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Status, Distribution, and Life History Investigations of Warner Suckers, 2006-2010

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Sunset on Hart Lake looking southwest with the Warner Mountains in the background.
Photo credit: S. Starcevich

Paul Scheerer[1], Steven Jacobs[1], Mark Terwilliger[2], Stephanie Miller[1], Stephanie Gunckel[1], Shannon Richardson[1], and Michael Heck[3]

[1]Oregon Department of Fish and Wildlife
Native Fish Investigations Project
28655 Highways 34, Corvallis, Oregon 97333

[2]Oregon State University
Department of Fisheries and Wildlife
Nash Hall, Corvallis, Oregon 97330

[3]U.S. Geological Service
Forest and Rangeland Ecosystem Science Center
3200 SW Jefferson Way, Corvallis, Oregon 97331

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INTRODUCTION

The Warner sucker *Catostomus warnerensis* is endemic to the Warner Valley, a subbasin of the Great Basin in southeastern Oregon and northwestern Nevada. This species was historically abundant (Snyder 1908) and its historical range includes three permanent lakes (Hart, Crump, and Pelican), several ephemeral lakes, a network of sloughs and diversion canals, and three major tributary drainages (Honey, Deep, and Twentymile creeks). Warner sucker abundance and distribution has declined over the past century and it was federally listed as threatened in 1985 due to habitat fragmentation and threats posed by the proliferation of piscivorous non-native game fishes (U.S. Fish and Wildlife Service 1985).

The Warner Valley is a northeast-southwest trending endorheic basin that extends approximately 90 km (Figure 1). The elevation of the valley floor is approximately 1,370 m and the basin is bound by fault block escarpments, the Warner Rim on the west and Hart Mountain and Poker Jim Ridge on the east. The Warner basin was formed during the middle Tertiary and late Quaternary geologic periods as a result of volcanic and tectonic activity (Baldwin 1974). Abundant precipitation during the Pleistocene Epoch resulted in the formation of Pluvial Lake Warner (Hubbs and Miller 1948). At its maximum extent approximately 11,000 years ago, the lake reached approximately 100 m in depth and 1,300 km^2 in area (Snyder et al. 1964; Weide 1975).

The Warner sucker inhabits the lakes and low gradient stream reaches of the Warner Valley. The metapopulation of Warner suckers is comprised of two life history forms: lake and stream morphs. The lake suckers display a lacustrine-adfluvial pattern in which they spend most of the year in the lake and spawn in the streams. However, when upstream migration is hindered by low stream flows during drought years or by irrigation diversion dams, lake suckers may spawn in nearshore areas of the lakes (White et al. 1990). Large lake-dwelling populations of introduced fishes in the lakes likely reduce sucker recruitment by predation on young suckers (U.S. Fish and Wildlife Service 1998). Periodic lake desiccation also threatens the lake suckers. The stream suckers display a fluvial life-history pattern and spawn in the three major tributary drainages (Honey, Deep, and Twentymile Creeks). Threats specific to the stream form include water withdrawals for irrigation and impacts from grazing. Stream suckers recolonized the lakes after past drying events (mid-1930's and early-1990's).

The Recovery Plan for the Threatened and Rare Native Fishes of the Warner Basin and Alkali Subbasin (U.S. Fish and Wildlife Service 1998) sets three recovery criteria for delisting the species. These criteria require that: (1) a self-sustaining metapopulation is distributed throughout the drainages of Twentymile Creek, Honey Creek, and below the falls on Deep Creek, and in Pelican, Crump, and Hart Lakes; (2) passage is restored within and among these drainages so that individual populations of Warner suckers can function as a metapopulation; and (3) no threats exist that would likely threaten the survival of the species over a significant portion of its range.

The Oregon Department of Fish and Wildlife's (ODFW's) Native Fish Investigations Project conducted investigations from 2006 through 2010 to describe the conservation (recovery) status of Warner suckers. The objectives of our investigations were to: 1) describe the current distribution of suckers in the Warner subbasin, 2) estimate their abundance in the lakes and streams, 3) collect life history information, and 4) describe the primary factors that currently limit the sucker's ability to maintain a functioning metapopulation, including connectivity/fragmentation of habitats and factors affecting successful recruitment in the lake and stream environments. Previous similar studies were conducted in 1990, 1991, 1994, 1995, 1996, 1997, and 2001 (White et al. 1990; White et al. 1991; Allen et al. 1994; Allen et al. 1995; Allen et al. 1996; Bosse et al. 1997; Hartzell et al. 2001).

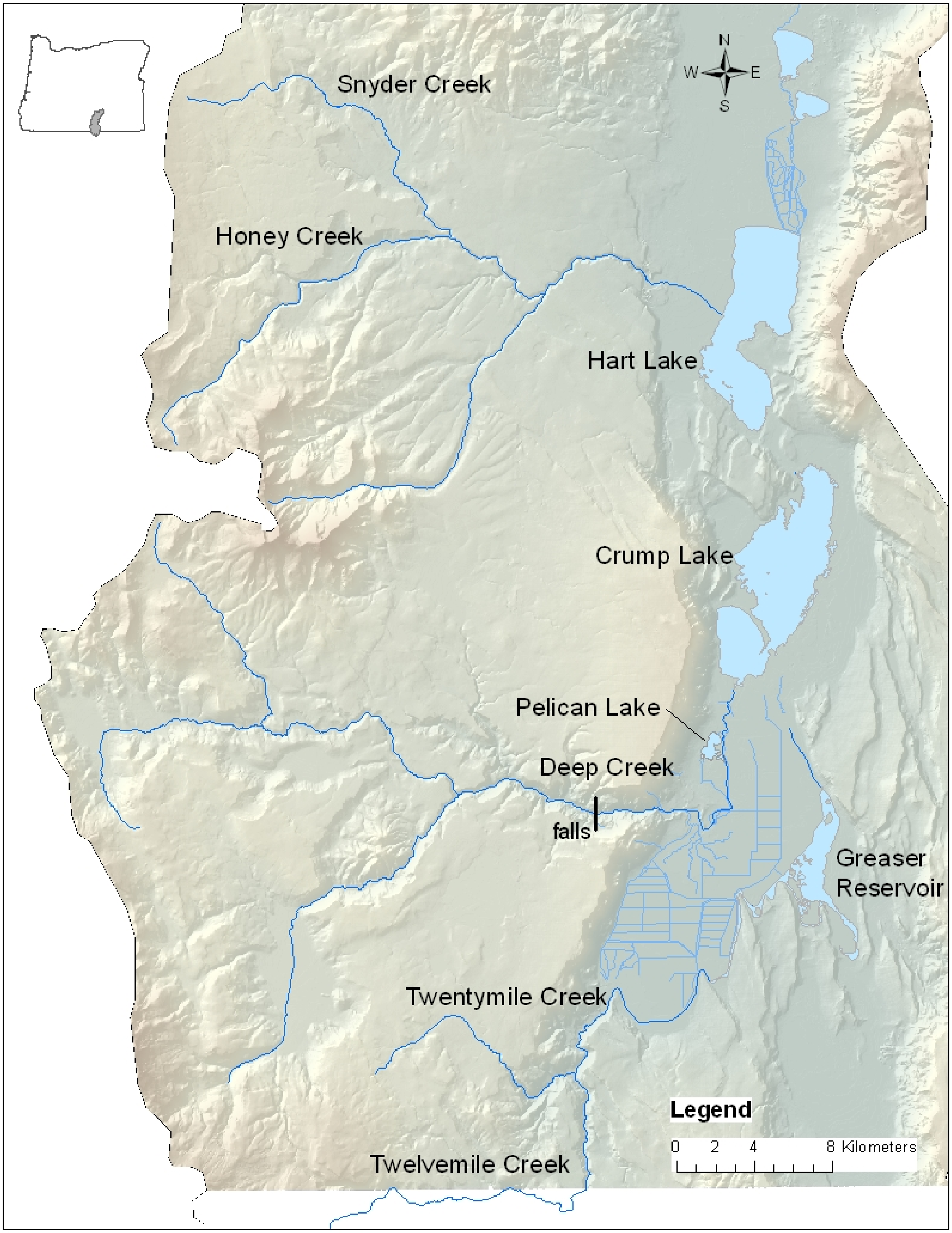

Figure 1. Map of the study area in the Warner basin, Oregon. Dark blue lines are tributaries and light blue lines are irrigation canals.

We addressed these objectives by implementing the following tasks: 1) conducting surveys in Hart and Crump Lakes to describe the distribution and quantify the abundance of Warner suckers, search for evidence of recent recruitment, estimate sucker abundance relative to nonnative fish abundance, and describe certain life history characteristics, 2) tagging suckers with Passive Integrated Transponder (PIT) tags in the lakes and tributaries to estimate growth rates and describe seasonal movements, 3) radio tracking suckers in the lakes and tributaries to describe seasonal movements, 4) fishing screw traps in Warner basin tributaries to monitor downstream movements, 5) operating a trap at a fish ladder on a Warner tributary to assess upstream passage success, 6) conducting surveys in Warner basin tributaries to describe the current distribution of stream resident populations of Warner suckers and to quantify their abundance, 7) describing associations between the distribution of suckers and habitat variables in Twentymile Creek, 8) trapping larval suckers in the tributaries to describe the relative abundance and timing of larval movements, 9) describing life history parameters including growth rates, length frequency distributions, length at maturity, and weight-length relationships, 10) evaluating a non-lethal ageing technique, 11) describing the distribution and abundance of the Warner suckers at Summer Lake Wildlife Management area, where a self-sustaining population became established after fish salvage from Hart Lake during the 1992 drought, and 12) collecting tissue samples for future genetic analyses. This report compiles the results of this work, synthesizes and interprets findings relative to the conservation status of the species, and recommends future studies.

METHODS

Distribution and Abundance of Suckers in the Warner Lakes

We used trap nets to capture Warner suckers to describe the current distribution and abundance in the Warner Lakes. We sampled in Hart and Crump Lakes from 3 April to 22 June 2006 (12 nets) and 1 April to 17 June 2008 (18 nets), in Crump Lake (12 nets) from 8 April to 4 June 2010, and in Greaser Reservoir from 20 May- 21 May 2010 (2 nets). The trap nets had wide rectangular openings that measured 0.9 m tall by 1.8 m wide and narrowed to a vertical slot that was 0.9 m tall by 0.22 m wide, followed by four funneling hoops that measured 0.76 m in diameter with 0.15 m diameter fyke openings. Nets were a total of 3.7 m long with a lead net measuring 15 m long by 0.9 m tall. Twelve of the nets had 19 mm mesh and six had 13 mm mesh.

From 2006 through 2010, spring lake elevations varied depending on the amount of snow pack and spring precipitation. Tributary flows were high in 2006 (Figure 2), both Crump and Hart Lakes filled, and water spilled into the ephemeral lakes to the north. From 2007 through 2010, stream flows were below average and Hart and Crump Lakes did not fill completely. In 2010, Hart Lake was too shallow to trap effectively (<0.3 m deep), as was the northern portion of Crump Lake in 2008 and 2010. In 2006, we set individual nets perpendicular to the shoreline, connected the lead nets to a metal “T” fence post driven into the substrate at the lake shore or the shoreline of small islands, and stretched the nets tight with a boat with the trap pots oriented in an offshore direction. Because the lakes did not fill in 2008 or 2010 and mud flats extended out from the shoreline as far as 100 m, we set the nets off-shore in pairs, with their lead nets tied together. We attached an additional lead net, measuring 15 m long by 0.9 m tall with 19 mm mesh, between the lead nets on the trap nets when we fished paired nets. In all cases, we pulled the purse ropes tight and weighed them down with 3.6-4.5 kg navy anchors.

We accessed the nets using a 6.1 m sled boat powered by a 150 hp jet outboard motor. We typically set nets on Mondays, checked and reset them approximately every 24 hr during the week, and removed them from the water after checking them on Fridays (four overnight net sets per week). At each trap location, we recorded the time the net was set, the time the net was

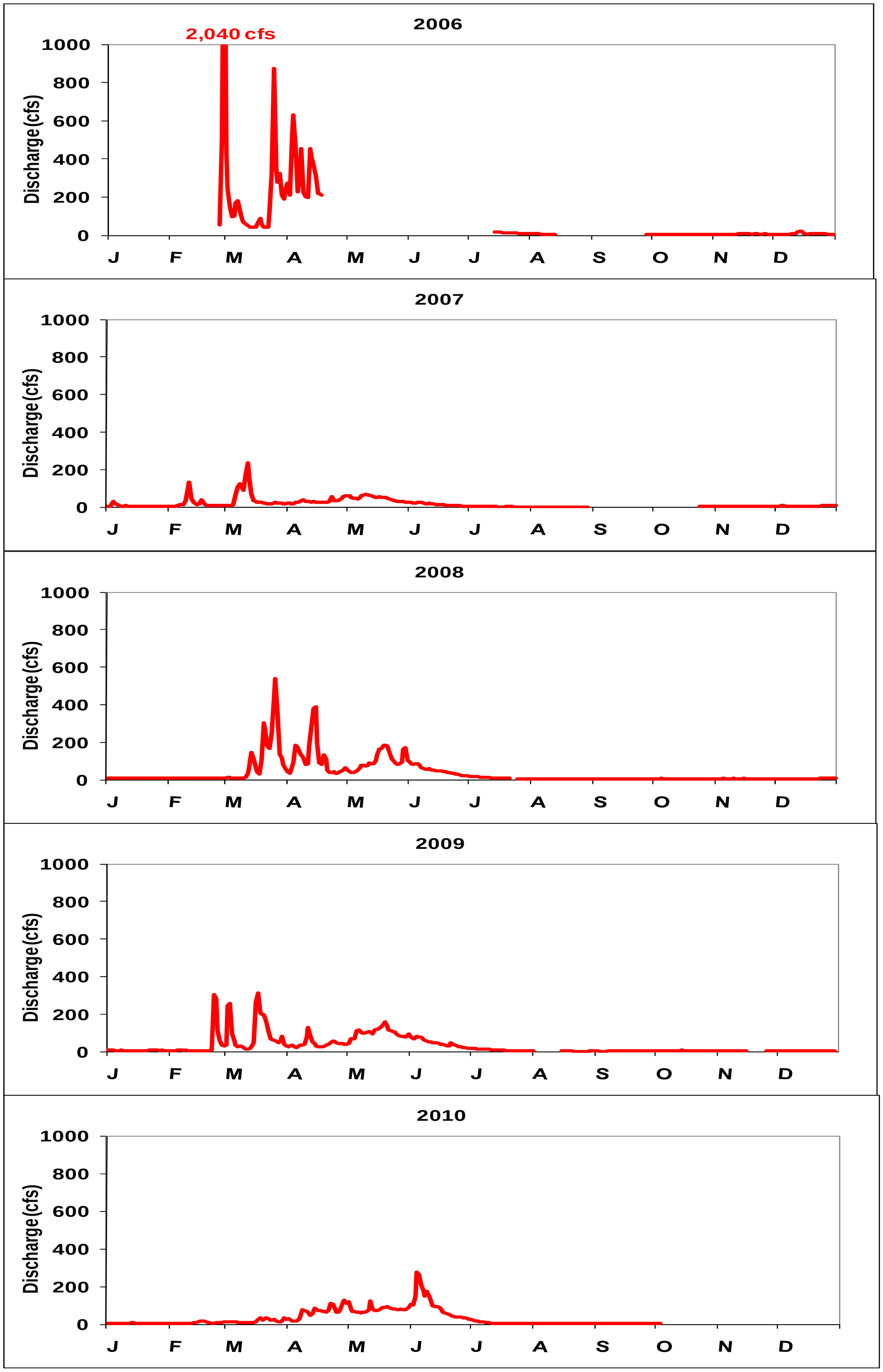

Figure 2. Hydrographs for Twentymile Creek, 2006-2010. Data is from the gaging station located near Adel, Oregon (see Figure). Note, when the gage malfunctioned gaps in the hydrograph occurred.

checked, water depth, water temperature, air temperature, current weather conditions, and trap location. We recorded the trap locations from a hand-held global positioning system (GPS).

Distribution and Abundance of Suckers in the Warner Tributaries

We employed two approaches to describe Warner sucker distribution and obtain estimates of abundance in Warner Valley tributaries. In 2007, we used a probabilistic sampling design to choose random sampling sites in the Honey, Twentymile, and Deep subbasins and obtained multiple-pass depletion estimates at these sites. Due to low precision of these estimates, we obtained a comprehensive mark-recapture abundance estimate in the Twentymile subbasin in 2009.

Random Sampling Design and Multiple-pass Depletion Estimates

In the summer of 2007, we employed the Generalized Random Tessellation Stratified (GRTS) design, developed by the U. S. Environmental Protection Agency (Stevens and Olsen 2002, 2004), to draw representative tributary sample sites from a known sample frame in the Warner basin. The GRTS employs a probabilistic sampling design that allows resource assessment over large areas based on data from representative sample locations. The design involves a spatially balanced, random sampling strategy that distributes sample locations evenly throughout the area of assessment (Overton et al. 1990; Stevens 2002; Stevens and Olson 2004). The GRTS design takes into account spatial patterns of resource distribution when calculating estimates of variance to provide higher precision for a given level of sampling effort (Stevens and Olsen 2002).

We based our sample frame on a 1:24,000 digital stream coverage. Potential Warner sucker stream distribution totaled 100.4 km (Figure 3) and was determined by consulting ODFW and Bureau of Land Management (BLM) biologists, examining past sampling efforts, and using professional judgment. We chose a total of 120 sample sites in the initial draw, including 50 sites in the Honey Creek drainage, 50 sites in the Twentymile Creek drainage, and 20 sites in the Deep Creek drainage. We selected additional sites in each subbasin for use as replacements when sites were unsuitable (e.g., stream channel was dry or access permission was denied on private property). We associated each site with a priority ranking that maintained the random and spatially-balanced statistical properties of the sample. Our actual sampling effort was less than the target due to time constraints, but sampled sites followed the selection priority order.

Standard surveys involved estimating fish abundance at these randomly chosen sample sites using backpack electrofishing and collecting measurements to quantify site dimensions and to describe site habitat complexity. At locations where electrofishing was impractical due to conditions which made this method inefficient (high turbidity, very wide or deep channels), we used alternate gears (fyke nets, hoop nets, seines, and/or minnow traps) to determine sucker presence.

