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Patterns of Larval Sucker Emigration from the Sprague and Lower Williamson Rivers of the Upper Klamath Basin, Oregon, after the Removal of Chiloquin Dam—2009–10 Annual Report

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U.S. Department of the Interior
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Patterns of Larval Sucker Emigration from the Sprague and Lower Williamson Rivers of the Upper Klamath Basin, Oregon, after the Removal of Chiloquin Dam—2009–10 Annual Report

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Executive Summary

In 2009 and 2010, drift samples were collected from six sites on the lower Sprague and Williamson Rivers to assess drift patterns of larval Lost River suckers (*Deltistes luxatus*) (LRS) and shortnose suckers (*Chasmistes brevirostris*) (SNS). The objective of this study was to characterize the drift timing, relative abundance, and growth stage frequencies of larval suckers emigrating from the Sprague River watershed. These data were used to evaluate changes in spawning distribution of LRS and SNS in the Sprague River after the 2008 removal of Chiloquin Dam. Drift samples were collected at four sites on the Sprague River and one site each on the Williamson and Sycan Rivers.

Data presented in this report is a continuation of a research project that began in 2004. Larval drift parameters measured in 2009 and 2010 were similar to those measured from 2004 to 2008. Most larvae and eggs were collected at the two drift sites downstream of the former Chiloquin Dam (river kilometer 0.7 on the Sprague River and river kilometer 7.4 on the Williamson River). Mean and peak sample densities increased with proximity to Upper Klamath Lake. Peak larval densities continued to be collected between 1 and 3 hours after sunset at Chiloquin, which is the drift site nearest a known spawning area. Catch distribution of larvae and eggs in the lower Sprague and Williamson Rivers suggests that most SNS and LRS spawning continues to occur downstream of the site of the former Chiloquin Dam. The sizes and growth stages indicate that larval emigration from spawning areas resulting from drift occurs within a few days after swim-up. Larval suckers appear to move downstream quickly until they reach suitable rearing habitat.

Introduction

The Upper Klamath Basin has several endemic fish species, two of which, the Lost River sucker *Deltistes luxatus* (LRS) and the shortnose sucker *Chasmistes brevirostris* (SNS) were listed as endangered under the Endangered Species Act in 1988 (U.S. Fish and Wildlife Service, 1988). Like other lake suckers of western North America [for example, cui-ui (*Chasmistes cujus*) and June sucker (*Chasmistes liorus*)], both LRS and SNS are described as being long-lived (greater than 25 years) obligatory lake dwellers that typically use the primary tributaries of the lakes they inhabit for spawning (Koch, 1973; Scoppettone, 1988; Scoppettone and Vinyard, 1991; Modde and Muirhead, 1994; Cooperman and Markle, 2003). The Klamath largescale sucker (*Catostomus snyderi)* (KLS) is also endemic to the Upper Klamath Basin and was identified by the U.S. Fish and Wildlife Service as a species of concern, primarily because of its limited distribution (Oregon Natural Heritage Information Center, 2007). Klamath largescale suckers are more of a riverine species than the LRS and SNS, although they also can be found in Upper Klamath Lake (Moyle, 2002).

Prior to the federal listing of LRS and SNS, little empirical information existed regarding the distribution and extent of spawning areas used by these populations in the Sprague and Williamson Rivers. Recent research on spawning migrations of LRS, SNS, and KLS has identified apparent spawning locations in the lower Williamson River between river kilometer (rkm) 10.0 and 17.5, and in the Sprague River from its confluence with the Williamson River to the former Chiloquin Dam (rkm 0.0–1.3), the Nine Mile area (rkm 13.0–46.0), and Beatty Gap (rkm 112.0–120.0) (Ellsworth and others, 2007a, 2007b). A small number of radio tagged fish also were detected migrating into the Sycan River and the North Fork of the Sprague River (Ellsworth and others, 2007a, 2007b). There also appears to be some level of spatial and temporal separation in the spawning locations and timing among LRS, SNS, and KLS in the Sprague River and lower Williamson drainages. Telemetry data, as well as concurrently collected larval drift data, indicate that most KLS spawn in the upper reaches of the Sprague River (rkm 100–120) early in the spring (March–April), although SNS primarily spawn in the lower Sprague (rkm 0–10) and Williamson (rkm 10–17) Rivers later in the spring (April–May). These same telemetry and larval drift data show that spawning areas used by LRS generally overlap those areas used by KLS and SNS, but LRS generally spawn earlier than KLS in the upper reaches of the Sprague River and earlier than SNS in the lower reaches of the Sprague and Williamson Rivers.

Data presented in this report summarize larval drift collection efforts for 2009 and 2010, following the removal of Chiloquin Dam in autumn 2008. These data are part of a multi-year study with the objective to characterize the drift timing, spawning area distribution, relative abundance, and growth stage frequencies of larval suckers emigrating from the Sprague River watershed before and after the removal of the dam. This study has occurred concurrently with other studies that involved the monitoring of adult sucker movements in the Sprague and Williamson Rivers during their spawning seasons (Tyler and others, 2007; Ellsworth and others, 2007a, 2007b; Janney and others, 2008).

Description of Study Area

The Sprague River originates to the east of Upper Klamath Lake in the Gearhart and Quartz Mountains, draining an area of approximately 4,092 km^2. The lower 140 km of the Sprague River is a low-gradient river (about 0.4 m/km) and is characterized by broad valleys with extensive riverine meanders interspaced with low canyons or gaps created by uplifts or block faulting geology. Associated with these uplifted areas is an upwelling of groundwater that recharges the Sprague River as it cuts through these formations (Gannett and others, 2007). The Sprague River is the principal tributary of the Williamson River, which also originates east of Upper Klamath Lake in the Yamsay Mountains. Combined, the Williamson and Sprague Rivers provide about 50 percent of the annual inflow to Upper Klamath Lake (Kann and Walker, 2001). The hydrographs for both rivers typically are dominated by a late winter to early spring snowmelt peak followed by low base flows during summer and autumn.

Chiloquin Dam was located at rkm 1.3 on the Sprague River and approximately 19.0 rkm upstream of Upper Klamath Lake. The dam was approximately 3.4 m high and 58 m wide and was constructed to serve as a diversion structure to supply irrigation water for the Modoc Point Irrigation District. In 2000, the U.S. Geological Survey (USGS) implemented a sampling program at the Chiloquin Dam fish ladder to monitor the composition, timing, and relative abundance of spring spawning runs of suckers in the Sprague River as part of a larger effort to monitor LRS and SNS populations in the Upper Klamath Basin (Shively and others, 2001). Regular sampling showed that the number of suckers entering the fish ladder was highly variable among years. Some movement of KLS, LRS, and SNS through the Chiloquin Dam fish ladder was documented, but the dam was identified as a significant barrier to fish migration on the Sprague River and in some years, the dam likely prevented the upstream spawning migrations of these and other migratory fish species (National Research Council, 2004; U.S. Fish and Wildlife Service, 2008). In 2002, the Bureau of Reclamation headed a group that examined several alternatives to improve fish passage at Chiloquin Dam. Ultimately, it was decided that dam removal was the best alternative, and the dam was removed in summer 2008.

Methods

Drifting larval suckers and eggs were collected in the lower Sprague and Williamson Rivers at six sites in 2009 and 2010 (fig. 1). Sites were selected from available bridge crossings in the drainage basin that facilitated sampling the river at the thalweg and provided representation of larval sucker emigration from known and suspected spawning areas. The Williamson River was sampled at Modoc Point Road (Williamson, rkm 7.4); the Sprague River was sampled at a private bridge in Chiloquin, Oregon (Chiloquin, rkm 0.7), at Chiloquin Ridge/USFS Road 5810 near Chiloquin (Power Station, rkm 9.5), at Stow Mountain-Pit Road near Lone Pine, Oregon (Lone Pine, rkm 52.7), and at Godowa Springs Road near Beatty, Oregon (Beatty, rkm 108); and the Sycan River was sampled at Drews Road (Sycan, rkm 4.7). Sampling at all locations began on March 23, 2009, and March 25, 2010. Both dates were prior to the detection of most suckers migrating past the Williamson River fish weir located at rkm 10 (U.S. Geological Survey, unpub. data, 2009, 2010). Sampling concluded on July 9, 2009, and July 14, 2010, after the number of larvae being collected had decreased to just a few individuals per night and no new spawning activity had been observed for more than 4 weeks.

Drift samples were collected three times a week on Sunday, Tuesday, and Thursday nights resulting in a total of 1,815 samples in 2009 and 1,817 samples in 2010 (table 1). Samples were collected by three technicians; each assigned two sites per night. This sampling schedule allowed hourly samples to be collected at Williamson, Chiloquin, Beatty, and Sycan sites. Samples at Power Station and Lone Pine sites were collected once every other hour. Samples were collected between 0.5 hours before sunset and 8.0 hours after sunset throughout the larval drift period (table 2).

Drift samples were collected using modified plankton nets 2.5 m in length with a 0.3 m diameter circular opening. Nets were constructed of 800 µm Nitex® mesh and were fitted with a removable collection cup with 500 µm Nitex® mesh windows. A General Oceanics Model 2030R flow meter with a standard rotor was used to record water velocities at the mouth of the net at sites where water velocities were great enough to keep the net suspended in the water column. At the Williamson site, where water velocities were not great enough to keep the net suspended in the water column, the net was modified with a polyvinyl chloride (PVC) hoop fixed to the net opening to keep the net from collapsing around the flow meter, and a polystyrene float fixed to the collection cup to keep the net horizontal in the water column. A General Oceanics Model 2030R6 flow meter with a low-velocity rotor was used to record water velocities at this site. A 6-mm rope was attached to one side of a stainless steel ring fitted into the opening of the net to permit it to be deployed and retrieved from bridges at all sites. A pancake-shaped weight (either 3.6 or 4.5 kg depending on water velocity) was attached to the opposite side of the ring to hold the net opening perpendicular to the river flow. Drift samples were collected in the thalweg for 10 minutes from the downstream side of each bridge.

Following the retrieval of a drift net, any larvae or debris impinged on the sides of the net was rinsed into the collection cup with a portable water sprayer. Larvae and debris were then transferred into sample bottles and preserved in 10 percent formalin. Fish specimens were sorted from sample debris within 24 hours of collection. Fish specimens were then enumerated and stored in 95 percent ethanol for later identification and measurement. Larvae were identified under magnification (2–10×) to the lowest possible taxonomic level using a key for larval fishes of the Upper Klamath Basin (Oregon State University, unpub. data, 2004). Identification of larval sucker species was based primarily on differences in pigmentation (dorsal melanophores), which generally allows for separation of LRS larvae from SNS and KLS larvae. Because the pigmentation patterns between SNS and KLS are similar, we were unable to positively identify larvae of either of these species; therefore, larvae identified as either SNS or KLS were combined and designated as SNS-KLS for this report. Larval suckers exhibiting intermediate characteristics were designated as unidentified sucker larvae (UIS). Larvae that were damaged to the point where identification could not be made also were designated as UIS. Developmental stage was determined by the degree of caudal fin development, and individuals were categorized into preflexion, flexion, or postflexion groups. Individuals designated with an undetermined growth stage typically were damaged in a way that prevented the determination of growth stage. Notochord length was measured for preflexion larvae (generally < 9 mm), and standard length was measured for flexion larvae (usually 9–14.5 mm), and postflexion larvae (generally >14.5 mm), and juvenile suckers. Median larval sucker lengths were calculated using standard length and notochord length measurements. In drift samples where the number of larvae exceeded 50 individuals, a subsample consisting of 25 of each species or species complex was measured for length. Furthermore, metalarvae and small juvenile suckers collected in 2009 and 2010 were X-rayed to determine species or species complex using an identification method based on vertebral counts (Markle and others, 2005) because an identification key based on external morphology does not yet exist for these early life history stages. Due to the small size of X-rayed fish, we could not use lip morphology or gill raker counts to further distinguish SNS-KLS metalarvae and small juveniles into SNS or KLS.

