Lost River and shortnose suckers. Lake levels below 4,142.0 ft severely diminish available spawning habitat and likely pose significant risk to successful spawning by suckers at spring sites in Upper Klamath Lake.

7.2 REARING HABITAT OF LARVAL AND JUVENILE SUCKERS IN RELATION TO LAKE LEVEL

In recent decades, recruitment of year classes into the adult Lost River and shortnose sucker population has been extremely variable, with only a few years from 1970 to the late 1990s having strong year classes in Upper Klamath Lake (Buettner and Scoppettone 1990; Perkins et al. 2000a; Simon et al. 2000b; Markel et al. 2000). Small changes in mortality rates in early life stages can cause substantial variation in or failure of recruitment in fishes (Houde 1987), and the importance of early life history stages in maintaining and increasing numbers of adult suckers in Upper Klamath Lake is widely recognized (Klamath Tribes 1996; Simon et al. 2000b; USFWS 1993). Consequently, there has been a great deal of recent research on habitat requirements, distribution patterns, feeding, and growth rates of sucker larvae in Upper Klamath Lake, much of which is summarized in Sections 4.1 and 4.2.

It is evident from research done to date that emergent marsh habitat plays an extremely important role for larval and probably juvenile suckers in Upper Klamath Lake. Because the Williamson and Sprague rivers are where most of the spawning takes place for the Upper Klamath Lake populations of Lost River and shortnose suckers, the loss of most of the marsh habitat around the Williamson River delta has substantially diminished the availability of rearing habitat for larval suckers, and maintaining accessibility of the small amount of remaining rearing habitat to larval suckers in this area is critical. Emergent vegetation habitat is important to larval suckers because it provides shelter from predators and turbulent water, provides food resources, and in some locations may provide improved water quality.

The main period during which larvae utilize emergent marsh is from early May through late June, but there is lower, steady larval production up to mid-July (Markle et al. 2000, Simon et al. 2000b). Furthermore, larvae produced later are also more likely to survive until September (Simon et al. 2000b). It is unclear to what extent juveniles utilize marsh habitat, but juveniles have been found in marsh areas and in emergent vegetation bordering dikes in late July by Klamath Tribes biologists (Klamath Tribes 1996) and in August (this study) and early September by USGS investigators (Rip Shively, USGS, personal communication). Given the regular use of marsh rearing habitat by larvae at least up to mid-July and the greater importance of late developing larvae in the surviving year class, lake levels sufficient to provide access and utilization of shoreline marsh areas should be maintained until at least July 15.

As presented in Chapter 6, lake levels needed to inundate and provide usable habitat to larval and juvenile suckers have been assessed by Dunsmoor et al. (2000) and by R2 using USBR data (this report). Dunsmoor et al.'s analysis indicates that approximately 80 percent of emergent habitat volume is inundated in lake shore areas at a lake level of 4,142.8 ft and 50 percent of emergent habitat volume is inundated at a lake level of 4,142.0 ft. R2's analysis showed that nearly all of marsh edge and interior habitat in the larger marsh areas along the northern lakeshore is available to suckers at a lake level of 4,142.0 ft (Figure 5-3). R2's analysis estimated that approximately 80 percent of emergent habitat is usable by larval suckers (i.e., has a depth $1 ft) at a lake level of 4,141.5 ft and 80 percent of marsh edge habitat is available to suckers at a lake level of 4,141.2 ft. Both Dunsmoor et al.'s (2000) and R2's analysis, as well as an assessment of inundation using aerial photographs by Chapin (1997b), indicate that emergent vegetation habitat is almost completely unavailable to suckers at lake levels below 4,140.0 ft.

To determine a lake level adequate to maintain most of the remaining emergent vegetation rearing habitat presently used by sucker larvae (i.e., along the delta shoreline), the results of Dunsmoor et al.’s (2000) analysis would be the most prudent to use. Because their analysis was made in areas most heavily used by sucker larvae under present lake conditions and because their data were collected with a high degree of spatial resolution, they represent a more accurate quantification of larval habitat likely to be used by existing sucker populations. However, if the marshes of the Williamson river are restored and the shoreline becomes similar to that along the northern marsh areas, the results of R2’s analysis (Section 5.1.2.2) would be more appropriate for determining adequate lake levels.

A lake level of 4,142.0 ft would be a minimum level to maintain the availability of a significant volume of emergent habitat/vegetation areas currently used by larval and juvenile suckers. This level would make nearly all of the edge habitat in the marshes analyzed by R2 accessible to larval suckers (Section 5.1), but would provide only about half of the available habitat volume in shoreline emergent vegetation where most sucker larvae occur (Dunsmoor et al. 2000). Lowering lake level below 4,142.0 ft not only eliminates the majority of emergent habitat most used by sucker larvae and juveniles, it also likely results in greater fragmentation and discontinuity of emergent habitat between the mouth of the Williamson River and other rearing areas along the lake shoreline, such as Goose Bay. Reducing the lake level below 4,142.0 ft before July 15 very likely would result in reduced habitat available for larval and perhaps juvenile fish in a given year to be less than half the potential emergent habitat available to sucker larvae and juveniles and what is available will likely be more fragmented. Survival of larvae and juvenile sucker would likely be reduced. Reducing lake level below 4,142.0 ft before September 1 will also affect continued use of emergent habitat by juvenile suckers, which are known to utilize emergent vegetation beyond the period when larval suckers are found there. More information on the use of marsh habitat by juvenile suckers is needed before effects of lake level on juvenile suckers can be more thoroughly assessed.

Dunsmoor et al.’s (2000) and R2's analyses reported here show that very little emergent habitat is available as lake levels drop below 4,141.0 ft and that emergent vegetation is essentially inaccessible to young suckers at a lake elevation of 4,140.0 ft. Given the high importance of emergent vegetation to larval suckers, and possibly to juvenile suckers, lake levels below 4,141.0 ft will likely result in significant adverse effects to age 0 suckers.

Because of both water quality benefits and the importance of maximizing the remaining amount of sucker larval habitat, lake level is a key control point in managing and improving fish habitat conditions in Upper Klamath and Agency lakes. Maintaining lake levels above a minimum elevation of 4,142.0 ft will ensure that larval and juvenile suckers have access to the limited rearing habitat available to them.

7.3 ADULT HABITAT AVAILABILITY AND LAKE LEVEL

Because of the bathymetry of Upper Klamath Lake, relatively small incremental reductions in lake level can result in major reductions in the usability of and access to areas of emergent vegetation and marsh habitats by fish. These same relatively small changes can also result in large changes in the overall areas of certain water depth classes within the lake. Our analysis of existing USBR radio-tagging data explored the hypothesis that adult suckers within Upper Klamath Lake utilize and more importantly prefer certain water depths. This was postulated on the theory that adult suckers would, given the choice, seek out certain depths of water that would meet their requirements of food, cover (predator avoidance), and space (holding, staging), and at the same time would provide suitable water quality conditions. The identification of certain water depths as “preferred” or “utilized” by suckers would allow an incremental analysis of lake levels with such depths, much like is done in streams using the Physical Habitat Simulation (PHABSIM) models in which streamflow vs habitat relationships are defined.

Our assessment proceeded from an initial depth-frequency analysis of sucker radio-telemetry data in which depths of all Lost River and shortnose suckers located by boat were segregated into 3 ft depth increments from 0 ft to 15 ft. The analysis indicated that both sucker species used similar depths in the spring and summer months, thereby allowing the pooling of their data into a combined depth-frequency distribution. Overall, the analysis indicated that over 95 percent of the observations were found in waters that encompassed a depth range of from 3 to 15 ft; one percent were found in depths < 3 ft and 3 to 4 percent were found in depths > 15 ft (Figure 5-9). We hypothesized that the shallow water depths were avoided by the suckers due to absence of cover and to increased turbulence in those areas. The deeper waters of Upper Klamath Lake may not be used as readily by suckers due to seasonal shifts in water quality that occur in those areas (e.g., low DO in summer months), water temperature differences, and possibly differences in bottom substrates at those deeper locations.

We confirmed sucker depth preference and avoidance by comparing depth utilization with available bottom areas for six depth intervals, as defined by radio tagging data from September and October 1994. These months were selected since they represent a period in which water quality would not likely influence the distribution of fish (i.e., water quality conditions generally improve in the fall), and therefore, sucker use of specific water depths would most likely reflect their preference for such. The results (Figure 5-11) demonstrated a strong preference for the 6-9 ft depth interval and a strong avoidance of the 1-3 ft depth interval.

We applied the frequency analysis to the lake bathymetry data for Upper Klamath Lake to determine the areal extent of each depth interval class over a range of lake surface elevations (Figure 5-12; Table 5-8). That analysis demonstrated the sensitivity to changing lake levels for each of seven depth interval classes. Importantly, the area of the depth interval most often used by adult suckers (6-9 ft, as determined from the radio tagging analysis) changes relatively little between full pool and lake elevation 4,142 ft. Below that level and extending to elevation 4,138 ft, the amount of area meeting that depth interval diminishes substantially. We subsequently displayed the combined depth intervals preferred, used, and avoided by suckers as a percentage of full pool area for the full range of lake levels (Figure 5-13). That figure clearly demonstrated an inflection point at lake elevation 4,142 ft at which point the area of lake having both preferred and utilized depths begins to decline. The rate of decline increases substantially below lake elevation 4,141 ft.

The adult sucker population represents one of the key components necessary to effect a recovery trajectory for the two species. Sustained recruitment to the populations can only occur if the reproductively active fractions of the populations are healthy and viable. The fish kills that have occurred in Upper Klamath Lake appear to be selective for adult fish and could, if on a frequent enough basis, deplete the adult populations to levels where recovery becomes improbable. Thus, lake management must include measures to protect adult suckers. Based on our assessment of depth utilization, we believe Upper Klamath Lake levels should be held at or above 4,141 ft during the July–September period in order to protect important adult sucker habitats.

7.4 REDUCED WATER QUALITY AND FISH HABITAT USE

Poor water quality periodically causes significant levels of mortality in Lost River and shortnose suckers, redband trout, and many other fish species in Upper Klamath Lake. In addition, as water quality is degraded during summer months as a result of *Aphanizomenon flos-aquae* blooms, available habitat to trout is greatly reduced to clear-water areas near stream and spring inflow. Consequently, much of Upper Klamath Lake is unused by trout during most summers, which undoubtedly reduces the productivity of the Upper Klamath Lake trout population due to restricted access to lake food and habitat resources.

Data also suggest that during mid to late summer adult suckers preferentially go to areas in the northern end of the lake that appear to have more favorable water quality conditions than the rest of the lake. As with trout, this restricted distribution pattern of suckers would result in reduced productivity, since they do not exploit food resources in much of the lake. It is unclear to what extent juvenile suckers avoid poor water quality and adjust their distribution in response to the effects of algal blooms, but our analysis suggests that they do select areas of higher water quality when lake water quality declines.

In 1993, 1994, and 1995, radio tagged adult suckers begin to experience substantial combined stress from pH and DO in bottom waters as early as the first week in June (1994) that increases to maximum values in July, and then declines through August and September. In 1996, 1997, and 1998, there were generally lower maximum values and many fewer occurrences of high stress experienced by adult suckers after mid-August than in the previous three years. The large increase in un-ionized ammonia stress in the last three years of the study may have sensitized fish to better enable them to avoid DO/pH combined stress.

Comparisons of combined DO/pH stress experienced by adult suckers with that at fixed location monitoring stations in the northern part of the lake showed that the frequency of zero-stress, low-stress, and intermediate-stress did not differ statistically between fish and fixed locations over six years of study. The combined DO/pH high-stress comparison showed that significantly fewer fish than expected from the fixed-location stress levels were found where combined DO/pH stress equaled 1.0. This indicates that adult suckers only avoid the most severe stress conditions and do not avoid or do not sense lower levels of stress that may still have adverse physiological effects. The results also show that adult suckers do not generally congregate in non-stressful bottom-water area or cannot find such areas that exist because of the pervasive nature of the poor water quality that dominates the northern area of Upper Klamath Lake in the late-spring through summer months.

The effects of total stress potentially experienced by adult suckers (including un-ionized ammonia concentrations) in the bottom waters of northern Upper Klamath Lake was investigated using a stress summation index based on the Klamath Tribes' water quality monitoring data at three northern sites. From 1990 to 1995, the results show a seasonal sequence of pH stress, followed by or overlapping with DO stress, and then rare instances of un-ionized ammonia stress. This pattern changes remarkably from 1996 through 1998. In these latter years, the increased concentrations and frequency of high un-ionized occurrences result in a 69 percent increase in the instances of total bottom-water stress levels at 1.0 or greater, compared to the previous 6 years. Such an increase in the incidence of total stress imposed on adult suckers by deteriorating water quality conditions in the lake may have contributed to the fish mortalities observed in 1996 and 1997. This is consistent with Perkins et al. (2000b), who concluded that fish kills were preceded by and in some cases initiated during, a period of high pH, high un-ionized ammonia, and low off-bottom dissolved oxygen, followed by several days of low dissolved oxygen that extended throughout the water column.

Since poor water quality in Upper Klamath and Agency lakes causes reduced habitat availability, as well as significant mortality, of both suckers and trout, improving water quality in the lakes should result in increased productivity and increased survivorship. As shown in R2 (2001b), higher lake levels are important to improving overall water quality in Upper Klamath Lake.

7.5 RECOMMENDATIONS

Based on our findings and analytical results highlighted above, we recommend the following temporally distinct but ecologically linked lake levels as defined by one or more life history components for important fish species in Upper Klamath Lake:

- March 1 – May 31: lake levels of $4143 ft (maximum habitats provided at 4143.3 ft) –

maximize in-lake spawning habitats for adult suckers

- June 1 – July 15: lake levels $4142 ft (80% habitats provided at 4142.8 ft) – maintain important emergent vegetation for larval and juvenile suckers; provide conditions that promote increased larval and juvenile survival
- July 16 – September 30: lake levels $4141 ft (maximum habitat provided at 4143.3 ft) maintain > 80 percent of preferred depth habitats of adult suckers and provide use of and access to refugia habitats by adult and habitat for juvenile suckers, and adult redband trout during periods of degraded water quality; provide conditions that promote increased adult survival during summer months.

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APPENDIX A

Analysis of the Distribution and Stability of Existing Marsh Vegetation Bordering Upper Klamath and Agency Lakes

(Chapin 1997a)

Analysis of the Distribution and Stability of Existing Marsh Vegetation Bordering Upper Klamath and Agency Lakes

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-CONFIDENTIAL-

Analysis of the Distribution and Stability of Existing Marsh Vegetation Bordering Upper Klamath and Agency Lakes

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Analysis of the Distribution and Stability of Existing Marsh Vegetation Bordering Upper Klamath and Agency Lakes

Introduction

This study consisted of mapping marshland around the shorelines of Upper Klamath and Agency lakes and an assessment of potential effects of changing lake level on these marshes. It was carried out in support of a larger study conducted by R2 Resource Consultants under subcontract to EA Engineering, Science, and Technology to evaluate fish habitat around the two lakes with respect to how different lake levels affect the quality and quantity of habitat. Previous work has shown that emergent wetlands along the lake shorelines are important habitat for larval and juvenile suckers (including the Klamath largescale sucker (*Catostomus snyderi*), the Lost River sucker *(Deltistes luxatus*), and the shortnose sucker (*Chasmistes brevirostris*), providing protection from wave action and predators (Coleman et. al, 1989; Klamath Tribes, 1991; 1995).

The first portion of the study consisted of mapping the extent of existing marshland around the perimeter of the two lakes. The results of the vegeation mapping were then used as a baseline in determining how the distribution of marshland has changed in the two lakes and how it might change under different management regimes of lake level. A review of literature and a related study on water requirements of marsh species from Klamath Marsh was used to evaluate potential changes in marsh structure and extent as a result of potential changes in lake water level.

The term “marsh” is used to denote the vegetation mapped in this study, with the acknowledgement that the definition of marsh vegetation varies according to region and purpose. For this study, marsh included areas dominated by emergent and rooted aquatic plants with a period of inundation ranging from 9 to 12 months of the year (in most years). The identification of these areas was based on vegetation-hydroperiod relationships determined at Klamath Marsh, located approximately 20 miles northeast of the Upper Klamath and Agency lakes area (EA, 1994). This would include the wetter end of emergent vegetation as defined by the U.S. Fish and Wildlife Service (USFWS) classification system (Cowardin et al., 1979), but would not include areas commonly referred to as “wet meadow”. It would also include some areas defined by the the USFWS as aquatic bed vegetation, which in this study were dominated by yellow pond-lily, or wocus (*Nuphar polysepalum*). The reasons for including both emergent and aquatic bed classes together is explained below in the section on methodology.

Methodology

Vegetation Mapping

Mapping of marsh vegetation was conducted primarily using black and white aerial photographs taken in June, July, and August, 1985 at a scale of 1:30,000 (WAC Corporation, Eugene, OR). The aerial photographs were interpreted using a Sokkia MS16 mirror stereoscope (magnification 1.5x) and a 10x magnification loupe lens.

Vegetation was classified into five different classes based on vegetation structure and degree of interspersion. The five classes included:

- shrub vegetation (areas dominated primarily by willow [Salix spp.]);
- emergent vegetation, low interspersion: areas where there was emergent vegetation but few to no patches of open water;
- emergent vegetation, moderate interspersion: areas with emergent vegetation and a few scattered patches of open water (< 1:4 ratio of open water to vegetation)
- emergent vegetation, high interspersion: areas with emergent vegetation and abundant patches of open water (> 1:4 ratio of open water to vegetation); and
- open water: the open lake areas and continuous channels within the delineated marshland.

No attempt was made to determine species of emergent vegetation, which based on casual observations by the author in 1990 included a mosaic of hardstem bulrush (*Scirpus acutus*), burreed (*Sparganium* sp.), cattail (*Typha latifolia*), sedges (*Carex* spp.), and spikerush (*Eleocharis palustris*). Also present were extensive stands of yellow pond-lily, known by the Klamath Tribes as wocus (*Nuphar polysepalum*), which are more accurately classified as aquatic bed vegetation (following the USFWS classification system (Cowardin et al., 1979). The pond-lily areas were not readily distinguishable from the emergent vegetation in the black and white aerial photography and were included within the emergent classes.

A few oblique color aerial photographs taken by the author from a helicopter using a 35 mm camera in September 1990 were used to better interpret the black and white aerial photographs. No color infrared or natural color aerial photographs were used in the study.

Vegetation polygons were mapped by examining the aerial photographs under magnification, determining the vegetation class of a given area, then determining the boundaries of the polygon in relation to neighboring map units. The boundary was then drawn on a mylar overlay of a 1:24,000 scale (7.5 minute) USGS quadrangle maps. The USGS maps were 1985 edition based on 1980 aerial photography, and included the following Oregon quadrangles:

- Crystal Spring
- Agency Lake
- Pelican Bay
- Shoalwater Bay
- Modoc Point
- Howard Bay
- Wocus
- Klamath Falls.

These maps showed the location of the marsh-lake border and many of the internal marsh-open water boundaries, which generally corresponded well with the 1985 aerial photographs. Using these features, the boundaries of the marsh types could usually be transposed with good accuracy from the aerial photographs onto the USGS quadangles. Where map features within the marsh areas were not present, location of points along the polygon boundaries were located on the USGS quandrangles by calculating the approximate distances from two mapped features on the aerial photograph. The lake shoreline was mapped as the lakeward edge of the marshland; or where no marsh areas occurred, the lake shoreline delineated on the USGS quadrangle was used.

The minimum polygon size for a map unit depended on whether or not the location was along the lake shoreline or was part of a more extensive marsh area extending shoreward from the lake. Islands of emergent vegetation and patches of willow near the shoreline were often relatively small (i.e., one to a few acres), but were distinctively different from the extensive emergent marshland anddelineated on the maps. In contrast, the interspersion class of emergent marsh areas were averaged over larger areas (i.e., greater than 25 acres) and consequently were not mapped at such a fine scale.

The maps were digitized into an Arc/INFO database by Joetta Zablotney of EA Engineering, Science, and Technology. Checkplots were examined and edited maps were subsequently produced. No field verification has been conducted to date.

Assessment of Vegetation Stability

The stability of marsh vegetation along the margins of Upper Klamath and Agency lakes was assessed using two approaches. The first was an historical evaluation of the distribution of marshland using aerial photography dating back to 1952 and maps dating back to 1894. The second approach was based on previous studies examining vegetation-hydroperiod relationships of some of the dominant plant species occurring in these marshes.

Results and Discussion

Existing Marsh Vegetation along Margins of Upper Klamath and Agency Lakes

Most of the marshland along the margins of Upper Klamath Lakes is located in the north end of the lake, particulary from Coon Point south of Pelican Bay to the outlet of Agency Lake (See map of Upper Klamath and Agency Lake vegetation produced by EA Engineering, Science, and Technology). These marshlands extend up the western shore of Agency Lake and shoreward for several miles in some places, forming an extensive network of marsh and water channels within the Upper Klamath National Wildlife Refuge. These marshlands were once more extensive but have been reduced in area by diking and draining. Other relatively large areas of remaining marshland are Wood River Marsh at the north end of Agency Lake, Hanks Marsh along the southeastern shore of Upper Klamath Lake, and Squaw Point Marsh on the north shore of Howard Bay. Smaller patches of marsh are scattered elsewhere along the lake shoreline. Among these are islands of emergent vegetation that parallel the shore between the mouth of the Williamson River north along the shore of Upper Klamath Lake into Agency Lake.