We located sample sites using Universal Transverse Mercator (UTM) coordinates (North America Datum 83). We contacted landowners to obtain permission to access sites located on private land. The field crew navigated to the site using topographic maps and GPS units that were pre-programmed with the site coordinates. Once we located the coordinates on the stream, this point became the lower site boundary. If the coordinates did not fall in the stream, then we assigned the lower site boundary to the location on the stream that was nearest to the pre-assigned coordinates. We determined the upper site boundary by measuring the wetted stream channel width and measuring 30 channel widths upstream or 30 m, whichever was greater. If 30 channel width measurements exceeded 100 m, then the upper boundary was approximately 100

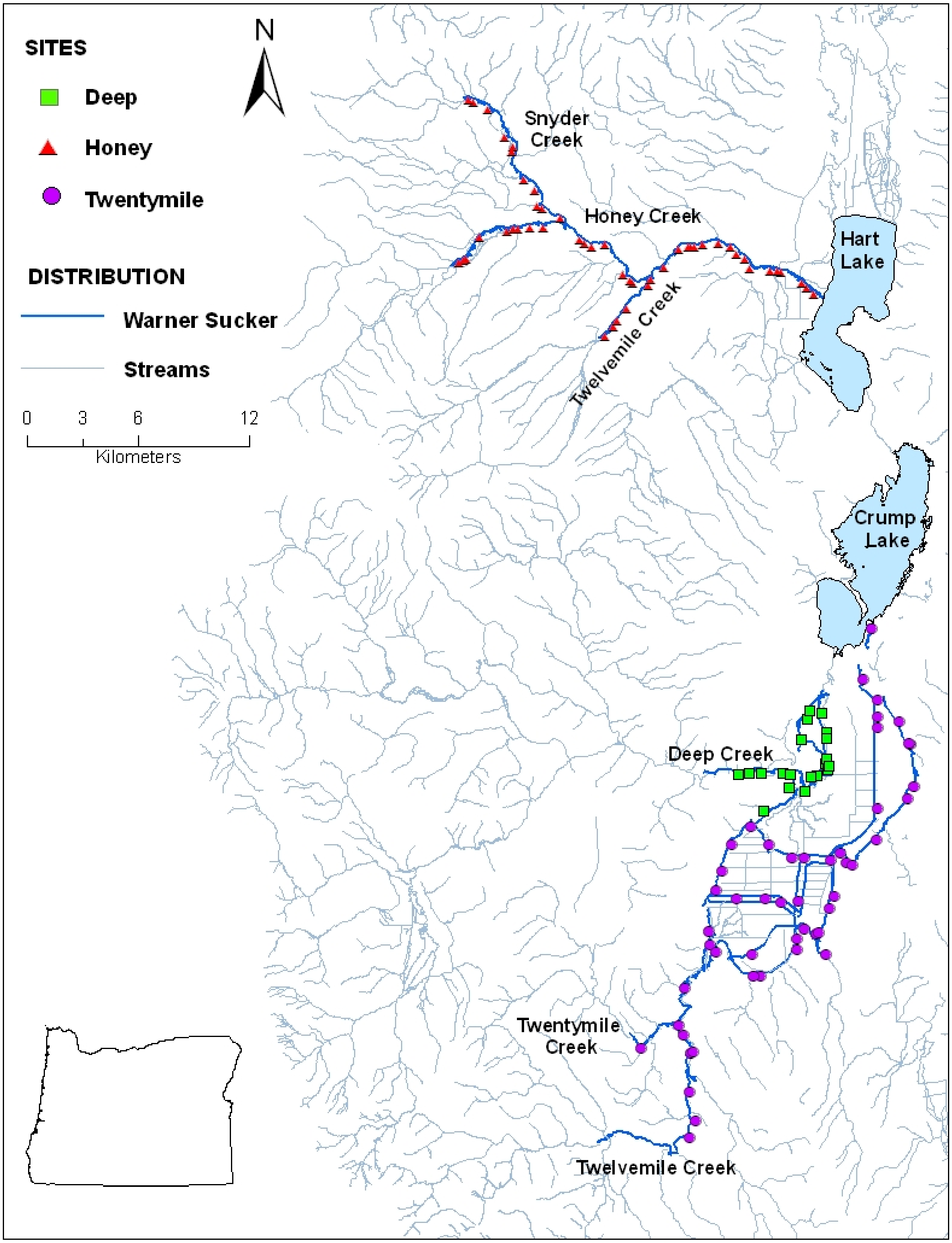

Figure 3. Sample frame (dark blue lines) and corresponding sample points for estimating Warner sucker abundance in the three major subbasins (Honey, Deep, and Twentymile Creeks) of the Warner Basin, 2007.

meters from the lower boundary. We occasionally modified site boundaries to avoid splitting channel units (e.g., so a site boundary was not located in the middle of a pool). After the site boundaries were located, we installed block nets at the upper and lower stream boundaries to prevent fish movement into or out of the site while the depletion estimate was being obtained.

We used multiple-pass depletion backpack electrofishing to obtain abundance (density) estimates at each site. We made a minimum of two passes, with each pass consisting of an upstream and a downstream sweep. The sampling crew electrofished upstream, starting at the downstream block net and moved to the upstream block net. The crew proceeded systematically, shocking discrete channel units and strategically working complex areas (e.g. undercut banks and woody accumulations). At the upstream block net, the crew turned and continued back towards the downstream block net, using approximately one-half to one-quarter the effort used for the upstream pass. On the downstream half of the pass, the crew used a sweeping motion to 'herd' fish into the bottom block net, where the netter could collect fish off the block net. The crew recorded the electrofisher settings (pulse width, voltage, and frequency), the starting and ending times, and the water temperature. We placed captured fish in buckets that we placed along the stream margins. We exerted approximate equal sampling effort during each electrofishing pass. If the reduction in number of Warner suckers collected between the first and second passes was greater than 50%, then we conducted no further sampling. If the reduction in fish numbers between the two passes was less than 50%, then we completed two additional passes. If a 50% reduction did not occur between the sum of numbers of fish captured during passes one and two and the sum of numbers of fish captured during passes three and four, then the estimate failed, and the site was not included in the subbasin abundance estimate.

We anesthetized all captured fish prior to processing with buffered methyl sulfonate (MS-222). We identified all of the fish that we captured to species and counted them. We measured the fork length (FL) of each sucker to the nearest millimeter and weighed each fish on a spring balance to the nearest 10 g. We measured the fork length of a subsample of the other species collected to the nearest millimeter. We scanned each sucker for a PIT tag with an Allflex® RS200-3 hand held reader. If a tag was present, we recorded the code. If no tag was present, then we surgically implanted a 23 mm half-duplex tag in all suckers $\geq$100 mm (described in following section). We determined the sex of each sucker, when possible, using a combination of the following characteristics: presence of breeding tubercles, presence of eggs or milt, anal fin morphology, and spawning coloration (Coombs et al. 1979). Following processing, we allowed fish to fully recover in fresh aerated water. After recovery, we released the fish near the location where they were captured.

We calculated removal estimates of population abundance at individual sampling sites using the methods described by White et al. (1982). We calculated fish abundance from the equation: $\hat{N} = p_1^2/(p_1-p_2)$, where $\hat{N}$ is the abundance estimate, p_1 is the number of fish captured in pass 1 and p_2 is the number of fish captured in pass 2. If four passes were needed to achieve the 50% depletion, then p_1 was sum of the numbers of fish captured in passes 1 and 2, and p_2 was the sum of the numbers of fish captured in passes 3 and 4. We only calculated removal estimates for fish $\geq$60 mm FL. We calculated fish density by dividing the site estimate by the site length. We calculated estimates of population abundance within strata (population or basin) and associated precision using local neighborhood estimator methods described by Stevens and Olsen (2002). We adjusted sample probabilities used to extrapolate population totals for the occurrence of non-target and non–response sites using the weight-modified inclusion density method described in Stevens (2002).

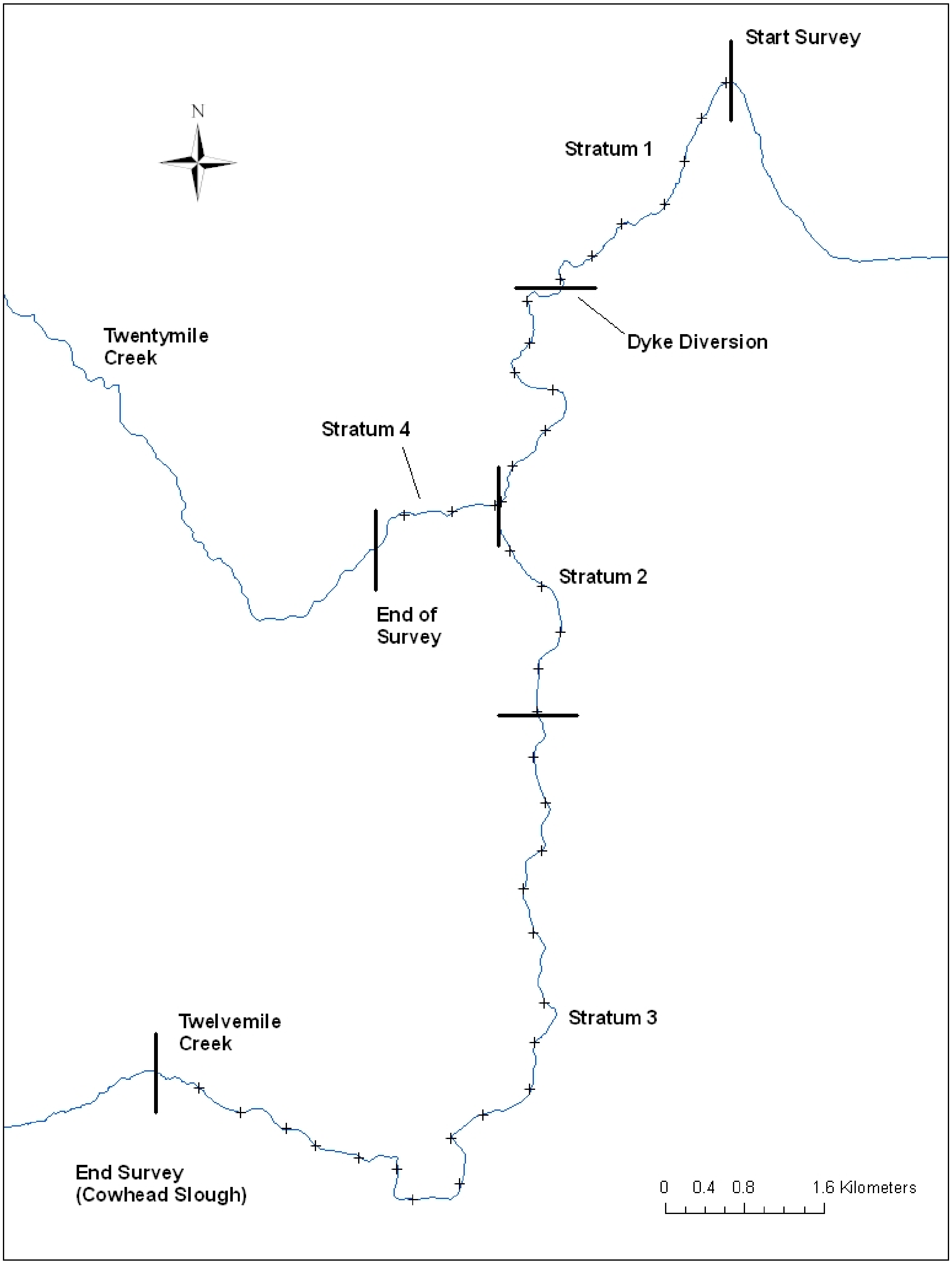

Figure 4. Study area for 2009 Warner sucker mark-recapture abundance estimate in the Twentymile Creek drainage. The stream was divided into 500 m long reaches (plus signs) and four strata (bold vertical or horizontal lines). Strata were based on changes in stream gradient, valley form, and discharge. Also shown is the location of the farthest upstream irrigation diversion.

Comprehensive Mark-Recapture Abundance Estimate

In the summer of 2009, we surveyed approximately 21 km of the mainstem of Twentymile Creek and its primary tributary, Twelvemile Creek (Figure 4). The sample frame included the suspected geographical extent of suckers in the subbasin. We chose Twentymile Creek in 2009 because our 2007 data indicated that it supports the largest stream population of Warner suckers and because we were able to secure access to private land in this subbasin. We used backpack electrofishers to obtain a two-pass mark-recapture abundance estimate. We estimated population abundance for the entire Twentymile Creek subbasin in 2009 using single-sample mark-recapture procedures (Ricker 1975). We divided the Twentymile Creek basin into four strata based on changes in geomorphology, gradient, and physical habitat characteristics (Figure 4) and obtained separate estimates for each of these strata. We also estimated the abundance of adult suckers and calculated the ratios of adult to juvenile fish. Suckers larger than 160 mm FL were considered mature (Scheerer et al. 2008b). We calculated 95% confidence intervals for our estimates using a Poisson approximation (Ricker 1975). Block nets were not deployed during the survey; however, we installed a PIT-tag antenna above the upstream-most diversion, to estimate the magnitude of downstream movement of fish out of the sample reach during our study (Figure 5).

We divided the sample frame into forty-three 500 m reaches, which we measured using a hip chain. Sample reaches were further divided into 100 m stream sections for fish sampling. We electrofished each 100 m stream section in a single upstream pass and placed all captured fish in buckets. We enumerated and measured all Warner suckers and recorded the approximate abundance and distribution of all other fish species observed. At the upstream end of each 100 m section, we processed the fish and released them back to the approximate location from which they were captured. Prior to processing, we anesthetized all suckers that we captured using buffered MS-222. Once anesthetized, we measured fork lengths (FL), and marked all suckers $\geq$60 mm FL with fin clips. We alternated between upper and lower caudal fin clips every 1,000 m (every second sample reach) throughout the extent of the sample frame to examine small scale movements of fish between pass 1 and pass 2. We placed a subsample of fin clips in 95% ethanol for genetic analysis. We examined anal fin morphology according to Coombs et al. (1979) to determine the sex of each sucker. During the initial electrofishing pass, we scanned each sucker $\geq$100 mm FL for the presence of PIT tags and recorded detections. If no tag was detected, we surgically inserted a 23 mm half-duplex PIT tag in all suckers $\geq$100 mm FL (described in following section). During the second electrofishing pass, we recorded the number of marked and unmarked suckers and scanned each fish for existing PIT tags. If no PIT tag was detected, we installed a PIT tag in all suckers $\geq$100 mm FL. An average of 35 d (range 17-71 d) elapsed between the first and second passes.

Habitat Associations

Following the second pass of the mark-recapture survey, we collected habitat data for each 500 m sample reach. Habitat parameters included: wetted width (m), average depth (m), length and maximum depth of backwater pools (m^2), maximum depth (m), water temperature ($^{\circ}$C), aquatic vegetation (as a percentage of total surface area), dominant substrate type, dominant riparian cover type, and number of pools. Width, depth, substrate and aquatic vegetation measurements were taken at transects located every 100 m, starting approximately 50 m from the downstream boundary of each reach. We calculated average depth by summing depth measurements collected at 25%, 50% and 75% of the wetted width and dividing by four, to account for zero depth at the stream margins. Maximum depth was the single deepest water depth in each reach. We measured the length, width, and maximum depth of backwater habitats when they occurred at a transect location. We determined the dominant substrate from seven equally-spaced points along each transect. At each point (10 cm circle), we recorded whether the majority of the substrate was fines (<0.063 mm), sand (0.063-2 mm), gravel (3-64 mm), cobble (65-256 mm), boulder (>256

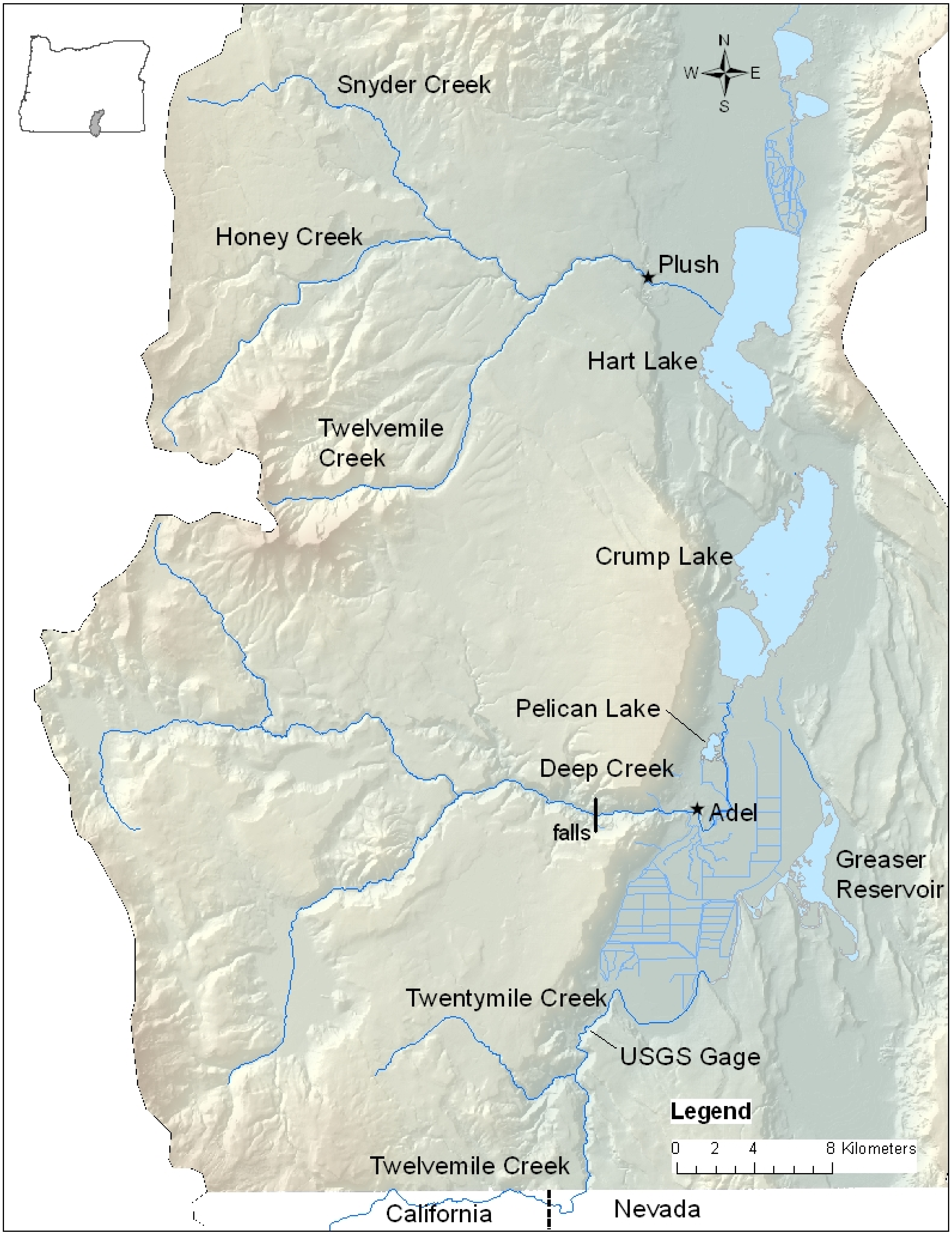

Figure 5. Locations of downstream-migrant screw traps, the upstream-migrant trap at a fish ladder, PIT antennas, and a radio antenna in the Twentymile Creek drainage, 2006-2010. Note: we also fished a screw trap at the mouth of Honey Creek in 2006 and operated a PIT antenna there in 2009 (not shown on map).

mm), bedrock (native consolidated rock), or embedded. We identified dominant riparian cover categorically (conifer, deciduous, grasses and shrubs, and limited vegetation). At the beginning and end of each 500 m reach, we recorded stream temperature (^{o}C) and recorded UTM coordinates and stream elevation. We took photographs at the beginning of each reach.