Mean densities of LRS, SNS-KLS, and UIS larvae and eggs for samples collected between the first and last capture were used to compare densities among sites. A natural log-transformation was made to the nightly mean larval densities plus one to better visualize seasonal larval drift trends. The standard addition of one was required to prevent obtaining an error when means were zero; the natural log of one is zero therefore keeping that value constant. Cumulative percentages of larvae and eggs captured over time were calculated to present differences in seasonal drift timing between larval and egg LRS and SNS-KLS. Larval sucker and egg catches were expressed as the number of larvae or eggs per unit volume (larvae or eggs/m^3) for summaries of and comparisons among sampling sites. Discharge and temperature data for 2009 and 2010 were obtained from the Sprague River gage near Chiloquin at rkm 8.7 (USGS stream gage 11501000) and from the Williamson River gage at rkm 16.6 (USGS stream gage 11502500).

Results

Species Composition and Density

LRS and SNS-KLS larvae were collected at five of the six sites in 2009 and 2010; Sycan site was the exception with no LRS captured in either year. Mean and peak larval densities for LRS and SNS-KLS larvae were highest at the two sites closest to Upper Klamath Lake, with mean larval densities mostly an order of magnitude higher than at the remaining sites (tables 3 and 4). The two sites farthest from Upper Klamath Lake had slightly higher mean and peak densities than the two sites located just downstream of these uppermost sites. However, some of the highest mean larval densities were recorded for SNS-KLS at the Sycan and Williamson sites in 2010 and LRS at the Williamson site in 2009. Dominant species in the larval catch at the Williamson site switched between years from LRS in 2009 to SNS-KLS in 2010.

Seasonal and Nightly Emigration Timing

Larval drift generally occurred over a 2–6 week period of time with the collection of larvae from mid-April to early June at sites upstream of the former Chiloquin Dam and from mid-May to early July at sites downstream of the former Chiloquin Dam (figs. 2 and 3). Plots of the mean nightly densities (figs. 2 and 3), as well as the cumulative catch curves (figs. 4 and 5), show that the seasonal drift period at the four sites upstream of the former Chiloquin Dam location typically occurred earlier in the year than those sites downstream of the former dam location. Cumulative catch curves show that LRS larvae typically drifted earlier in the season than SNS-KLS larvae (figs. 4 and 5).

Nightly peaks in larval emigration were discernible at sites where larvae were collected on a consistent basis (figs. 6 and 7). Timing of nightly peaks appeared to vary among sites with larvae drifting later in the night as the distance between sampling location and the nearest known spawning area increased. Larval drift at the Chiloquin site (site closest to a known spawning area) generally peaked from 1 hour before sunset to 1.5 hours after sunset, whereas larval drift at the Williamson site (a site farther from known spawning areas) peaked 5 to 7 hours after sunset. Nightly peaks at the Sycan and Beatty sites were similar to those at the Williamson site, occurring well past sunset. Low catches at the Lone Pine and Power Station sites made it difficult to distinguish a nightly peak in larval emigration at these sites.

Size and Stage of Larvae

Most of the larvae collected from the drift in 2009 and 2010 were in the flexion growth stage (table 5). With one exception, the median length of larvae in the flexion growth stage collected at the Sycan, Beatty, Lone Pine, and Power Station sites was greater than larvae collected at Chiloquin or Williamson for 2009 and 2010 (table 6). Median length of Lost River suckers collected from Chiloquin in 2009 was the exception, displaying the highest median growth from the six sites. Although the 2010 data showed a distinct difference between the median lengths of larvae from Chiloquin and Williamson sites versus the four remaining sites—with as much as a 1.0–1.2 mm difference for SNS-KLS and LRS—the 2009 data showed less of a spread with median lengths of all SNS-KLS within 0.4 mm and LRS within 0.3 mm of each other.

Most of the preflexion larval suckers (< 9.0 mm) were collected at the Chiloquin site in 2009 and 2010. Suckers greater than 14.5 mm generally were in the postflexion stage or juveniles, and similar low numbers were collected over the six sites. A total of 23 suckers were collected in 2009 that were large enough to be X-rayed and identified using vertebral counts. Sixteen of these fish were identified as being SNS-KLS, whereas the remaining seven fish had identification characteristics indistinguishable between LRS and SNS-KLS. A total of 23 suckers, large enough to be X-rayed and identified using vertebral counts, also were collected in 2010. Nineteen of these fish were identified as being SNS-KLS, whereas the remaining four fish had identification characteristics indistinguishable between LRS and SNS-KLS.

Distribution, Duration, and Nightly Timing of Egg Drift

Catostomid eggs were collected from most locations in 2009 and one-half the sites in 2010, with most eggs collected at the Chiloquin site in both years (table 7). Egg drift at the Chiloquin site occurred earlier and over a shorter period of time in 2009 than in 2010 (fig. 8). Eggs were collected from April 12 to June 9, 2009, and from April 15 to June 27, 2010 (figs. 9 and 10). Peaks in egg drift matched peaks in adult sucker detection on the remote PIT tag array at the former Chiloquin Dam site. Peak egg drift in 2009 and 2010 began with peak detection of KLS and continued with LRS and SNS detections over the remainder of the spawning season. Mean water temperatures between the first detection of eggs in the drift and peak egg drift (April 21, 2009, and April 25, 2010) were 11.4^{o}C in 2009 and 2010. Mean and peak egg densities at the Chiloquin site in 2009 were several times higher than those measured before dam removal. In 2010, egg-drift densities at the Chiloquin site returned to pre-dam removal levels (table 7). Peak egg collection during our nightly sampling period also differed in 2009, with most eggs collected several hours after sunset. In 2010, peak egg collection returned to a similar pattern to pre-dam removal where more eggs typically were collected early in the evening during the first and second sampling efforts of the night with egg collections slightly lower yet fairly constant the remainder of the night (fig. 11). Egg collections at all other sites were insufficient to detect any nightly patterns in either year.

Discussion

Key Findings

Spawning of LRS, KLS, and SNS appears to continue both upstream and downstream of the former Chiloquin Dam site as identified in the earlier phases of this study. Larval LRS and SNS-KLS densities continue to be substantially higher at the two sampling sites downstream of the former Chiloquin Dam site when compared to the sampling sites upstream of the former dam site. Most larvae recovered from the drift were in the flexion growth stage generally between 9.0 and 14.5 mm in length. The larvae collected upstream of the former dam were longer on average than those larvae collected downstream of the former dam. Postflexion larvae and small juvenile suckers (KLS and possibly LRS and SNS) were collected in the Sprague and Williamson Rivers, indicating that there is some degree of in-river rearing for these species. Larval drift begins prior to sunset and peaks shortly after sunset at the Chiloquin study site, while larval drift generally peaks several hours later at the remaining sites. The timing of the nightly peak larval drift at any particular sampling site appears to be related to the distance between the nearest upstream spawning area and that sampling site. Egg drift downstream of the former Chiloquin Dam was several times higher in 2009 than before dam removal. In 2010, egg drift downstream of the former Chiloquin Dam site was similar to pre-dam removal levels.

Species Composition and Density

Larvae identified as both LRS and SNS-KLS were collected from five of the six sampling sites indicating that spawning for LRS and either KLS or SNS (or both) is occurring upstream and downstream of the former Chiloquin Dam. A concurrent radiotelemetry study found that most tagged KLS and some tagged LRS migrated to several relatively discrete spawning areas in the upper reaches of the watershed while most tagged LRS and most tagged SNS remained in the lower Sprague and Williamson Rivers downstream of the former Chiloquin Dam (Ellsworth and others, 2007a, 2007b; Tyler and others, 2007). Larval densities measured at the six sampling sites indicate that most of the spawning activity occurs downstream of the former dam site. Although there appears to be suitable spawning habitat between the former Chiloquin Dam site and the bottom of Chiloquin Narrows, it appears that use of this habitat did not substantially increase after Chiloquin Dam was removed. Similar to the 2004–06 findings, the spawning areas on the Sprague and Sycan Rivers near Beatty Gap appear to be used more than the other sites on the Sprague River upstream of the former Chiloquin Dam site. Results from the adult telemetry data suggest that larval suckers classified as SNS-KLS found at the two uppermost sites (Beatty and Sycan) were KLS (Ellsworth and others, 2007a, 2007b).

Seasonal and Nightly Emigration Timing

Seasonal and nightly patterns in the onset, magnitude, timing, and duration of larval drift were similar to those seen from 2004 to 2008. As noted in previous years, larval drift upstream of the former Chiloquin Dam continued to begin earlier in the year than larval drift at the Chiloquin or Williamson sites. In 2009 and 2010, LRS and SNS-KLS larvae were collected upstream of the former Chiloquin Dam primarily from mid-April to early June whereas drift at the Chiloquin and Williamson sites occurred from mid-May to early July. This temporal separation in larval drift appears to support the possibility of multiple spawning groups of suckers in the Sprague River, with KLS and a group of LRS spawning in its upper reaches earlier in the spring and SNS and a group of LRS spawning in its lower reaches later in the spring (see Ellsworth and others, 2007a, 2007b). As in previous years, we observed bimodal peaks in LRS drift upstream of the former Chiloquin Dam, with the first peak more pronounced and the second peak coinciding with LRS drift downstream of the former dam. This phenomenon suggests that there may have been some level of spawning activity by LRS upstream of the former dam at approximately the same time LRS were drifting from an earlier spawning event.

Distinct nightly emigration patterns were observed at the Chiloquin, Williamson, Beatty, and Sycan sites in 2009 and 2010. As in samples collected from 2004 to 2008, LRS and SNS-KLS larvae appeared to initiate drift shortly before sunset (Ellsworth and others, 2008, 2009, 2011). Peak larval drift for LRS and SNS-KLS at the Chiloquin site occurred from 1 to 3 hours after sunset. In contrast, peak larval drift at the Williamson, Beatty, and Sycan sites occurred from 6 to 8 hours after sunset for LRS and SNS-KLS. This indicates that there is a time lag between the initiation of drift and when larvae actually arrive at these three sites. This time lag probably is due to the distance between sampling locations and sites where larvae are entering the drift each night. Due to low capture rates, no nightly drift pattern was evident at the Lone Pine or Power Station sites in either 2009 or 2010.

Size and Stage of Larvae

Larval LRS and SNS-KLS appear to be most active in the drift at the flexion growth stage. Individuals in other developmental stages also were collected in 2009 and 2010, suggesting that younger and older fish also were present in the system but were less likely to be collected with our sampling gear. The collection of preflexion larvae, primarily at the Chiloquin site, may be an indication that larvae are being flushed from the interstitial spaces in the gravel before they are physiologically ready to drift. The collection of postflexion larvae and juveniles, again primarily at the Chiloquin site, may be due in part to the hydraulics at this site being more likely to sweep fish that typically would not be found in the drift into our sampling gear. The collection of more developed larvae in the Sprague and Williamson Rivers continues to indicate that there may be some level of in-river rearing for KLS, and possibly LRS and SNS in the Sprague River drainage (table 5).

Although median lengths were greater at the four sites upstream of the former dam compared to those downstream of the former dam in 2010, there was no such distinction in 2009 (table 6). We found similar patterns from 2004 to 2008, which were attributed to differences in temperature and discharge (Ellsworth and others, 2008, 2009, 2011). The early spike in discharge during May 2009 (fig. 10) may have dislodged the eggs and/or larvae of earlier spawned suckers resulting in a tighter range of larval sucker lengths. We saw a similar reduction in range in 2004 when an early spike in discharge also may have flushed progeny of the earlier spawned suckers downriver (Ellsworth and others, 2008). Although there were similar discharge spikes during the other years of the study, the timing of those spikes was less likely to dislodge eggs or larvae (Ellsworth and others, 2008, 2009, 2011).