The vegetation in the larger marshes occurs in a complex pattern of interspersion classes. Nearly half of the marsh vegetation mapped around the lakes was in the emergent - low interperion class (Table 1). Most of the remaining vegetation was mapped in the emergent - moderate and high vegetation classes and was fairly equally divided between the two. A minor amount of vegetation was mapped as willow shrub.

Table 1. Area within each vegetation class mapped in Upper Klamath and Agency lakes.

Vegetation Class	**Area (acres)**	**Percent of Total Area**
Emergent - low interspersion	7,763	47
Emergent - moderate interspersion	4,652	28
Emergent - high interspersion	3,856	23
Willow Shrub	252	2
Total	**16,523**	

Several channels were evident that connected the interior portions of the larger marshland to the open water of the lakes. Major channels included Recreation and Crystal Creek near Pelican Bay, Thomason Creek between Pelican Bay and Agency Lake, Odessa and Short Creek south of Pelican Bay, and the Wood River flowing through Wood River Marsh. These channels provide considerable edge between marsh and aquatic habitat in addition to that along the lakeshore itself.

In Upper Klamath and Agency lakes, the three interperion classes are likely to roughly reflect different hydroperiods. (Hydroperiod is defined as the depth, duration, and frequency of inundation.) Marsh areas with high interspersion are places where plant species are most likely growing at the margins of their tolerance for inundation. In contrast, areas of low interspersion have a continuous cover of vegetation with very little open water, indicating that there is relatively little area that is beyond the depth tolerance of emergent plant species growing in the area. Emergent vegetation with a moderate amount of open water patches within emergent vegetation tend are probably intermediate in average depth and duration of inundation.

Although there are alternative explanations for variation in interspersion, an examination of historical evidence, lake levels, and species dominance patterns support this explanation for varying interspersion in Upper Klamath and Agency lakes. There is further discussion of this issue in the section below on vegetation stability.

This study did not address the distribution of species within the marsh vegetation around Upper Klamath and Agency Lakes, but previous reconnaissance identified a mosaic of several community types that tended to be dominated by one species. Common dominant species included hardstem bulrush, burreed , cattail , sedges, spikerush, and yellow pond-lily (wocus). All of these species except yellow-pond-lily tend to grow with a high density of stems and occur where surface water recedes to near the surface or below the surface by late summer(EA, 1994). In contrast, yellow pond-lily is a semi-aquatic species with floating leaves where water is typically around 2 feet deep even in late summer. Patches of yellow pond-lily are scattered throughout the marshland especially in areas closer to the lake shoreline. These areas represent semi-aquatic habitat that is in many cases connected to channels and open water bodies and contribute to a complex of emergent, semi-aquatic, and aquatic habitat composing the extensive marshland around these lakes.

Past Stability of Marsh Vegetation

The mapping of vegetation described above was primarily based on aerial photographs taken in 1985. As such, this represents a snapshot in time of marshland that is possibly quite dynamic. An examination of older aerial photographs and maps is valuable for addressing the question of how stable marsh vegetation in these lakes has been within the past 50 to 100 years. This historical analysis and information available on hydroperiod of some of the dominant plant species present can then be used to address future stability of marsh vegetation.

Changes in Marshes Since 1885

The earliest maps found that show the extent of marshland around Upper Klamath and Agency lakes with reasonable accuracy are 1:250,000 scale topographic maps produced by the U.S. Geological Survey (USGS) in 1894, which were based on surveys conducted in 1885 to 1887 (Ashland and Klamath quadrangles). These maps show the presence of marshland using the standard topographic map symbol.

Along the lake shorelines, marshland is shown on the 1894 maps in all locations where marshland is presently located, except for the Hanks Marsh area. In addition there are many areas mapped as marshland that have since been converted (i.e. “reclaimed”) to agricultural land. The lake-marsh boundary appears remarkably similar between that shown in the 1894 maps and the present boundary. Major areas of conversion include:

- marshland west and north of Agency Lake

- Williamson River delta,
- Caledonia and Wocus marshes south of Howard Bay,
- marshes around Ball Bay, and
- marshland along the southeastern shoreline north and south of Hanks Marsh.

Although no quantification of the amount of converted marshland was made for this study, it is apparent that well over half of the marshland in these lake systems has been lost. An examination of 1957 USGS maps (1:62,500 scale) that were based on 1955 aerial photography indicates that most of this conversion had been completed by 1955. Prior to 1955 only a portion of the conversion of marshland west and north of Agency Lake had taken place, and since that year considerably more land was converted from marsh to agricultural land in this area.

Changes in Marshes Since 1952

To assess more recent changes in vegetation, the four vegetation classes mapped from 1985 aerial photographs were mapped using the same methodology from 1952 aerial photographs (1:20,000 scale, black and white). (The results of this delineation, however, have not been digitized into an Arc/INFO database.) This comparison indicated some changes in marsh conditions around the two lakes over this recent 33 year period. These changes included direct conversion of marshland to agricultural land by diking and draining in the Wood River area, which was discussed above, and qualitative changes in remaining marshland.

Qualitative changes in marshland from 1952 to 1985 that were evident in the black and white aerial photographs were differences in the degree of vegetation - open water interspersion. In the marshland extending from west of Pelican Bay to Agency Lake there has been a progressive change from higher to lower interspersion. In other words, the marsh is more densely vegetated, and the amount of aquatic habitat is much reduced. A brief inspection of aerial photographs from 1960 and 1968 indicate that this change began sometime between 1960 and 1968, which is also when a major increase in the conversion of marshland to agricultural land took place immediately north of this area. In Wood River Marsh, at the mouth of the Wood River, this change in interspersion is not apparent. In contrast, it appears that in Hanks Marsh vegetation - open water interspersion has increased.

Difference in lake level at the time of the aerial photography between September 1952 and June-July 1985 do not explain the decrease in interspersion in the Pelican Bay - Agency Lake area. September 1952 lake level was 4140.59 feet mean sea level (msl) elevation, while June-July 1985 lake levels were 4142.43 to 4141.23 feet msl elevation. Higher lake levels in June-July 1985 would, if anything, make open water areas more apparent in aerial photographs taken at those times. The higher water levels in the 1985 aerial photographs could have, however, contributed to the greater interspersion apparent in Hanks Marsh.

The islands of marsh vegetation along the shoreline north of the Williamson River into Agency Lake are present in the 1952 photograph, and may be related to the dike construction around this area that resulted in the conversion of the marshy delta to agricultural land. There appears to be some decrease in the number and width of these islands from the time of the 1952 to the time of the 1985 photographs.

Lake Level Records

An analysis of lake levels over the period of record from 1906 to 1988 is useful for identifying changes in marsh hydroperiod around Upper Klamath and Agency lakes (Figure 2). This record shows an annual amplitude of 2 to 2.5 feet from 1906 to about 1920. Starting in the mid 1920s, the annual amplitude is 3 to 4 feet. There was a sharp decline in average, maximum, and minimum water levels in the late 1920s. Another period of low minimum water levels occurred in the late 1930s until the mid 1940s. Water levels were generally high between 1950 and 1957, and were variably high and low from 1958 to 1986. Minimum water levels, however declined to record lows in 1980. Average annual mean, maximum, and minimum water level over the period of record are 4,140.98, 4142.62, and 4,139.16 feet msl elevation, respectively.

Interpreting Historical Stability of Marsh Vegetation

The close similarity between the marsh-lake boundary in 1894 and that of 1985 (in areas where conversion of marsh to agricultural land has not occurred) indicates that the marshes remaining along the lake margin are not retreating from or advancing into the lake, but are stable in their overall area. Information on marsh conditions prior to 1952 was not examined for this study, but qualitative changes in these marshes since 1952 are evident. The loss of interspersion in the more extensive marshland from Pelican Bay to Agency Lake appears to be a progressive change starting sometime between 1960 and 1986, but does not appear to be linked to a change in lake water level. If a change in water level were responsible for this change, a decline in annual mean or maximum water level would be expected, which is not apparent during this period in the record of lake water level. Moreover, Hanks Marsh shows an increase in interspersion, which is evidence against a change in lake water level since 1952 causing the evident changes in interspersion.

Relatively high interspersion can occur under both stable and unstable water regimes. When the hydroperiod is relatively stable from year to year, emergent plant species can not persist in deeper areas where inundation is at a depth and duration beyond the tolerance of any species (Marble 1992). However, in slightly shallower areas within the flood tolerance range of local species, patches of vegetation can persist. This results in mosaic of interspersed vegetation and water. Under unstable conditions where water levels have recently risen beyond the tolerance of the local emergent species, areas of high interspersion can be the result of vegetation dying out and represent an intermediate step between the conversion of emergent wetland to open water (Van der Valk and Davis, 1980).

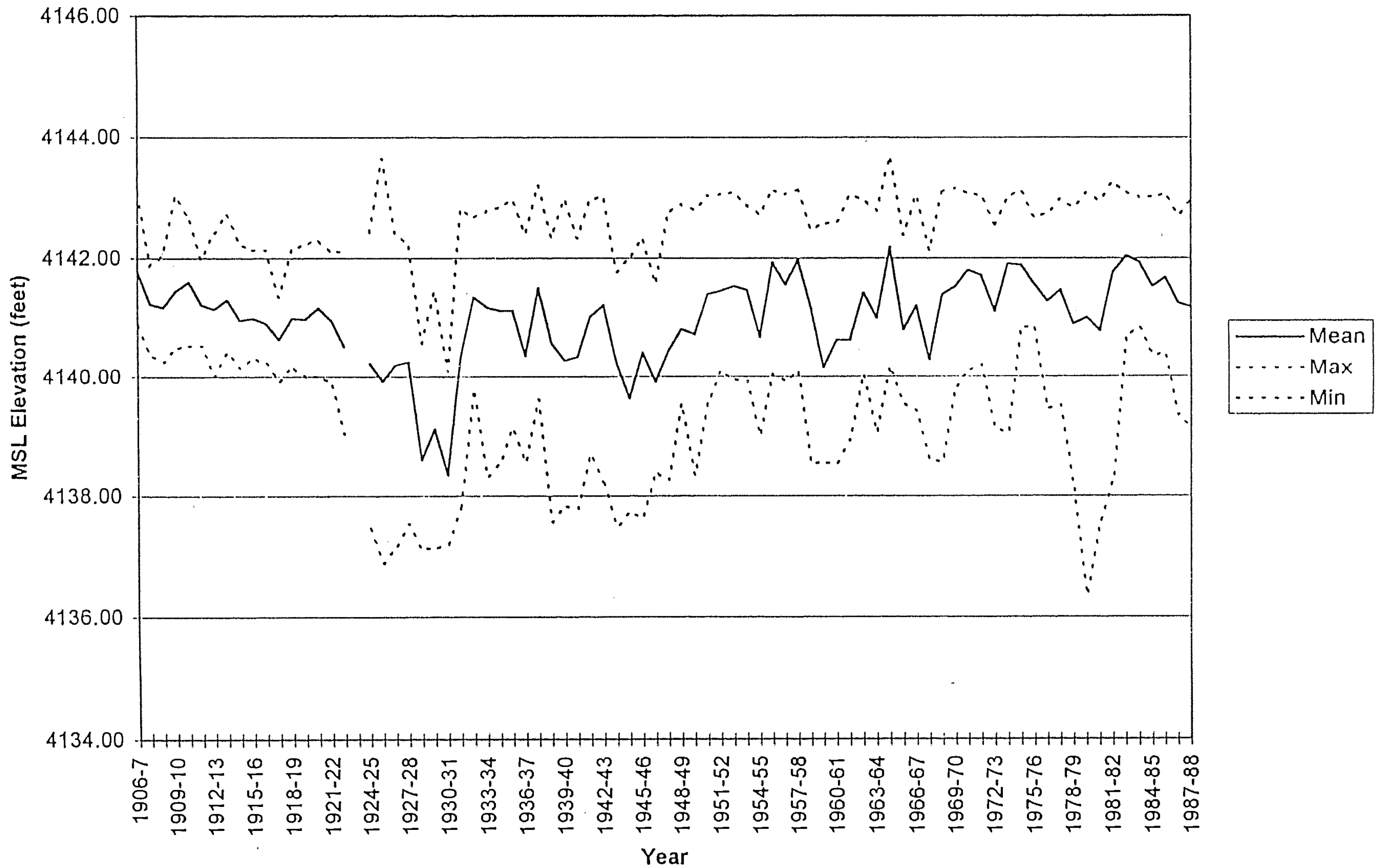

Figure 1. Annual mean, maximum, and minimum water level in Upper Klamath Lake, 1906 to 1988.

Source: Klamath Tribes Natural Resources Department

In the marshes around Upper Klamath and Agency lakes, marshes characteristic of relatively stable water regimes appear to occur. Unstable water regimes, exemplified by prairie potholes that go through cycles of drying and reflooding, typically have repeated large scale changes from emergent vegetation to open water and back to emergent vegetation. In contrast, the marshes around the two lakes assessed here appear to be undergoing progressive changes on a much slower time scale that are likely driven by different processes than wet-dry cycles.

The loss of interspersion in the marshes between Pelican Bay and Agency Lake could be related to a change in hydrology or in nutrient cycling brought about by the conversion of adjacent marsh to agricultural land, which happened about the same time. Rerouting of water through the marsh could have lowered water levels. Although the direct connection of the marshes to the overall lake level would argue against this hypothesis, the loss of water from the Wood River valley above the marshes may have resulted in somewhat lower marsh water levels than in the past. Alternatively, greater nutrient loading into the marsh might be leading to increased primary productivity and increased accumulation of organic matter, allowing vegetation to expand into areas that previously were too deeply inundated. Evaluating these or other potential hypotheses would require much more extensive research than that conducted for this study.

Despite the qualitative changes apparent in these marshes over the last 30 to 40 years, we can conclude that the area of marsh vegetation not converted to agricultural land has been relatively stable for over a hundred years. While some changes are taking place, these marshes have remained intact within the historic variation in lake water level.

Potential Effects of Changing Lake Level on Stability of Marsh Vegetation

Literature on Vegetation-Hydroperiod Relationships

Hydroperiod is one of the most important environmental factors controlling the extent of wetland vegetation and the distribution of different species within wetlands (Mitsch and Gosselink, 1986). The lack of oxygen in soils brought about by inundation limits the growth and survival of plants to those that have physiological and morphological adaptations to tolerate anoxic soils. Those that can persist under periodic to permanent inundation, often termed hydrophytic species, also differ in the depth of water and the duration of flooding that they can tolerate. These differences and the competitive interactions among species are what lead to the characteristic zonation of plant communities along a water depth gradient in marshes and along lake shorelines.

Although the fundamental importance of hydrology to marsh vegetation is widely recognized, there is relatively little literature available on hydroperiods of individual species. Most of the literature reports short-term measurements, and often seasonal fluctuations are not even measured. A review of literature that have hydroperiod data on species or closely related species to those that occur in the marshed discussed here provides some information and is shown in Table 2.

Table 2. Summary of published water depth data for major species or genera in marshes around Upper Klamath and Agency lakes.[1]

Species	Minimum Depth (ft	Maximum Depth (ft)	Location	Source
Nuphar sp.	1.31	>1.97	Saskatchewan	Jeglum 1971
	1.97	4.59	Iowa	Niemeier and Hubert 1984
Scirpus acutus	-1.28	1.97	Saskatchewan	Jeglum 1971
	0	2.62	Manitoba, Alberta	Shay and Shay 1986
	0.98	5.25	Iowa	Niemeier and Hubert 1984
	1.97	4.92	Saskatchewan	Dabbs 1971
Typha latifolia	No data	1.64	Iowa	Niemeier and Hubert 1984
	-1.28	>1.97	Saskatchewan	Jeglum 1971
	-0.49	2.62	Michigan	Grace and Wetzel 1981
	No data	2.95	Manitoba, Alberta	Shay and Shay 1986
	No data	3.12	Arkansas	Grace 1989
Sparganium eurycarpum	-1.28	2.95	Quebec	Shipley et al. 1991
Carex rostrata	-2.62	>1.97	Saskatchewan	Jeglum 1971

[1] Negative water depth data show distance to water table below the soil surface; positive data show depth of water above the soil surface

An investigation conducted at Klamath Marsh (15 to 20 miles north of Agency Lake) as part of the Upper Klamath Basin water rights studies included an intensive analysis of vegetation-hydroperiod relationships for several of the major dominant plant species present around Upper Klamath and Agency lakes (EA, 1994) The data in that study, together with the availabe data in the literature, provide a basis on which to predict how much change in water level might be necessary to result in signficant changes in marsh vegetation around the two lakes.

In the EA investigation, field measurements over a two year period were related to an 18 year record of marsh water level that yielded a relatively long term characterization of hydroperiod for several vegetation types, including a sedge-rush type (*Carex rostrata-Juncus balticus*), bulrush type (*Scirpus acutus*), and a yellow pond-lily type(*Nuphar polysepalum*) (Table 3). These vegetation types, or very similar types, also occur in the marshes around Upper Klamath and Agency lakes. The cattail and burreed vegetation types, present around Upper Klamath and Agency lakes but not assessed in the Klamath Marsh study, likely fall between the bulrush and the sedge/rush types in overall hydroperiod based on the literature data shown in Table 2 and personal observations.

The differences in average annual mean depth of water for each vegetation type are an approximation of the differences in elevation among the three types. The maximum and minimum over the period of record represent the extreme range of water levels over which they can be expected to persist, while the average annual maximum and minimum provide an approximation of what seasonal variation is characteristic of these vegetation types at Klamath Marsh.

One difference between Klamath Marsh and Upper Klamath and Agency lakes that may affect the extrapolation of hydroperiod data between the two locales is the difference in annual variation in water depth. The average annual variation in water depth at Klamath Marsh over the period of record is about 2 feet compared to an average of approximately 3.5 feet at Upper Klamath Lake over the same period. The data from the literature (Table 2) indicate that the common species in the lake marshes can tolerate the greater range of variation occurring in the lakes, but the difference in annual variation between the two marsh systems suggests that some caution should be exercised in applying vegetation-hydroperiods from Klamath Marsh to the lake marshes.

Table 3. Mean, maximum, and minimum water depths for vegetation types at Klamath Marsh (EA, 1994).

Dominant Species	Average Annual Mean Depth (ft)	Average Annual Max/Min (ft)	Long Term Max/Min (ft)
Nuphar polysepalum	2.52	3.54 1.69	5.42 0.64
Scirpus acutus	1.08	2.05 0.49	3.63 -0.39
Carex rostrata/ Juncus balticus	0.65	1.39 -0.30	3.10 -1.25

Potential Changes in Marsh Structure Due to Increases in Lake Water Level

For purposes of this study, only increases in water level are assessed, since only increases in lake level are being suggested to benefit catostomid and salmonid fish species. The effect of an increase in water level on vegetation depends on which parameter of water depth changes - mean, maximum or minimum. Each of these will be addressed separately.

The reference water levels used in this analysis for evaluating changes in marsh vegetation due to increases in lake water level are the average annual mean, maximum, and minimum over the 1906 to 1988 period of record. Although it could be argued that water levels for a more recent period would be more appropriate, the general stability of these marshes over the past 100 years and the desire to maintain marsh vegetation within

the range of historic variability suggests that the longer record is reasonable as a reference point.
Based on the data from Klamath Marsh, an increase in average annual mean depth of the lake greater than 0.5 feet (4,141.48 feet msl elevation) would likely lead to loss of sedge/rush communities and commensurate increase in bulrush (*Scirpus*), cattail, and burreed vegetation. Increase in average annual mean depth of greater than 1.5 feet (4,142.48 feet msl elevation) would likely lead to conversion of much emergent marsh dominated by bulrush, cattail, and burreed to yellow pond-lily and possibly to open water. Such an increase would also result in areas now dominated by yellow pond-lily becoming open water. Conversion of marshes to open water as a result of increases in water level have been well documented in lakes elsewhere (Farney and Bookhout, 1982; Van der Valk and Davis, 1980). It could take as long as ten years for these changes to occur, and would require at least 2 to 3 years (Harris and Marshall, 1963; Millar, 1973).

The depth and duration of maximum seasonal water level, rather than overall mean water depth, may in some cases be the most important factor controlling how far a species can extend into deeper water. Differences among vegetation types in average annual maximum water depth (Table 3) at Klamath Marsh were similar to differences in average annual mean water depth. Consequently, increases in average annual maximum water depth at Upper Klamath and Agency lake marshes in the same range as those just discussed for mean depth could be expected to have a similar effect on distribution of vegetation types: an increase in average annual maximum water level above 4,143.12 feet msl elevation resulting in a conversion of sedge/rush to bulrush, cattail, and burreed; and average annual maximum water levels above 4,144.12 feet msl elevation for conversion of emergent vegetation to pond-lily and open water.