Statistical Analyses

We analyzed differences in mean length of male and female suckers captured in Crump Lake in 2006, 2008, and 2010 and in Twentymile Creek in 2007 using an analysis of variance (ANOVA) with length as the main effect and year and sex as the explanatory variable. In addition, we analyzed similar data collected from Hart Lake between 2006 and 2010, from Hart and Crump Lakes for 2006 and 2008 combined, and from Hart and Crump lakes for all years combined.

We analyzed differences in weight-length relationships of male and female suckers captured in Hart and Crump Lakes in 2006, 2008, and 2010 and of male and female suckers in Twentymile Creeks in 2010 using an analysis of covariance (ANCOVA) with log-length as the main effect, year and sex as the explanatory variables, and log-weight as the covariate. Data met assumptions for homogeneity of variance and normality. We also compared weight-length relationships of male and female suckers captured in Twentymile Creeks with those captured in Hart and Crump lakes in 2010 using an ANCOVA with log-length as the main effect, source (lake or stream) and sex as the explanatory variables, and log-weight as the covariate. Analysis of data was conducted using the PROC GLM procedure and *post hoc* comparisons using REGWQ (SAS version 9.1.3). Data met assumptions for homogeneity of variance, tested using chi-square test statistic, and normality, which was assessed from visual plots.

We explored relationships between habitat variables and total fish captured (sum of both electrofishing passes) using linear regression (SAS® Institute Inc., Cary, NC). The habitat variables described above had high degrees of co-linearity and as such, we removed those with the highest degrees of co-linearity (>0.50) from the analysis. We also removed reaches where habitat data was not collected from the analysis (data from a few upstream reaches in both Twentymile and Twelvemile Creeks where we collected no suckers). The remaining variables that we included in the model were maximum temperature recorded per reach, reach area, area of backwater habitat, number of pools, maximum depth, minimum depth, percent embedded substrate, percent bedrock substrate, and mean percentage of aquatic vegetative cover per reach. We used a log transformation to normalize the data and tested assumptions of normality and homogeneity of variance. We selected the most parsimonious final model based on both adjusted R^2 and mallow C_p model selection criteria (Burnham and Anderson 2002). Our model did not exceed one independent variable for every ten sample sites.

Seasonal Movement of Warner Suckers

We studied the seasonal movements of Warner suckers to describe the functional status of the current Warner sucker metapopulation, specifically to assess the ability of suckers to move freely within and between lake and stream environments, to access spawning habitats, and to recruit into the lake populations. We used a range of methods, including the use of downstream-migrant rotary screw traps, an upstream-migrant trap at a fish ladder, PIT tags, radio tags, and larval drift nets.

PIT and FLOY® Tagging

During our lake and stream sampling, we inserted PIT tags into all captured suckers $\geq$100 mm FL to assess movement and growth. We anesthetized the fish with MS-222, made a small

~0.5 cm incision in the ventral cavity, and inserted a half-duplex PIT tag (23 mm x 3 mm) into the peritoneal cavity. We disinfected all equipment prior to surgery and applied an antibiotic (oxytetracycline) to the scalpel and the tag. In the lake studies, we double-tagged the suckers with colored FLOY® t-bar anchor tags directly below the dorsal fin to assess tag loss. Following processing, we allowed the fish to recover and then released them near their capture location. We obtained information about movements by recapturing tagged suckers using a backpack electrofisher, trap nets, or trammel nets, and from flat- plate PIT-tag antennas that we placed at the mouth of Honey Creek from 6 April 2009 through 8 June 2009, in Twelvemile Creek from 8 June through 12 September 2009, and at three locations in the Twentymile Creek subbasin, including one in an irrigation diversion ditch downstream of the Dyke diversion, from 13 April through 24 July 2010 (Figure 5).

Radio Tagging

We surgically implanted radio transmitters via surgery into ten suckers in 2006 (five each in Hart and Crump lakes), 32 suckers in 2008 (25 in Hart Lake and 7 in Crump Lake), and 30 suckers in 2010 in the Twentymile Creek subbasin. In 2006, we used Lotek® coded nano-tags (NTC-3-1) that weighed 0.8 g, measured 6 mm wide by 4 mm tall by 15 mm long and had a battery life of 41 days at a 5.0 second burst rate. In 2008, we used Lotek® coded tags (SR-11-25) that weighed 8 g, measured 11 mm in diameter and 53 mm in length and had a battery life of 641 days at a 5.0 second burst rate. In 2010 we used Lotek® coded nano-tags (NTC-3-2) that weighed 1.1 g, measured 6 mm wide by 4 mm tall by 16 mm long and had a battery life of 80 days at a 5.0 second burst rate and coded nano-tags (NTC M-3) that weighed 0.55 g, measured 7 mm wide by 4 mm tall by 15 mm long and had a calculated battery life of 41 days at a 5.0 second burst rate. To restrict the tag weight to less than 4% of the fish weight (Moser et al. 1990; Jakober et al. 1998), the minimum size of fish that we tagged with the SR-11-25 tags was ~265 mm (~223 g), ~140 mm (~28 g) with the NTC-3-1 and NTC-3-2 tags, and ~100 mm (~14 g) with the NTC M-3 tags. All radio tags used in 2008 and 2010 had a frequency of 150.380 MHz. In 2006, the tags we used in Hart and Crump Lake had frequency of 148.680 MHz and 150.680 MHz, respectively. We used surgical procedures similar to those used for inserting the PIT tags, except that we made the incision larger (~1 cm), used a canula to thread the trailing antenna, and applied one or two sutures to close the incision. We held most radio-tagged fish in a live box for 24 h prior to release. We released tagged fish near the point of initial capture, except for five radio-tagged suckers captured in Hart Lake in 2008, which we released into Honey Creek at the Plush bridge crossing upstream of the lower irrigation diversion dams. We tracked the movements of radio-tagged fish using a radio receiver (Lotek, SRX-400) either from the boat, truck, all terrain vehicle, an Oregon State Police airplane, or on foot. In 2010, we installed a fixed tracking station and antenna downstream of the Dyke diversion that provided coverage for both Twentymile Creek and the Dyke irrigation diversion ditch (Figure 5). Each time a fish was located, we recorded the date, the power reading, the tag code (when possible), and the geographic coordinates from a hand held GPS receiver.

Downstream Migrant Trapping

To determine whether suckers were moving, we placed a 1.5 m diameter rotary screw trap at the mouth of Honey Creek from 1 May through 2 June, 2006 (19 trap nights), in Twelvemile Creek from 8 April through 17 June 2008 (43 trap nights), and in Twentymile Creek from 6 April through 8 June 2010 (33 trap nights) (Figure 5). The trap was not fished on weekends. We checked the trap daily (approximately every 24 h), counted all fish, and released them back into the creek. Before release, we measured and weighed all Warner suckers, scanned the fish for existing PIT tags, and tagged all suckers ≥100 mm FL with PIT tags using the same procedure described above. We recorded the time the trap was lowered, the time the trap was checked, water depth, trap speed (RPM), water temperature, air temperature, and weather. We identified all fish captured and measured, weighed, and determined the sex of all suckers captured, as described in the previous section.

Upstream Trapping at Dyke Diversion Fish Ladder

To assess upstream passage at an irrigation diversion dam, we installed a fish trap in the upstream end of the fish ladder at the Dyke diversion and fished the trap from 18 April through 17 June, 2006 (35 trap nights) (Figure 5). We checked the trap daily (approximately every 24 h). We recorded the time the trap was checked, water and air temperature, and weather.

Sampling Larval Drift

To determine the timing and extent of downstream migration of larval suckers in the tributaries, we used larval drift nets, (28 cm by 47 cm with 500 µm mesh), and/or larval light traps. We set the drift nets in pool tail outs (i.e., transition point from pool to riffle) that were located downstream from where adult suckers were known to congregate and in areas downstream from where we captured larval suckers using dip nets. We fished two larval drift nets and two larval light traps at the mouth of Honey Creek on 20 May, 28 May, and 8 June 2009. We fished four larval drift nets in the Twentymile Creek drainage on 11 occasions from 15 June through 23 July 2010. To determine whether larval suckers were present in the stream, but perhaps not moving, we sampled backwater pools and macrophyte beds using an aquatic macroinvertebrate dip net, measuring 30 cm in diameter with 1.6 mm mesh, during these same time periods. In 2006, we used a macroinvertebrate dip net with 1 mm mesh to collect larval suckers from the mouth of Honey Creek. We identified larval fish with the assistance of Dr. Douglas Markle and Mark Terwilliger, Oregon State University.

Comparison of Ageing Techniques

We evaluated methods for non-lethal ageing of Warner suckers in 2009. We examined five hard structures commonly used to age fish: 1) lapillar otoliths, 2) scales, 3) opercles, 4) pectoral fin rays, and 5) pelvic fin rays. We collected 16 Warner suckers (mortalities from the stream investigations) for analysis. To increase sample size, we also examined hard structures from several non-listed species of western suckers, including largescale suckers (*C. macrocheilus*, n=25), bridgelip suckers (*C. columbianus*, n=5), and mountain suckers (*C. platyrhynchus*, n=2), and assumed that growth marks observed on hard structures would be comparable among species. Hard structures were removed from the right-hand side of all fish, except in a few cases when a structure was lost or damaged during dissection; in those cases, the left compliment was used. Preparation procedures varied for each hard structure as described below:

Lapillar otoliths

We embedded lapilli in EpoThin® epoxy resin and made a 1.0 mm thick oblique section, running anterodistal-posteromedial, which included the core using a Buehler Isomet® low-speed saw with a diamond-tipped wafering blade. We decided that an oblique section was necessary because the main growth axis of the lapillus projects ventrally, the core is not centrally located, and the longest axis of the lapillus sits at an oblique angle relative to the head of the fish. We mounted sections on glass slides using Crystal Bond® adhesive, sanded with 600-1200 grit wet/dry sandpaper to remove saw marks and gain proximity to the core, and polished on a felt pad with 0.5 µm alumina powder. We flipped the otolith several times during grinding and polishing to create a thin section showing visible increments from core to edge (see Secor et al. 1992). We examined lapilli using a Leitz Biomed® compound microscope with transmitted light. We assigned ages from counts of growth increments that were comprised of a wide translucent and narrow opaque band. Ageing otoliths required us to first sacrifice the fish.

Pectoral and Pelvic Fin Rays

We removed the two anterior-most fin rays from each fish by cutting the rays at the articulation point with a scalpel. We allowed the fin rays to air dry before embedding them in EpoThin® epoxy resin, and then made cross-sections using a Buehler Isomet® low-speed saw with a diamond-tipped wafering blade. We made five serial sections (0.5 mm thick) from the base of each ray towards the distal tip, to assess annuli loss with distance away from the body. The first section was made at the point where the proximal end of the fin ray curved away from the body toward the distal tip. We mounted sections on glass slides using Crystal Bond® adhesive and examined growth increments using a Leitz® Biomed compound microscope with transmitted light.

Opercles

We clipped the entire opercle from each fish, trimmed off excess tissue, and allowed the structure to air dry. To prepare them for reading, we placed opercles in boiling water for several minutes, after which we removed the integument and other tissue using forceps. We again allowed the structure to air dry. Larger opercles exhibited fenestrated reinforcement bone immediately ventral to the hyomandibular socket that prevented observation of the earliest growth marks; in those cases, we used a Dremel® tool to remove the reinforcement bone so that all growth marks were viewable. We aged opercles using a light table for background illumination. For large opercles, we used a swing-arm stereoscopic dissecting microscope to enumerate growth marks at the edge of the structure. Ageing opercles also required us to first sacrifice the fish.

Scales

We used a scalpel to remove scales from an area dorsal of the lateral line and anterior to the dorsal fin. We removed mucus and epidermis from each scale by immersing it in tap water and gently scraping with a scalpel. We sandwiched five scales from each fish between two microscope slides and examined growth increments using a dissecting scope and reflected light.

We estimated within-reader precision in terms of indices of absolute percent error (APE) as outlined in Beamish and Fournier (1981). Growth increments on all structures were counted three times by an experienced ager, without information regarding fish size, species, or capture date. We used the median age obtained to compare ages among structures. We also evaluated the ease of reading each structure by examining the percentage of time when all three age determinations for a structure agreed.

To determine the relationship between otolith age and ages obtained from other hard parts, we assigned the median age to each sample and constructed age-bias plots using lapilli as our standard for true age. We decided to use otoliths as a standard based on our level of experience ageing these structures and the nature of somatic growth in these species. As a group, western suckers display determinate growth (Terwilliger et al. 2010); therefore, as somatic growth slows with age, so does growth of skeletal structures, which then become increasingly difficult to age as growth marks become narrow and pack on the edge of the structure. Otoliths continue to grow even as somatic growth slows or stops, resulting in relatively easy to read and evenly spaced growth marks. In 2010, we initiated an ageing validation study to describe the annular marks that are deposited on hard structures used for ageing. We injected PIT-tagged Warner suckers with oxytetracycline (OTC), mixed one part OTC to three parts 0.9% sterile buffered saline, at a dosage of 50 mg OTC per kg of fish weight. After PIT-tagging captured suckers, we injected the solution using a 24-gauge hypodermic needle at the base of the dorsal fin. Ideally, the OTC will deposit a mark on the hard structures (otolith or pectoral fin ray), at a known time, that can be used to validate annual marks on fish that are recaptured in the future.

RESULTS

Distribution and Abundance of Warner Suckers in the Warner Lakes

Most of the Warner suckers that we captured in the Warner Lakes were collected from locations on the west side of Hart Lake, including the mouth of Honey Creek, and in the southern part of Crump Lake, south of the peninsula. We were unable to obtain reliable mark-recapture estimates for Warner suckers in the Warner Lakes or estimate tag loss, because we recaptured so few of the fish we marked in the lakes. In the past 15 years of study dating back to 1990, 1996 was the only year when a sufficient number of suckers was captured to obtain a reliable mark-recapture population estimate (estimate = 493 adults; 95% CL: 439-563) (White et al. 1990; White et al. 1991; Allen et al. 1994; Allen et al. 1995; Allen et al. 1996; Bosse et al. 1997; Hartzell et al. 2001; Scheerer et al. 2006; Scheerer et al. 2008a).

Despite recent trapping effort that exceeded past efforts, the 2006, 2008, and 2010 trap net catches were some of lowest on record (Table 1). We urge caution when comparing Warner sucker catch-per-unit-of effort (CPUE) over time for several reasons. First, environmental conditions varied dramatically over time; for example, the Warner basin experienced severe drought from 1987 through 1992 and the lakes were completely desiccated in 1992. Second, time periods when sampling occurred each year were not consistent and there was relatively low sampling effort in Crump Lake prior to 2006. In addition, we found that our catch rates varied substantially across our sampling periods and varied between lakes (Figure 6). Nonetheless, recent sucker catch in Hart Lake was substantially lower than peak catches in 1990, 1996, 1997, 1999, and 2001.

Table 1. Warner sucker CPUE for trap nets fished in Hart and Crump Lakes, 1990-2010.

	Number of suckers		Number of trap nights		Suckers per trap night		Sampling dates	
Year	Hart	Crump	Hart	Crump	Hart	Crump	Hart	Crump
1990	190	16	122	9	1.6	1.8	4/4 - 7/27	4/1 - 5/15
1991	103	0[a]	175	-	0.6	-	3/19 - 7/31	3/19 - 7/31
1993	0	-	70	-	0.0	-	6/11 - 8/15	6/11-8/15
1994	93	3	40	15	2.3	0.2	7/12 - 8/14	7/12 - 8/14
1995	19	1	104	40	0.2	0.0	6/12 - 7/20	6/12 - 7/20
1996	835	11	252	36	3.3	0.3	4/24 - 6/6	4/24 - 6/6
1997	193	2	137	60	1.4	0.0	4/29- 6/12	4/29 - 6/12
1998	0	0	2	2	0.0	0.0	8/25	8/25
1999	201	2	9	8	22.3	0.3	5/18, 5/19, 11/16	5/18, 5/19, 11/16
2001	176	5	63	24	2.8	0.2	4/14 - 5/22	4/14 - 5/22
2004	0	1	0	6	-	0.2	-	5/25
2005	0	0	9	14	0.0	0.0	7/28	5/25; 7/21
2006	41	60	214	238	0.2	0.3	4/3 - 6/21	4/3 - 6/21
2008	76	27	473	258	0.2	0.1	4/2 - 6/17	4/2 - 6/17
2010	0[b]	30	-	199	-	0.2	-	4/8 - 6/4

[a] In 1991, 69 suckers were collected from the Crump Lake shoreline (apparent winterkill).

[b] In 2010, Hart Lake was too shallow to sample (avg. 0.3 m).

Although we were unable to obtain a mark-recapture estimate for Warner suckers in 2006, 2008, and 2010, we were able to obtain an estimate in Hart Lake using the 2008 catch (n=76) and recaptures (n=4) of fish marked in 2006. We applied a mortality rate of 33% (a conservative estimate which may be higher than the actual rate) to the 54 fish marked in Hart Lake in 2006 and calculated an estimate of 565 suckers (95% CL: 250-1,114) larger than 155 mm FL (minimum size captured in trap nets). This estimate is similar to the 1996 mark-recapture population estimate of 493 suckers (95% CL: 439-563) in Hart Lake (Allen et al. 1996).