Distribution, Duration, and Nightly Timing of Egg Drift

As in previous years, the vast majority of sucker eggs collected in the drift were found at the Chiloquin site during 2009–10. The high density of eggs found in the drift is believed to be due to the close proximity to the spawning area in the lower Sprague River. Although it was hypothesized that the removal of Chiloquin Dam would decrease egg drift at the Chiloquin site, this was not the case. In fact, our collection of eggs in the drift during 2009 was at least an order of magnitude higher than eggs collected from 2004 to 2008 and in 2010. One potential hypothesis is that the short-term peak of egg drift in 2009 may have been caused by increased sedimentation after dam removal, with the fine sediment filling the interstitial spaces and therefore preventing the eggs from finding a resting place. Furthermore, with 2010 egg drift levels back to the 2004-08 levels, it is assumed that there was some stressor in 2009 that was removed before the 2010 spawning event. Therefore, the data collected after the removal of the dam suggests that our original hypothesis that the dam was responsible for crowding fish, thereby increasing egg drift, probably is incorrect. Larval drift downstream of the former Chiloquin Dam site was fairly consistent from 2004 to 2010, indicating that the increased egg drift of 2009 did not affect the larval drift densities in that year. Although preflexion larvae found at the Chiloquin site was an order of magnitude higher in 2009 than 2010, implying a link between increased egg drift and number of preflexion larvae in the drift, the pre-dam removal data also showed such an increase in preflexion larvae found during 2007 when egg drift was low. The 2007 data further supports our hypothesis that the increased egg drift in 2009 was a singular event likely caused by the dam removal.

Prior to the installation of the remote PIT tag detection systems for migrating adult suckers, the timing of egg drift had been compared with the catches of adult suckers in the Chiloquin Dam fish ladder. In those comparisons, egg drift typically occurred after the peak catches of KLS and coincided with the capture of LRS and SNS in the fish ladder (Ellsworth and others, 2008, 2009, 2011). The timing of larval drift, with LRS larvae typically drifting before SNS-KLS larvae, still indicates that these earlier running KLS are not spawning in the lower Sprague River, and that the eggs drifting at the Chiloquin site primarily are being spawned by LRS. If this assessment is accurate, this data would show that KLS are migrating through the lower Sprague River at the same time LRS are actively spawning, and the KLS migration may contribute to egg drift. Although increased discharge events could contribute to increased egg drift, the increase in egg drift does not appear to consistently coincide with increased discharge events. In 2010, peak egg drift occurred before any increased discharge event, indicating that discharge alone cannot account for increased egg drift.

Environmental Conditions and Spawning

Water discharge for the Sprague River near Chiloquin during 2009 and 2010 were once again less than the average for these water years. Water discharge was 60 percent of the mean (1922–2009) in 2009, and was 55 percent of the mean (1922–2010) in 2010. Although the discharge pattern in 2009 was similar to previous years with the first peak discharge event occurring in early March, peak discharge events in 2010 occurred much later with the first peak discharge occurring at the beginning of May.

The timing of sucker spawning runs in the Sprague and Williamson Rivers has been correlated to water temperatures with 10^{o}C as an approximate threshold for cueing upstream migrations for most of these fish (Janney and others, 2009). Similar water temperatures early in 2009 and 2010 resulted in similar timing of the migration of the suckers.

Summary and Conclusions

The highest densities of drifting larvae in 2009 and 2010 were concentrated at the two drift sites downstream of the former Chiloquin Dam. Very few larvae and eggs were collected at the two drift site located immediately upstream of the former dam, while slightly more larvae were found at the two uppermost sites. The highest larval densities occurred at the sampling location nearest Upper Klamath Lake. Seasonal drift timing occurred earlier in the year upstream of the former dam site than at the Chiloquin or Williamson sites. This is an indication that there continues to be some level of temporal separation between fish spawning in the upper and lower reaches of the Sprague River.

There also appears to be some level of temporal separation of spawning between species with LRS larvae typically drifting before SNS-KLS. Larval drift at the Chiloquin site (the site nearest to a known spawning area) began before sunset with peak drift occurring 1–3 hours after sunset. Peak drift at the Williamson site (a site farther from a known spawning area) occurred 6–8 hours after sunset. Environmental conditions, such as water temperature, timing and duration of runoff, and magnitude of river discharge, likely contributed to observed differences in spawning run timing, egg drift, and larval drift among years.

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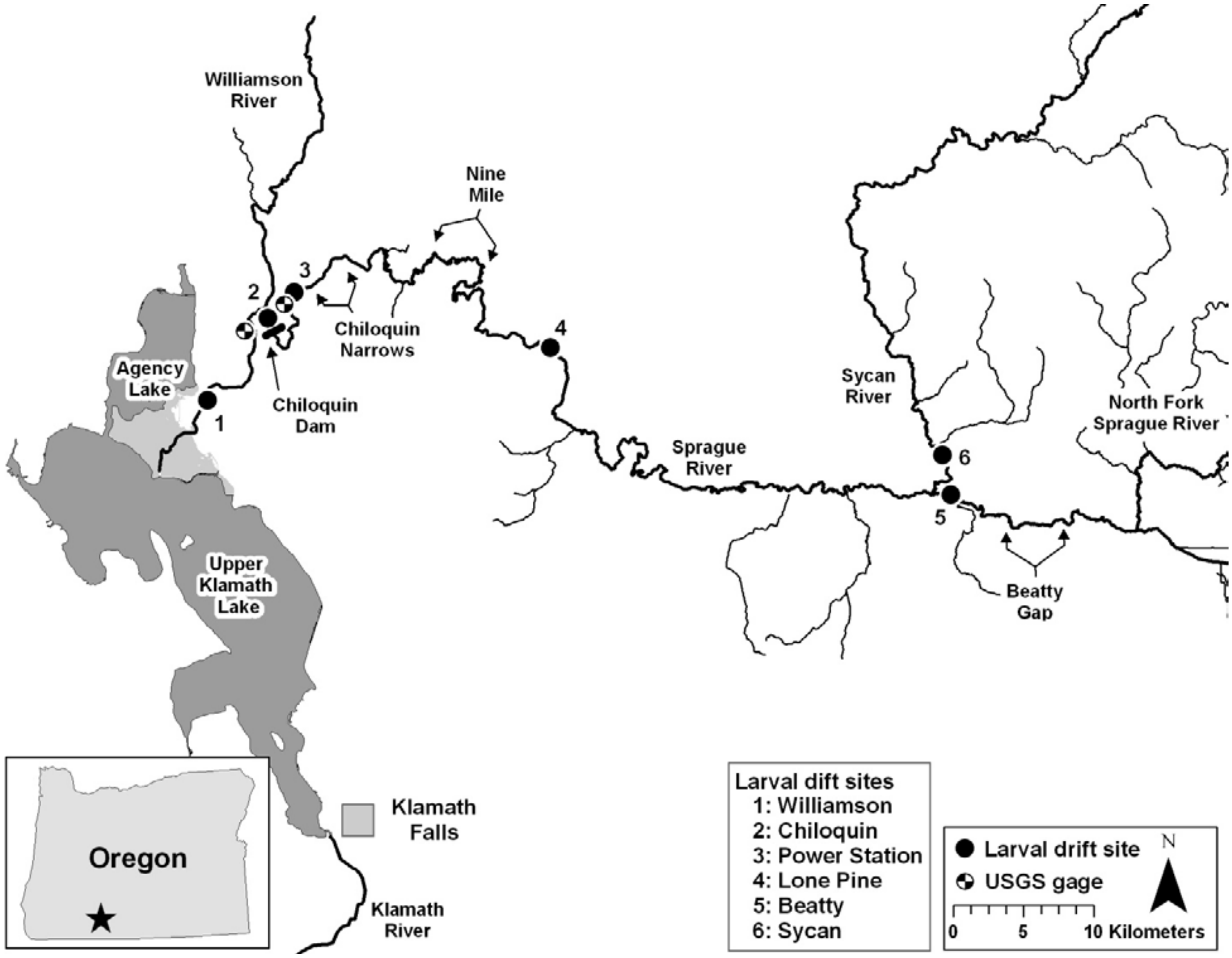


Figure 1. Map of the study area identifying larval sucker sampling sites used to assess the post-dam removal larval drift patterns of Lost River and shortnose suckers in the Sprague and Williamson Rivers, Oregon, in 2009 and 2010.

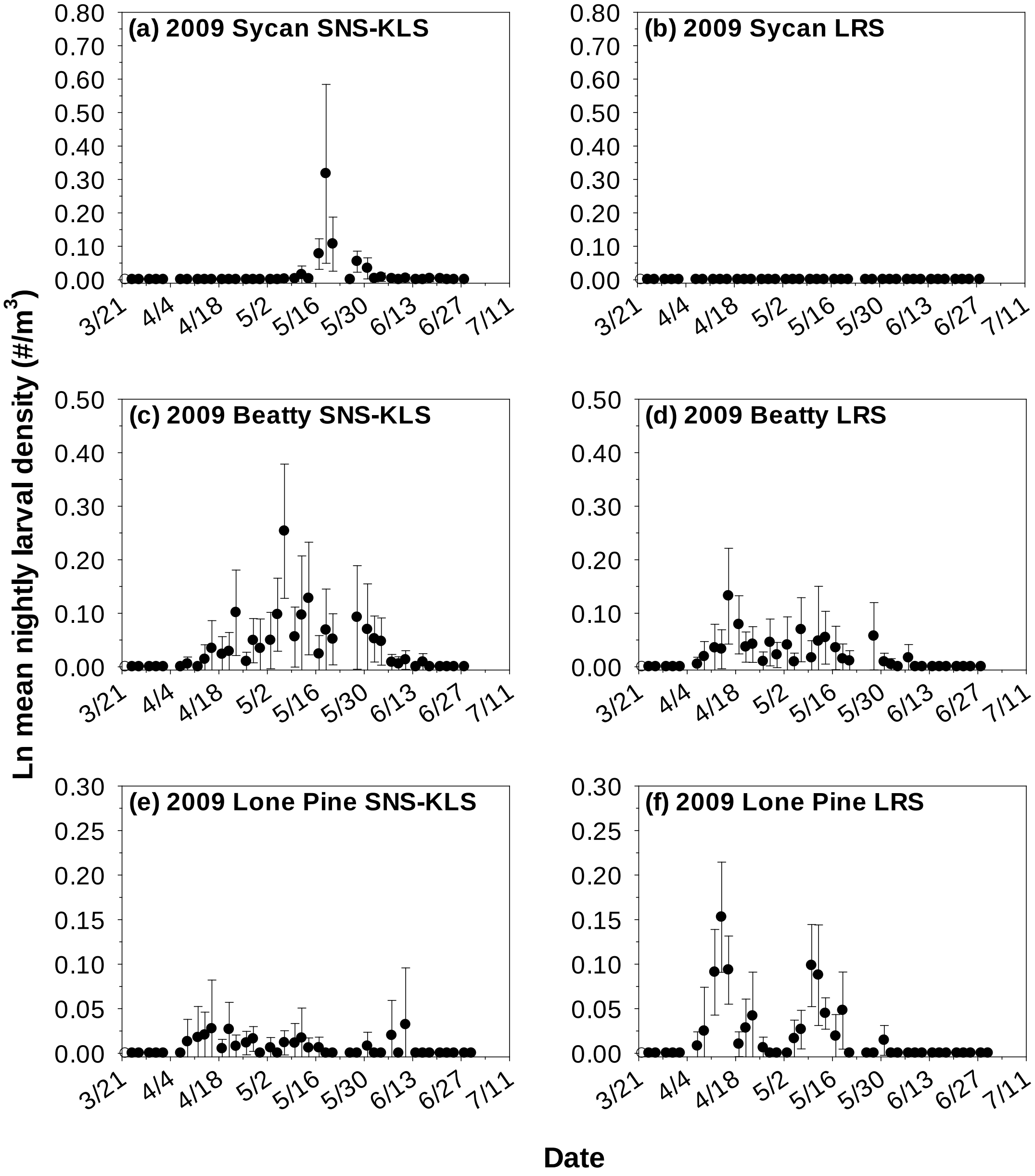


Figure 2. Natural log transformed nightly (± SD) mean density of Lost River sucker (LRS) and shortnose sucker or Klamath largescale (SNS-KLS) larvae at sample locations in 2009. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1. Note changes in scale for the y-axis among figures.