An increase in minimum water depths would not be expected to have as much effect as changes in maximum water depths. Even yellow-pond-lily, the species that can survive in the deepest water depths among those considered here, can tolerate conditions where surface water has disappeared, as long as soils remain saturated. Some conversion of communities from lower on the depth gradient to those higher on the gradient (e.g. *Scirupus* to *Nuphar*) as a result in higher minimum water levels might be expected over time, however.

Potential Changes in Marsh Area Due to Increases in Water Level

As discussed above, an analysis of 1894, 1957, and 1985 USGS topographic maps indicates that the lake-marsh boundary of marshes around Upper Klamath and Agency lakes has been fairly stable over the past 100 years (except where marsh has been converted to agricultural land by diking and draining). This suggests that the total area of remaining marsh is not likely to change if lake levels are maintained within historic levels.

A decrease in total marsh area might be expected if lake level were to rise sufficiently high to convert substantial marsh area to open water. Some new areas of marshland could be created as a result of upland areas becoming newly inundated as a result of rising lake level. However, it is unlikely that this new area of marsh would be extensive, since the slope of the shoreline in most places around the lake has a steeper elevational gradient than the shallow margins around the lake where the marshes occur. In some cases these steeper gradients are the result of dike construction. Based on the measured hydroperiods of *Scirpus* and *Nuphar* from Klamath Marsh and other regions (Tables 2 and 3), a lake level increase of 1.5 to 2 feet from the historic average annual mean or maximum could be expected to result in an overall decrease in marsh area. In terms of actual lake level this corresponds to a range of 4,142.48 to 4,142.98 feet above msl for average annual mean water level and a range of 4,144.12 to 4144.62 feet above msl for average annual maximum water level.

Islands comprised primarily of marshland, such as those along the shoreline north of the mouth of the Williamson River into Agency Lake, could be converted to open water, with no creation of similar island habitat elsewhere. These islands appear to be relects of old marshland or artifacts of dredging activities associated with constructing dikes around the Williamson River delta. The vegetation of these islands was mapped as “tule” in an unpublished survey conducted by Oregon State University (Arc/INFO GIS database provided to R2 Resource Consultants by Klamath Tribes Natural Resources Department). Tule is often used as a common name for *Scirpus acutus,* although there is also a “bull rush” vegetation category in the Oregon State University data, which is also a common name for *Scirpus acutus*.

Assuming that these islands are primarily composed of *Scirpus acutus,* an increase in mean or maximum water levels of 1.5 feet or greater (4,142.48 and 4,144.12 feet msl elevation for average annual mean and maximum water levels) would likely result in their conversion to open water. That estimate, however, assumes that these *Scirpus* marshes are at the midpoint of their depth range. If they are actually toward the deeper end of the depth range for *Scirpus*, a smaller increase in water level could result in their conversion to open water. A more conservative estimate would be an increase in 1.0 foot (4,141.98 and 4,143.62 feet msl elevation for average annual mean and maximum water levels) to cause a conversion of these island marshes to open water. Yellow pond-lily would not be expected to establish in these areas due to the relatively exposed position along the open shoreline. The value of these islands to juvenile and larval fish (Klamath Tribes, 1991) suggests that their maintenance is an important consideration in evaluating effects of increased lake water levels on marsh fish habitat.

Conclusions: Effects of Increased Lake Level on Marsh Vegetation

From this analysis, it is apparent that increases in mean annual or maximum water level greater than 0.5 feet would likely lead to some changes in marsh plant communities. Increases of 1.5 feet in mean or maximum water level above historic levels would potentially lead to extensive conversion of emergent marsh plant communities to floating leaved types and to open water. Increases in minimum water levels would not be expected to have as strong an effect but could lead to some changes over time.

Stability of the lake-marsh boundary over the past 100 years suggests that conversion of marshland to open water is not likely to occur as long as lake levels are maintained within the range of historic levels. An increase in water level of 1.5 to 2.0 feet above the historic average annual mean or maximum could result in displacement of marsh vegetation shoreward, with an overall loss of marsh area. Artificial islands composed largely of *Scirpus* marsh near the mouth of the Williamson River and Agency Lake could be converted to open water with increases of 1.0 feet or greater.

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APPENDIX B

Photographs Depicting Klamath Lake Fish Sampling Sites and Methods

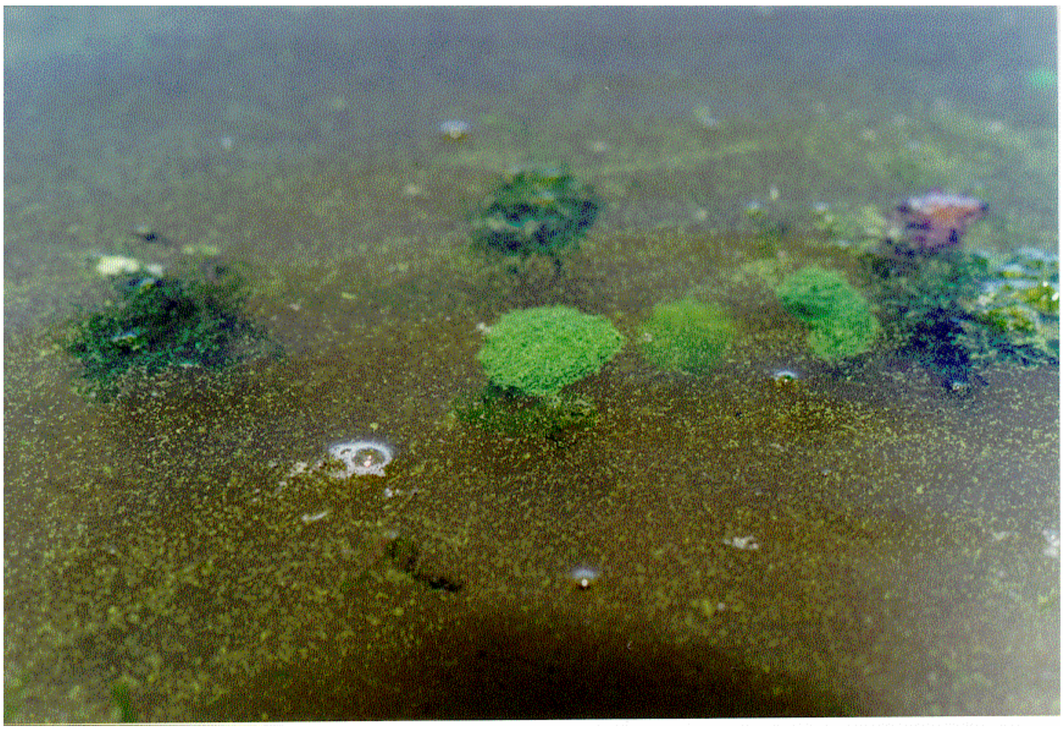


Figure B1. Algae (*Aphanizomenon flos-aqu*ae) clusters within Upper Klamath Lake, August 21, 1998.

Figure B2. Photo showing measurement of water quality parameters (dissolved oxygen, pH, conductivity, and temperature) in Upper Klamath Lake, August 21, 1998.

Figure B3. Emergent vegetation along shoreline areas of Upper Klamath Lake, near Goose Bay, July 29, 1998.

Figure B4. Dip netting for juvenile fish within emergent vegetation zones in Upper Klamath Lake, near Goose Bay, July 29, 1998.

Figure B5. Twin-bongo nets used for sampling larval fishes in Upper Klamath Lake, Oregon, during June 1999 surveys. Nets being readied for deployment.

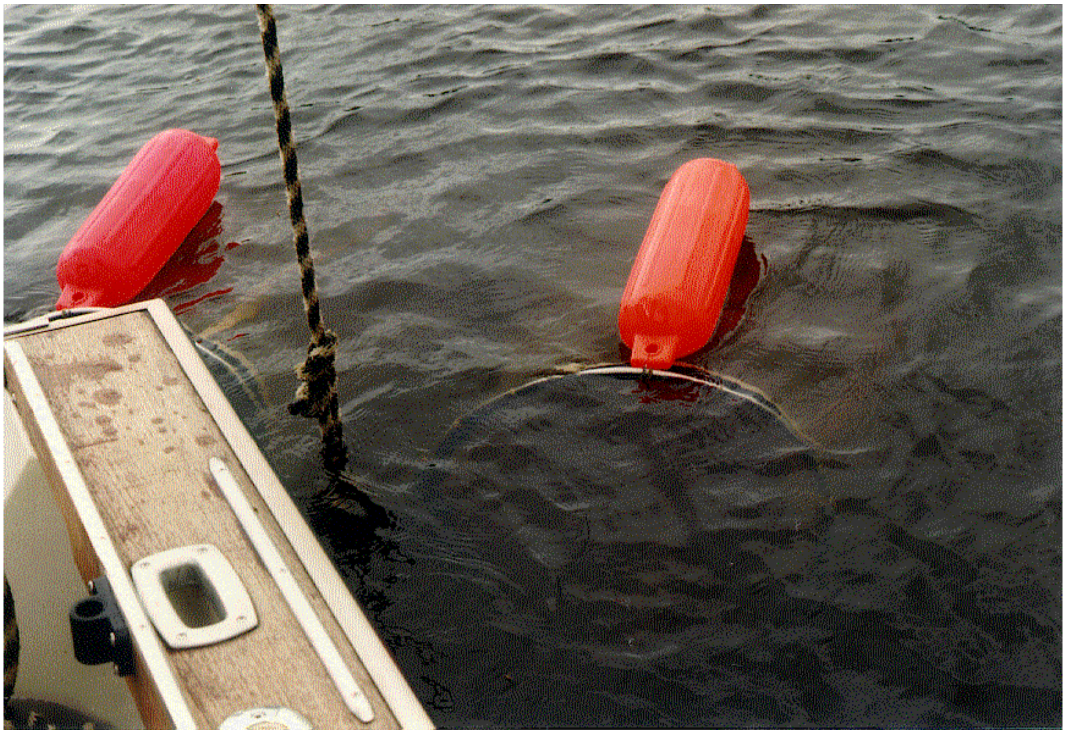


Figure B6. Recovery of twin-bongo nets, as collected in Upper Klamath Lake, Oregon, near mouth of the Williamson River, during June 1999 surveys.

Figure B7. Representative sample of plankton from nets, as collected in Upper Klamath Lake, Oregon, near mouth of the Williamson River, during June 1999.

Figure B8. Baited minnow traps deployed in littoral habitats in Upper Klamath Lake, Oregon, near Goose Bay, June 1999.

Figure B9. Pop nets deployed adjacent to emergent vegetation in Upper Klamath Lake, Oregon, near Goose Bay, June 1999.

Figure B10. Pop nets deployed in open water in Upper Klamath Lake, Oregon, near Goose Bay, June 1999.

Figure B11. Representative fishes captured in Upper Klamath Lake, Oregon during seine hauls near Goose Bay, June 1999.

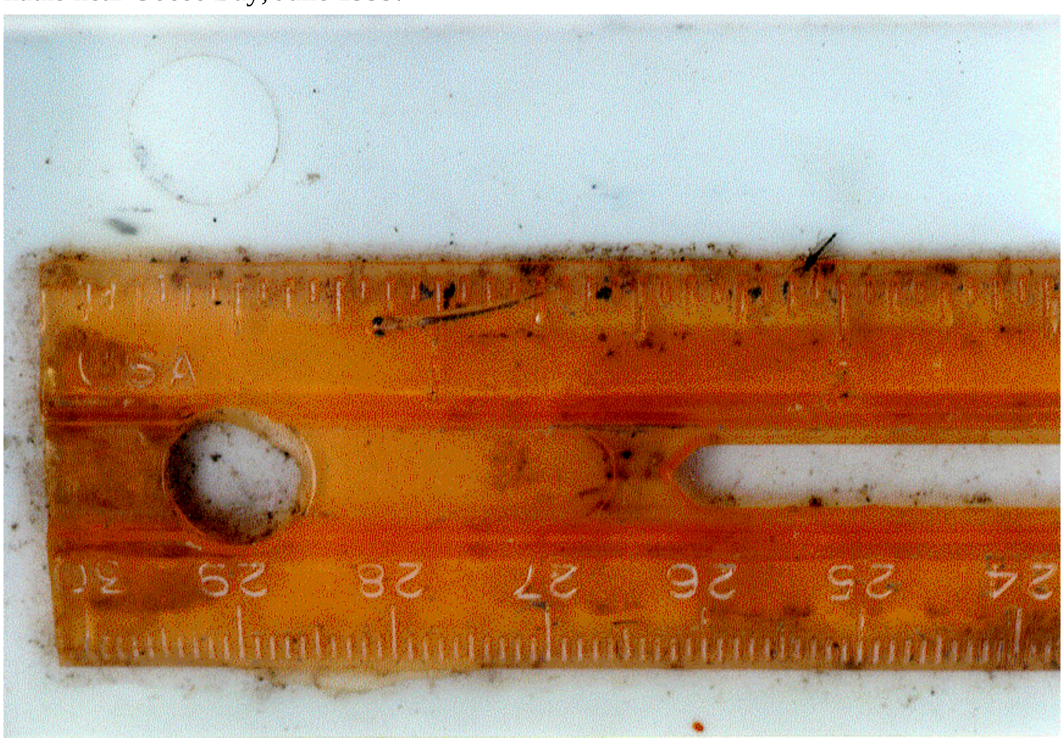


Figure B12. Larval fish collected in bongo nets near mouth of Williamson River, June 1999.

Figure B13. Representative view at outlet of Ouxy Springs within Upper Klamath Lake, Oregon, taken in July 1998.

Figure B14. Representative view at outlet of Ouxy Springs within Upper Klamath Lake, Oregon, taken in October 1998.

Figure B15. Representative views of Sucker Springs within Upper Klamath Lake, Oregon, showing exposed shoreline areas and gravels as depicted in July 1998.

Figure B16. Representative views of Sucker Springs within Upper Klamath Lake, Oregon, showing exposed shoreline areas and gravels as depicted in October 1998.

Figure B17. Gravels used for spawning by suckers in Upper Klamath Lake, Oregon.

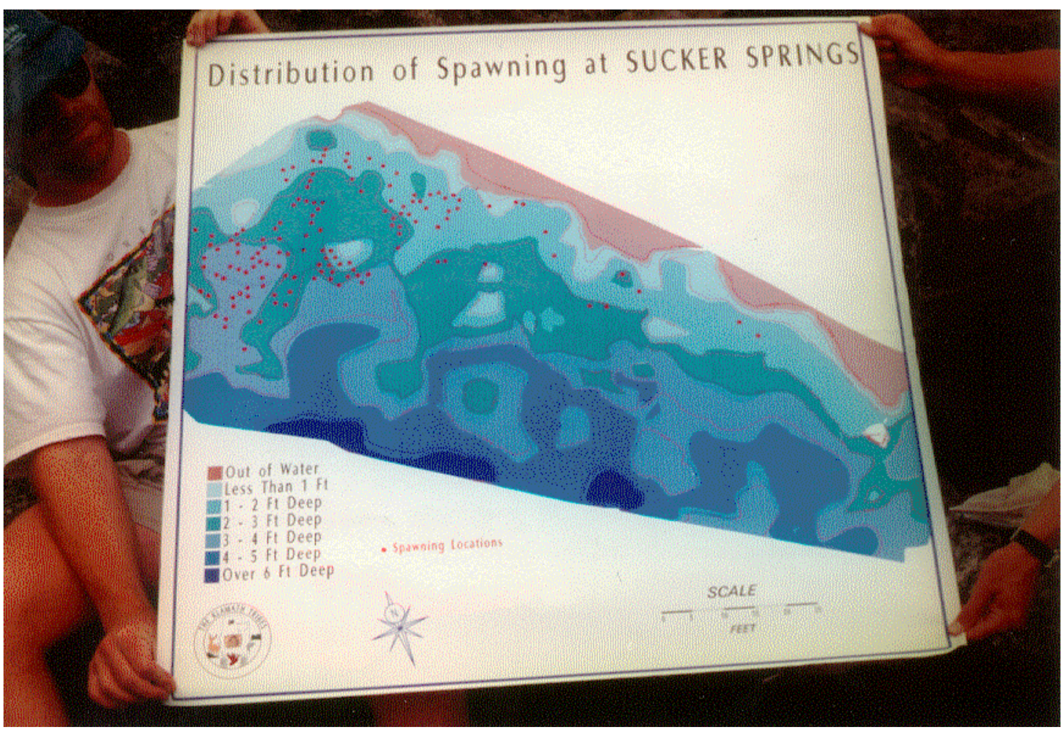


Figure B18. Map depicting distribution of known sucker spawning areas within Sucker Springs.

Figure B19. Representative view of Odessa Creek, Oregon, mid-channel, August 21, 1998.

Figure B20. Representative view of Odessa Creek, Oregon, near mouth adjacent to wocus, August 21, 1998.

Figure B21. Representative view of shoreline areas in Upper Klamath Lake Oregon, near Goose Bay, August 20, 1998.

Figure B22. Representative view of shoreline areas in Upper Klamath Lake Oregon, near Goose Bay, August 20, 1998.

Figure B23. Representative view of shoreline areas in Upper Klamath Lake, Oregon, near Goose Bay, October 19, 2000; note shoreline vegetation and water disconnect.

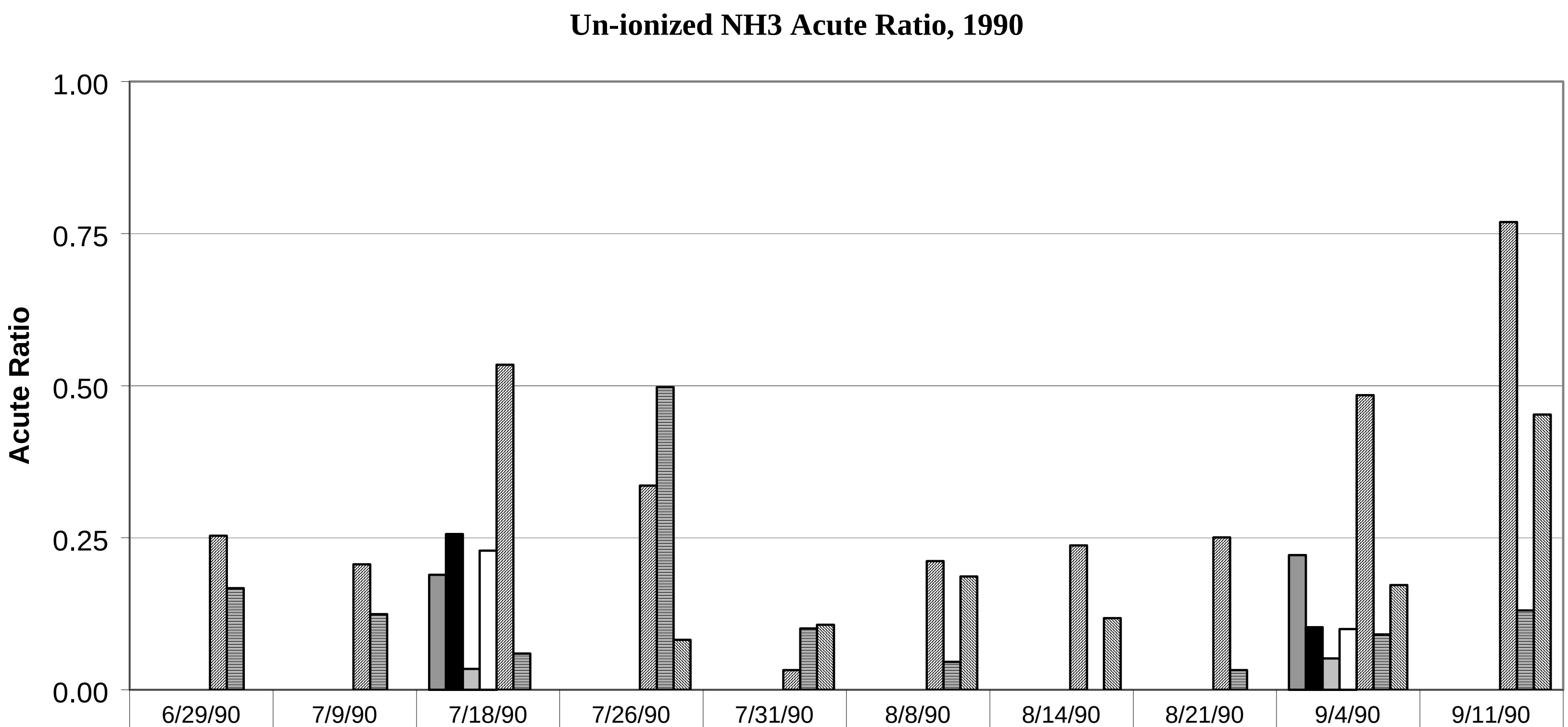
Figure B24. Representative view of shoreline areas in Upper Klamath Lake, Oregon, near Goose Bay, October 19, 2000; note disconnection of water level and shoreline vegetation.

Figure B25. Exposed shoreline vegetation within lower Williamson River, near mouth, October 2000.

Figure B26. View of Sucker Springs, Upper Klamath Lake, Oregon October 2000.