Length Frequencies and Length-Weight Relationships of Suckers in the Warner Lakes

The average length of suckers captured in the lakes has increased steadily since 1994 (Figure 7). This, combined with the relative absence of suckers <250 mm in the catch, suggests there has not been substantial recruitment in recent years. The length frequency distributions for Warner suckers captured in Hart and Crump Lakes in 2006, 2008, and 2010 are shown in Figure 8. Although we noted some recruitment of smaller fish into the population in 2008, the shift was primarily the result of the apparent mortality of suckers >250 mm in Crump Lake in 2007, when the lake levels were very low during the winter (Figure 8). In Crump Lake, mean lengths of suckers were significantly greater in 2006 than in 2008 and 2010. Lengths were not different between 2008 and 2010 (Table 2). The mean lengths of male and female suckers in Crump Lake were not significantly different ($p > 0.05$). In Hart Lake, both year and sex were significantly different (p-value: year = 0.008 and sex <0.0001). Lengths of suckers in Hart Lake were also significantly greater in 2006 than 2008 and females were significantly larger than males (Table 2). When we combined data for Hart and Crump Lakes for 2006 and 2008, we found a significant interaction effect ($p = 0.005$), suggesting that the trend changes depending on both year and sex. In 2006, females were substantially larger than males, but in 2008 they were virtually the same lengths. When we combine all years, we also found a significant interaction effect ($p = 0.005$). Females were larger in 2006 and 2008 than 2010, but mean length was only significant between sexes in 2006. We found no difference in mean lengths between males and females in the lakes (combined) in 2008 or 2010, although female suckers were more common in the larger size classes (≥400 mm) (Figure 9).

Strong log weight- log length relationships exist for both male and female Warner suckers (Figure 10). The slopes of the log-weight log-length relationships of suckers in Hart and Crump Lakes where significantly different between all years ($p = 0.001$), but not by sex.

Fish Assemblages in the Warner Lakes

In 2006 and 2008, trap net catch was dominated by nonnative fishes (71-81%), including white crappie *Pomoxis annularis* (31-53%), brown bullhead *Ameiurus nebulosus* (4-30%), *and* black crappie *P.nigromaculatus* (13-20%). Native tui chub *Gila bicolor* were also abundant (19-28%) in the catch (Table 3). Warner suckers were one of the least common fish captured (0.3-1.0%). In 2010, total trap net catch decreased relative to the catch in 2006 and 2008. The 2010 trap net catch was dominated by native tui chub (35%), due primarily to a reduction in the catch of nonnative bullheads, rather than an increase in the catch of tui chub. White crappie (32%) comprised a significant proportion of the 2010 catch.

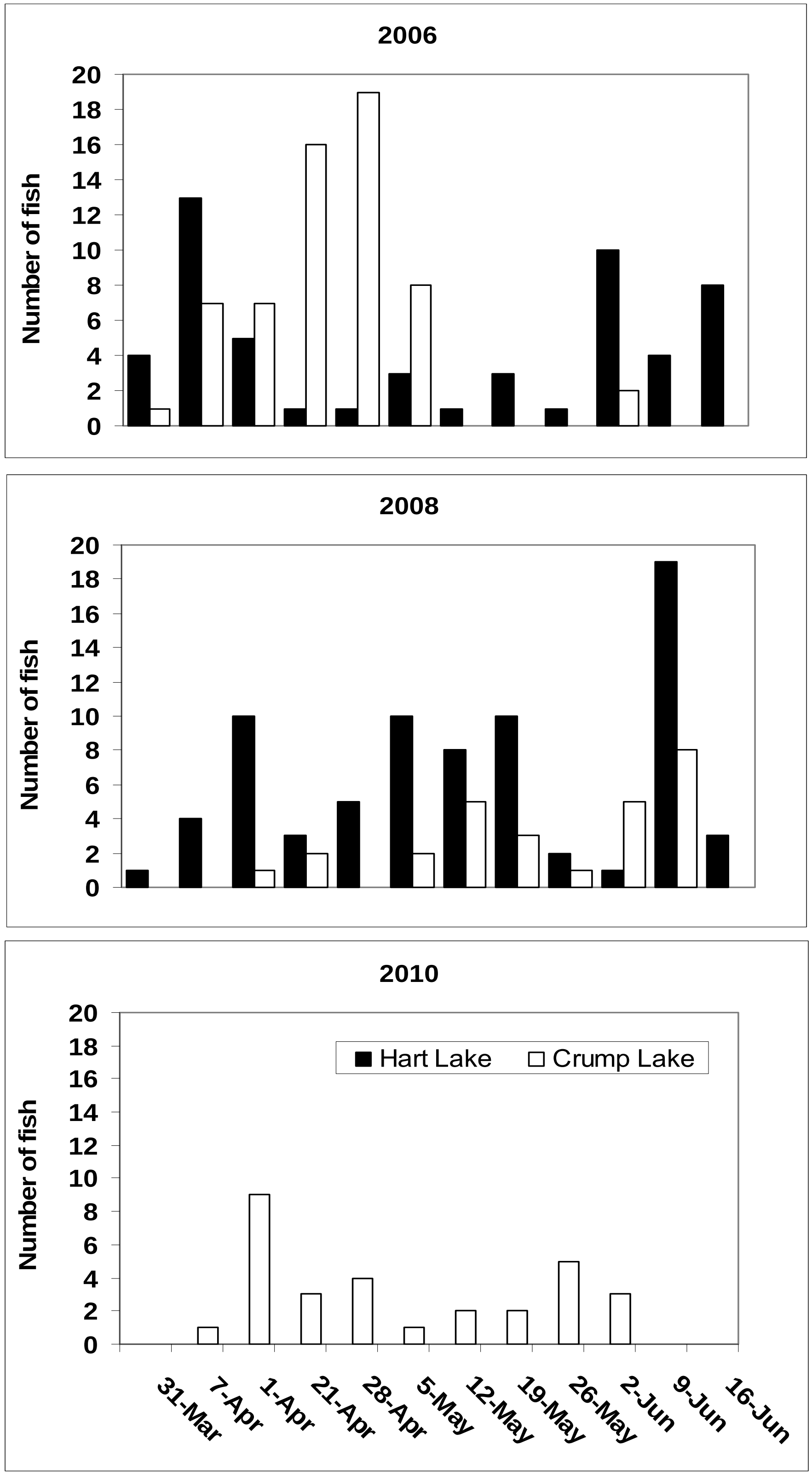

Figure 6. Weekly trap net catch of Warner suckers in Hart and Crump Lakes, 2006-2010.

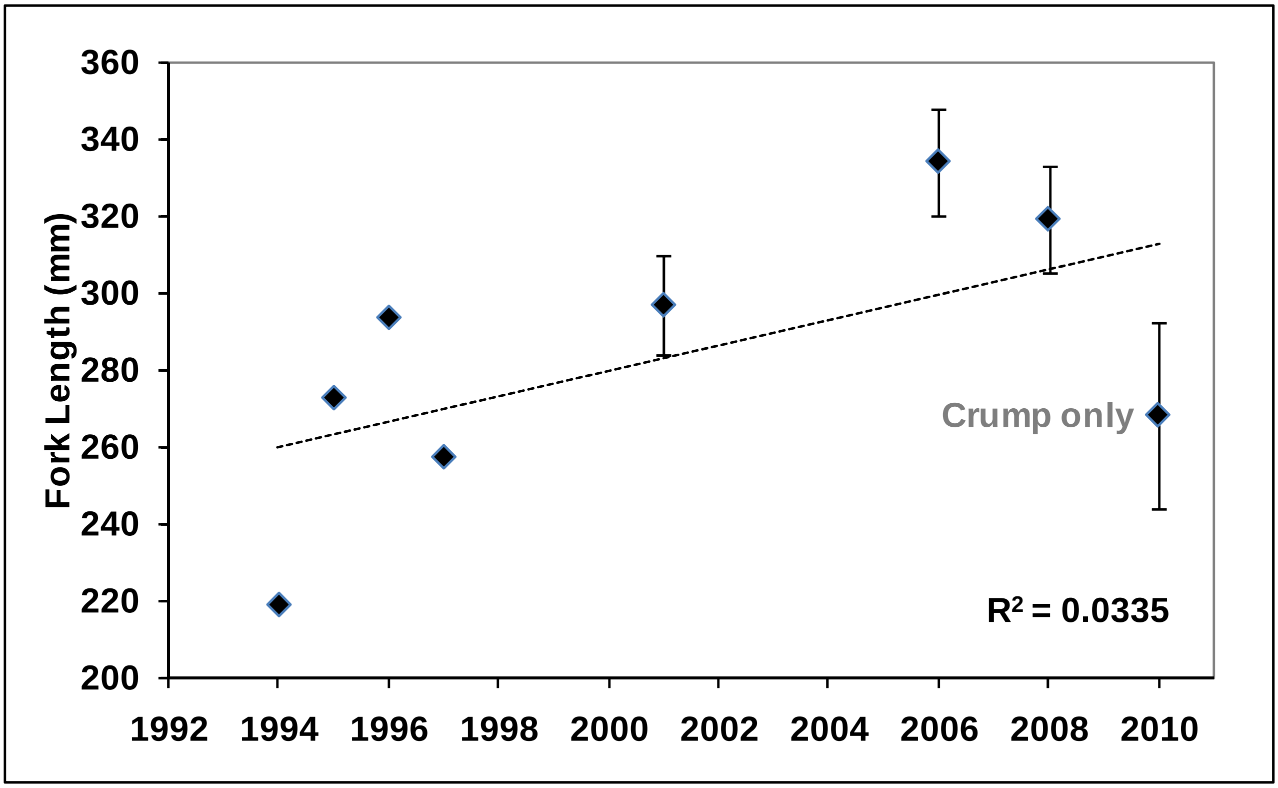

Figure 7. Relationship between the average fork lengths of Warner suckers collected in trap nets from the Warner Lakes and year. Vertical lines represent 95% confidence limits, although they were not available from past reports. The dotted line is a fitted regression line ($p = 0.03$).

Table 2. Mean length (FL) of Warner suckers captured in 2006, 2008, and 2010 from Crump and Hart Lakes. Note: Hart Lake was too shallow to sample in 2010. Differences in mean length between 2006 and 2008 in Hart and Crump Lakes were significant ($\alpha<0.05$). Differences in mean length between 2006 and 2010 in Crump Lake and between 2006 and 2008 for both lakes combined were not significant ($\alpha>0.05$).

		Mean	Confidence limits (95%)	
Location	Year	length (mm)	Lower	Upper
Crump Lake	2006	310	292	328
	2008	250	238	263
	2010	268	244	292
Hart Lake	2006	361	341	380
	2008	342	314	370
Both Lakes	2006	334	320	348
	2008	319	305	333

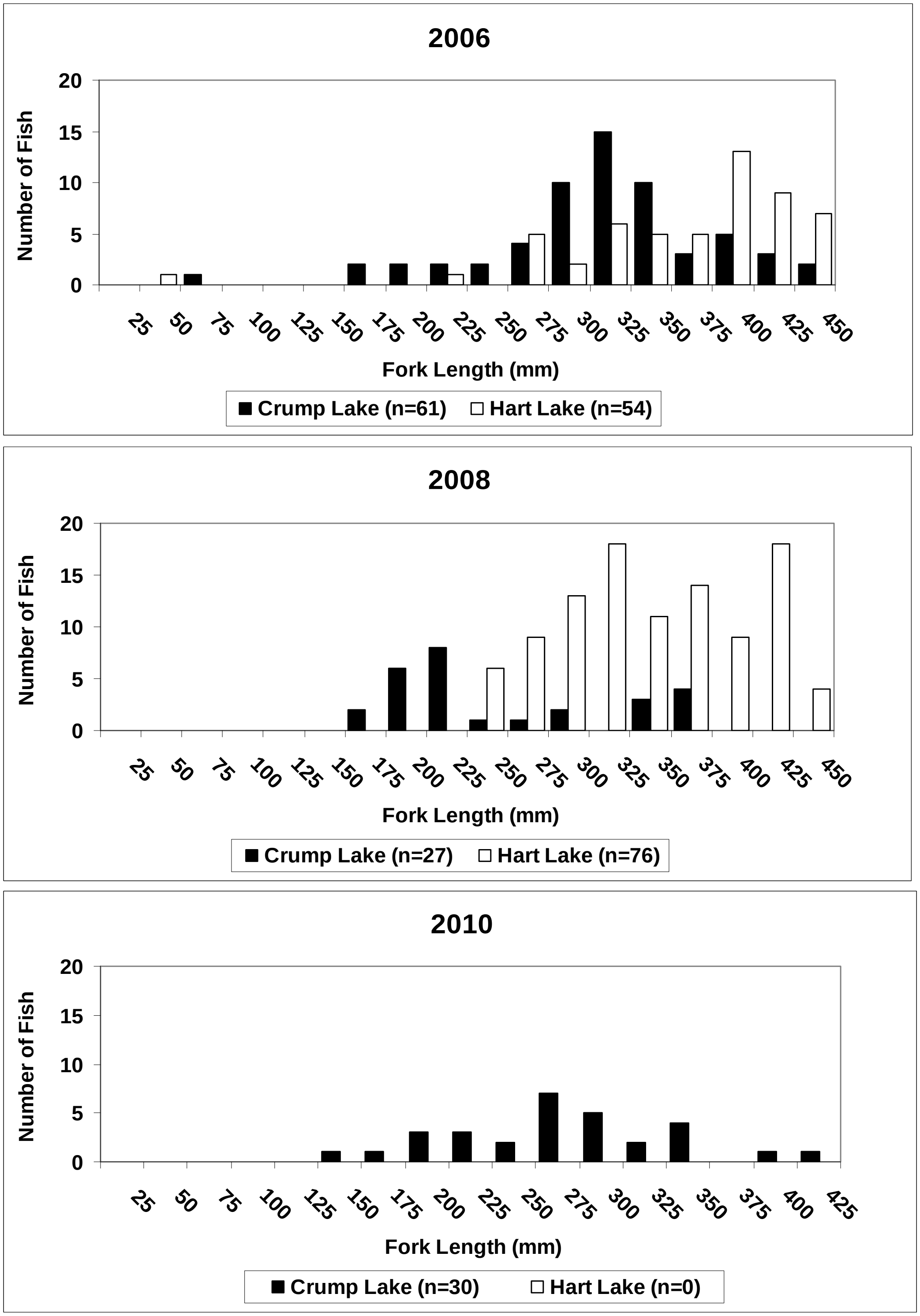

Figure 8. Length-frequency histograms for Warner suckers collected from Hart and Crump Lakes in 2006, 2008, and 2010. Note: Hart Lake was too shallow to trap in 2010.

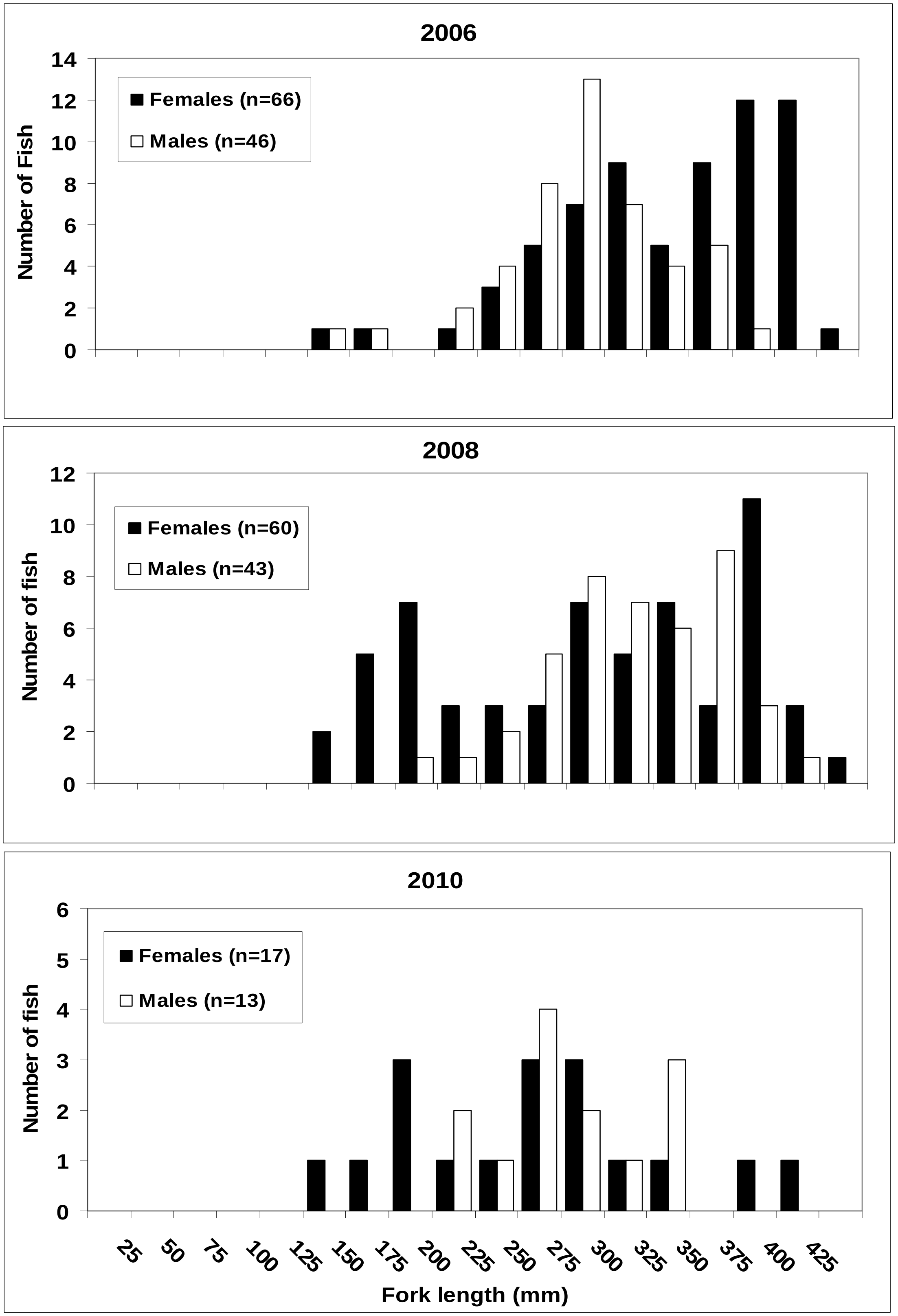

Figure 9. Length-frequency histograms for female and male Warner suckers from Hart and Crump Lakes in 2006, 2008, and 2010. Note: 2010 data only includes fish from Crump Lake.