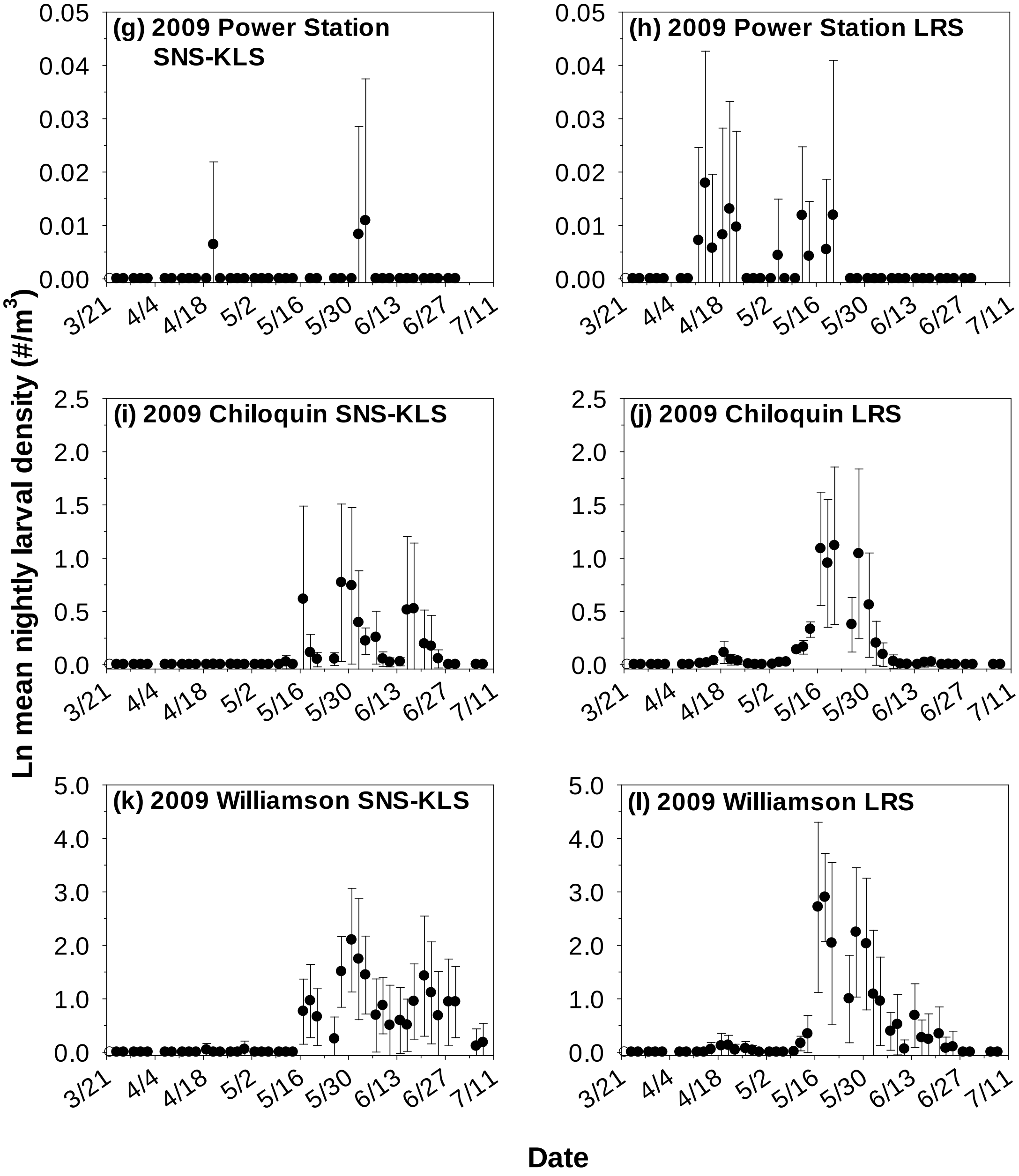


Figure 2. Natural log transformed nightly (± SD) mean density of Lost River sucker (LRS) and shortnose sucker or Klamath largescale (SNS-KLS) larvae at sampling locations in 2009.—Continued. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1. Note changes in scale for the y-axis among figures.

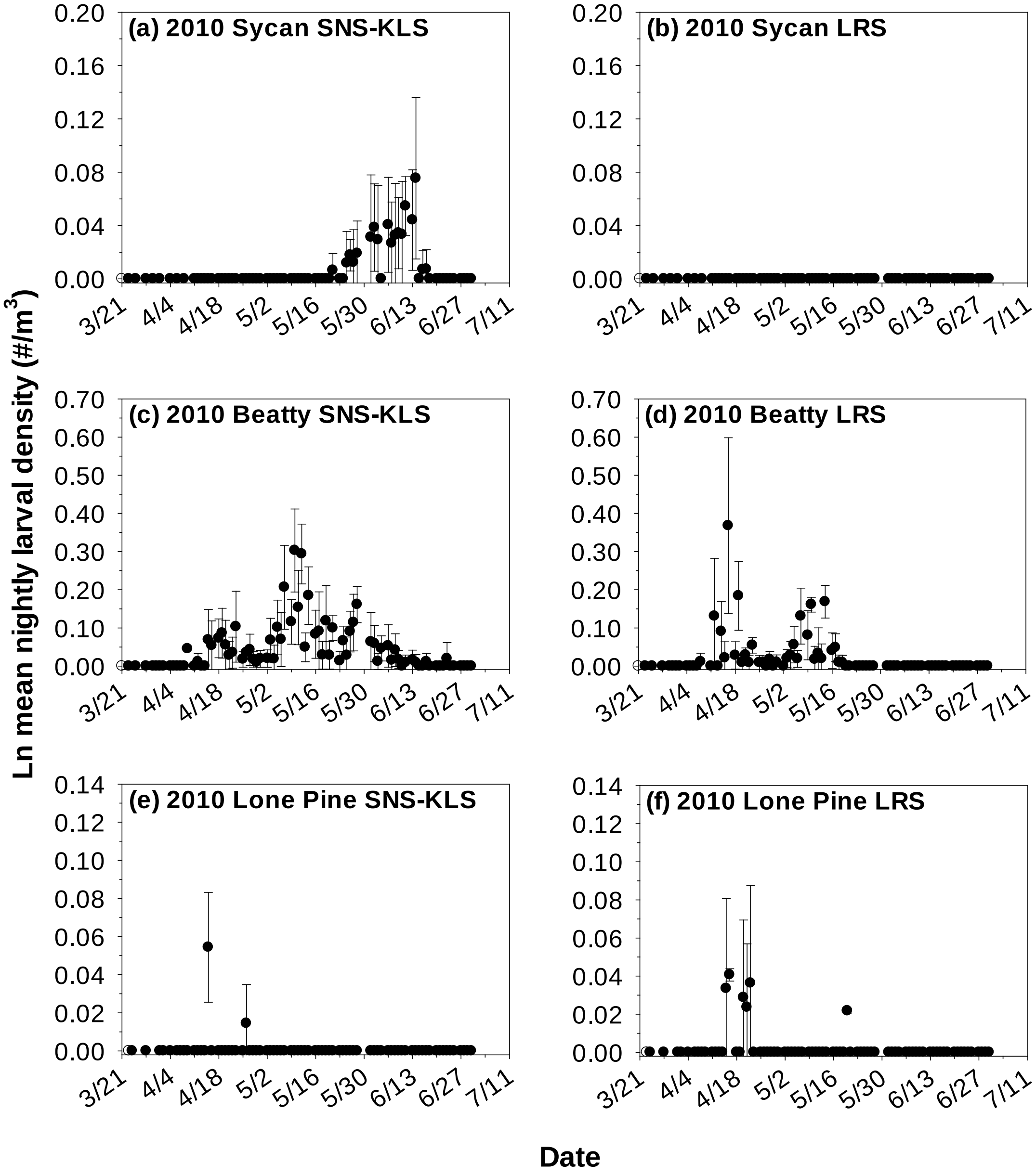
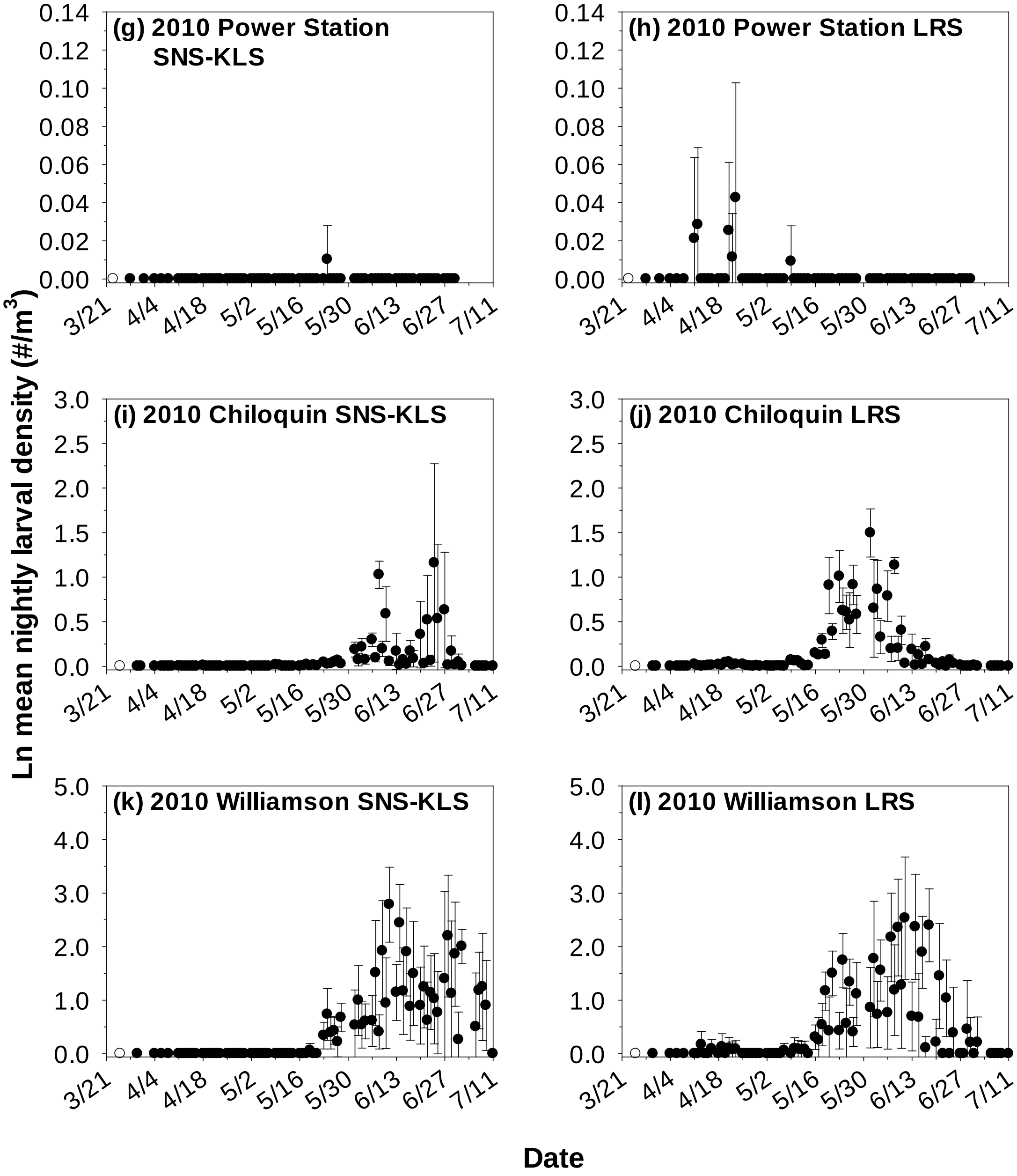


Figure 3. Natural log transformed nightly (± SD) mean density of Lost River sucker (LRS) and shortnose sucker or Klamath largescale (SNS-KLS) larvae at sampling locations in 2010. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1. Note changes in scale for the y-axis among figures.