APPENDIX C

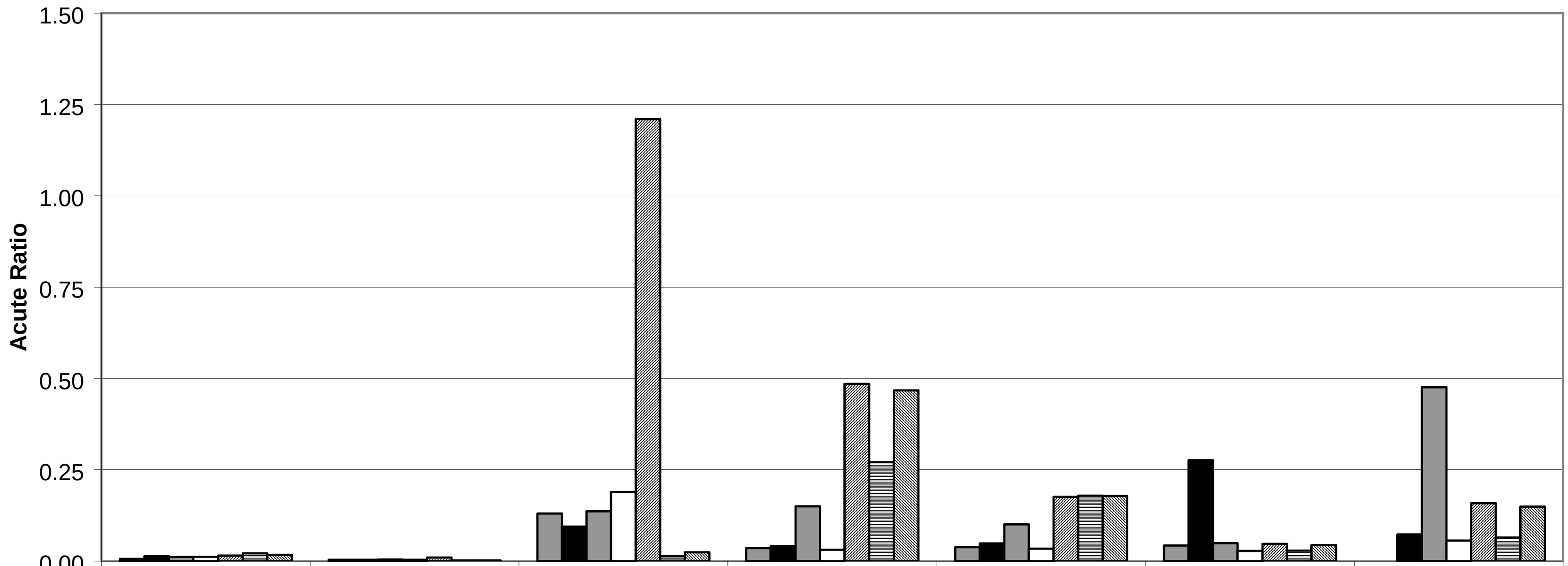
Figures Supporting Chapter 6



	6/29/90	7/9/90	7/18/90	7/26/90	7/31/90	8/8/90	8/14/90	8/21/90	9/4/90	9/11/90
PM			0.19						0.22	
NB			0.26						0.10	
WB			0.03						0.05	
ML			0.23						0.10	
ER	0.25	0.21	0.53	0.34	0.03	0.21	0.24	0.25	0.48	0.77
MN	0.17	0.12	0.06	0.50	0.10	0.05		0.03	0.09	0.13
SB				0.08	0.11	0.19	0.12		0.17	0.45

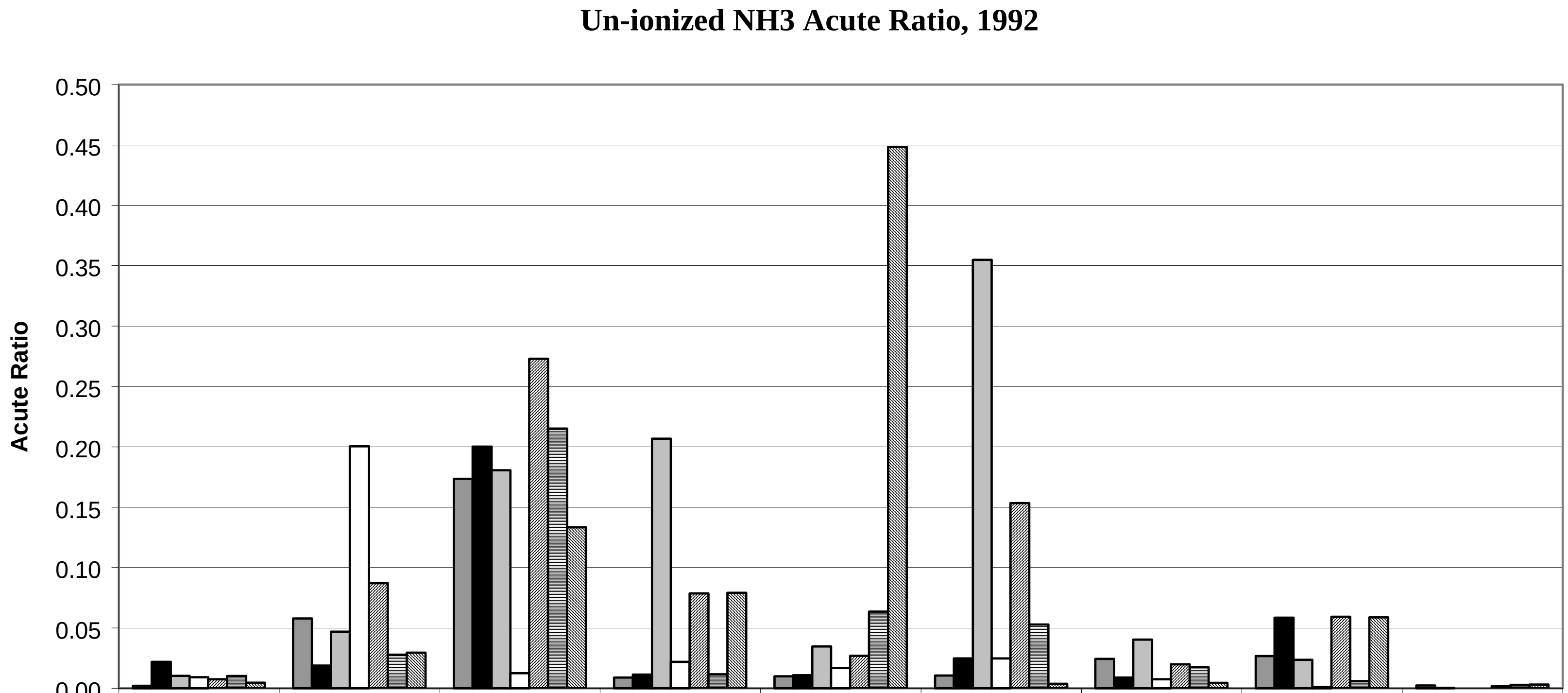
Figure C-1. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1990 in Upper Klamath Lake.

Un-ionized NH3 Acute Ratio, 1991



	4/30/91	6/5/91	7/1/91	7/17/91	8/1/91	8/14/91	9/11/91
PM	0.01	0.00	0.13	0.04	0.04	0.04	
NB	0.01	0.00	0.09	0.04	0.05	0.28	0.07
WB	0.01	0.00	0.14	0.15	0.10	0.05	0.48
ML	0.01	0.00	0.19	0.03	0.03	0.03	0.06
ER	0.02	0.01	1.21	0.49	0.18	0.05	0.16
MN	0.02	0.00	0.01	0.27	0.18	0.03	0.06
SB	0.02	0.00	0.02	0.47	0.18	0.04	0.15

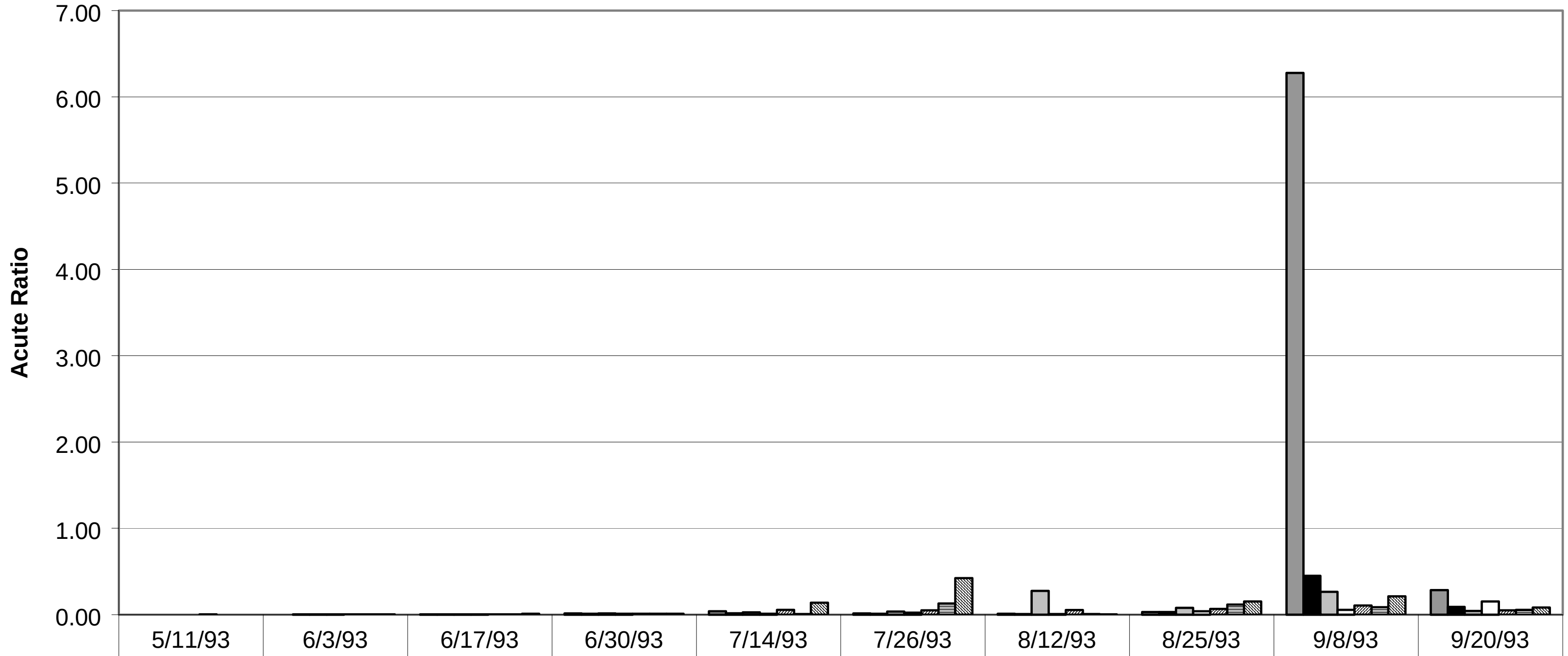
Figure C-2. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1991 in Upper Klamath Lake.



	5/20/92	6/3/92	6/17/92	7/2/92	7/14/92	7/29/92	8/13/92	8/26/92	9/22/92
PM	0.00	0.06	0.17	0.01	0.01	0.01	0.02	0.03	0.00
NB	0.02	0.02	0.20	0.01	0.01	0.02	0.01	0.06	0.00
WB	0.01	0.05	0.18	0.21	0.03	0.35	0.04	0.02	
ML	0.01	0.20	0.01	0.02	0.02	0.02	0.01	0.00	
ER	0.01	0.09	0.27	0.08	0.03	0.15	0.02	0.06	0.00
MN	0.01	0.03	0.21	0.01	0.06	0.05	0.02	0.01	0.00
SB	0.00	0.03	0.13	0.08	0.45	0.00	0.00	0.06	0.00

Figure C-3. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1992 in Upper Klamath Lake.

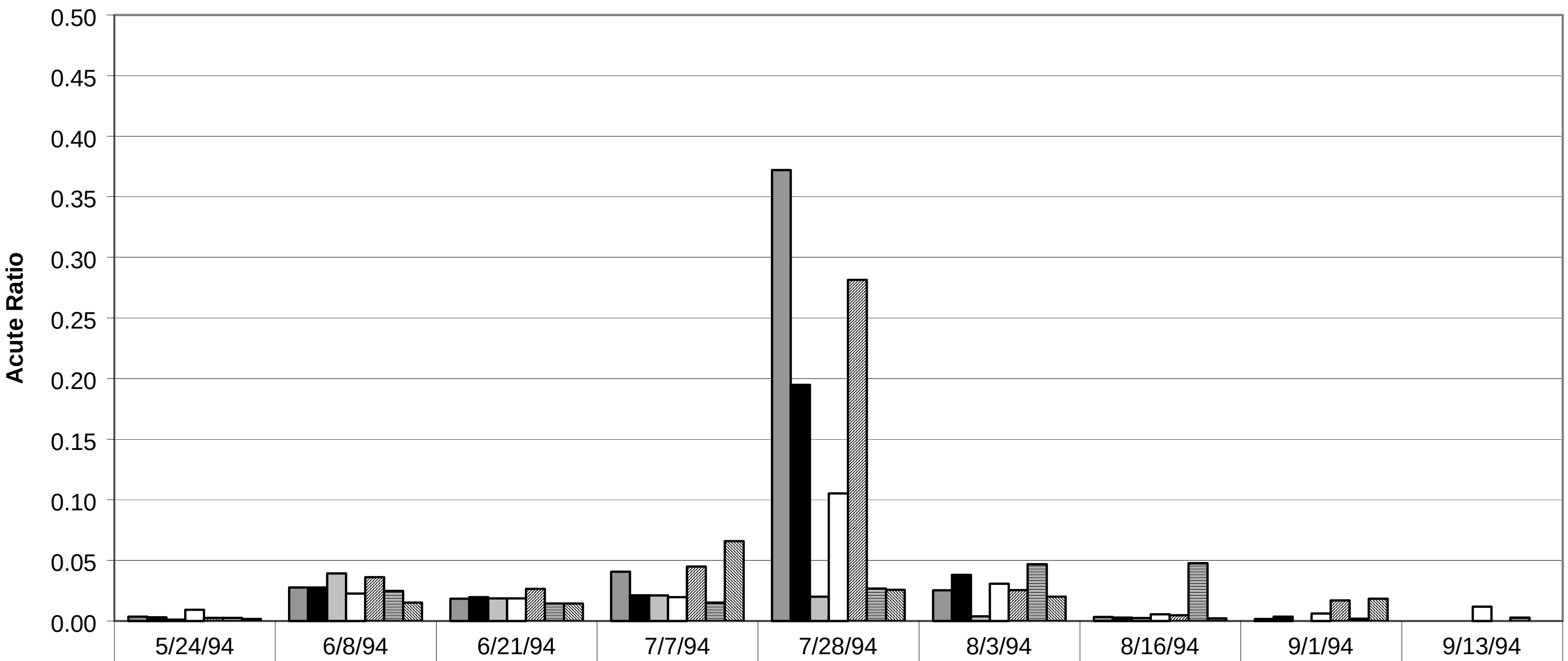
Un-ionized NH3 Acute Ratio, 1993



	5/11/93	6/3/93	6/17/93	6/30/93	7/14/93	7/26/93	8/12/93	8/25/93	9/8/93	9/20/93
PM	0.00	0.00	0.00	0.01	0.04	0.01	0.01	0.03	6.28	0.29
NB	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.03	0.45	0.09
WB	0.00	0.00	0.00	0.01	0.03	0.04	0.27	0.08	0.27	0.04
ML	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.04	0.06	0.15
ER	0.00	0.00	0.00	0.01	0.06	0.05	0.05	0.06	0.10	0.05
MN	0.00	0.00	0.00	0.01	0.01	0.13	0.01	0.12	0.09	0.06
SB	0.00	0.00	0.01	0.01	0.14	0.42	0.00	0.15	0.21	0.08

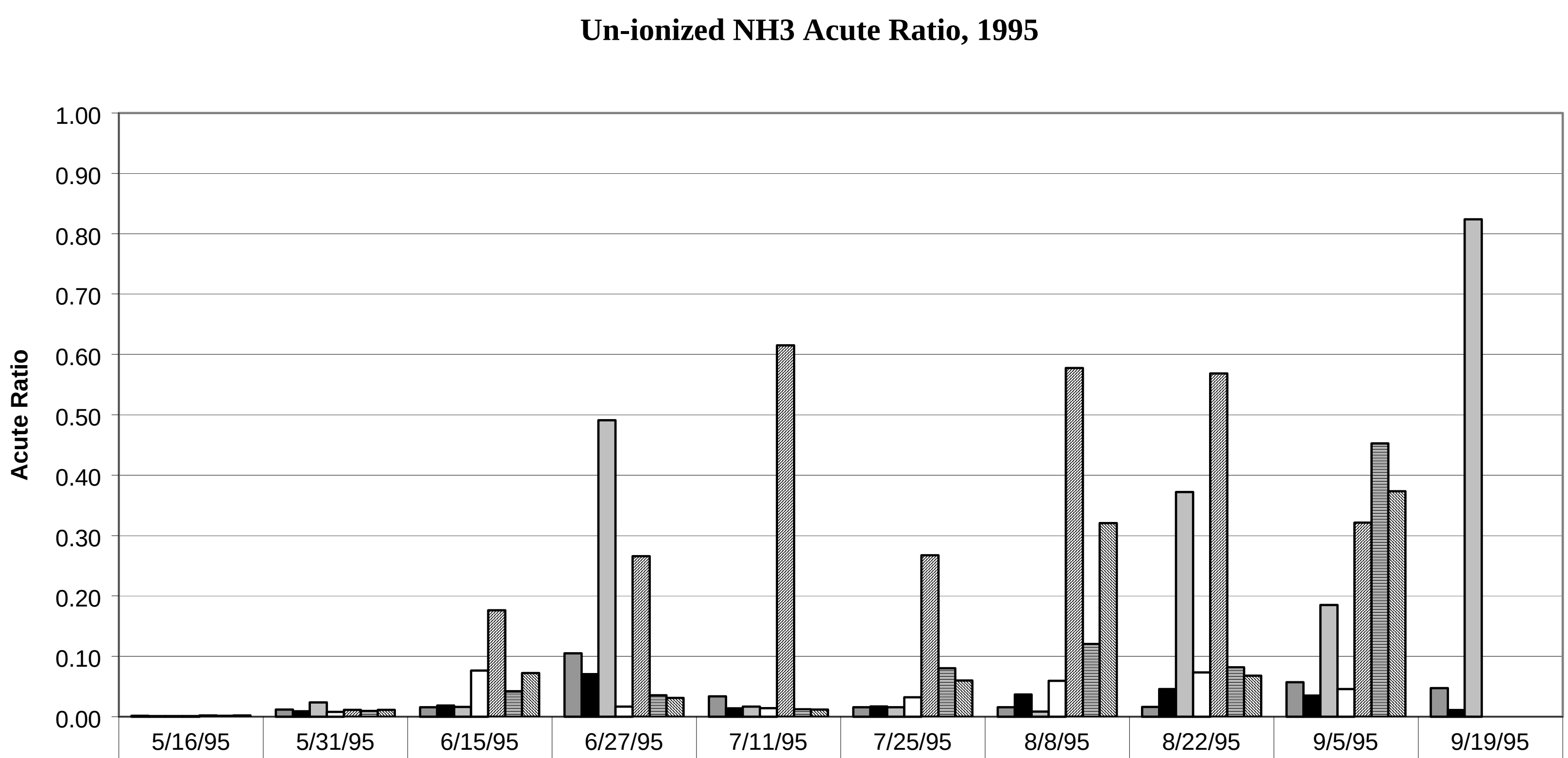
Figure C-4. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1993 in Upper Klamath Lake.