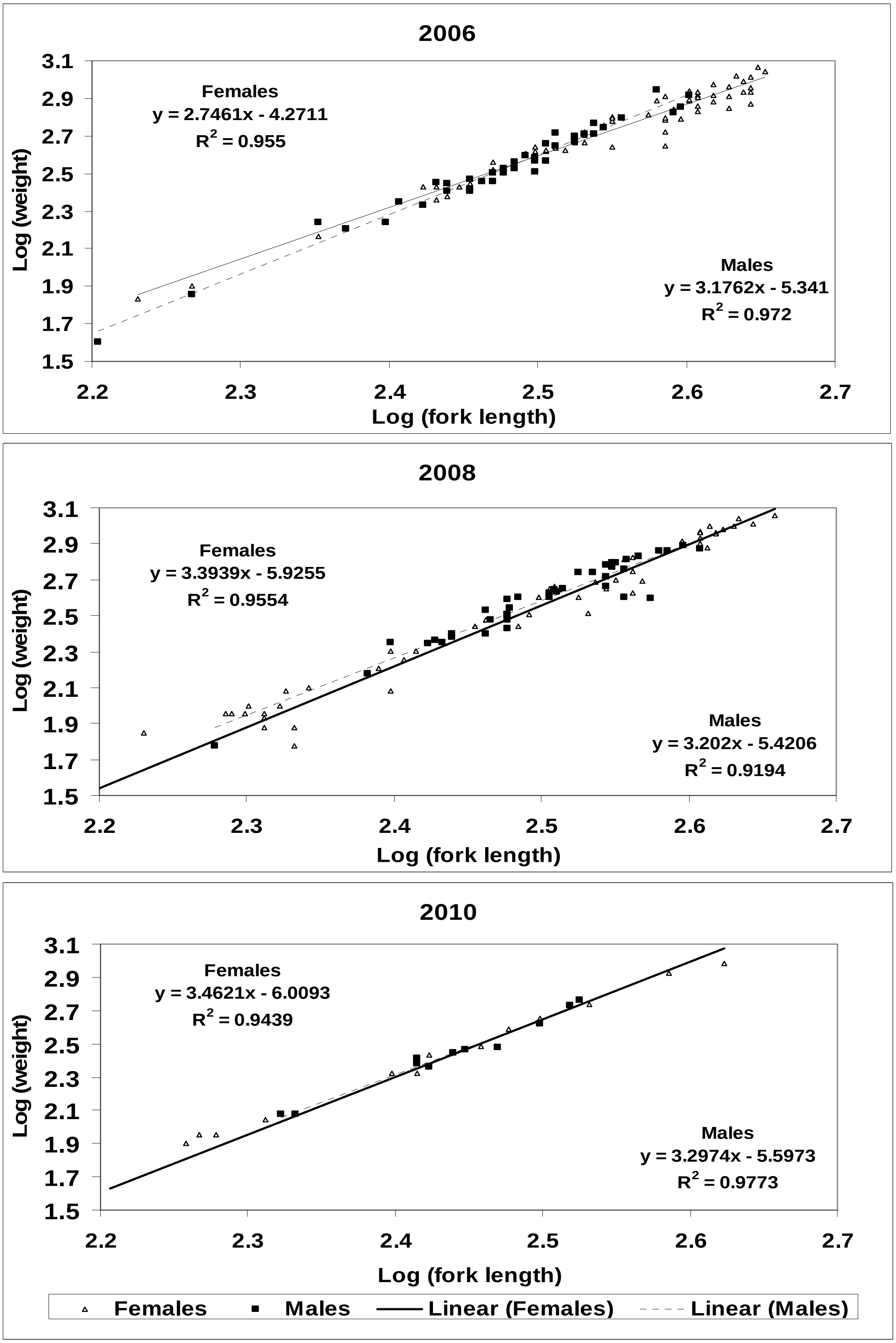

Figure 10. Power relationships of log weight (g) to log fork length (mm) for adult Warner suckers collected from Hart and Crump Lakes in 2006, 2008, and 2010.

Changes in species composition have occurred since sampling began in 1990 (Figure 11). Prior to the lakes drying in 1992, the catch was dominated by nonnative fishes, with white crappie being the most abundant nonnative fish captured. For several years following the drought, native fishes dominated the catch, with tui chub being the most abundant native fish captured. Since 1997, nonnative fish have rebounded and dominated the catch. Bullheads were the most abundant nonnative fish in the 2001 catch, whereas white crappies were the most abundant nonnative fish in the 2006, 2008, and 2010 catch.

Total CPUE for all fish species collected from Crump Lake in 2010 was 15.3 fish per trap night, a 46% reduction from the 2008 CPUE of 28.5 fish per trap night and a 48% reduction from the 2006 CPUE of 29.7 (Figure 12). This reflects an apparent die off of nonnative fishes, which may be due to the low lake levels resulting from the ongoing drought (Table 3). The 2010 CPUE was nearly as low as the CPUE during the drought in the early 1990's. Length frequency histograms for non-target fish species collected in 2008 and 2010 are shown in **APPENDIX A**. From these data, it appears that the reduction in total catch of white crappie in 2010 may have been due to differential mortality of larger individuals.

Sex Ratios and Size at Sexual Maturation for Suckers in the Warner Lakes

We determined the sex of 112, 103, and 30 Warner suckers from the Warner Lakes in 2006, 2008, and 2010, respectively. The female to male ratios were 1.4 to 1 in 2006 and 2008 and 1.3 to 1 in 2010. These ratios are nearly identical to results from 2001 (Hartzell et al. 2001).

In 2006 and 2008, we noted suckers in spawning condition, i.e. females with swollen bellies and/or extended vents and males with spawning tubercles on their anal and lower caudal fins and protruding vents, in the lakes from early-May through early-June. We captured spawned-out females in the lakes from late-May through June. In 2010, we noted suckers in spawning condition starting in late-April and we captured spawned-out females starting in early-June.

The smallest mature male and female suckers that we captured in the lakes from 2006 through 2010 measured 185 mm and 150 mm FL, respectively. All lake suckers $\geq$200 mm were mature.

Condition of Suckers in Crump Lake

A large proportion (70%) of the Warner suckers collected from Crump Lake in 2008 had noticeable lesions on their bodies (Figure 13). In many cases these sores were infected with fungus. In addition, a large proportion of the suckers and tui chubs had external parasites (*Lernaea* sp.). The near desiccation of Crump Lake in the winter of 2007 may have resulted in crowding of fish, which could have resulted in heavy parasite loads. In 2006 and 2010, we collected very few suckers (<15%) with lesions and/or parasites.

Table 3. Numbers and percentages of fish captured in trap nets in Hart and Crump Lakes in 2006, 2008, and 2010, by species.

2006

	Crump Lake		Hart Lake		Both Lakes	
Species	Number	Percentage	Number	Percentage	Number	Percentage
Warner sucker	60	0.8%	54	0.4%	114	0.5%
Redband trout	6	0.1%	0	0.0%	6	0.0%
Tui chub	2,259	31.3%	3,607	26.5%	5,866	28.2%
White crappie	3,688	51.1%	7,377	54.2%	11,065	53.1%
Black crappie	807	11.2%	1,879	13.8%	2,686	12.9%
Juvenile crappie	88	1.2%	242	1.8%	330	1.6%
Brown bullhead	312	4.3%	446	3.3%	758	3.6%
Largemouth bass	4	0.1%	6	0.0%	10	0.0%
total	7,224		13,611		20,835	
Natives	2,325	32.2%	3,611	26.9%	5,986	28.7%
Nonnatives	4,899	67.8%	9,950	73.1%	14,849	71.3%

2008

	Crump Lake		Hart Lake		Both Lakes	
Species	Number	Percentage	Number	Percentage	Number	Percentage
Warner sucker	27	0.4%	76	0.3%	103	0.3%
Redband trout	2	0.0%	0	0.0%	2	0.0%
Tui chub	904	12.2%	4,639	20.6%	5,543	18.6%
White crappie	3,002	40.7%	6,152	27.4%	9,154	30.6%
Black crappie	975	13.2%	4,925	21.9%	5,900	19.8%
Juvenile crappie	18	0.2%	54	0.2%	72	0.2%
Brown bullhead	2,437	33.0%	6,596	29.3%	9,033	30.2%
Largemouth bass	18	0.2%	46	0.2%	64	0.2%
	7,383		22,488		29,871	
Natives	933	12.6%	4,715	21.0%	5,648	18.9%
Nonnatives	6,450	87.4%	17,773	79.0%	24,223	81.1%

2010

	Crump Lake		Hart Lake		Both Lakes	
Species	Number	Percentage	Number	Percentage	Number	Percentage
Warner sucker	30	1.0%			30	1.0%
Redband trout	0	0.0%			0	0.0%
Tui chub	1,069	34.6%			1,069	34.6%
White crappie	1,001	32.4%			1,001	32.4%
Black crappie	536	17.4%			536	17.4%
Juvenile crappie	42	1.4%			42	1.4%
Brown bullhead	407	13.2%			407	13.2%
Largemouth bass	1	0.0%			1	0.0%
	3,086				3,086	
Natives	1,099	35.6%			1,099	35.6%
Nonnatives	1,987	64.4%			1,987	64.4%

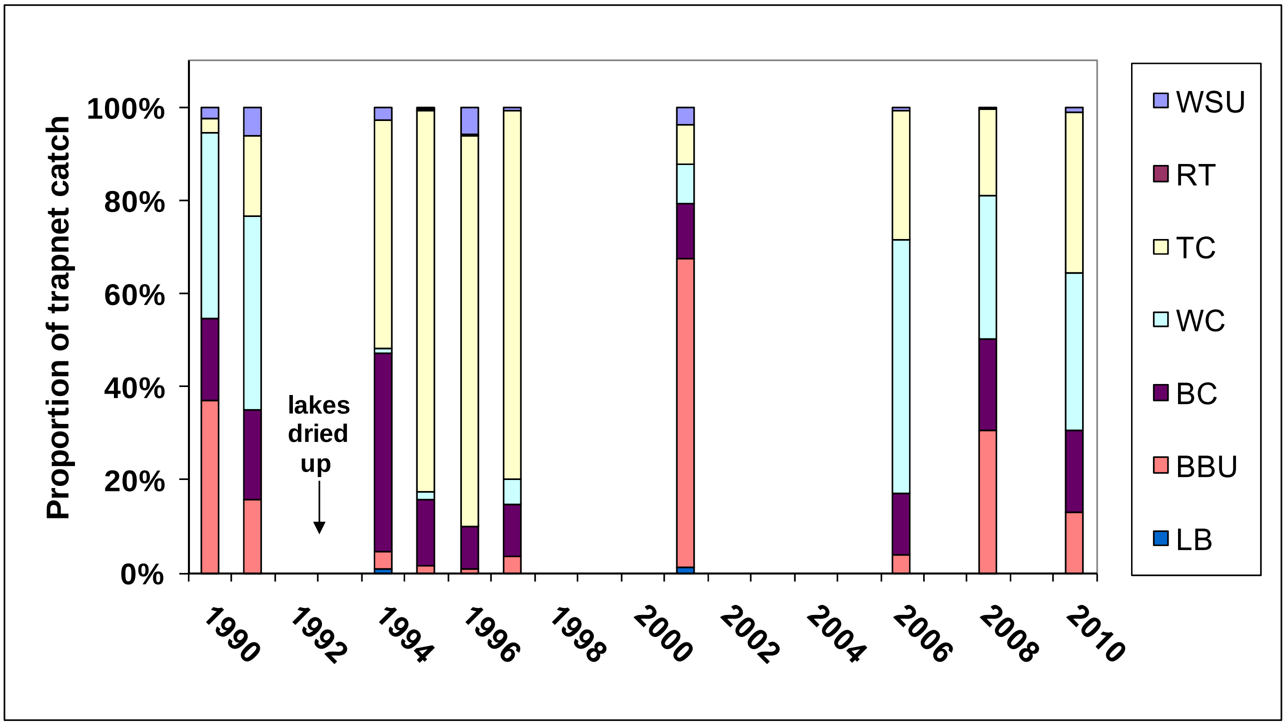

Figure 11. Fish species compositions from trapping in Hart and Crump Lakes, 1990-2010. Fish species codes are: WSU- Warner sucker, RT- redband trout, TC- tui chub, WC- white crappie, BC- black crappie, BBU- brown bullhead, and LB- largemouth bass. Note that the lakes desiccated in 1992.

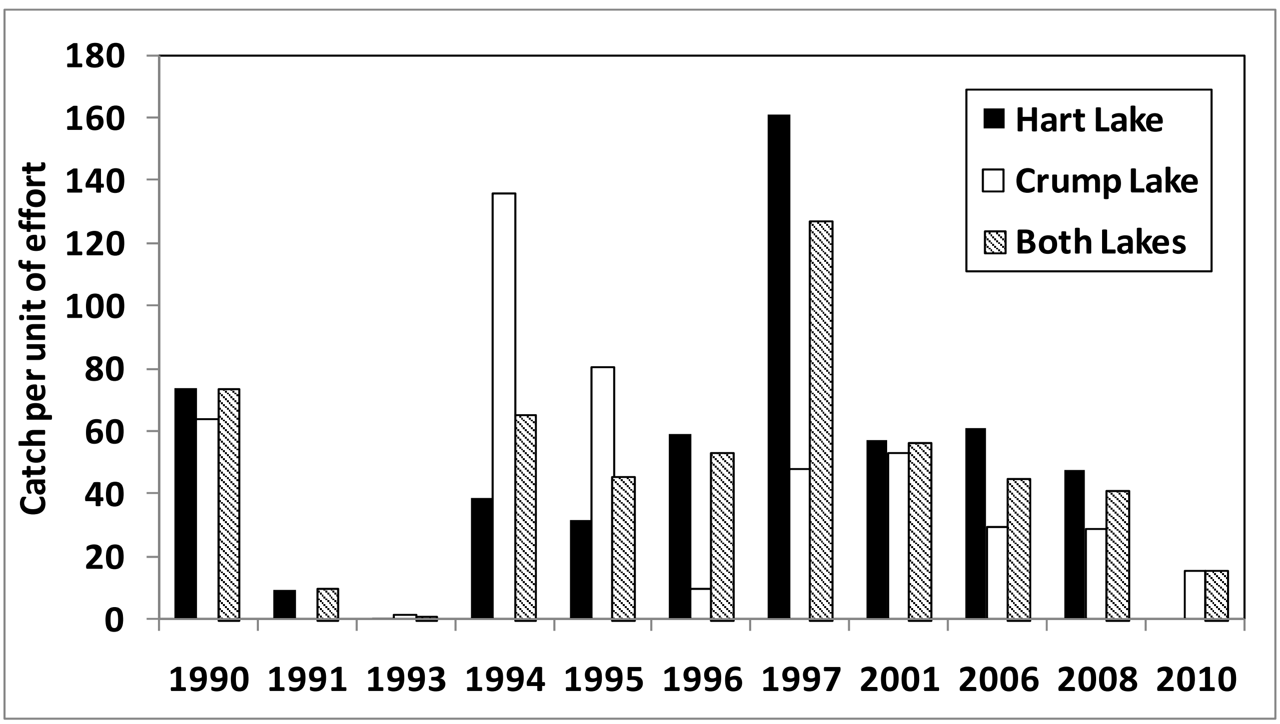

Figure 12. Catch per unit of trap net effort (trap net set overnight) for all fishes captured in the Warner Lakes, 2006-2010.

Figure 13. Examples of Warner suckers collected in Crump Lake in 2008 with external lesions and fungus.

Distribution and Abundance of Suckers in the Warner Tributaries

In 2007, we sampled 62 sites from our random spatially-balanced sample draw. We included nine additional sites that were part of a study targeting redband trout (*Oncorhynchus mykiss newberrii*) where Warner sucker data was also collected. These sites were included in the set of sites used to assess distribution and density patterns, but not included in the abundance estimate. Warner suckers were collected from 32 of the 71 sites (45%) sampled (Table 4).

Table 4. Length of the sampling frame (potential sucker distribution), length of stream sampled, and numbers of sites by outcome category (sites sampled, sites where suckers were collected, sites with dry channels, and sites where access was denied).

	Frame	Sampled	Number of sites			
Drainage	(km)	(km)	Sampled	With suckers	Dry	Denied access
Deep Creek	19.0	0.7	9	2	9	18
Honey Creek	37.4	2.9	38	17	3	18
Twentymile Creek	44.0	2.0	24	13	16	11
Total	100.4	5.6	71	32	28	47

We found the 2007 Warner sucker distribution was discontinuous in most of the Warner basin tributaries (Figure 14). Suckers were evenly distributed in the Twentymile drainage upstream of the irrigation diversion canal matrix, but were rare in the canals themselves. Suckers were fairly evenly distributed in lower Honey Creek and in the reach upstream of the Twelvemile Creek confluence (first major tributary entering Honey Creek from the south), but were rare in the canyon (downstream of Twelvemile Creek). Because access was denied to large portions of Snyder and Deep Creeks, we were unable to comprehensively assess the current distribution and status of Warner suckers in these tributaries.

Densities of suckers (fish per kilometer) in the basin in 2007 were typically low, but highly variable (Figure 15). Sucker densities tended to be highest in the Twentymile Creek drainage, intermediate in the Honey Creek drainage, and lowest in the Deep Creek drainage (Figure 16); however, because of inter-site variability none of these differences was statistically significant.

We obtained population estimates for Warner suckers ≥60 mm FL in each of the three major tributary basins and for the entire drainage (excluding lakes) in 2007. The basin estimate totaled approximately 6,852 suckers (+/-93%) (Table 5). Most of these fish occurred in Twentymile Creek (4,746 fish) followed by Honey Creek (2,202 fish). The large number of sites where no suckers were collected, combined with a few sites where relatively large numbers of suckers were collected, resulted in broad confidence intervals for our estimates (+/-81-192%). Further, removing the portion of the sample frame and associated samples located within the matrix of irrigation canals in the lower portions of Deep and Twentymile Creeks did not appreciably improve the precision of our estimates. Power analysis indicated that under the high degree of variation encountered in 2007, a sample size of approximately 600 sites would be necessary to reduce confidence limits to within +/-20%.

Other native fish species that we collected during our 2007 surveys included redband trout, speckled dace *Rhinichthys osculus*, tui chub, and Northern roach *Lavinia symmetricus mitrulus*. Nonnative fishes that we collected included white crappie, largemouth bass, brown bullhead, and brook trout (*Salvelinus fontinalis*) (Figures 17 and 18).