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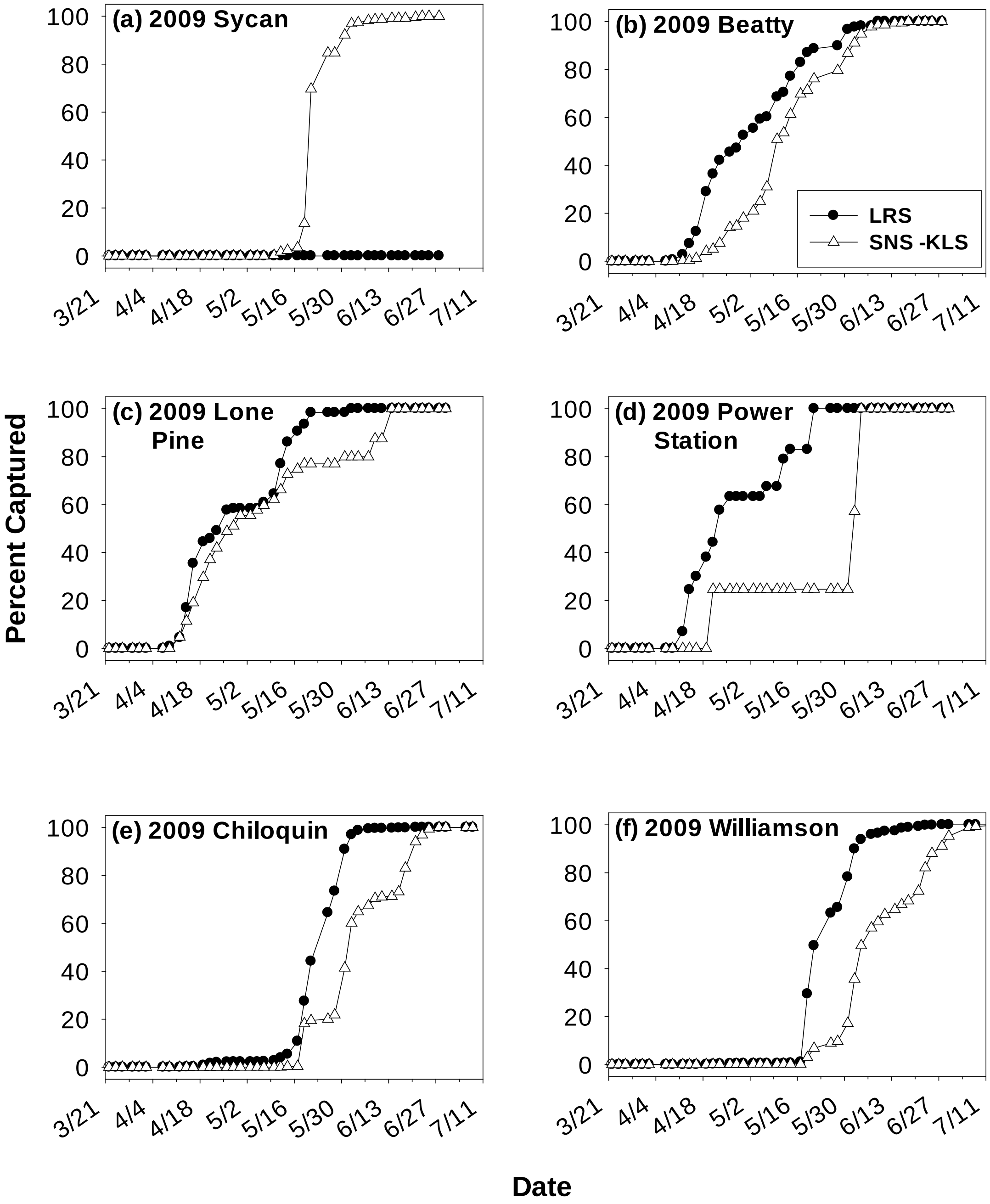

Figure 4. Cumulative percent of shortnose and Klamath largescale sucker (SNS-KLS) and Lost River sucker (LRS) larvae at sampling locations in 2009. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1.

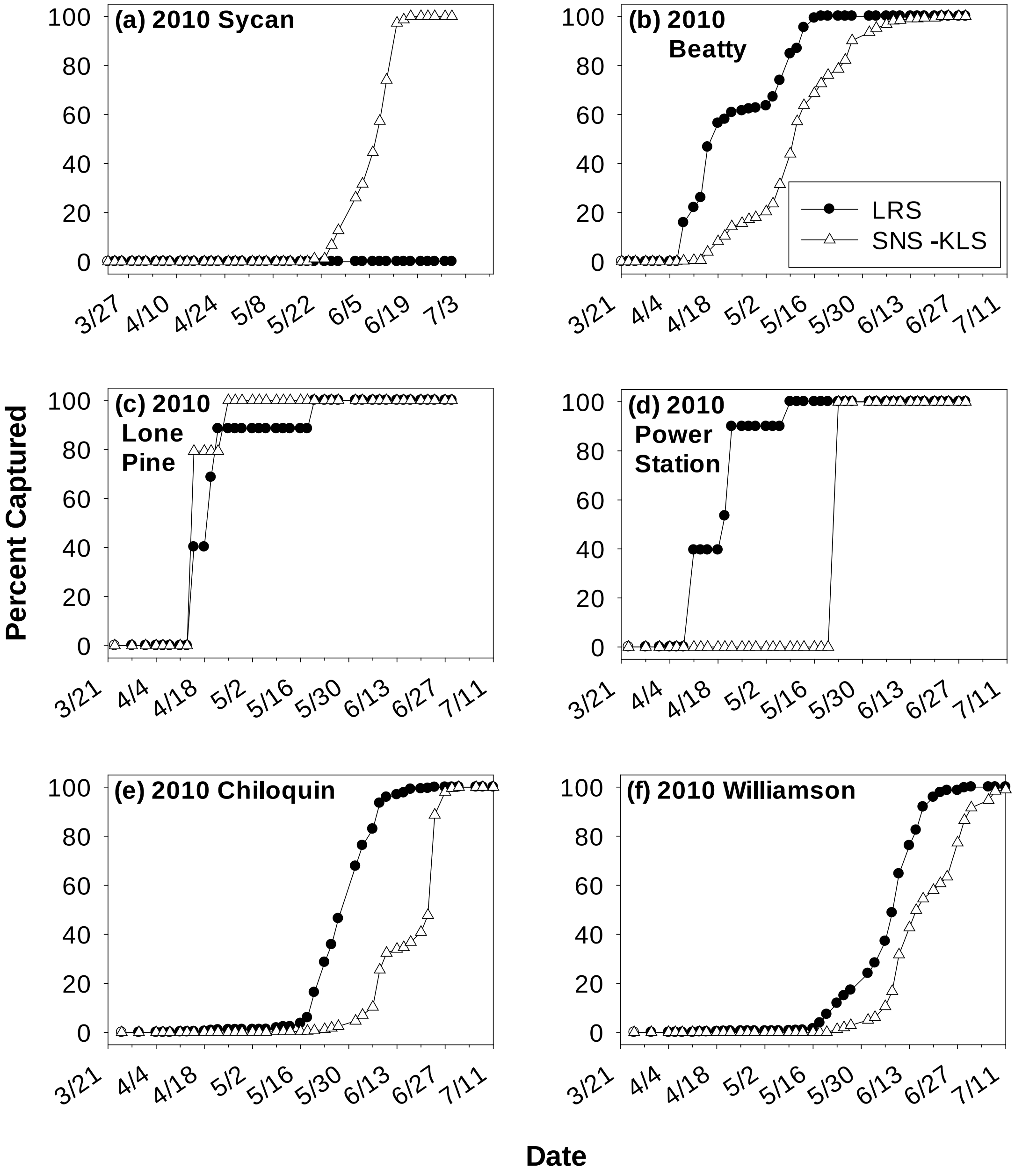

Figure 5. Cumulative percent of shortnose and Klamath largescale sucker (SNS-KLS) and Lost River sucker (LRS) larvae at sampling locations in 2010. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1.

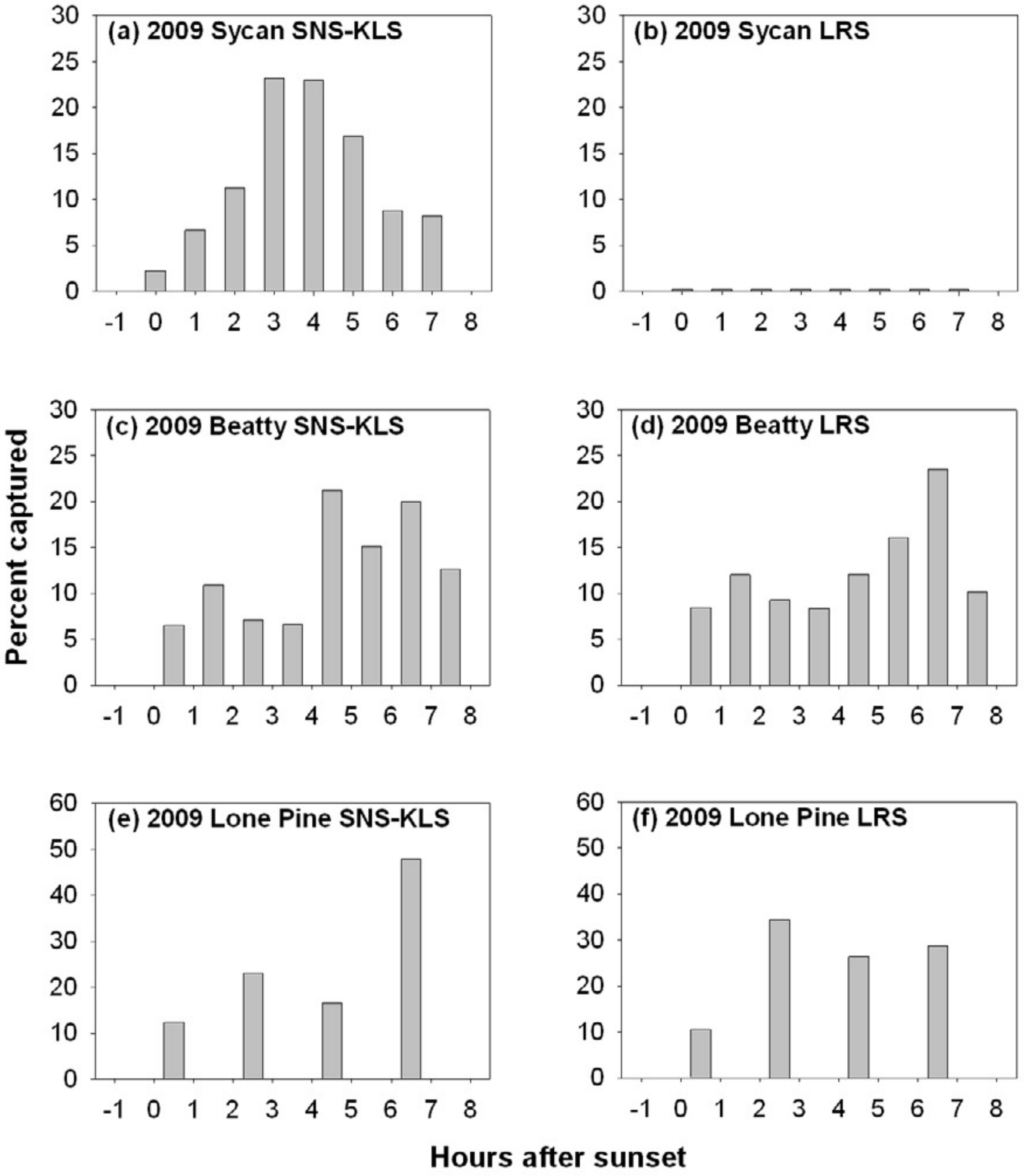

Figure 6. Percentage of shortnose and Klamath largescale sucker (SNS-KLS) and Lost River sucker (LRS) larvae capture at sampling locations by sample hour in 2009. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1.