Un-ionized NH3 Acute Ratio, 1994



	5/24/94	6/8/94	6/21/94	7/7/94	7/28/94	8/3/94	8/16/94	9/1/94	9/13/94
PM	0.00	0.03	0.02	0.04	0.37	0.03	0.00	0.00	
NB	0.00	0.03	0.02	0.02	0.19	0.04	0.00	0.00	
WB	0.00	0.04	0.02	0.02	0.02	0.00	0.00		
ML	0.01	0.02	0.02	0.02	0.11	0.03	0.01	0.01	0.01
ER	0.00	0.04	0.03	0.04	0.28	0.03	0.00	0.02	
MN	0.00	0.02	0.01	0.02	0.03	0.05	0.05	0.00	0.00
SB	0.00	0.02	0.01	0.07	0.03	0.02	0.00	0.02	

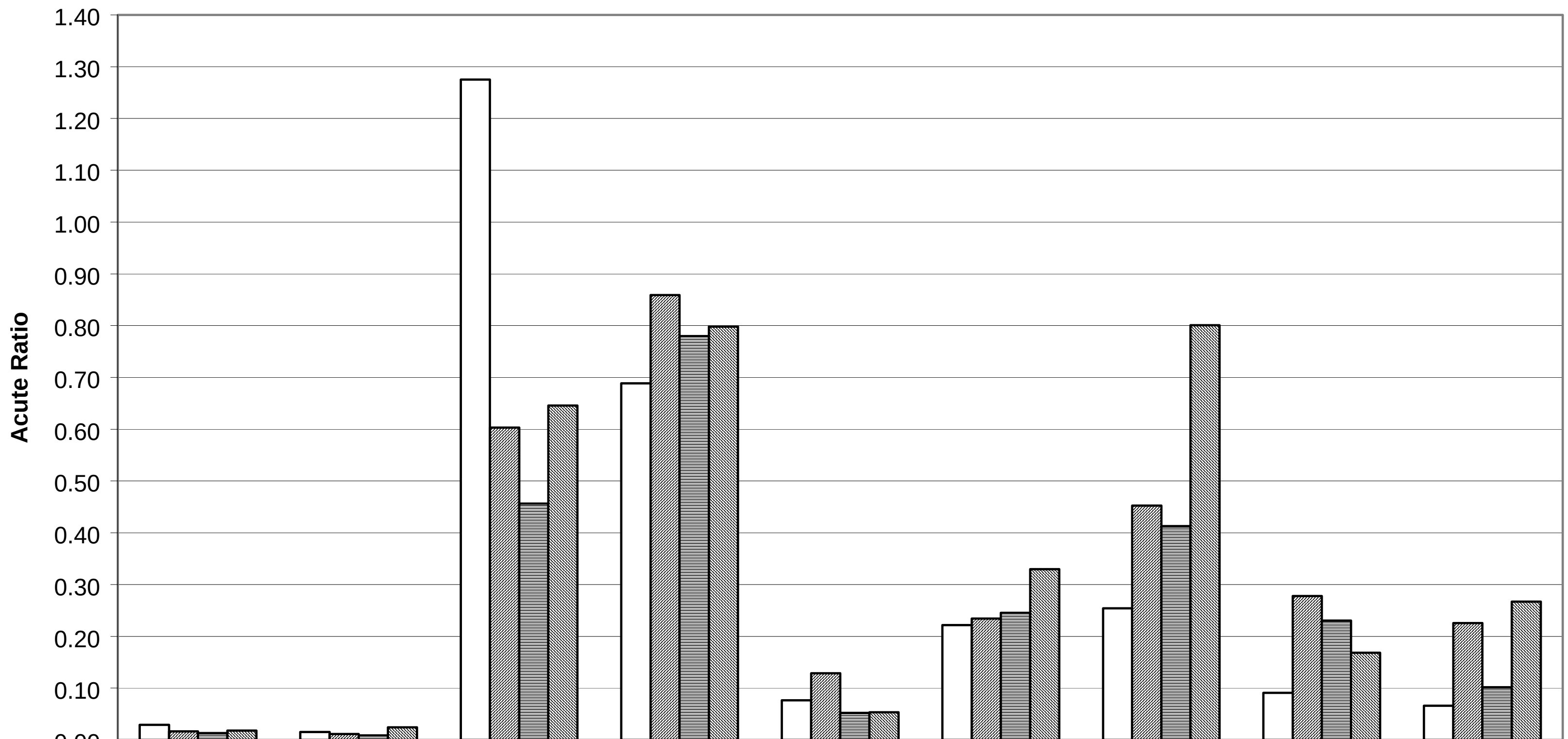
Figure C-5. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1994 in Upper Klamath Lake.



	5/16/95	5/31/95	6/15/95	6/27/95	7/11/95	7/25/95	8/8/95	8/22/95	9/5/95	9/19/95
PM	0.00	0.01	0.02	0.11	0.03	0.02	0.02	0.02	0.06	0.05
NB	0.00	0.01	0.02	0.07	0.01	0.02	0.04	0.05	0.04	0.01
WB	0.00	0.02	0.02	0.49	0.02	0.02	0.01	0.37	0.18	0.82
ML	0.00	0.01	0.08	0.02	0.01	0.03	0.06	0.07	0.05	
ER	0.00	0.01	0.18	0.27	0.62	0.27	0.58	0.57	0.32	
MN	0.00	0.01	0.04	0.04	0.01	0.08	0.12	0.08	0.45	
SB	0.00	0.01	0.07	0.03	0.01	0.06	0.32	0.07	0.37	

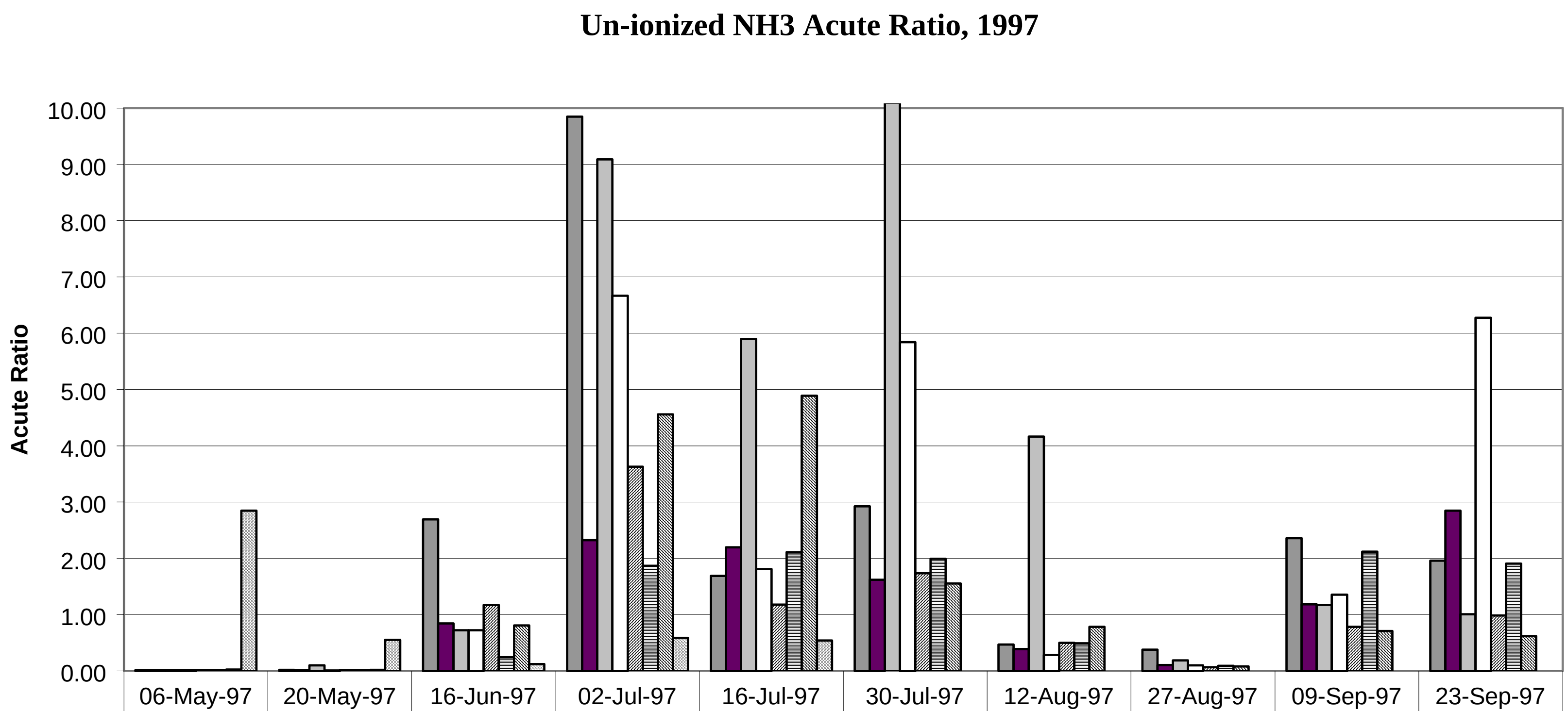
Figure C-6. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1995 in Upper Klamath Lake.

Un-ionized NH3 Acute Ratio, 1996



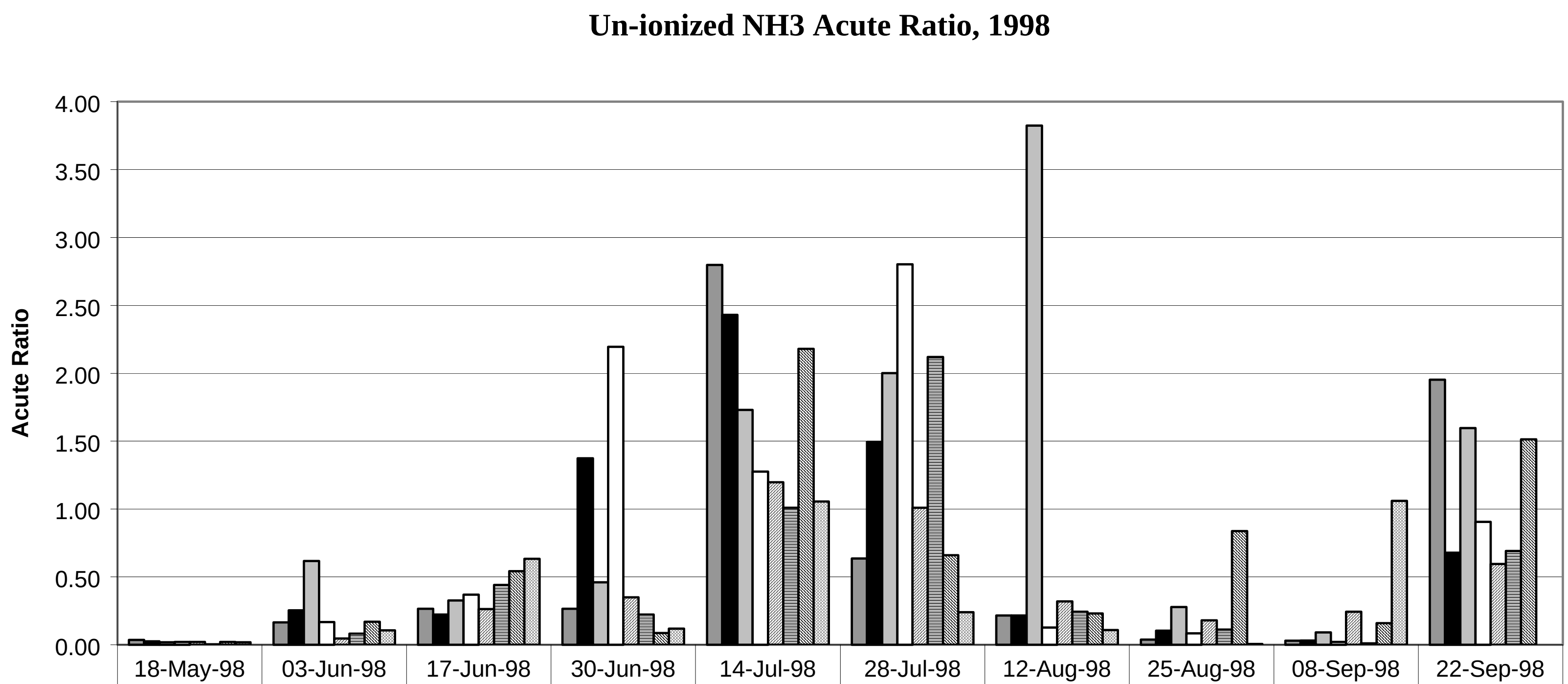
	29-May-96	11-Jun-96	24-Jun-96	08-Jul-96	24-Jul-96	06-Aug-96	20-Aug-96	04-Sep-96	16-Sep-96
ML	0.03	0.02	1.27	0.69	0.08	0.22	0.25	0.09	0.07
ER	0.02	0.01	0.60	0.86	0.13	0.23	0.45	0.28	0.23
MN	0.01	0.01	0.46	0.78	0.05	0.25	0.41	0.23	0.10
SB	0.02	0.02	0.65	0.80	0.05	0.33	0.80	0.17	0.27

Figure C-7. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1996 in Upper Klamath Lake.



	06-May-97	20-May-97	16-Jun-97	02-Jul-97	16-Jul-97	30-Jul-97	12-Aug-97	27-Aug-97	09-Sep-97	23-Sep-97
PM	0.01	0.02	2.69	9.85	1.69	2.92	0.47	0.38	2.36	1.96
NB	0.01	0.01	0.84	2.32	2.20	1.62	0.39	0.11	1.19	2.85
WB	0.02	0.10	0.72	9.09	5.90	10.10	4.16	0.19	1.18	1.01
ML	0.02	0.01	0.72	6.67	1.81	5.84	0.29	0.10	1.36	6.27
ER	0.01	0.02	1.18	3.63	1.18	1.74	0.50	0.07	0.79	0.98
MN	0.02	0.02	0.24	1.87	2.11	1.99	0.49	0.09	2.12	1.91
SB	0.02	0.02	0.81	4.56	4.89	1.55	0.78	0.08	0.71	0.62
CP	2.85	0.55	0.12	0.59	0.54					

Figure C-8. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1997 in Upper Klamath Lake.



	18-May-98	03-Jun-98	17-Jun-98	30-Jun-98	14-Jul-98	28-Jul-98	12-Aug-98	25-Aug-98	08-Sep-98	22-Sep-98
PM	0.04	0.16	0.26	0.27	2.80	0.64	0.22	0.04	0.03	1.95
NB	0.02	0.25	0.22	1.37	2.43	1.49	0.22	0.10	0.03	0.68
WB	0.02	0.62	0.33	0.46	1.73	2.00	3.82	0.28	0.09	1.60
ML	0.02	0.17	0.37	2.19	1.28	2.80	0.13	0.09	0.02	0.91
ER	0.02	0.05	0.26	0.35	1.20	1.01	0.32	0.18	0.24	0.60
MN	0.01	0.08	0.44	0.22	1.01	2.12	0.24	0.11	0.01	0.69
SB	0.02	0.17	0.54	0.09	2.18	0.66	0.23	0.84	0.16	1.51
CP	0.02	0.11	0.63	0.12	1.06	0.24	0.11	0.01	1.06	

Figure C-9. Acute ratio of un-ionized ammonia at Klamath Tribes sampling locations 1998 in Upper Klamath Lake.

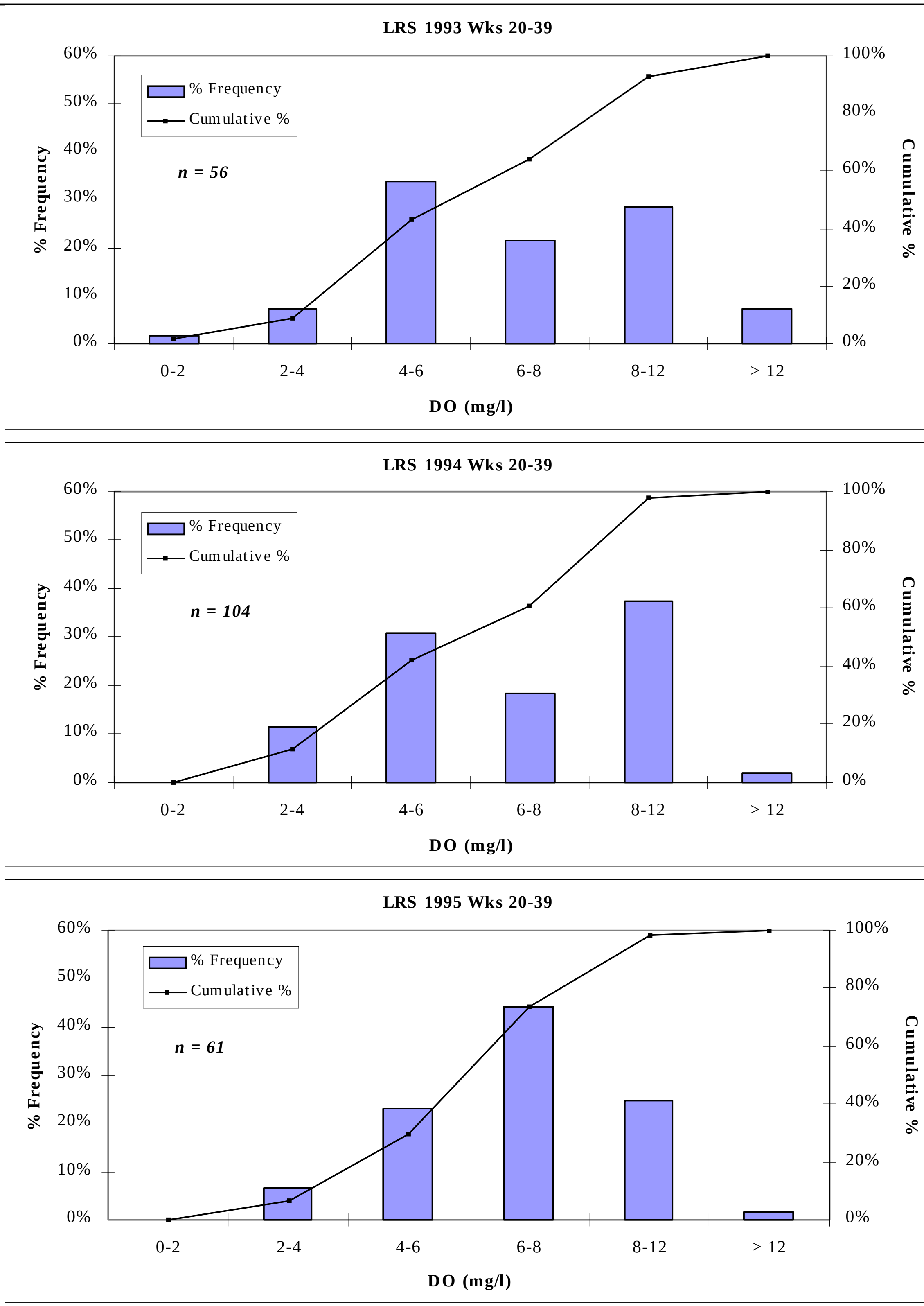


Figure C-10. Percent frequency and cumulative percent distributions of adult Lost River sucker exposures to bottom-water dissolved oxygen concentration intervals in Upper Klamath Lake north of Bare Island, May –September, 1993-1995.