In 2009, we estimated 4,612 (95% CI: 3,820-5,567) Warner suckers ≥60 mm FL (presumptive age 1+ fish) in the Twentymile Creek drainage. Of this total, 1,169 (95% CL: 969-1,412) were adults. We captured and marked suckers from each of the four strata, although we found the majority (86%) of the population in stratum two (3,786; 95% CI: 3,112-4,603) (Tables 6 and 7). We captured most of the suckers in stratum 2 (Figure 19). Sucker density estimates in the Twentymile Creek subbasin were nearly identical for 2007 (237 fish/km) and 2009 (217 fish/km). We also noted the distribution of other native fish species, including redband trout, speckled dace, tui chub, and Northern roach (Richardson et al. 2009). Nonnative species included largemouth bass and brown bullhead. Speckled dace, redband trout, and Warner suckers were found throughout the drainage, whereas the other species were limited to stratum one and the first 100 m of stratum two (Richardson et al. 2009).

In 2010, we conducted some limited sampling with trap nets in Greaser Reservoir to determine whether suckers were using this reservoir. The reservoir receives water from irrigation canals that originate in lower Twentymile Creek. We captured tui chub and bullheads from these nets; no suckers were captured.

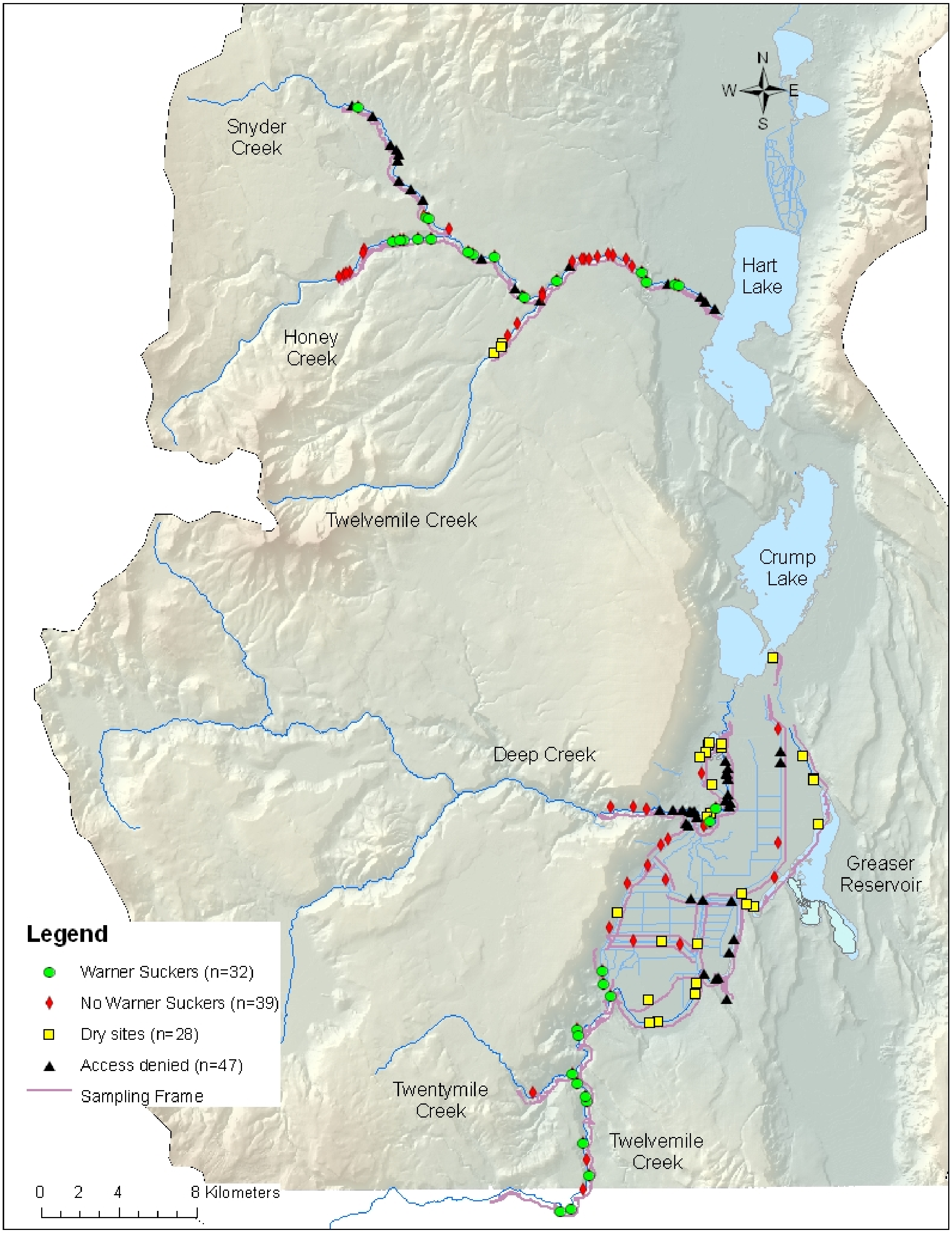

Figure 14. Map showing the sites where we collected Warner suckers, sites where no Warner suckers were collected, sites with dry channels, and sites where access was denied in 2007.

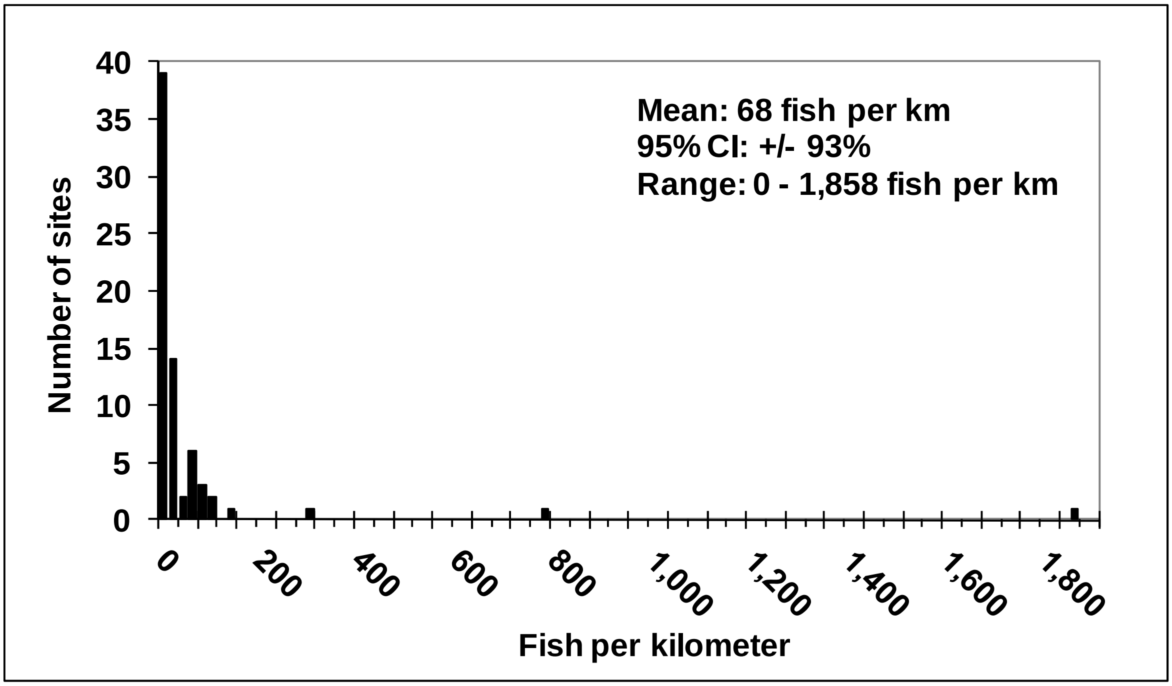

Figure 15. Histogram showing the frequency distribution of densities of Warner suckers (>60 mm FL) estimated at 71 sites sampled in Warner basin tributaries in 2007.

Table 5. Estimates of Warner sucker population abundance (fish >60 mm FL), with associated confidence limits, and sucker densities in streams in the Warner basin, summer 2007.

Stream	Frame (km)	Sampled (km)	N	Estimate	95% CI	Fish/km
Deep Creek	19.0	0.7	8	150	(0-288)	7.9
Honey Creek	37.4	2.9	33	2,202	(42-3,986)	58.9
Twentymile Creek	44.0	2.0	20	4,746	(0-7,783)	107.9
Entire basin	100.4	5.6	61	6,852	(480-13,224)	68.2

Table 6. Details of the 2009 mark-recapture estimate for Warner suckers in the Twentymile Creek drainage, listed by stream stratum (see Figure 19 for strata boundaries). Fish listed in the "marked" column were collected in the first pass; those in the "captured" and "recaptured" columns were collected in the second pass. Fish numbers in the total handled column represent unique individuals, not multiple captures of the same individual.

Stratum	Length (km)	Estimate	95% CI	Marked	Captured	Recaptured	Total handled
1	2.5	677	(299 - 1,334)	46	71	4	113
2	7.6	3,779	(3,112 - 4,603)	520	717	98	1,139
3	9.2	155	(63 - 311)	22	26	3	45
4	2.0	49	(15 - 85)	6	13	1	18
All	21.3	4,612	(3,820 - 5,567)	594	827	106	1,315

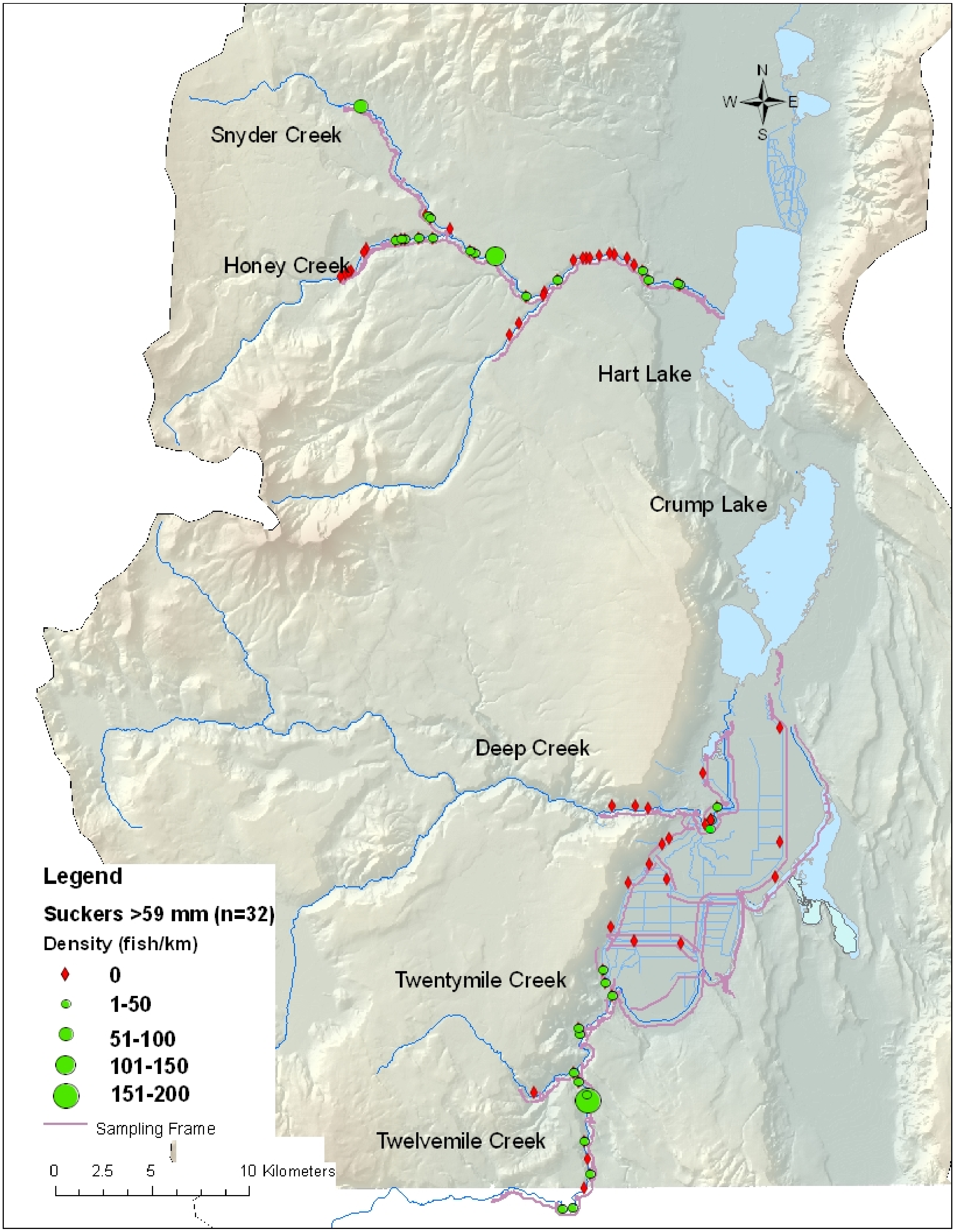

Figure 16. Map showing the 2007 distribution and densities of Warner suckers ≥60 mm FL in Warner subbasin tributaries.

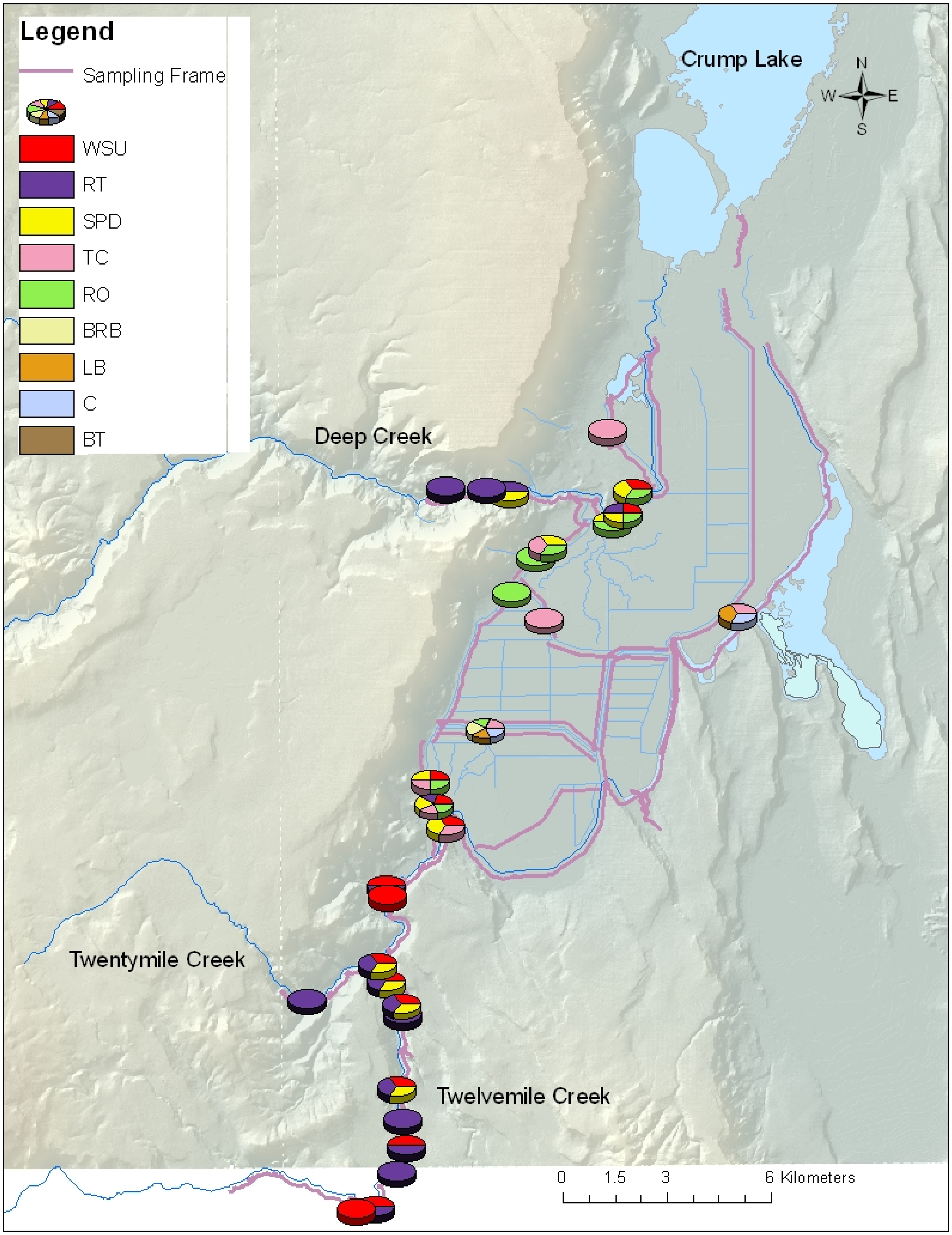

Figure 17. Map showing the distribution of all fish species collected in the Warner basin surveys in the Deep and Twentymile Creek drainages, 2007. Each species present is represented by an equal proportion of the pie.

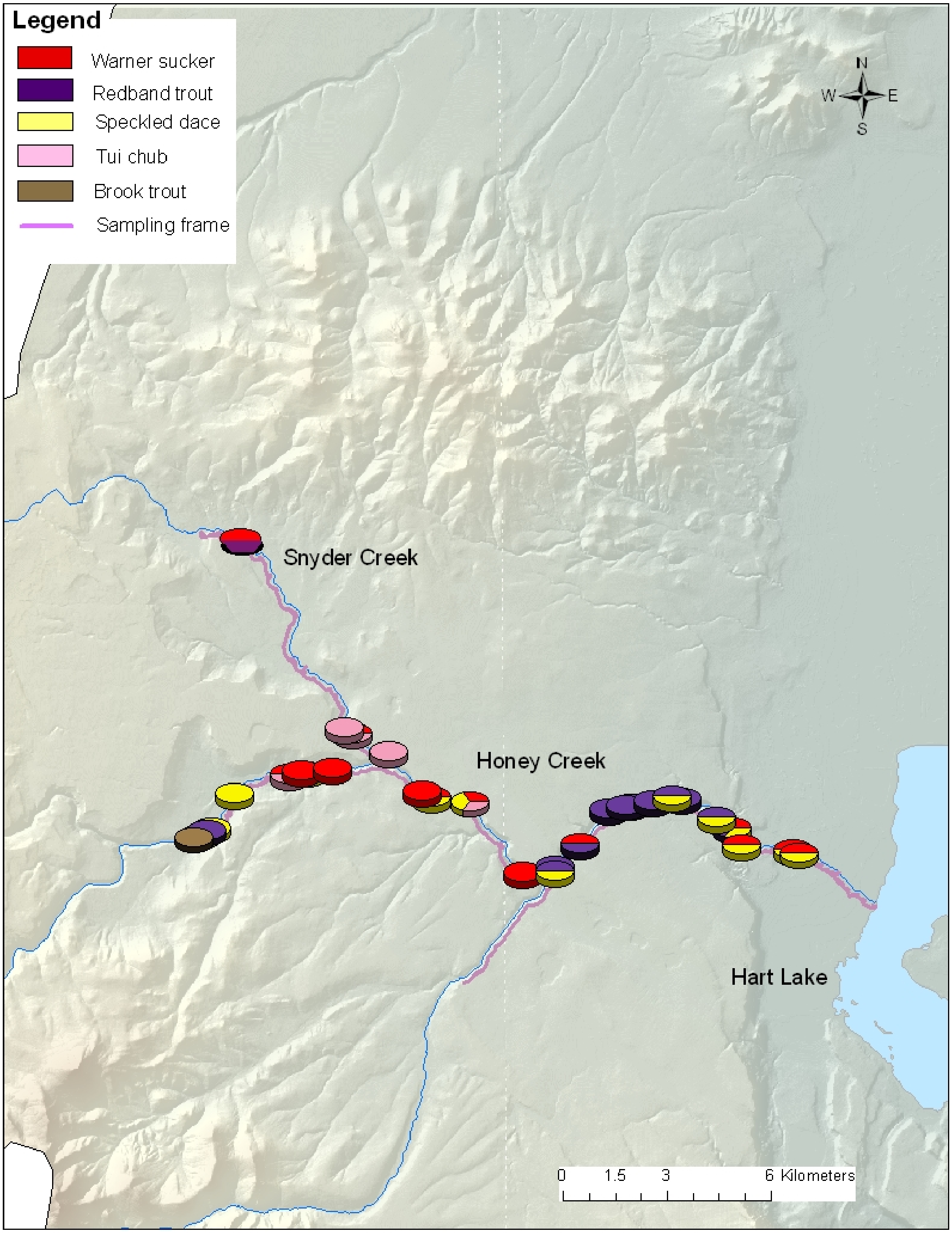

Figure 18. Map showing the distribution of all fish species collected in the Warner basin surveys in the Honey Creek drainage, 2007. Each species present is represented by an equal proportion of the pie.