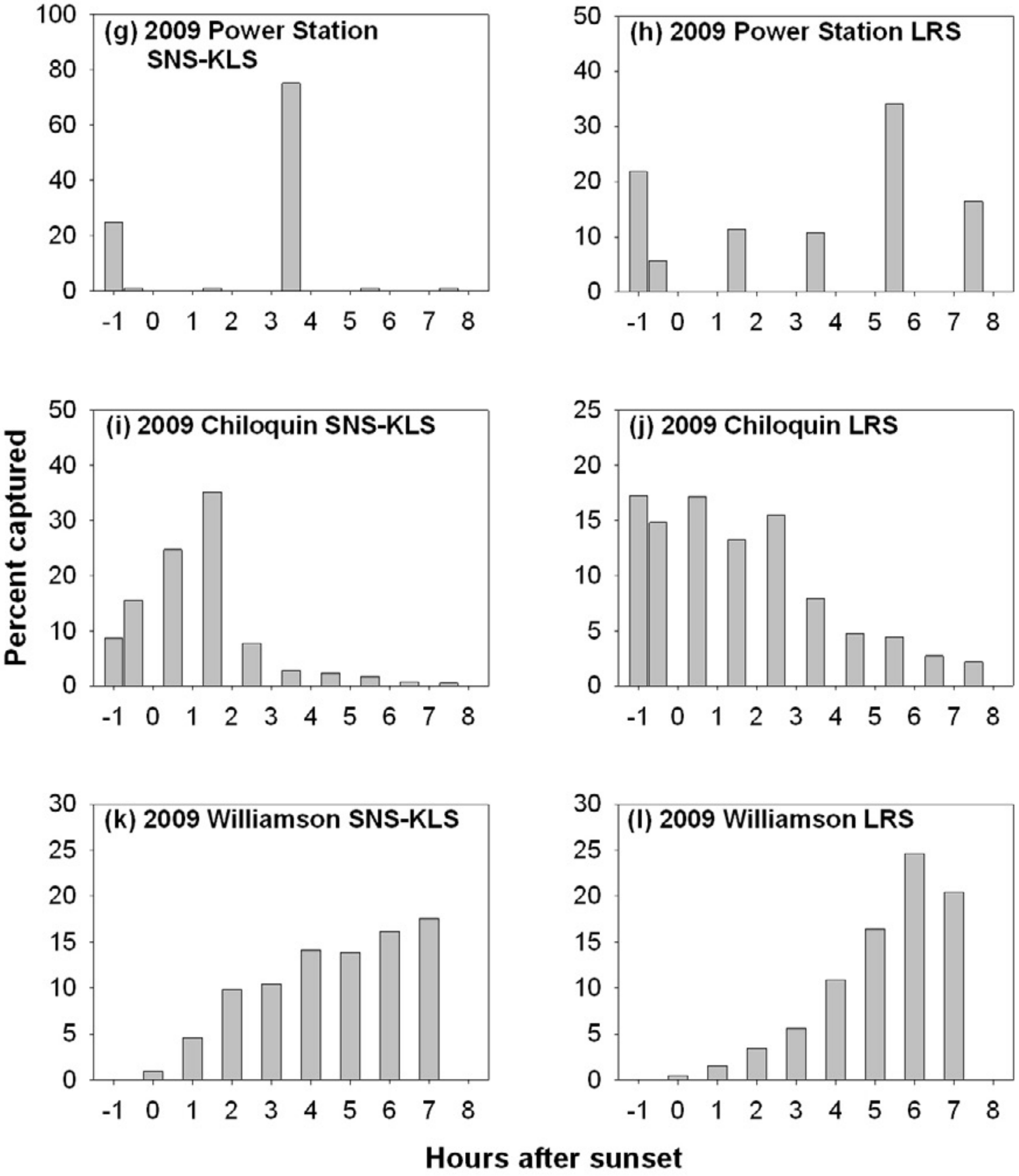

Figure 6. Percentage of shortnose and Klamath largescale sucker (SNS-KLS) and Lost River sucker (LRS) larvae capture at sampling locations by sample hour in 2009.—Continued. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1.

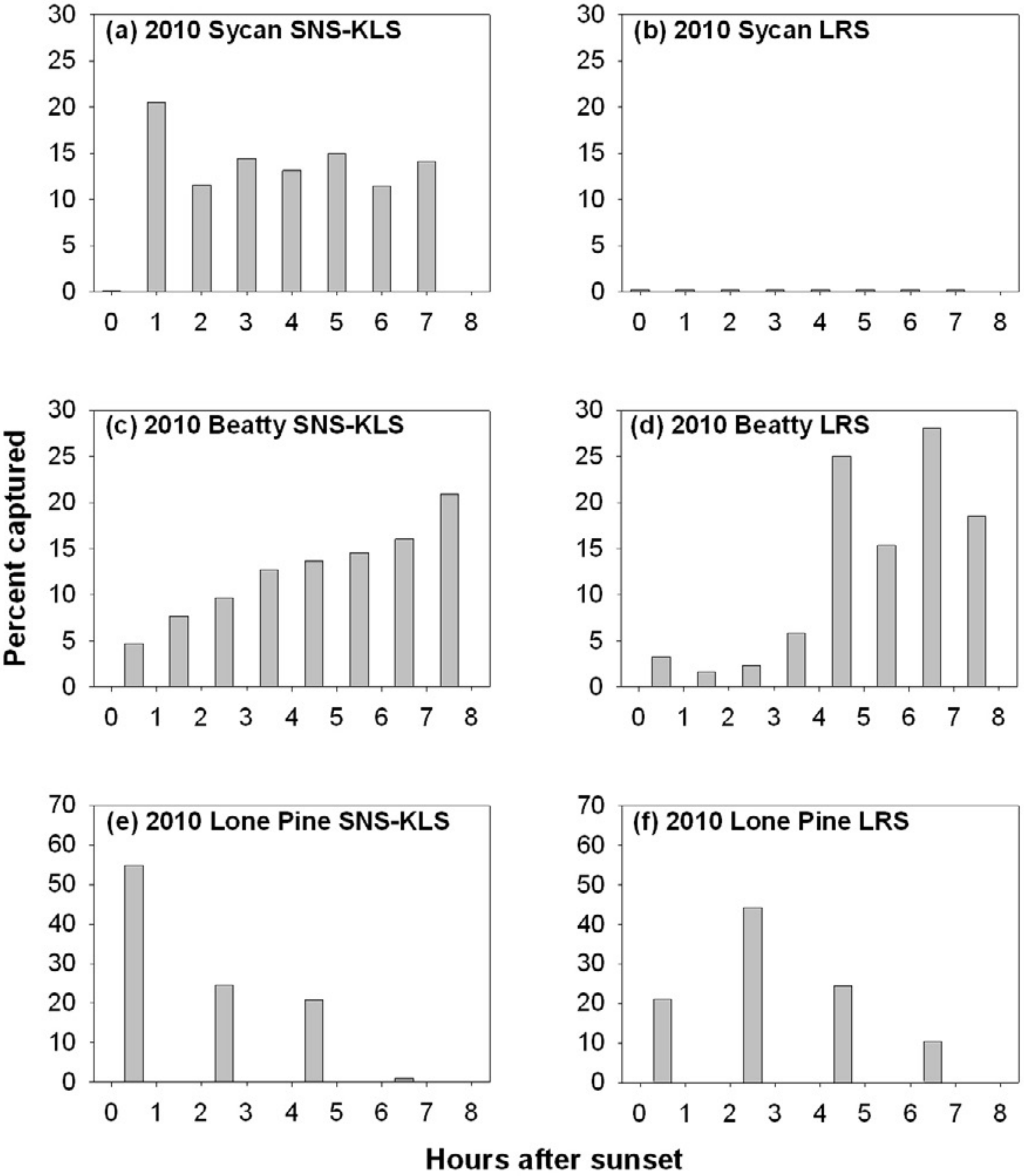

Figure 7. Percentage of shortnose and Klamath largescale sucker (SNS-KLS) and Lost River sucker (LRS) larvae capture at sampling locations by sample hour in 2010. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1.

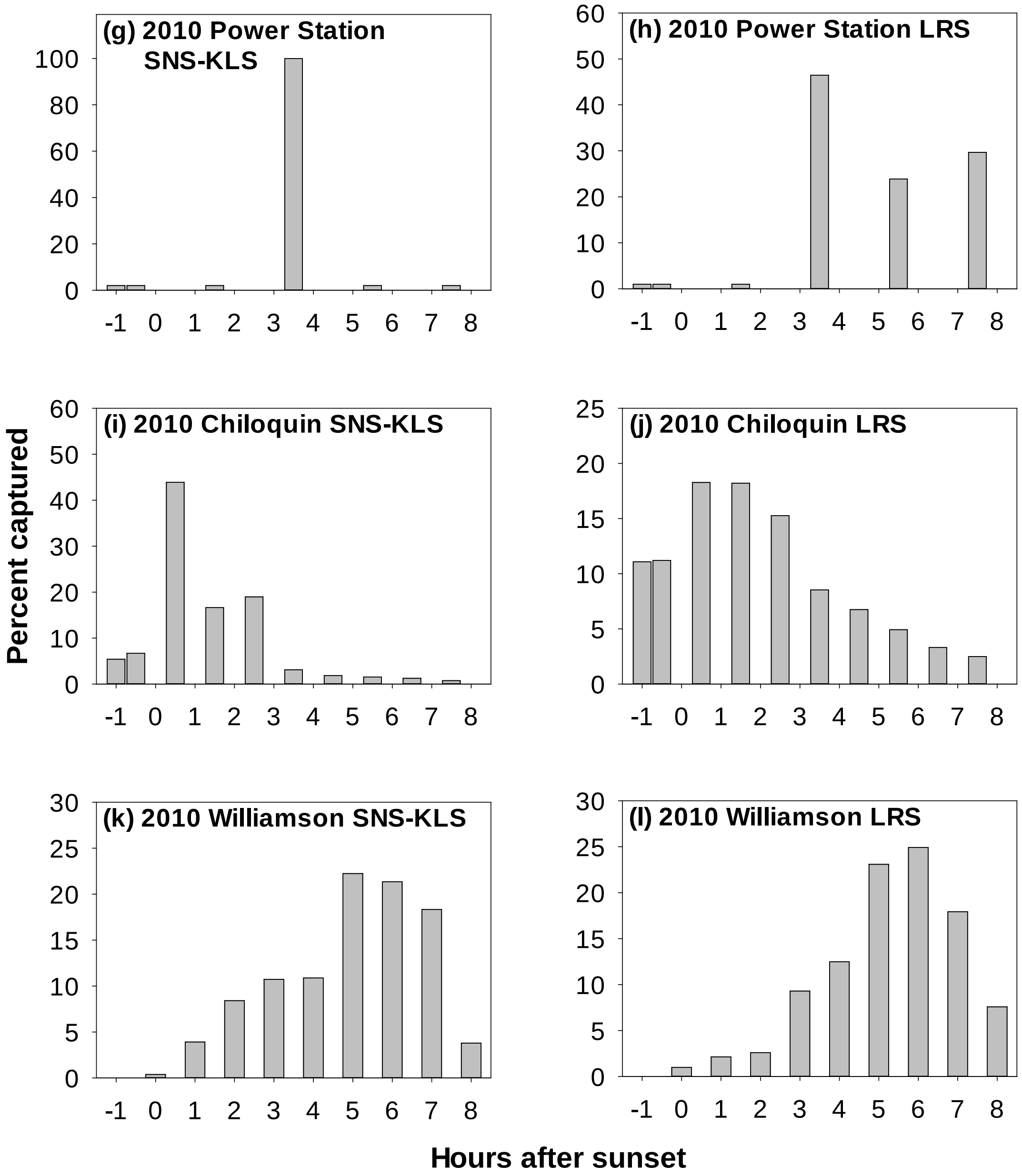

Figure 7. Percentage of shortnose and Klamath largescale sucker (SNS-KLS) and Lost River sucker (LRS) larvae capture at sampling locations by sample hour in 2010.—Continued. Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1.