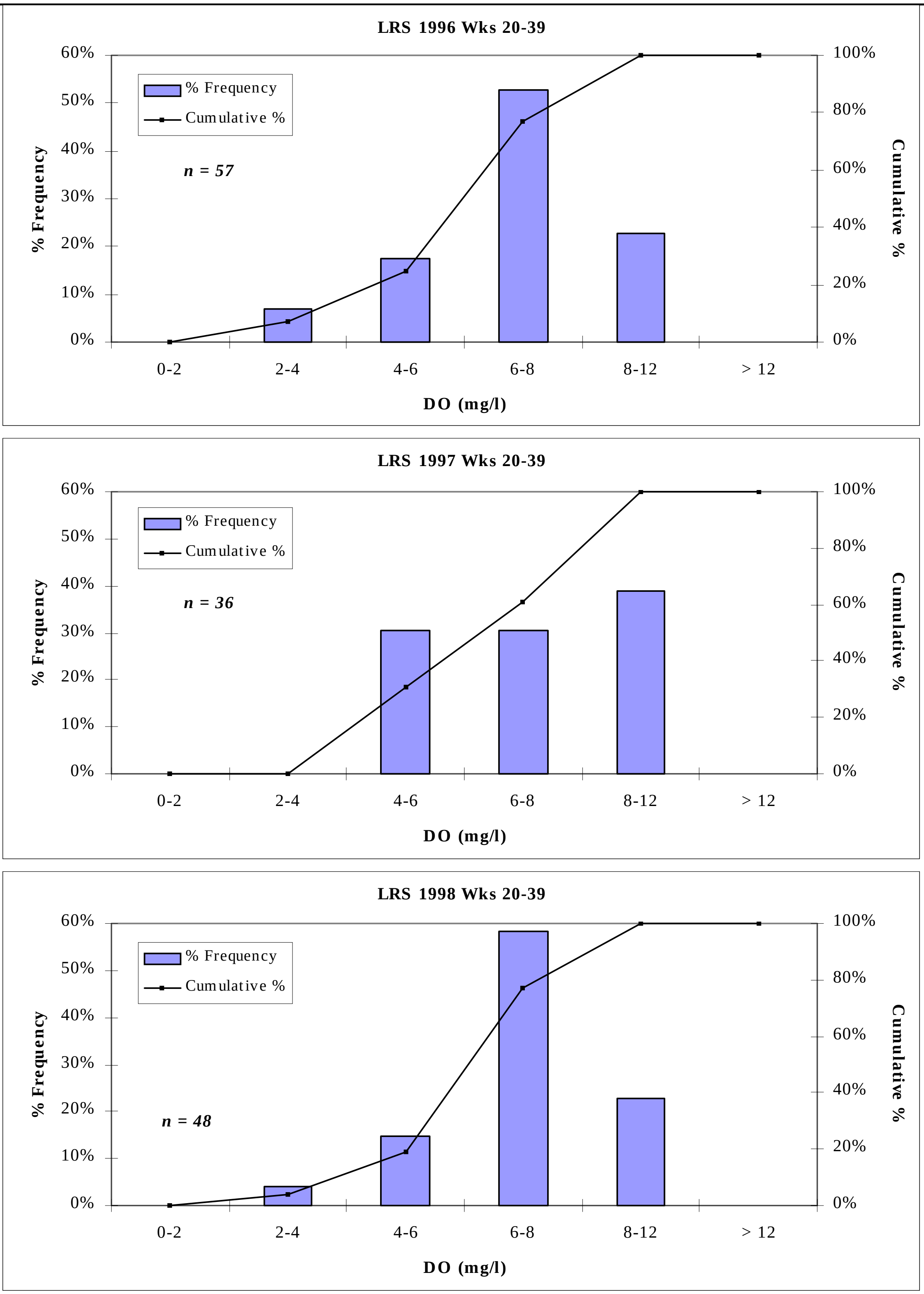
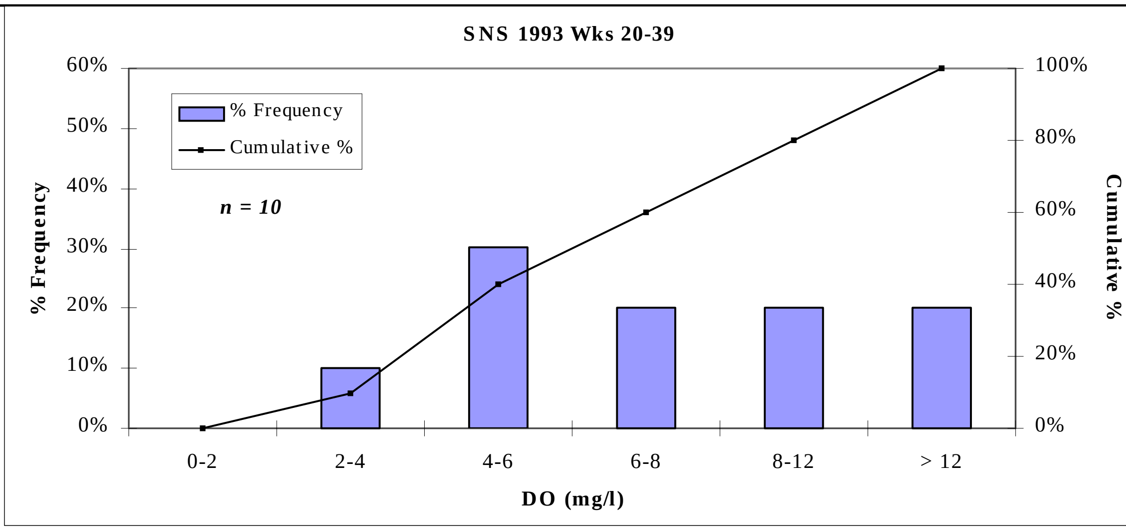
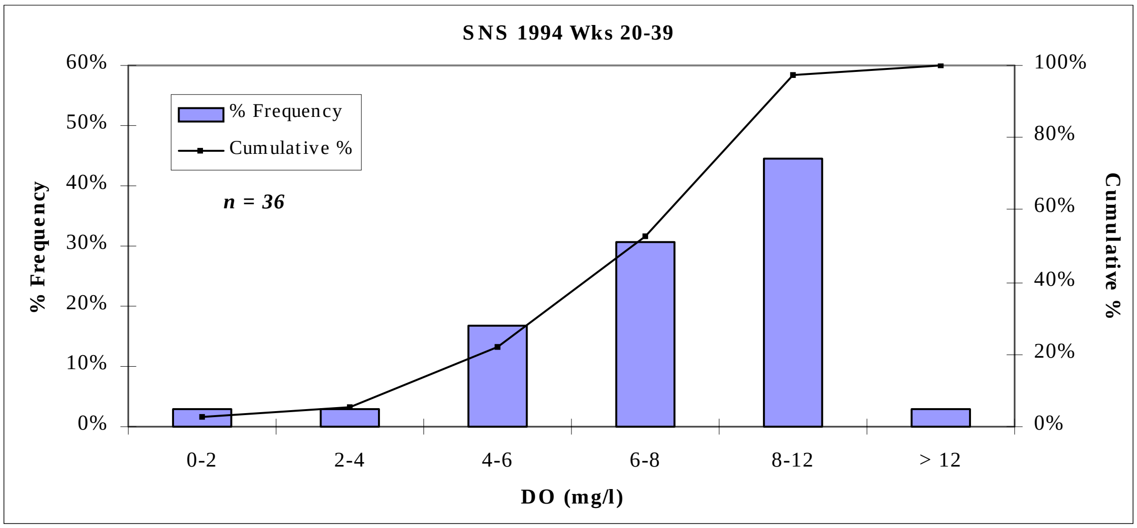


Figure C-11. Percent frequency and cumulative percent distributions of adult Lost River sucker exposures to bottom-water dissolved oxygen concentration intervals in Upper Klamath Lake north of Bare Island, May –September, 1996-1998.





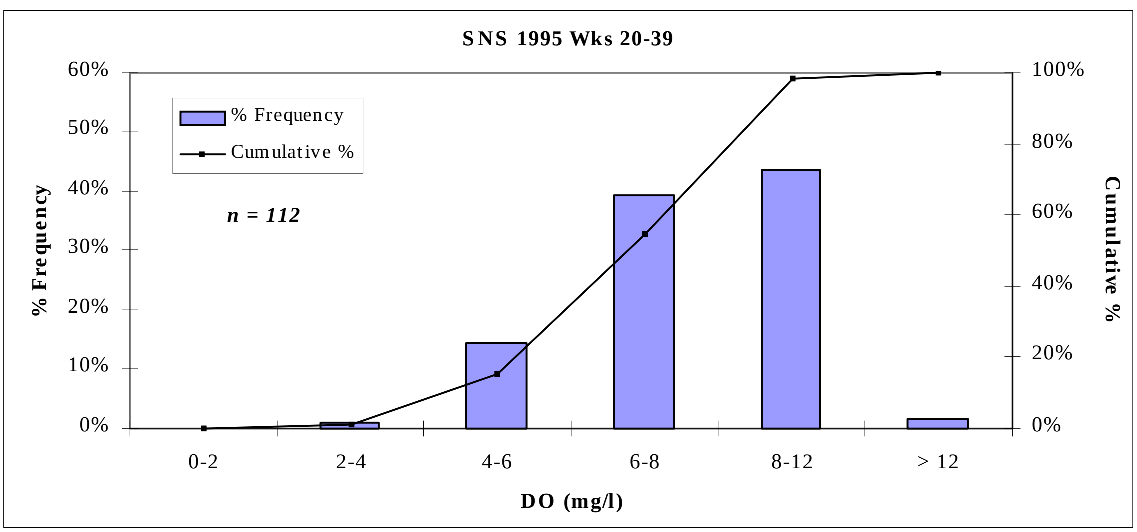


Figure C-12. Percent frequency and cumulative percent distributions of adult Shortnose sucker exposures to bottom-water dissolved oxygen concentration intervals in Upper Klamath Lake north of Bare Island, May –September, 1993-1995.

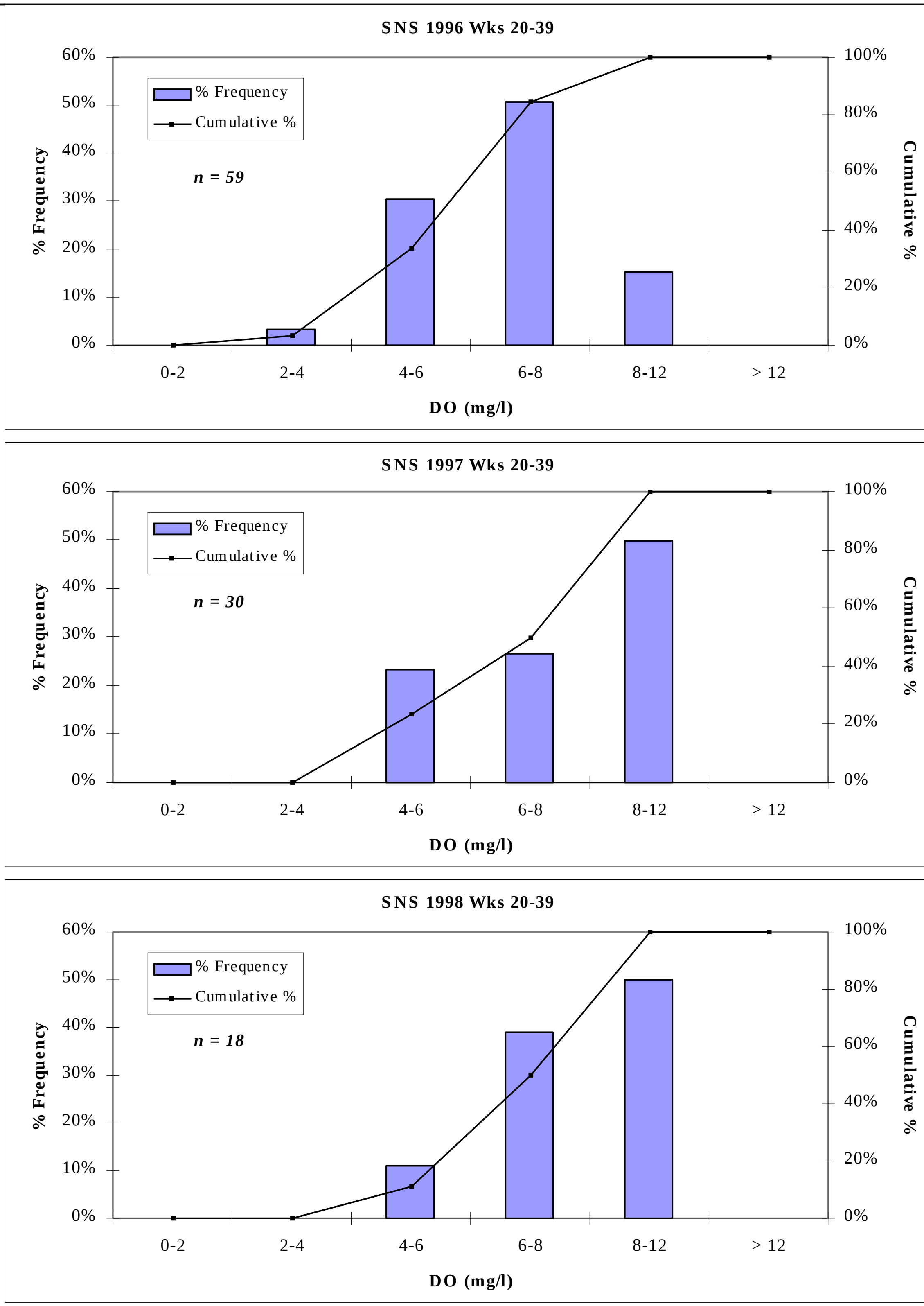


Figure C-13. Percent frequency and cumulative percent distributions of adult Shortnose sucker exposures to bottom-water dissolved oxygen concentration intervals in Upper Klamath Lake north of Bare Island, May –September, 1996-1998.

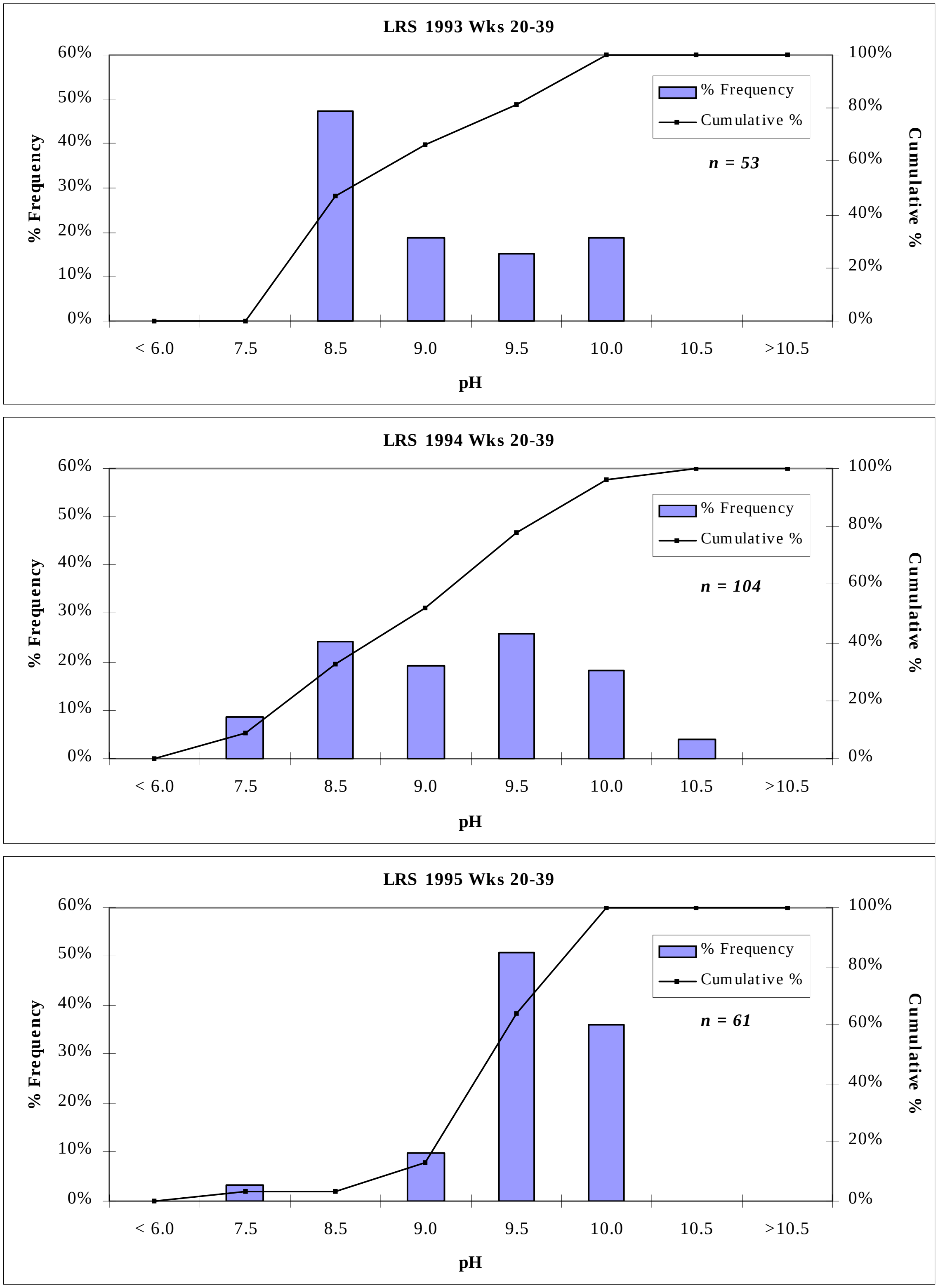


Figure C-14. Percent frequency and cumulative percent distributions of adult Lost River sucker exposures to pH level categories in Upper Klamath Lake bottom-water, north of Bare Island, May –September, 1993-1995.

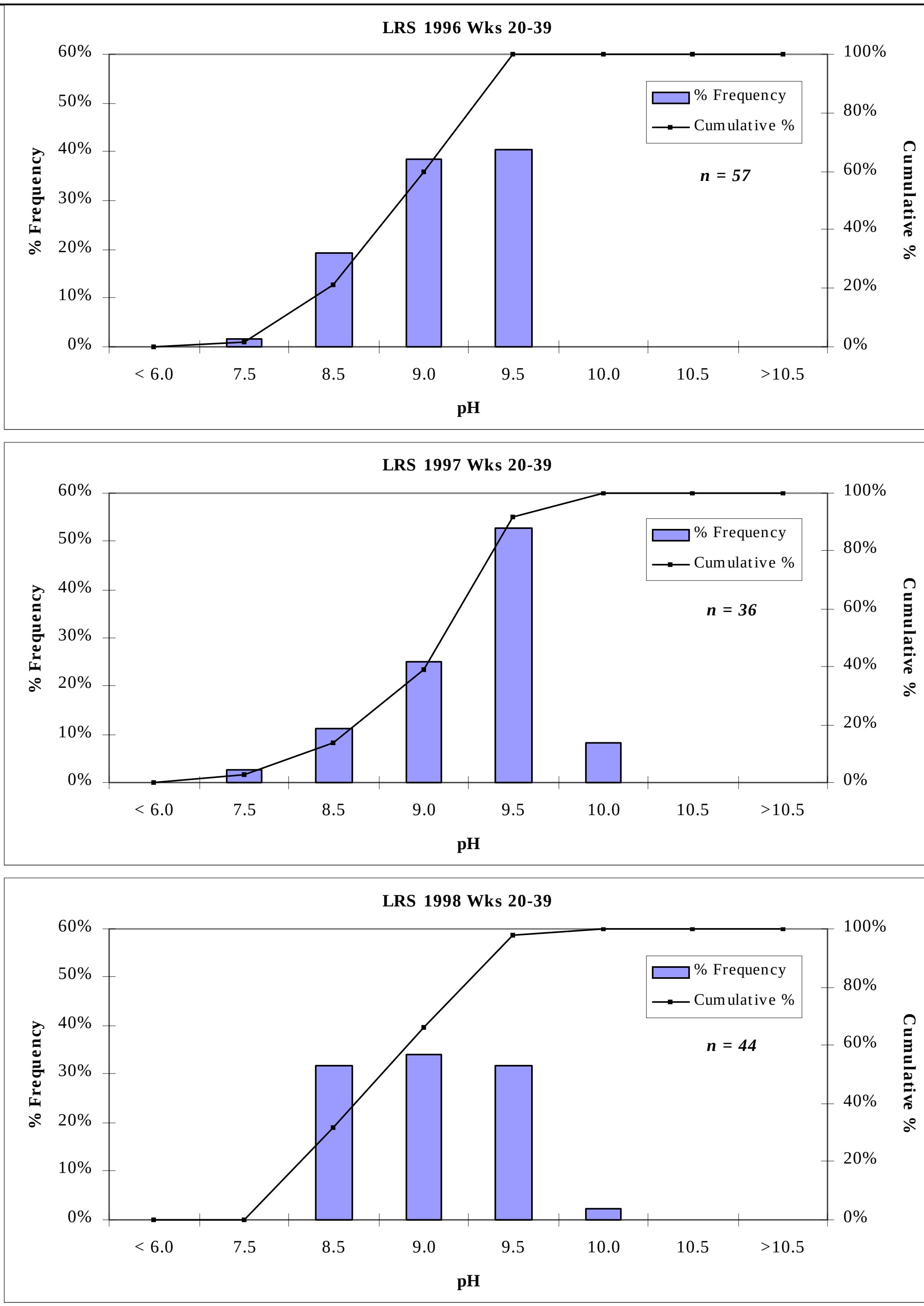


Figure C-15. Percent frequency and cumulative percent distributions of adult Lost River sucker exposures to pH level categories in Upper Klamath Lake bottom-water, north of Bare Island, May –September, 1996-1998.