Table 7. Warner suckers density estimates in the Twentymile Creek drainage in 2009, listed by stream stratum. Adult fish are ≥160 mm FL.

		Suckers per kilometer		
Stratum	Length (km)	All	Adults	Juveniles
1	2.5	271	66	204
2	7.6	498	121	377
3	9.2	17	15	2
4	2.0	25	1	24
All	21.3	217	55	162

Length Frequencies and Length-Weight Relationships of Suckers in the Warner Tributaries

The length frequency distributions for Warner suckers captured in 2007 and 2009 in the Warner basin tributaries were broad with one obvious peak at approximately 90 mm and 80 mm, respectively (Figure 20). In 2007, the suckers ranged in size from 22-330 mm FL ($\bar{x}$ =87.5; 95% CI= ± 13%; n=662) and only 5% of the suckers captured were adults (≥160 mm FL). In 2009, Warner suckers captured from Twentymile Creek drainage ranged in size from 50 mm to 383 mm FL ($\bar{x}$ =114.2; 95% CI= ± 3%; n=1,332) and adult suckers comprised a higher proportion (25%) of the catch.

In Twentymile Creek, mean length of suckers differed significantly between 2009 and 2010 ($p < 0.001$), but not by sex. We found strong log weight- log length relationships for both male and female Warner suckers in the Twentymile Creek drainage (Figure 21). The slopes of log-weight length relationship of male and female suckers were not significantly different in 2010. Also, the slopes of log-weight log-length relationships of suckers from the lakes compared to those from Twentymile Creek where not significantly different in 2010.

Sex Ratios and Sexual Maturation of Suckers in the Twentymile Subbasin

We determined the sex of 77 Warner suckers from the Twentymile Creek subbasin in 2008 (screw trap) and 2010 (electrofishing). The female to male ratio was 3.1 to 1. In 2008, we noted suckers in spawning condition (females with swollen bellies and/or extended vents and males with spawning tubercles on their anal and lower caudal fins and protruding vents) in the Twentymile Creek drainage in May. We captured spawned-out females in the creek starting in early-June. In 2010, we noted suckers in spawning condition starting in late-April and we captured spawned-out females in mid-June through early-July. The smallest mature male and female suckers that we captured in Twentymile Creek subbasin measured 155 mm and 130 mm, respectively. The presence of spawned-out females coincided with increasing stream temperatures and occurred on the descending limb of the hydrograph (see “Seasonal Movements” section).

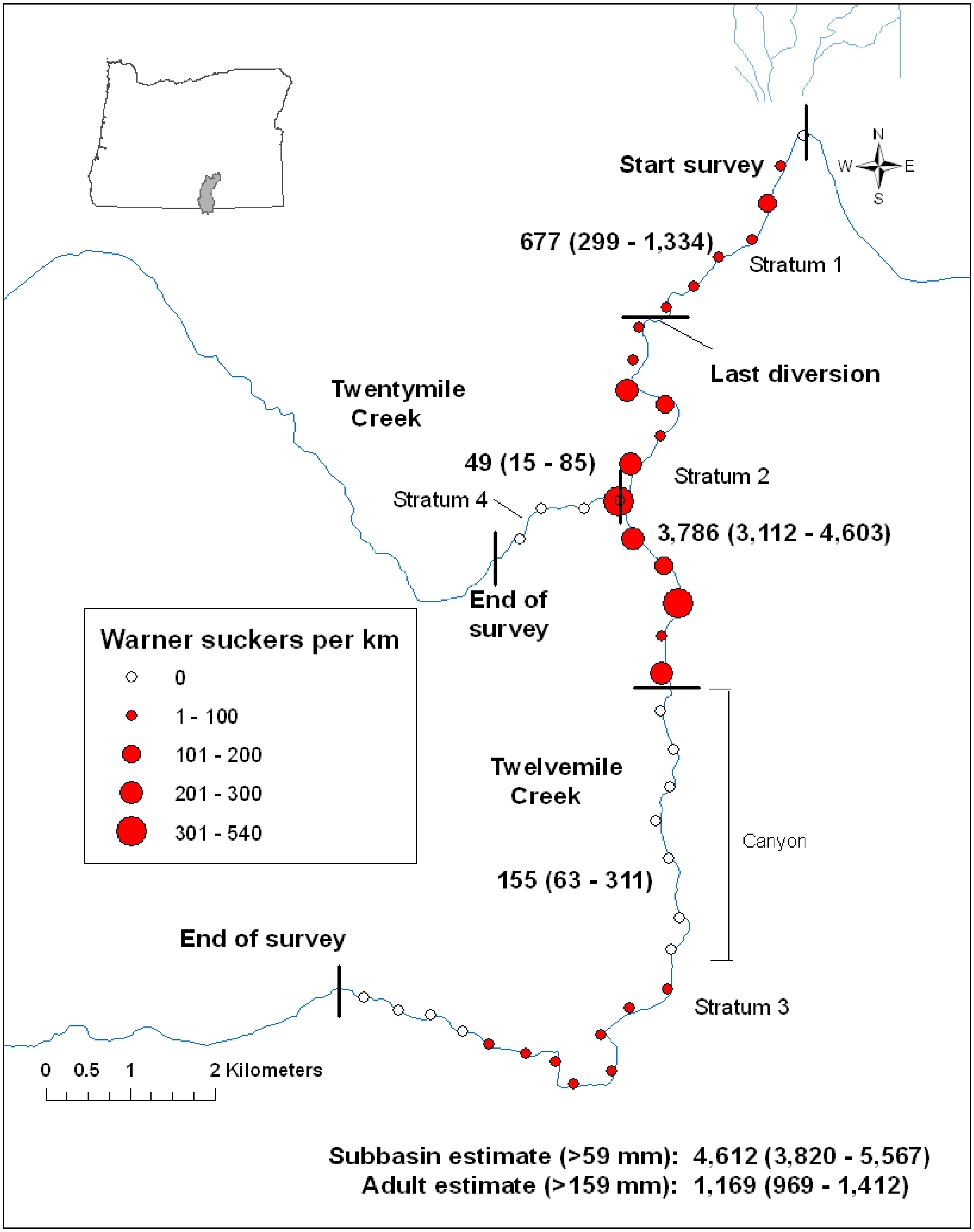

Figure 19. Distribution of Warner suckers in the Twentymile Creek drainage of the Warner subbasin in 2009. Numbers represent the total number of suckers captured in two electrofishing passes in each 500 m sample reach. Note: there were too few recaptures in each 500 m reach to provide reliable mark-recapture estimates at that scale. Strata boundaries are shown with bold vertical or horizontal lines. Note: stratum 1 has numerous irrigation diversions and stratum 2 starts upstream of the last diversion (Dyke Diversion).

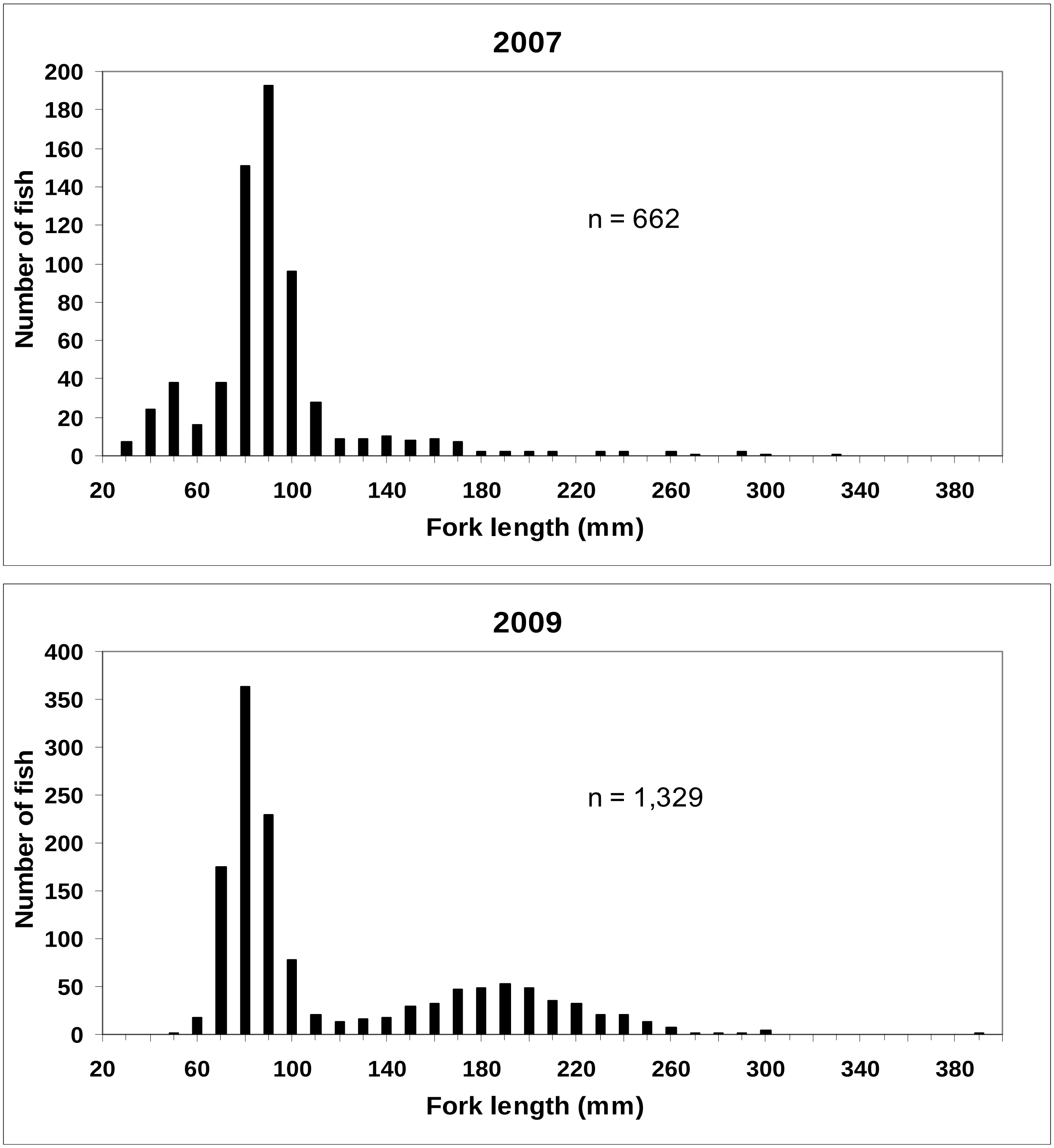

Figure 20. Length-frequency distributions for suckers collected from all Warner basin tributaries (combined) in 2007 and from the Twentymile Creek subbasin (only) in 2009.

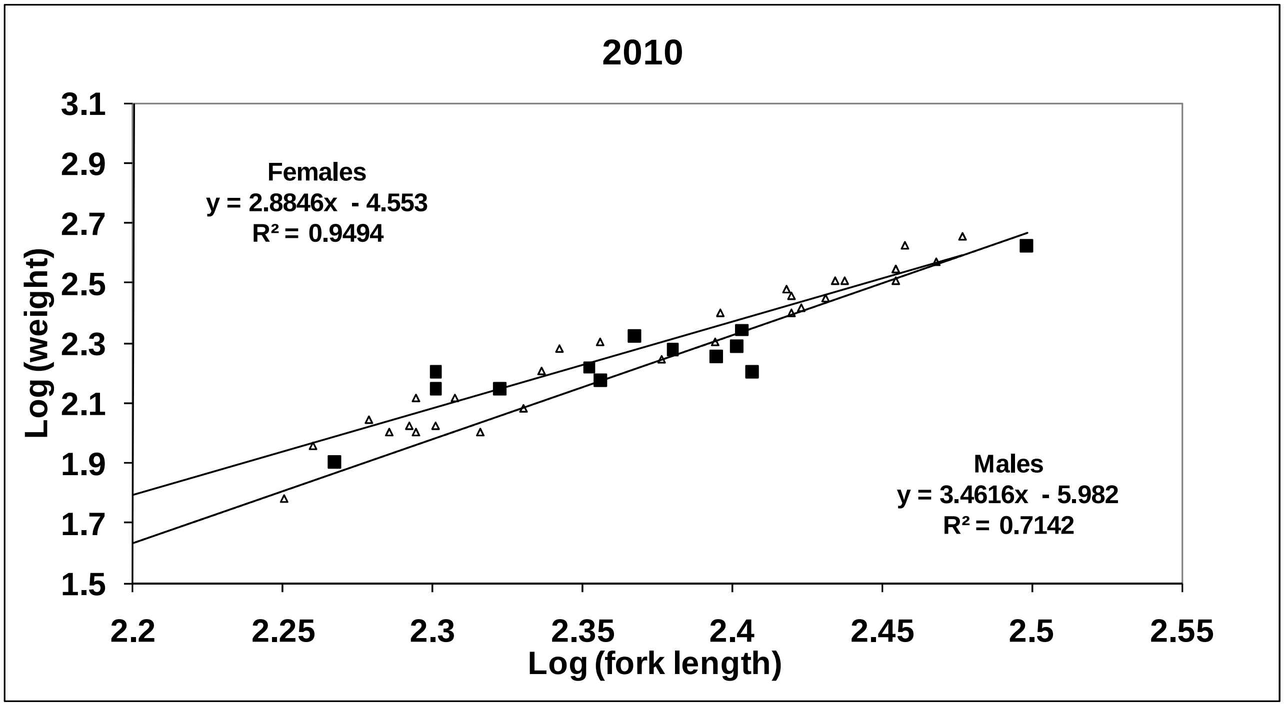

Figure 21. Power relationships of log weight (g) to log length (mm) for adult male (squares) and female (triangles) Warner suckers collected from Twentymile Creek in 2010. Slopes of these relationships for males and females were not significant (P>0.05).

Habitat Associations

In 2009, Warner suckers were most abundant in strata one and two in the Twentymile Creek drainage. These strata were characterized by low gradients, with a wide channel and deep pools. The stream channel in these strata had low water velocities, abundant macrophytes, and was dominated by fine substrates. We also captured high densities of suckers in backwater habitats. The highest captures of suckers were associated with the deepest sample reaches in stratum 2 (Figure 22). We found that suckers were commonly associated with aquatic macrophytes along the margins of deep pools. Suckers were most common in areas dominated by gravel-sized and smaller substrate. We developed a two-variable multiple regression model which accounted for 52% of observed variation in total number of suckers captured (P <0.0001, DF=2, 37). Significant variables included maximum recorded temperature (P =0.004) and mean depth (P =0.003), both of which were positively correlated with log [fish abundance]. The final model was log [fish abundance] = 0.14 (maximum temperature) + 5.250 (mean depth) - 7.86.

Condition of Suckers in the Twentymile Creek Subbasin

During our 2009 sampling in the Twentymile Creek subbasin, we noted that 64% of all suckers handled had parasites and/or lesions. We noted infected fish throughout the subbasin, although larger percentages of suckers were infected in the lower two strata. We found a significant positive relationship between elevated water temperature and parasite presence (*P*= 0.00002), although the regression only explains 36% of the total variation in incidence of infection between sites. However, we did not differentiate between levels of infection, i.e. a fish with a single lesion or parasite was recorded the same as a fish with multiple lesions or parasites. The lesions were likely caused by fish trying to rid themselves of the parasite, *Lernaea* sp., by scraping. These lesions commonly had secondary fungal infections (C. Banner, ODFW Pathology, personal communication). Other maladies affecting the suckers included exophthalmia (protruding eye), fleshy tumor-like growths, spinal deformities, and internal parasites (tapeworms). Notably, during our 2010 work in the Twentymile Creek subbasin, less than 5% of the suckers handled had parasites and/or lesions. This may be due to the cooler stream temperatures in 2010 compared to 2009 (**APPENDIX B**), which can affect the rate of infectious diseases in fish.