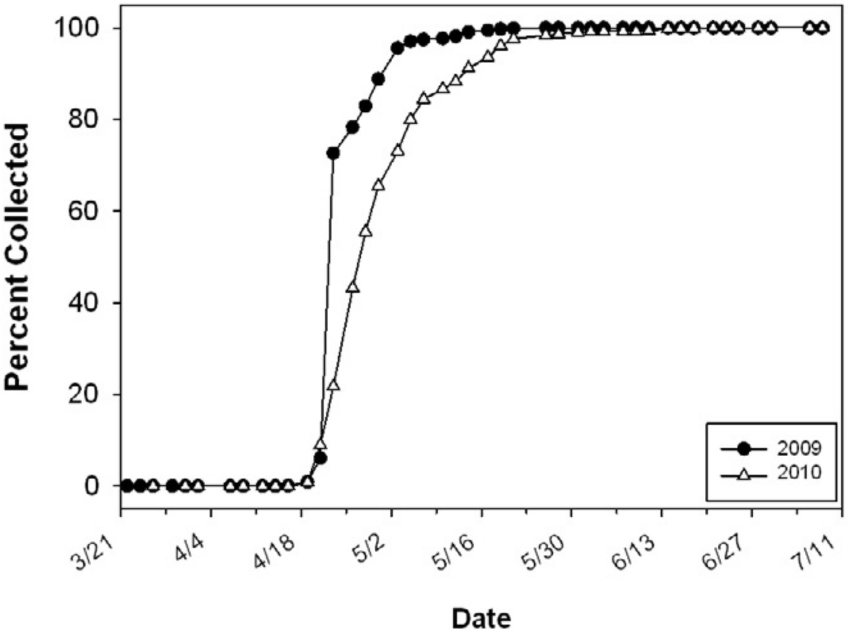

Figure 8. Cumulative percentages of sucker eggs collected at the Chiloquin site by date in 2009 and 2010. Site location is shown in figure 1.

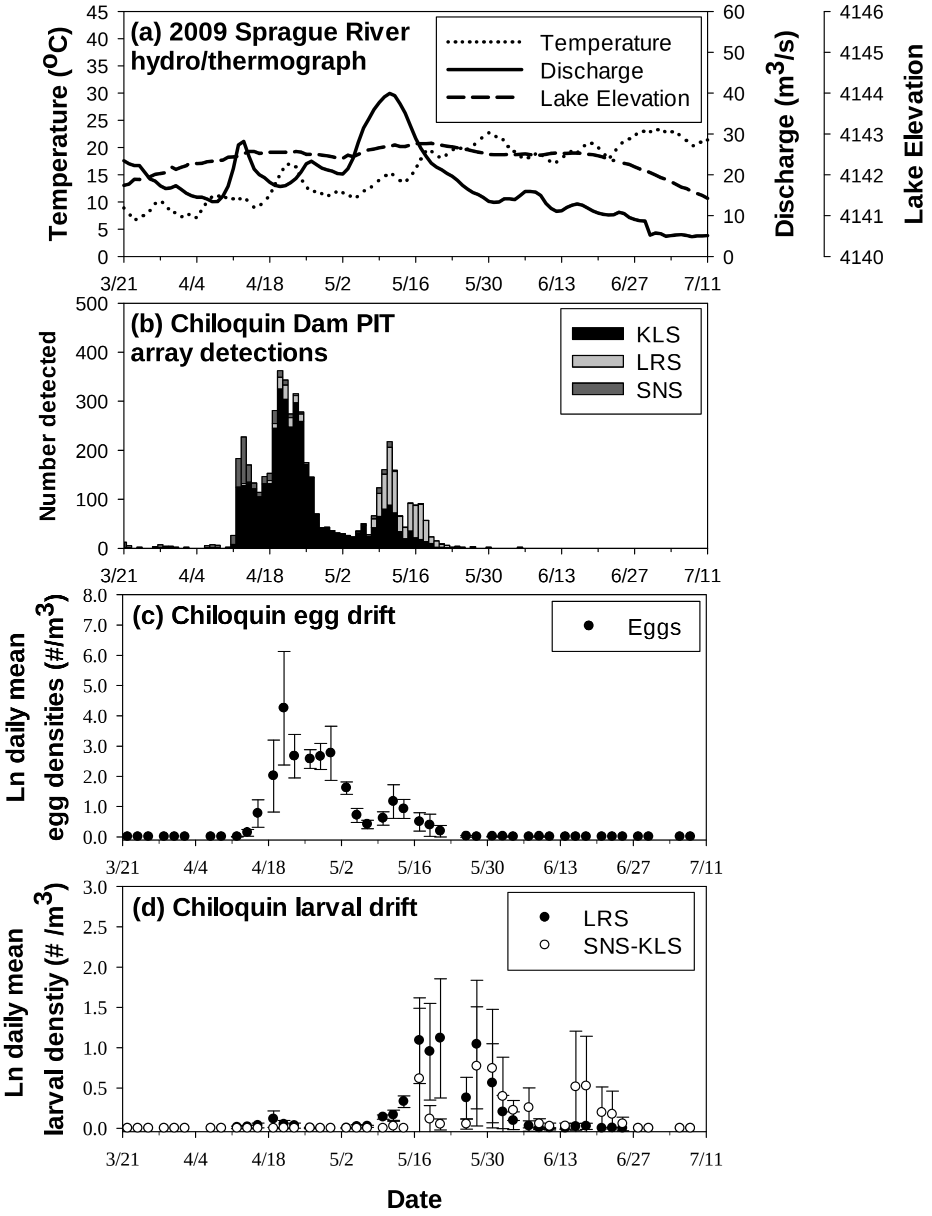

Figure 9. Sprague River temperature (C°) and discharge (m^3/s) and Upper Klamath Lake elevation (ft; a), date of passage or detection of passive integrated transponder (PIT) tagged adult Klamath largescale (KLS), Lost River sucker (LRS), and shortnose sucker (SNS) past the Chiloquin Dam on the Sprague River (b; U.S. Geological Survey, unpub. data, 2009), and natural log transformed mean nightly egg and larval densities at Chiloquin (c and d) in 2009. Larval shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site location is shown in figure 1.

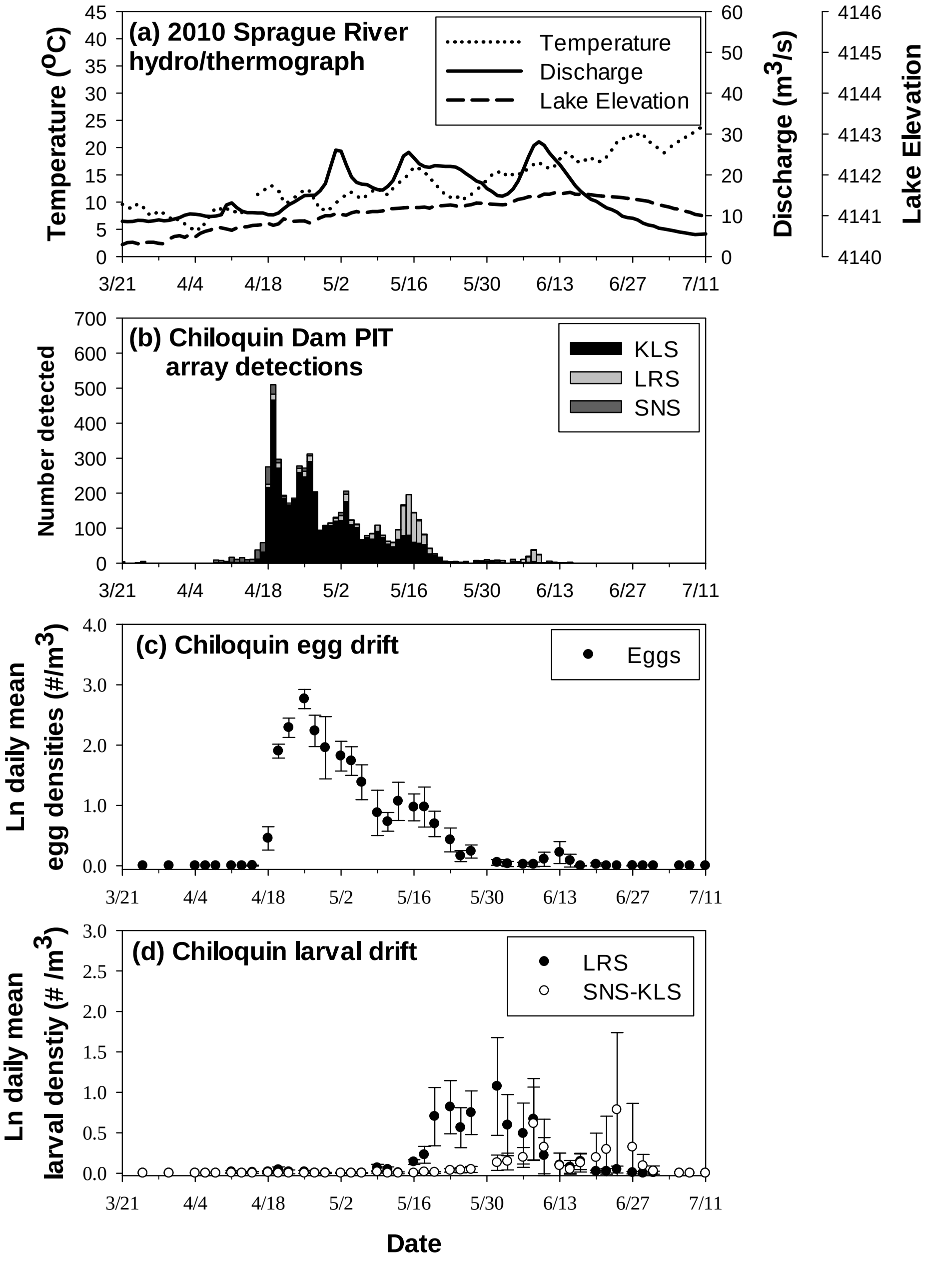

Figure 10. Sprague River temperature (C°) and discharge (m³/s) and Upper Klamath Lake elevation (ft; a), date of passage or detection of adult passive integrated transponder tagged Klamath largescale (KLS), Lost River sucker (LRS), and shortnose sucker (SNS) past the Chiloquin Dam on the Sprague River (b; U.S. Geological Survey, unpub. data, 2010), and natural log transformed mean nightly egg and larval densities at Chiloquin (c and d) in 2010. Larval shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Site location is shown in figure 1.