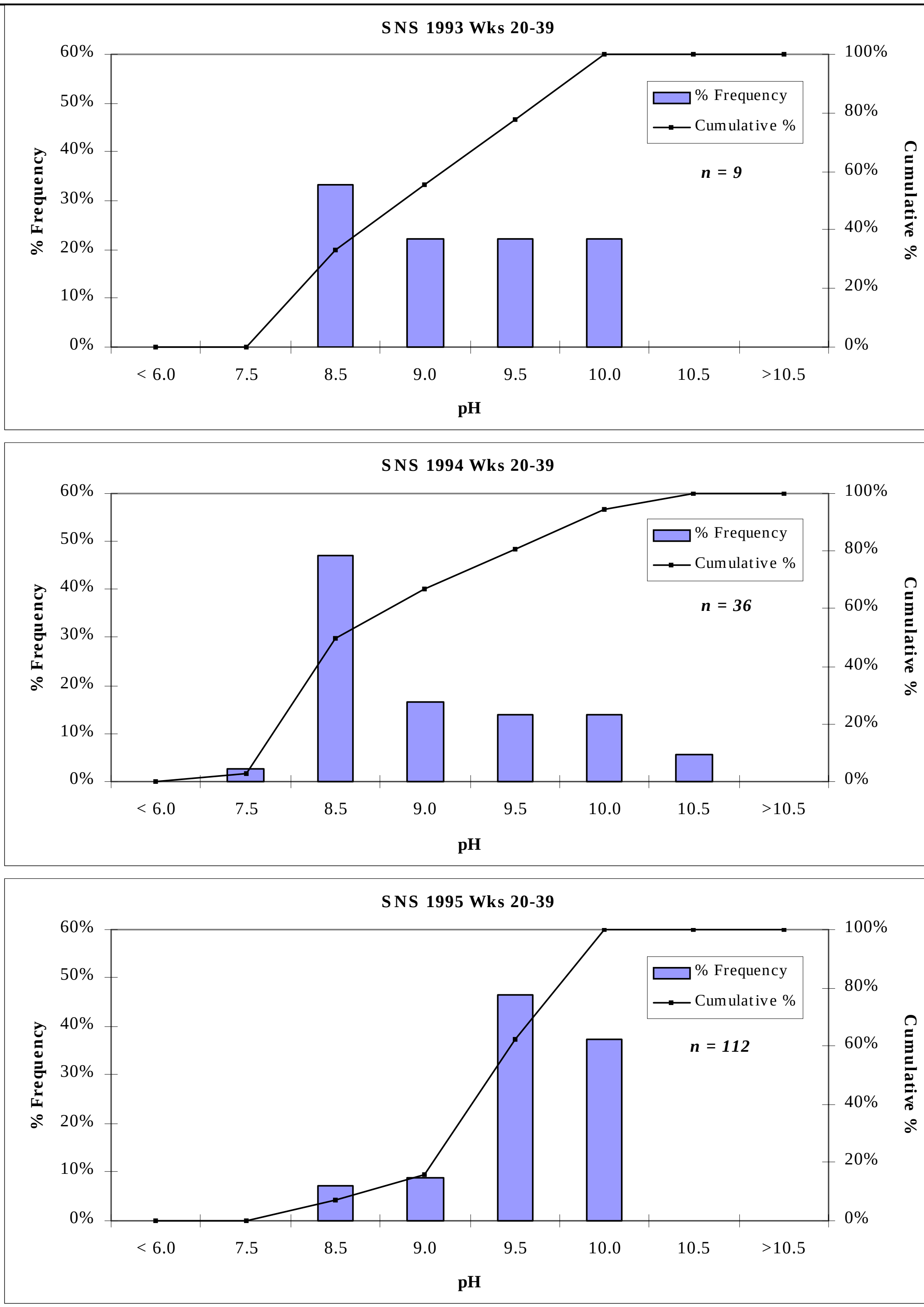
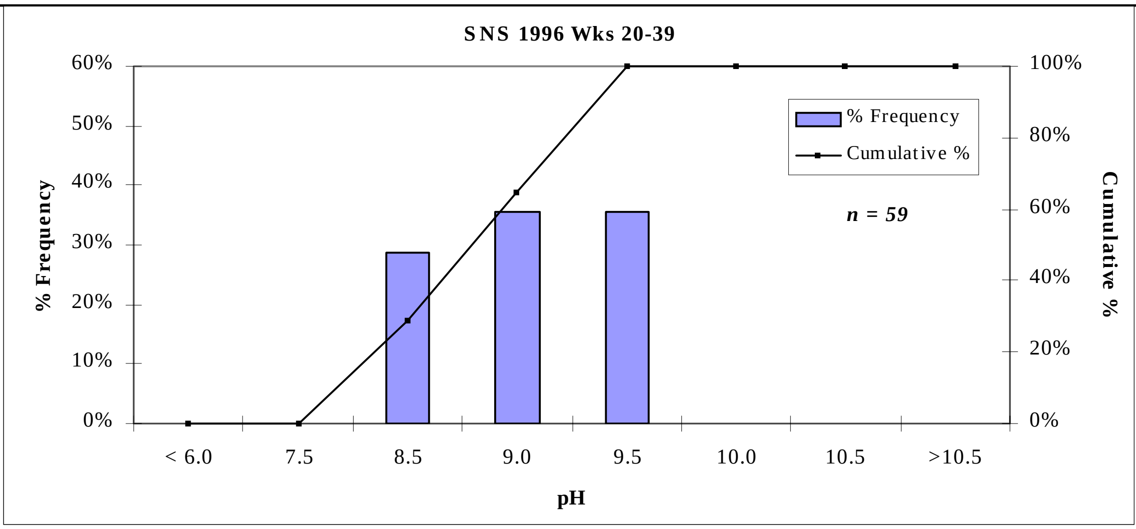
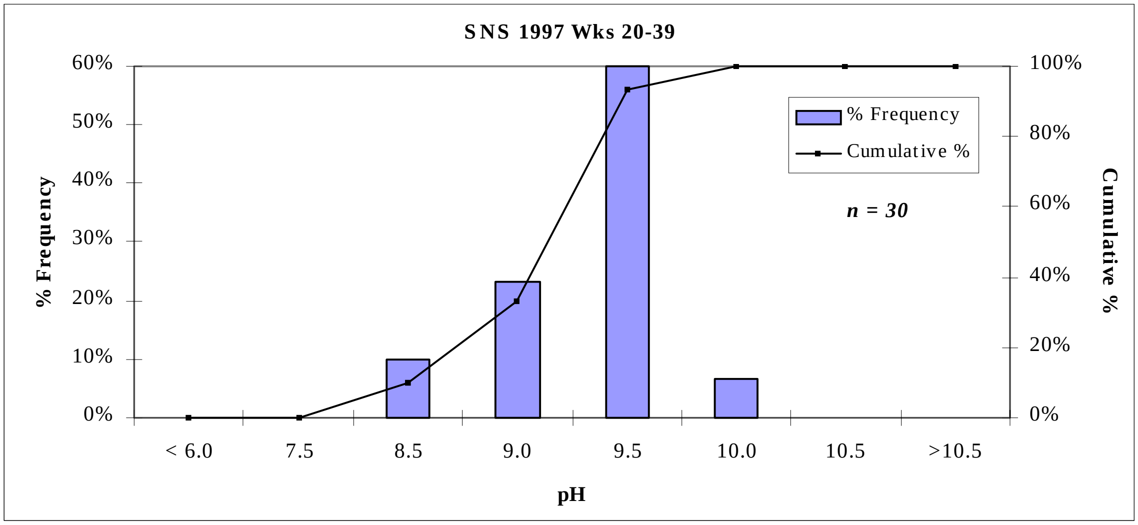


Figure C-16. Percent frequency and cumulative percent distributions of adult Shortnose sucker exposures to pH level categories in Upper Klamath Lake bottom-water, north of Bare Island, May –September, 1993-1995.





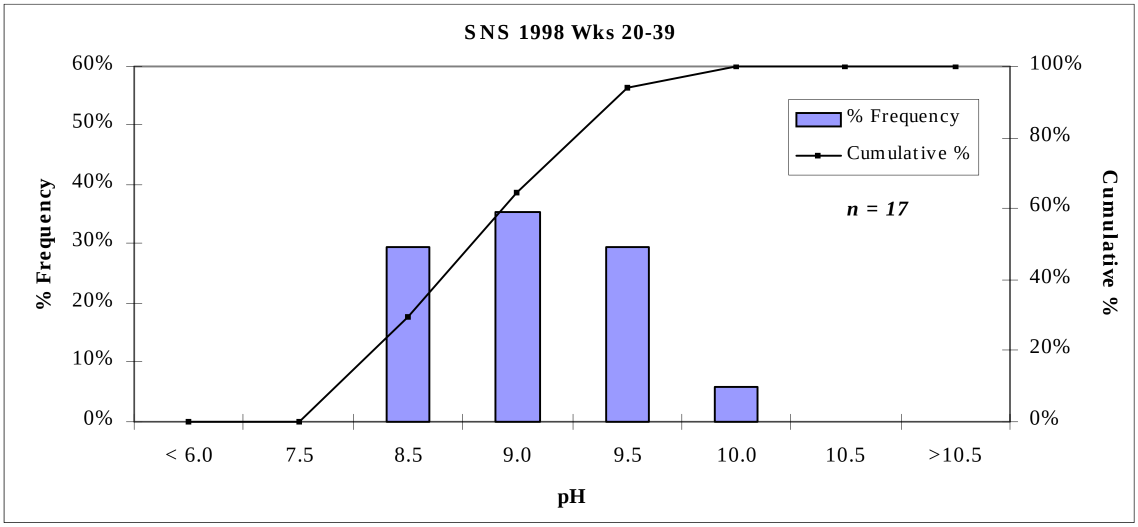


Figure C-17. Percent frequency and cumulative percent distributions of adult Shortnose sucker exposures to pH level categories in Upper Klamath Lake bottom-water, north of Bare Island, May –September, 1996-1998.

APPENDIX D

GIS Plots of Defined Depth Intervals as a Function of Lake Level

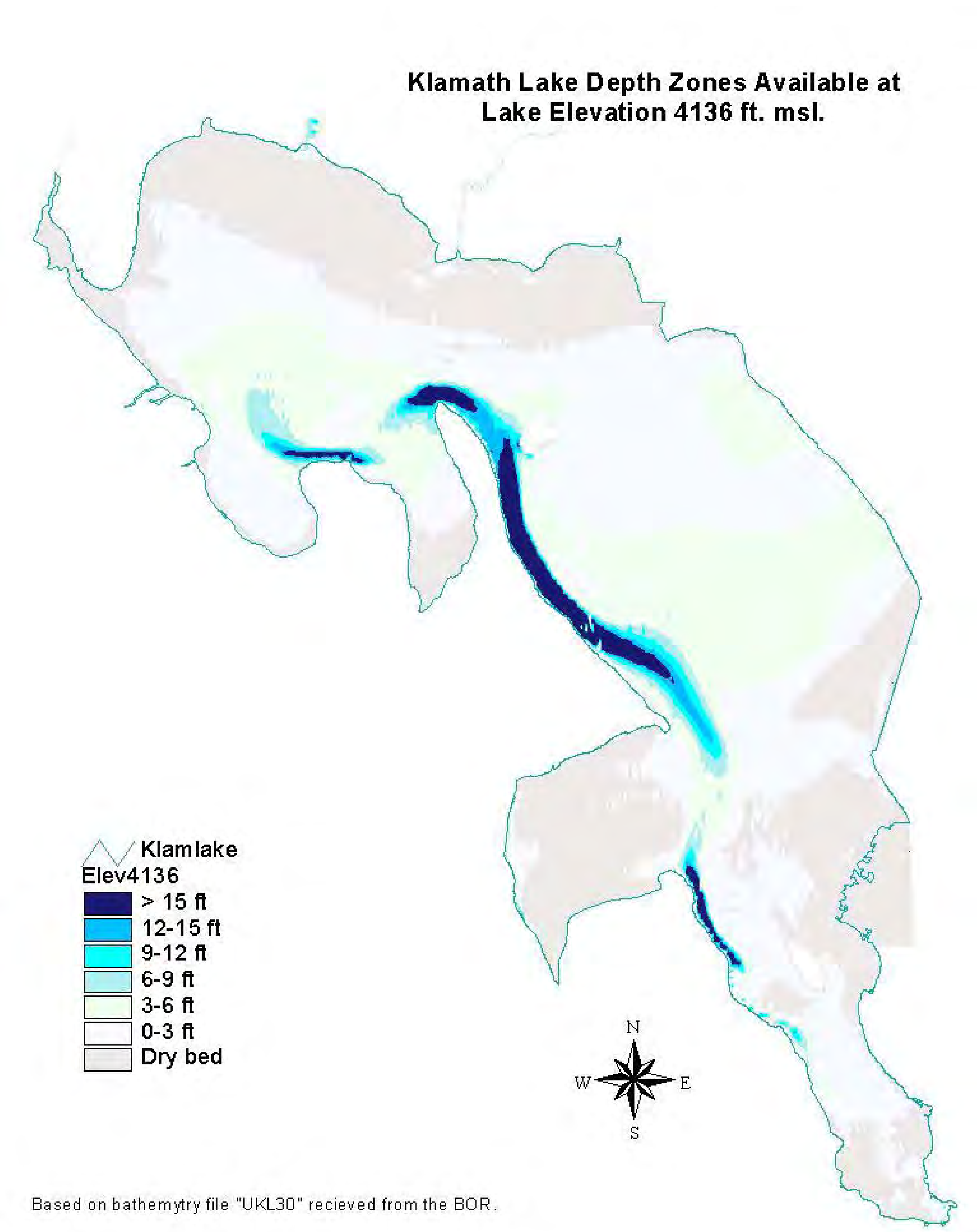


Figure D-1. Map showing Klamath Lake depth zones available at lake elevation 4136 ft. msl.

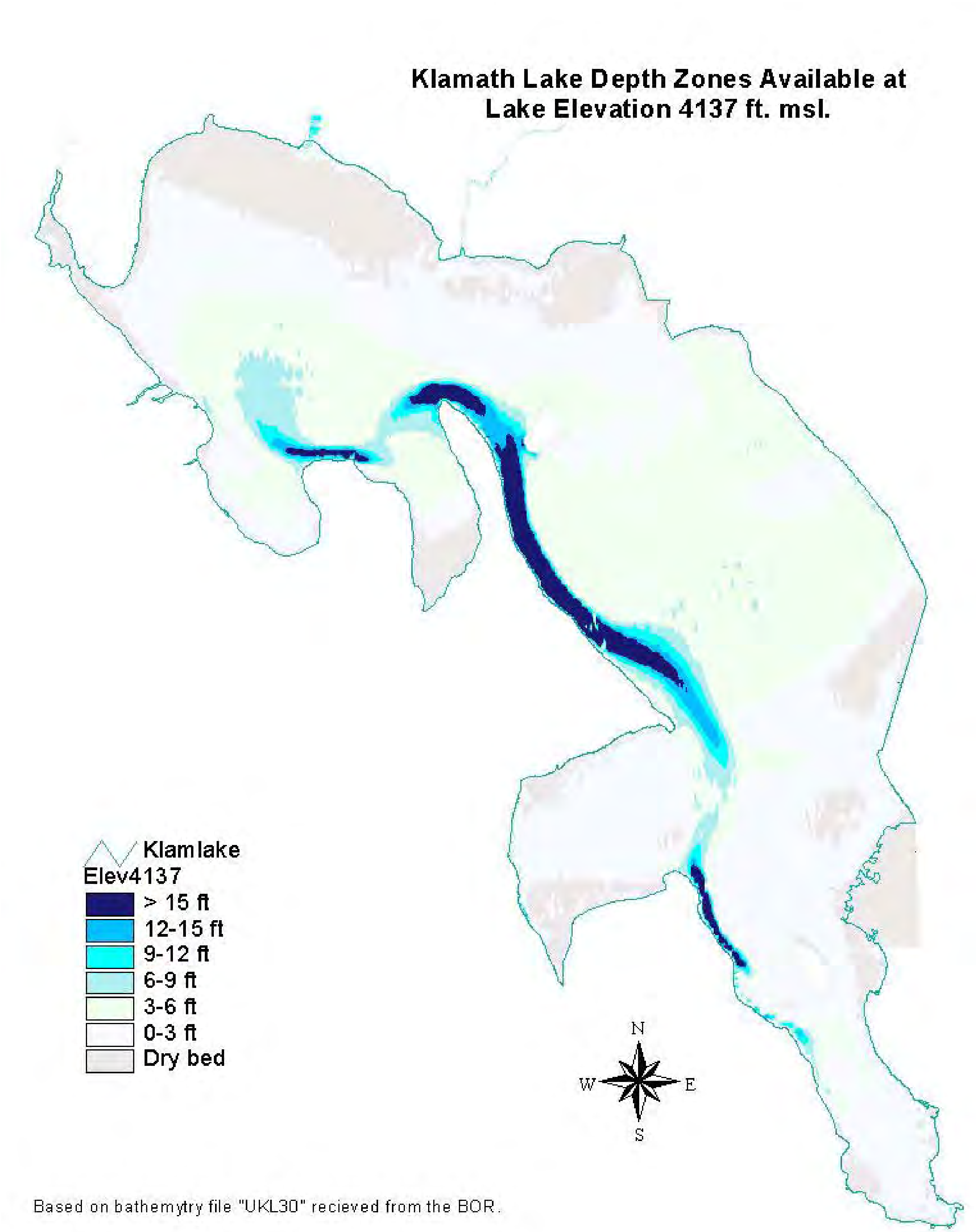


Figure D-2. Map showing Klamath Lake depth zones available at lake elevation 4137 ft. msl.

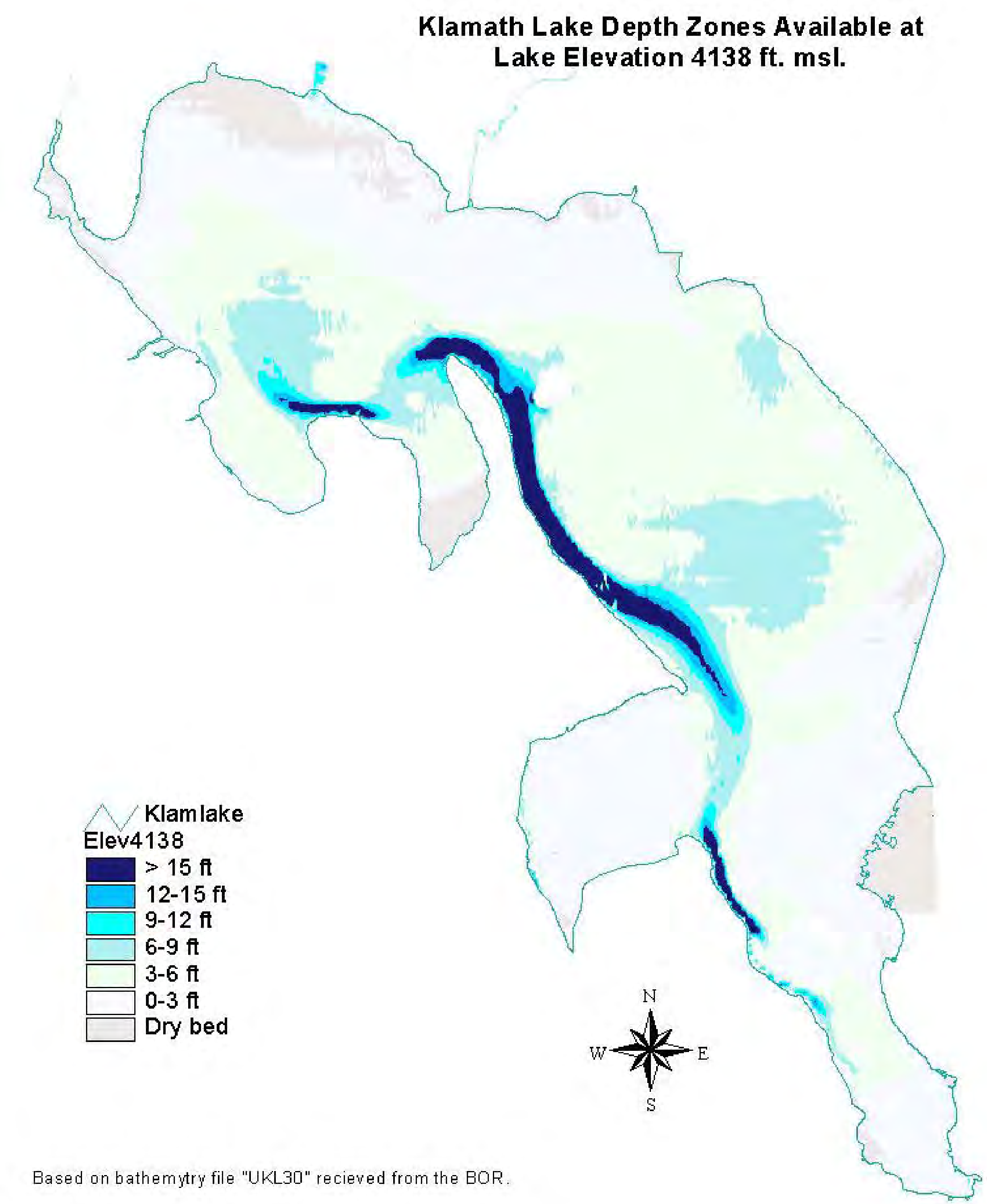


Figure D-3. Map showing Klamath Lake depth zones available at lake elevation 4138 ft. msl.

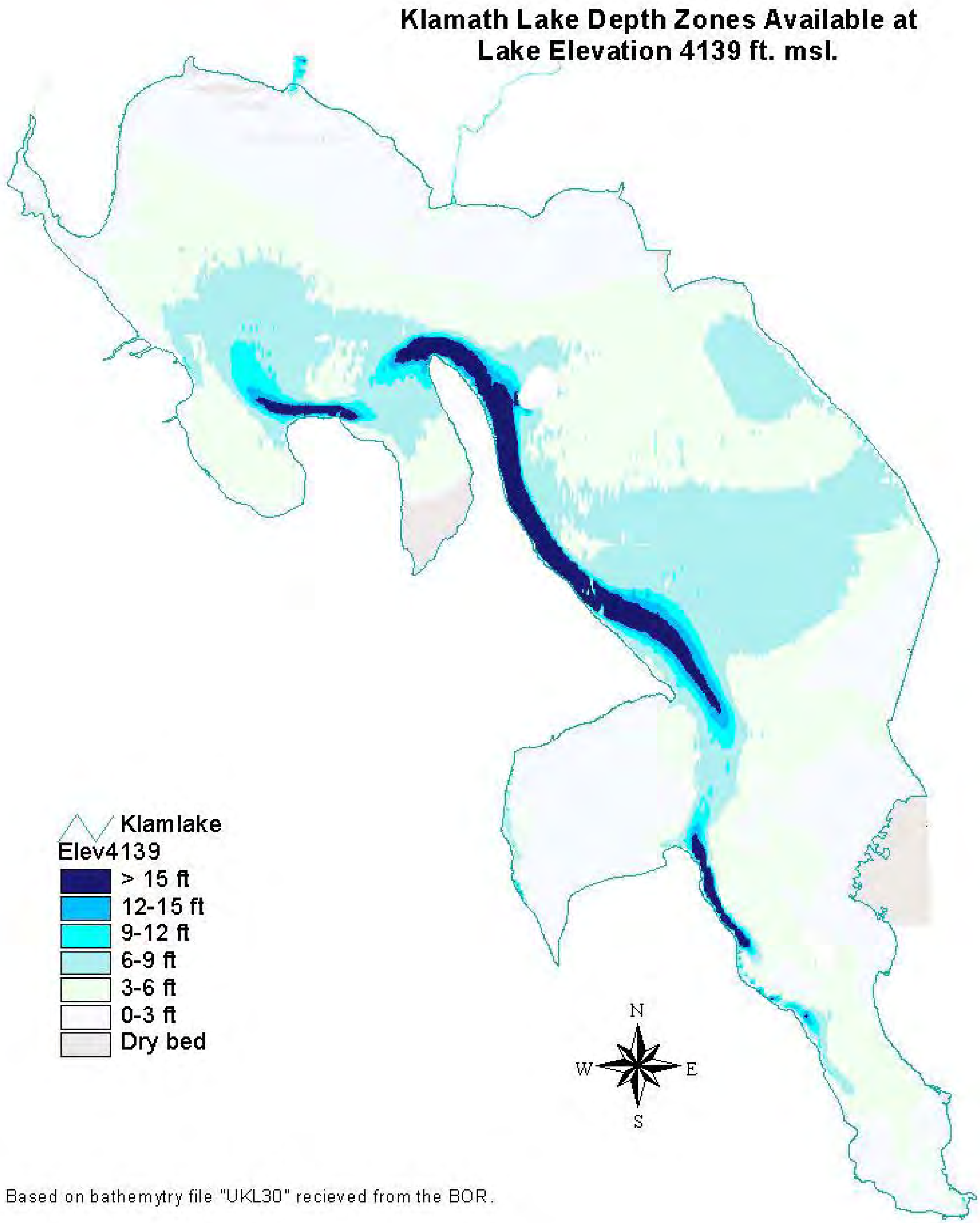


Figure D-4. Map showing Klamath Lake depth zones available at lake elevation 4139 ft. msl.

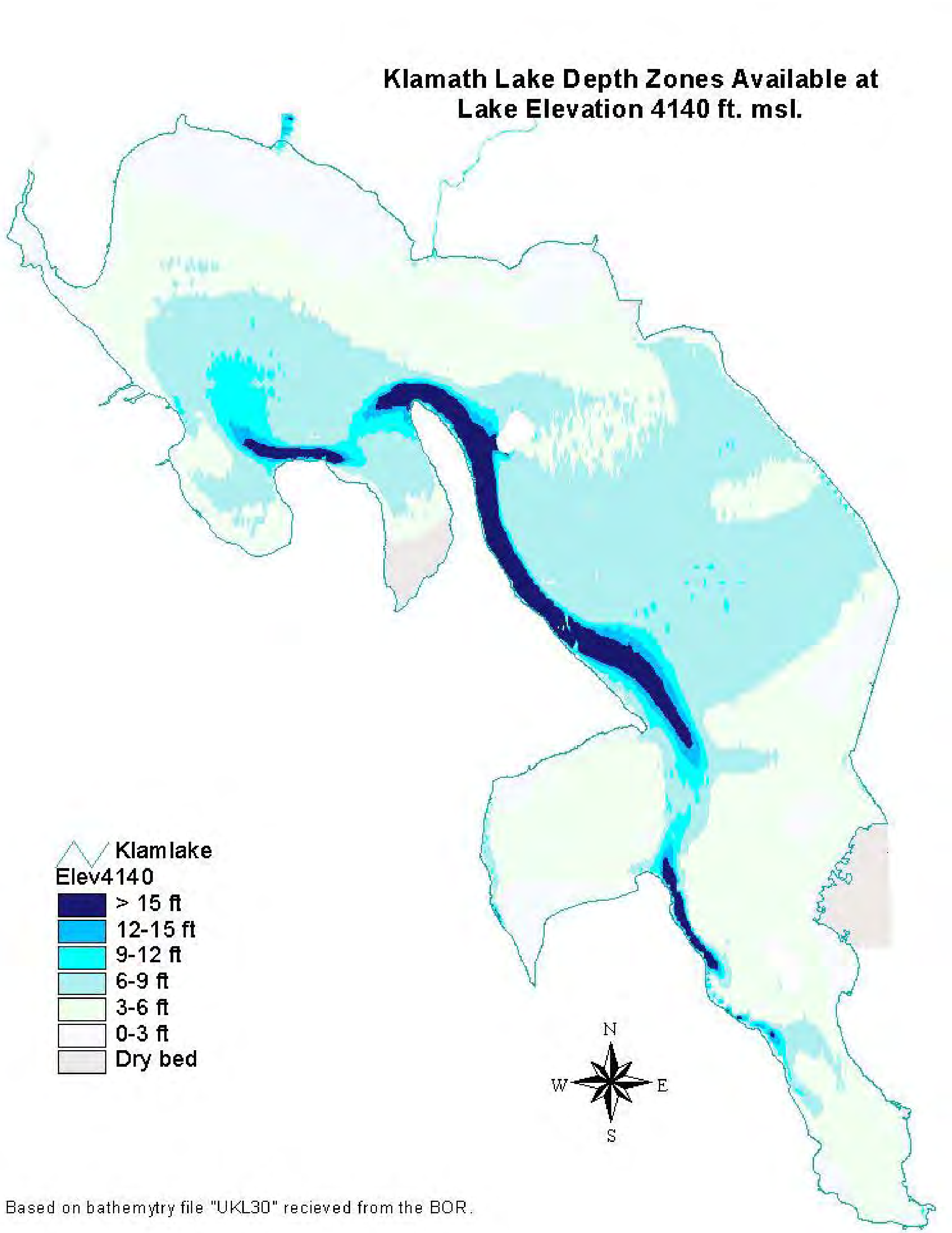


Figure D-5. Map showing Klamath Lake depth zones available at lake elevation 4140 ft. msl.

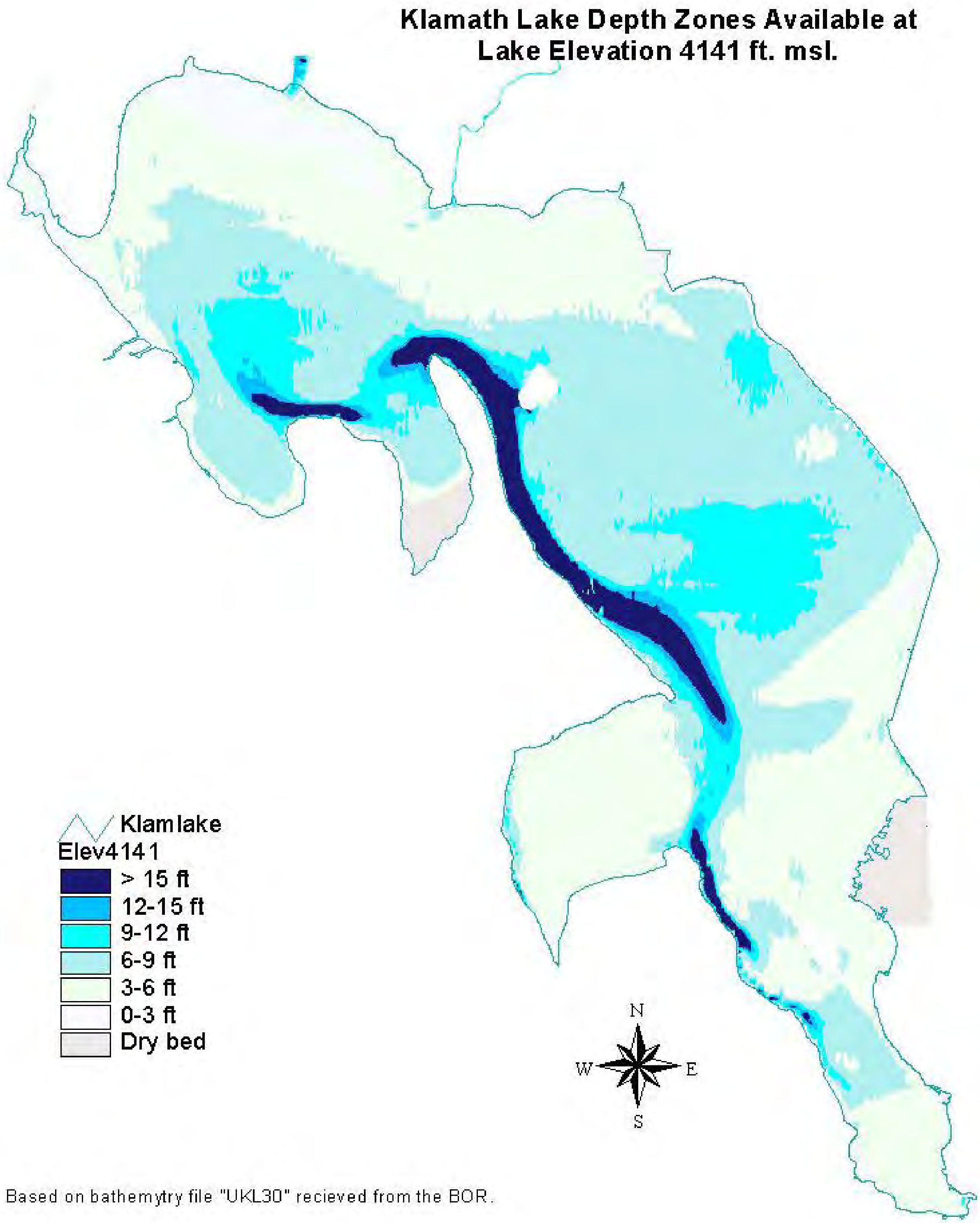


Figure D-6. Map showing Klamath Lake depth zones available at lake elevation 4141 ft. msl.

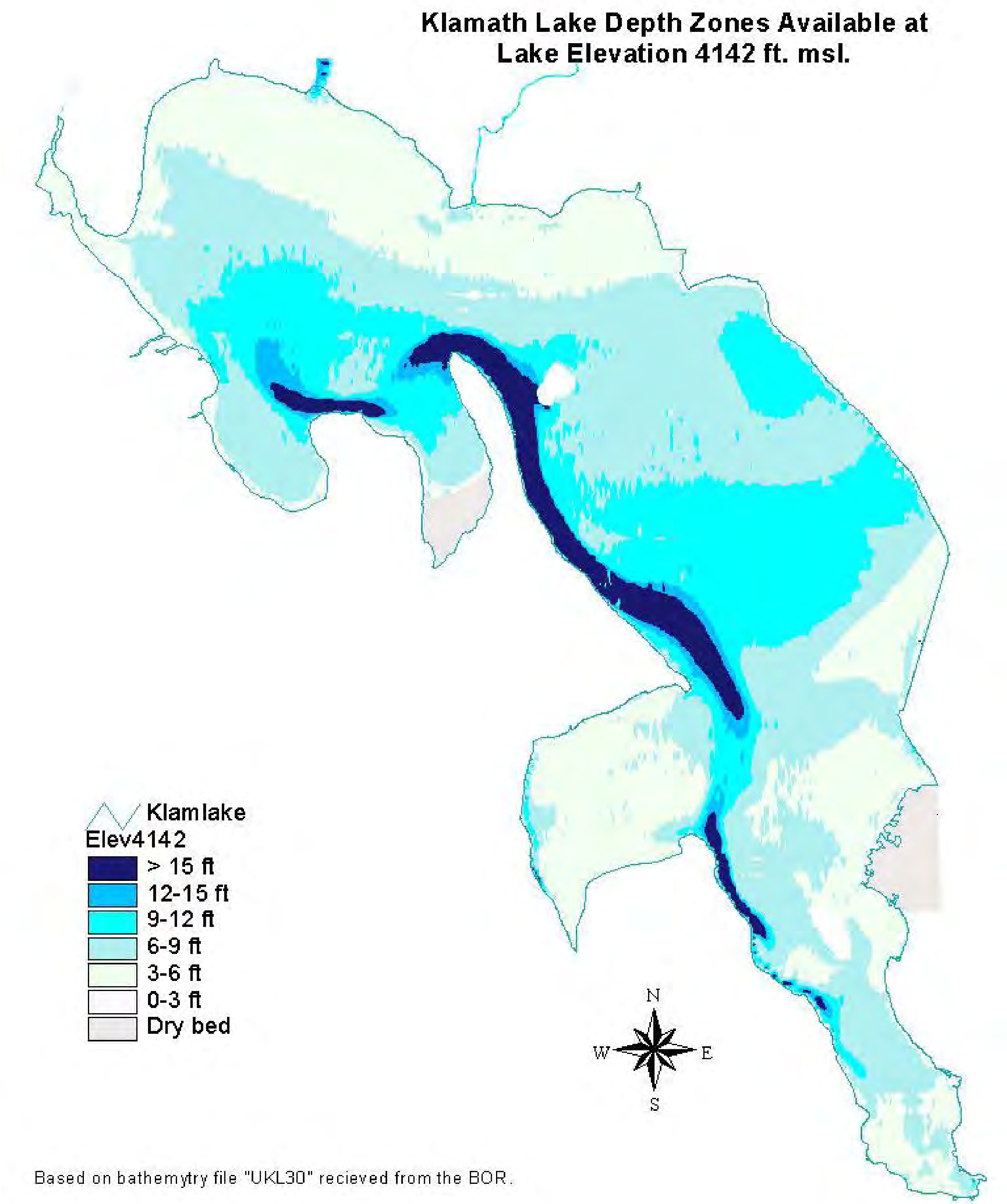


Figure D-7. Map showing Klamath Lake depth zones available at lake elevation 4142 ft. msl.

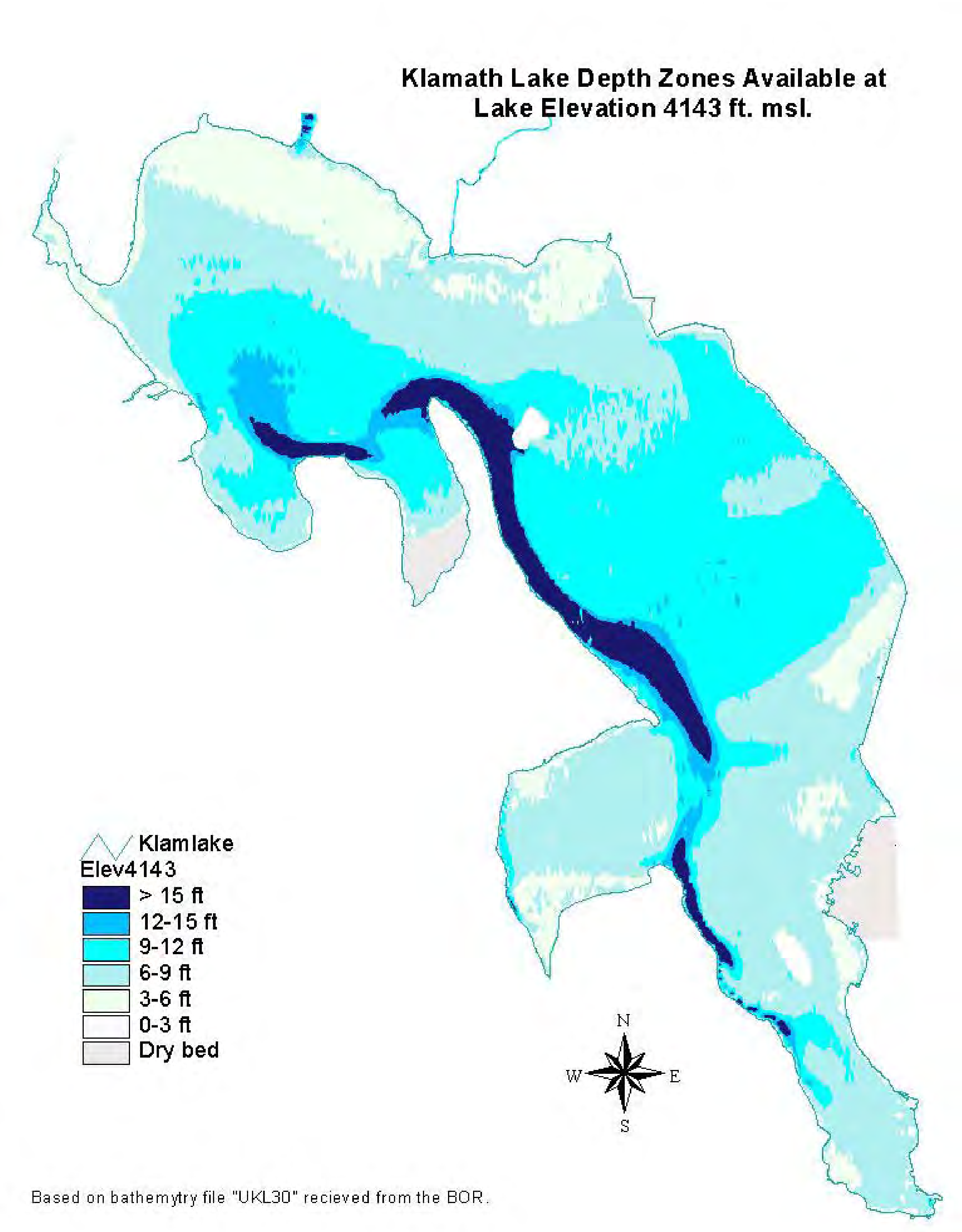


Figure D-8. Map showing Klamath Lake depth zones available at lake elevation 4143 ft. msl.

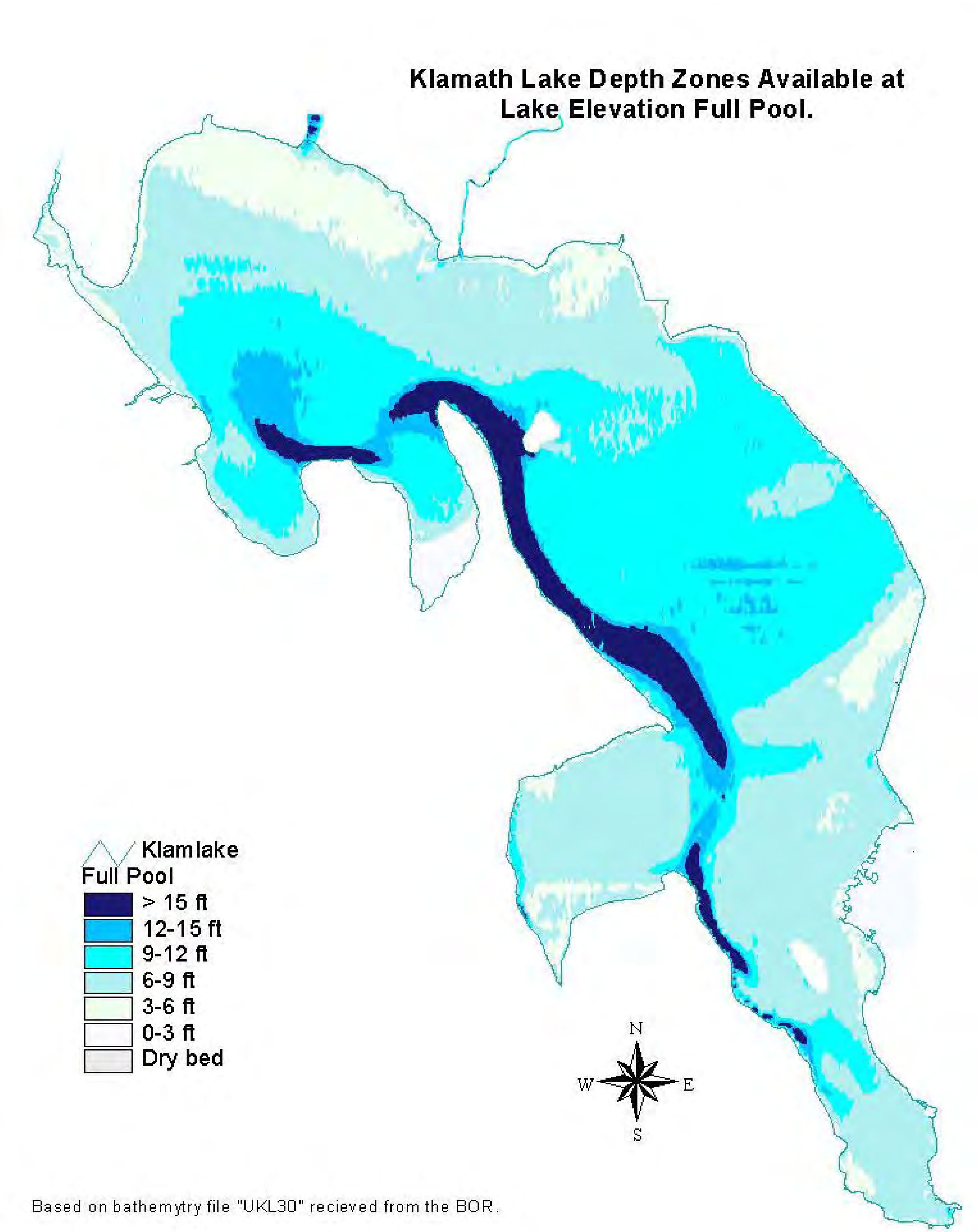


Figure D-9. Map showing Klamath Lake depth zones available at Full Pool.