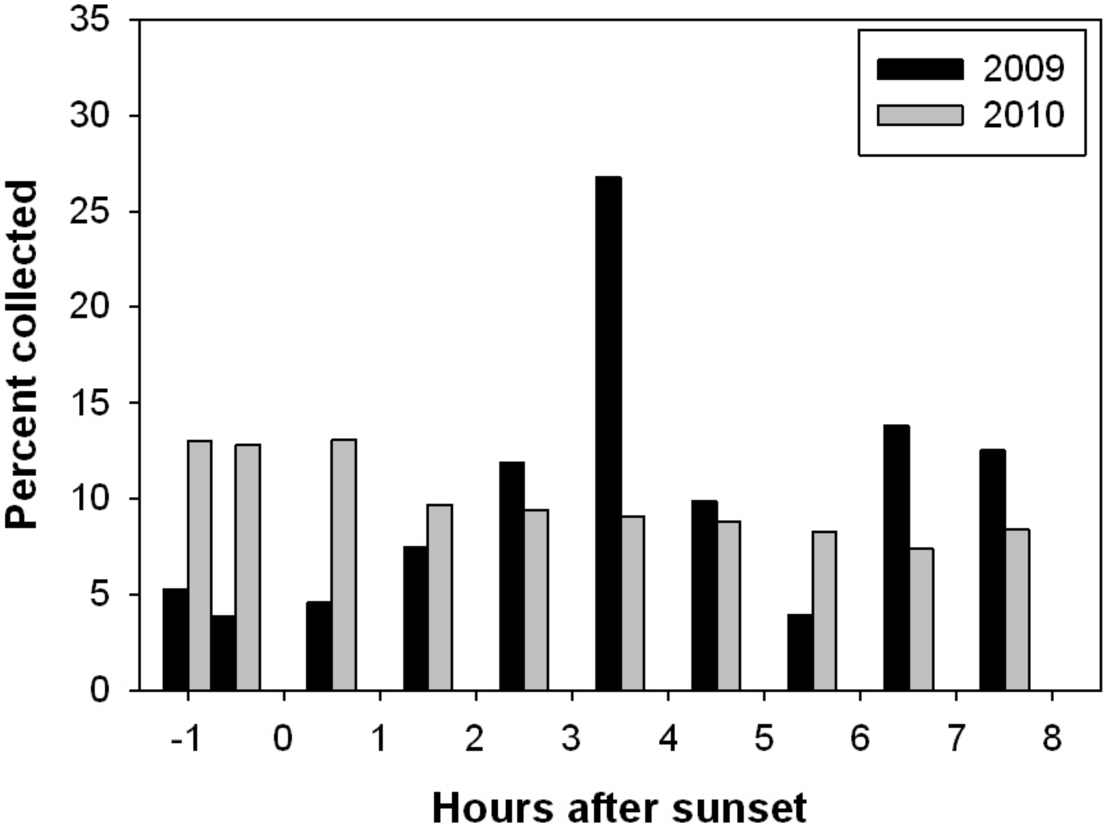

Figure 11. Percentage of sucker eggs collected in the drift by sample hour at the Chiloquin site in 2009 and 2010. Site location is shown in figure 1.

Table 1. Total number of samples collected and number of sampling events for the period between the first and last capture, including zero catches, of shortnose and Klamath largescale sucker (SNS-KLS), Lost River sucker (LRS), and unidentified sucker (UIS) larvae in the Sprague and Williamson Rivers in 2009 and 2010.

[Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Unidentified sucker larvae had intermediate identifying characteristics or were damaged and therefore were not classified as a particular species. Site locations are shown in figure 1]

Site	Year	Total number of samples collected at each site	Number of sampling events where species was collected		
			SNS-KLS	LRS	UIS
Sycan	2009	318	143	0	17
	2010	318	96	0	88
Beatty	2009	317	197	219	95
	2010	323	253	141	96
Lone Pine	2009	165	111	94	44
	2010	152	24	68	4
Power Station	2009	233	103	97	0
	2010	228	1	78	91
Chiloquin	2009	410	301	275	271
	2010	421	350	350	279
Williamson	2009	372	295	257	286
	2010	375	207	306	135

Table 2. Sampling schedule for larval drift sample sites in 2009 and 2010.

[First and last sample values indicate hours after sunset while the interval value indicates the time, in hours, between samples]

Site	First sample	Last sample	Interval
Sycan	0.0	7.0	1.0
Beatty	0.5	7.5	1.0
Lone Pine	0.5	6.5	2.0
Power Station	-1.0	7.5	[1]2.0
Chiloquin	-1.0	7.5	[1]1.0
Williamson	0.0	8.0	1.0

[1] First two samples of the night were spaced 0.5 hours apart.

Table 3. Mean larval densities (larvae/m^3) for drift samples collected during the period between the first and last capture of shortnose and Klamath largescale sucker (SNS-KLS), Lost River sucker (LRS), and unidentified sucker (UIS) larvae at sites on the Sprague and Williamson Rivers in 2009 and 2010.

[Shortnose and Klamath largescale suckers are grouped because larvae of these species cannot be morphologically differentiated. Unidentified sucker larvae had intermediate identifying characteristics and therefore were not classified as a particular species. Site locations are shown in figure 1]

Site	Sample year	SNS-KLS	LRS	UIS
Sycan	2009	0.0419	0	0.0097
	2010	0.2252	0	0.0026
Beatty	2009	0.0562	0.0360	0.0062
	2010	0.0617	0.0683	0.0035
Lone Pine	2009	0.0098	0.0379	0.0029
	2010	0.0293	0.0056	0
Power Station	2009	0.0015	0.0065	0
	2010	0.0312	0.0048	0.0009
Chiloquin	2009	0.3541	0.4255	0.0266
	2010	0.1923	0.3179	0.0408
Williamson	2009	1.6992	3.9347	0.1048
	2010	3.3021	2.0832	0.8573

Table 4. Date, hour, and density (larvae/ m^3) of peak catches of shortnose sucker-Klamath largescale (SNS-KLS) larvae and Lost River sucker (LRS) larvae at sample sites on the Sprague and Williamson Rivers in 2009 and 2010.

[Larval SNS and KLS are grouped because larvae of these species cannot be morphologically differentiated. Site locations are shown in figure 1]

		2009			2010		
Site	Taxa	Date	Hours after sunset	Peak larvae density	Date	Hours after sunset	Peak larvae density
Sycan	SNS-KLS	05/20/09	4.0	1.0668	06/14/10	4.0	0.1475
	LRS	--	--	--	--	--	--
Beatty	SNS-KLS	05/08/09	4.5	0.5146	05/10/10	7.5	0.5477
	LRS	05/13/09	6.5	0.3472	04/09/10	4.5	1.4747
Lone Pine	SNS-KLS	06/12/09	6.5	0.1363	04/15/10	0.5	0.0776
	LRS	04/14/09	2.5	0.2504	04/22/10	2.5	0.0753
Power Station	SNS-KLS	06/03/09	3.5	0.0673	05/24/10	3.5	0.0312
	LRS	05/20/09	7.5	0.0738	04/23/10	5.5	0.0889
Chiloquin	SNS-KLS	05/28/09	1.5	7.0330	06/24/10	0.5	15.4326
	LRS	05/19/09	0.5	7.8178	06/01/10	1.5	4.9601
Williamson	SNS-KLS	06/01/09	4.0	28.1690	06/11/10	7.0	39.1975
	LRS	05/18/09	6.0	79.8535	06/14/10	6.0	30.5660

Table 5. Growth stages for shortnose and Klamath largescale sucker (SNS-KLS), Lost River sucker (LRS), and unidentified sucker (UIS) captured in the Williamson and Sprague Rivers in 2009 and 2010.

[Larval SNS and KLS are grouped because larvae of these species cannot be morphologically differentiated. Unidentified sucker larvae had intermediate identifying characteristics and therefore were not classified as a particular species. Larvae categorized with undetermined growth stage typically were damaged in a way that prevented the determination of growth stage. Site locations are shown in figure 1]

		2009					2010				
Site	Taxa	Pre-flexion	Flexion	Post-flexion	Undeter-mined	Juvenile	Pre-flexion	Flexion	Post-flexion	Undeter-mined	Juvenile
Sycan	SNS-KLS	0	260	8	0	0	0	78	0	0	0
	LRS	0	0	0	0	0	0	0	0	0	0
	UIS	0	7	0	0	0	0	3	5	1	0
Beatty	SNS-KLS	1	320	2	0	0	0	394	0	0	0
	LRS	2	176	4	0	0	0	199	0	0	0
	UIS	1	12	0	1	0	0	5	3	1	0
Lone Pine	SNS-KLS	0	34	2	0	0	0	4	0	0	0
	LRS	0	140	0	0	0	0	10	0	0	0
	UIS	0	2	0	3	0	0	0	2	0	0
Power Station	SNS-KLS	0	3	0	0	0	0	1	0	0	0
	LRS	0	19	0	0	0	0	8	0	0	0
	UIS	0	0	0	0	0	0	0	1	1	0
Chiloquin	SNS-KLS	1,081	3,373	7	40	0	95	3,508	5	0	0
	LRS	953	6,181	1	0	0	67	6,197	0	0	0
	UIS	3	0	0	176	0	98	514	4	237	0
Williamson	SNS-KLS	1	763	2	0	0	0	1,214	1	0	0
	LRS	2	2,460	2	0	0	11	1,639	0	0	0
	UIS	0	15	0	31	0	1	277	0	54	0

Table 6. Median standard length and the number of larvae <9.0 mm and juveniles >14.5 mm collected for shortnose and Klamath largescale sucker (SNS-KLS), Lost River sucker (LRS), and unidentified sucker (UIS) captured in 2009 and 2010.

[Larval SNS and KLS are grouped because larvae of these species cannot be morphologically differentiated. Unidentified sucker larvae had intermediate identifying characteristics, thus were not classified as a particular species. Site locations are shown in figure 1]

		2009			2010		
Site	Taxa	Median	<9.0 mm	>14.5 mm	Median	<9.0 mm	>14.5 mm
Sycan	SNS-KLS	12.2	0	0	12.4	0	0
	LRS	--	--	--	--	--	--
	UIS	11.7	0	0	13.8	0	2
Beatty	SNS-KLS	11.8	0	0	12.1	0	0
	LRS	12.0	0	0	12.9	0	0
	UIS	11.7	0	0	13.2	0	3
Lone Pine	SNS-KLS	11.8	0	0	12.7	0	0
	LRS	11.9	0	0	12.9	0	0
	UIS	15.9	0	4	13.4	0	0
Power Station	SNS-KLS	11.8	0	0	12.8	0	0
	LRS	11.9	0	0	13.0	0	0
	UIS	0	0	0	13.7	0	0
Chiloquin	SNS-KLS	11.6	19	0	11.8	31	0
	LRS	12.1	6	0	11.8	2	1
	UIS	10.5	0	0	12.0	32	3
Williamson	SNS-KLS	11.6	0	0	12.0	0	0
	LRS	11.8	0	0	12.0	0	0
	UIS	0	0	0	12.2	0	0

Table 7. Total number of sucker eggs, average egg densities (eggs/ m^3), and peak egg densities (eggs/ m^3) for all sucker species combined for the period between the first and last capture, including zero catches, in 2009 and 2010.

[Site locations are shown in figure 1]

Site	Sample year	Total eggs	Average density	Peak density
Sycan	2009	19	0.0006	0.0783
	2010	261	0.0236	2.2040
Beatty	2009	2	0.0002	0.0415
	2010	2	0.0002	0.0774
Lone Pine	2009	4	0.0006	0.1029
	2010	0	--	--
Power Station	2009	2	0.0002	0.0257
	2010	0	--	--
Chiloquin	2009	101,887	6.2860	608.1693
	2010	38,215	1.6674	19.3676
Williamson	2009	0	--	--
	2010	0	--	--

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