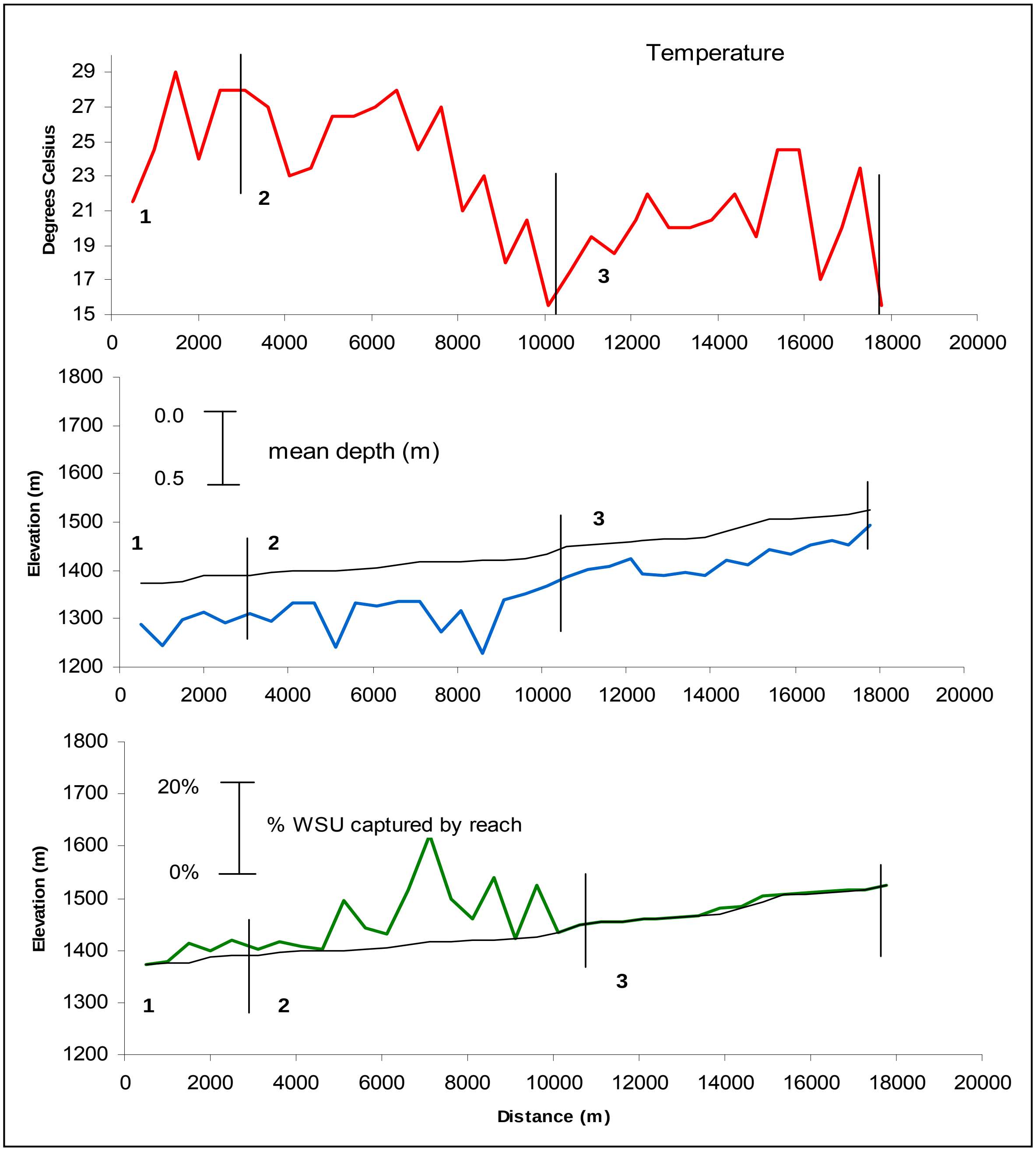

Figure 22. Relationships between the percentage of all Warner suckers (WSU) captured in each stream reach (bottom), mean water depth (middle), and the maximum recorded temperatures (top) recorded for each reach. Stream strata boundaries are marked with vertical bars and are numbered.

Growth of PIT-tagged Warner Suckers

During the 2006-2010 field seasons, we recaptured 19 suckers with PIT-tags that were implanted between 240 and 1,877 days prior, offering insight into sucker growth rates. Suckers grew an average of 23 mm per year (range, -3 to 76 mm) and were extant an average of 1.5 years. There was an inverse relationship between size at capture and annual growth (R^2=0.38) (Figure 23).

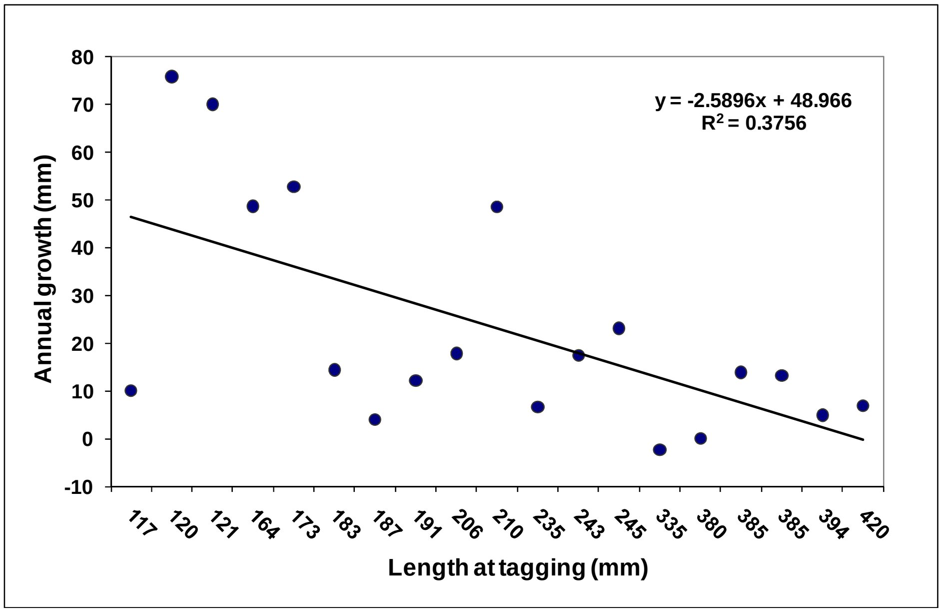

Figure 23. Annual growth of Warner suckers in the Warner subbasin, 2006-2010.

Seasonal Movements of Warner Suckers

We employed the following methods to assess seasonal movements of Warner suckers: 1) operation of downstream-migrant screw traps, 2) operation of an upstream-migrant trap at a fish ladder, 3) detections of PIT-tagged suckers at fixed antennas, 4) recaptures of PIT-tagged suckers, 5) tracking of radio-tagged suckers, and 6) deployment of larval drift nets and/or light traps.

<u>Downstream Migrant Trapping</u>

We captured three adult suckers and one juvenile sucker in the rotary screw trap that was fished at the mouth of Honey Creek from 1 May through 2 June 2006 (19 trap nights). All suckers were captured between 1 May and 17 May, which corresponds with the period of highest stream discharge and increasing temperatures (Figure 24). Temperatures recorded at the mouth of Honey Creek when the screw trap was operated ranged from 4.9 ^{o}C to 20.2^{o}C (Figure 24). We collected other species in small numbers including white crappie, brown bullhead, and tui chub.

We captured 28 Warner suckers, 38 redband trout, and hundreds of speckled dace in the screw trap that was fished near the mouth of the canyon on Twelvemile Creek from 7 April through 17 June 2008 (47 trap nights) (Figure 25). We captured over 75% of the suckers after mid-May, a time period that corresponds with consistently higher stream flows. Temperatures recorded at the trap site ranged from 1.5 ^{o}C to 15.0^{o}C during the period of operation.

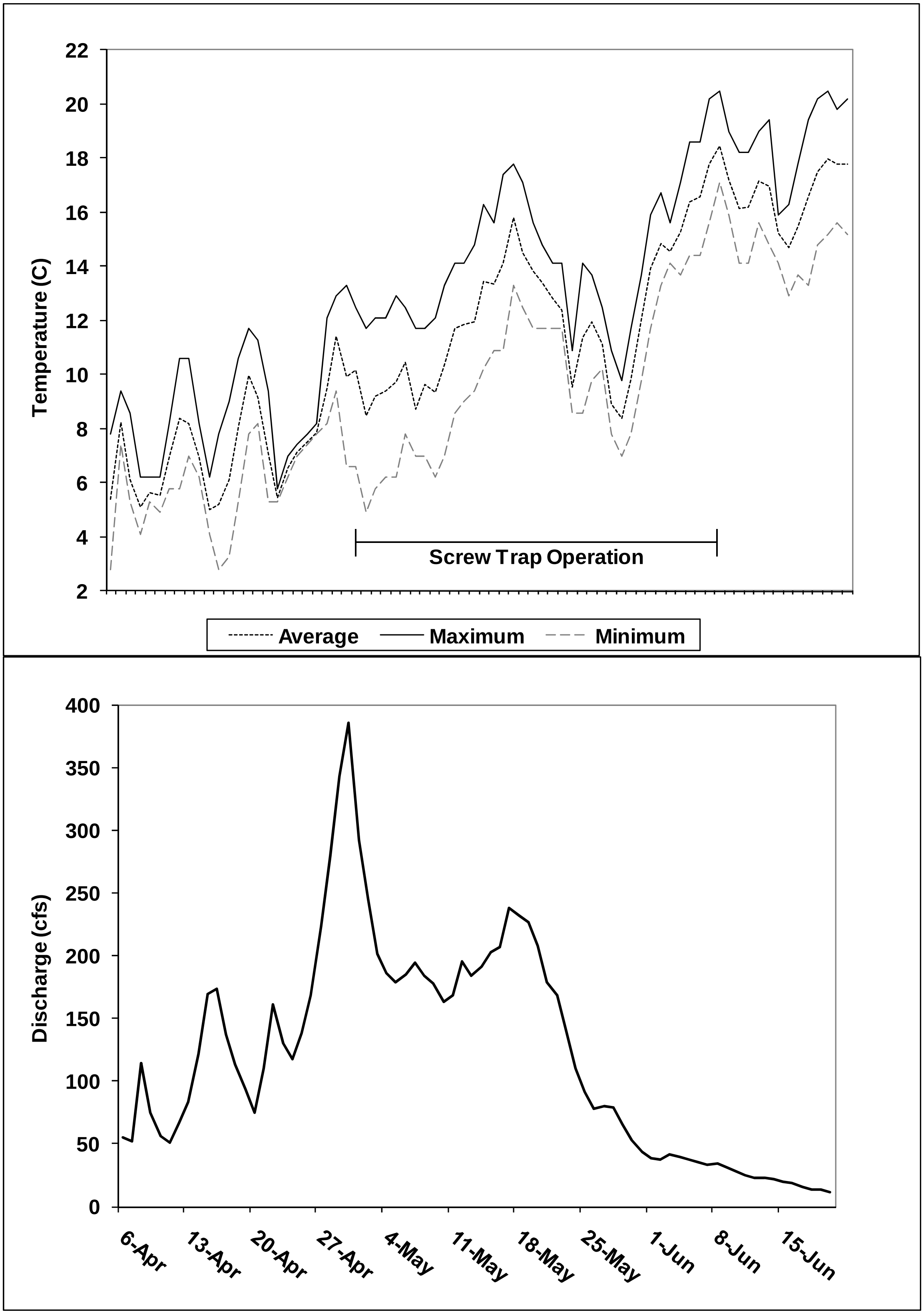

Figure 24. Water temperatures and stream discharge at the mouth of Honey Creek, spring 2006.

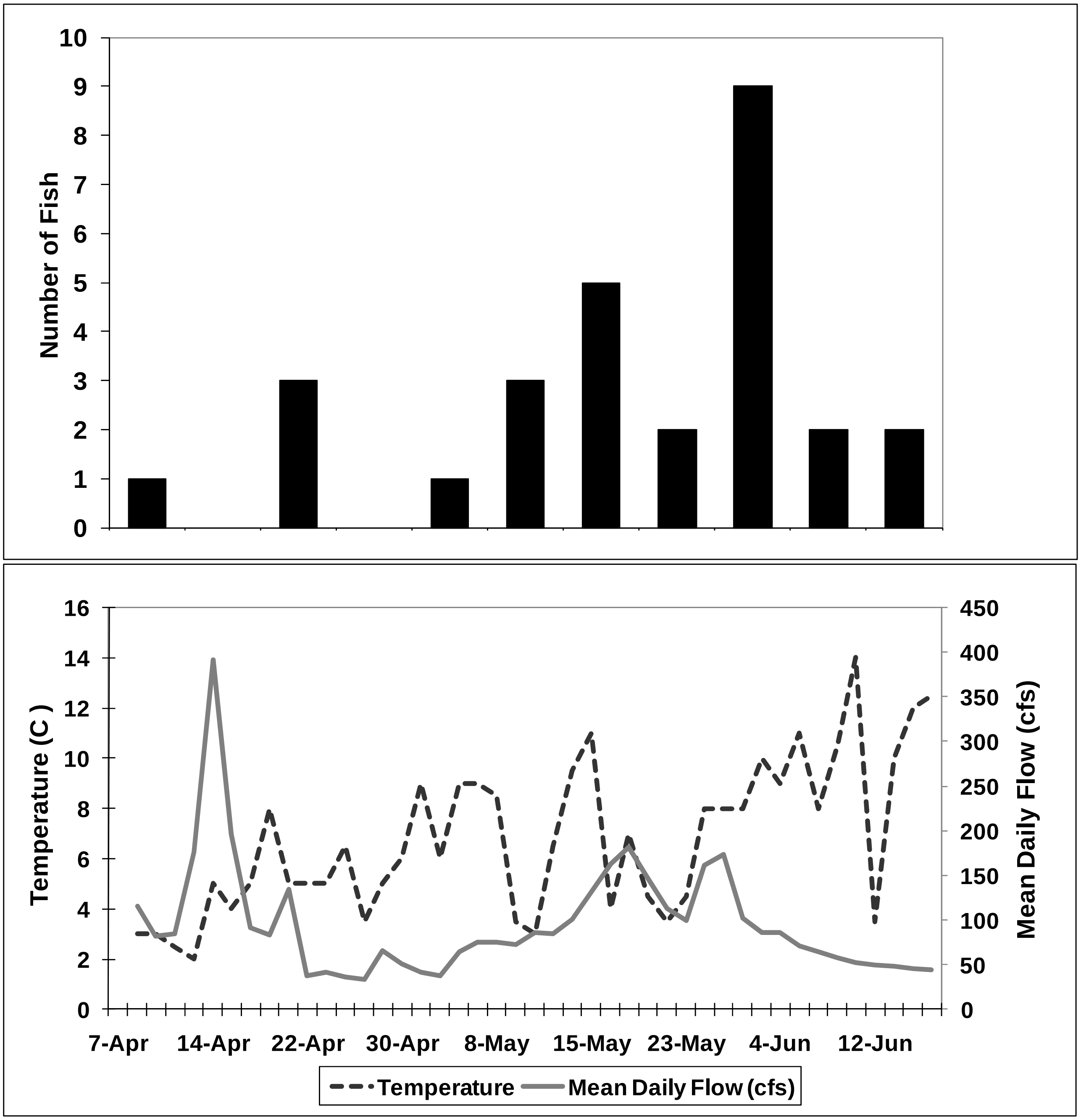

Figure 25. Weekly catch of Warner suckers in the downstream migrant rotary screw trap fished in Twelvemile Creek in 2008 (top). Water temperatures recorded at the trap site in Twelvemile Creek and mean daily flows at the Twentymile Creek gaging station in 2008 (bottom).

We captured 8 suckers (7 juveniles and 1 adult), 44 redband trout, and hundreds of speckled dace in the screw trap that was fished in Twentymile Creek from 6 April through 8 June 2010 (39 trap nights). Catch was distributed fairly evenly across the sampling period. Temperatures recorded at the trap site ranged from 6.2 - 16.8°C during the period of operation.

Upstream Migrant Trapping

No fish were captured in the trap that was placed in the fish ladder at the Dyke diversion (see Figure 4) between 18 April and 17 June. Stream temperatures ranged from 3.5°C to 14°C.

Movements of PIT-tagged Warner Suckers

A total of 800 Warner suckers were PIT-tagged and 72 were radio-tagged from 2006 through 2010 (Table 8). Of the 230 suckers tagged in the lakes, only one sucker, tagged in 2008, was recaptured in the same year that it was tagged (Scheerer et al. 2006; 2008a). Four suckers tagged in 2006 were recaptured in 2008. All were captured near the location where they were tagged two years prior. Also, two suckers tagged in 2001 near the mouth of Honey Creek were recaptured in 2006 from the same location.

Table 8. Numbers and capture locations of Warner suckers implanted with PIT tags and radio tags, 2006-2010.

		Number of	
Year	Capture location	PIT tags	Radio tags
2006	Crump Lake	59	5
	Hart Lake	45	5
2007	Twentymile / Twelvemile Creek	28	
	Honey / Snyder Creek	32	
2008	Crump Lake	25	7
	Hart Lake	74	25[a]
	Twelvemile Creek	26	
2009	Twentymile / Twelvemile Creek	421	
2010	Crump Lake	30	
	Twentymile / Twelvemile Creek	60	30
		800	72

[a]Five radio tagged fish captured in Hart Lake were released into Honey Creek upstream of the bridge crossing.

In 2009, we recaptured 63 suckers on the second pass of the electrofishing survey in the Twentymile Creek subbasin that we PIT-tagged on the first pass (Richardson et al. 2009). Of the 63 recaptured PIT-tagged fish, 55 (87%) were captured from the same reach where they were tagged. Of the eight fish (13%) that moved beyond the reach where they were tagged, six were recaptured upstream of the location where they were tagged and two were recaptured downstream. The average distance moved by all recaptured PIT-tagged fish was 100 m. Among fish that were recaptured in reaches other than those where they were tagged, average movement was 0.65 km (range ~0.4-1.2 km) from the tagging location. The fish traveling the greatest distance in the Twentymile Creek subbasin was marked below the Dyke Diversion and was recaptured above the Dyke diversion, indicating that this fish successfully navigated the fish ladder during the low water period.

In the spring of 2009, we monitored PIT-tag detections at an antenna installed at the mouth of Honey Creek (Richardson et al. 2009). Because the Hart Lake water elevation was low, the shallow Honey Creek channel (average ~0.3 m deep) extended over 100 m across the dry shoreline of Hart Lake before entering the lake. Three Warner suckers were detected crossing this PIT tag antenna during the spring of 2009. One male sucker, tagged on 1 June 2006, crossed the antenna on multiple occasions from 5 May and 26 May 2009. Another male sucker, tagged on 18 May 2006 in the screw trap fished at the mouth of Honey Creek, was detected on 8 June 2009. A female, tagged on 14 May 2008, crossed the antenna on multiple occasions between 25 April and 27 April 2009. All of the movements from these three suckers were nocturnal, occurring between 2030 hrs and 0430 hrs. We tested the PIT-tag antenna using a test tag daily (Monday-Friday) and detected no periods when the antenna was not operational. We did not estimate antenna detection efficiency using live PIT-tagged fish.

In the summer of 2009, we monitored PIT-tag detections at the antenna installed in lower Twentymile Creek (see Figure 5) (Richardson et al. 2009). Nine fish were detected at the antenna; eight were tagged in 2009 and one was tagged during the 2007 stream surveys. All nine fish were tagged in stratum two. No fish tagged in stratum one, which is located downstream of the Dyke diversion, were detected at the antenna, suggesting that few suckers pass upstream over the fish ladder during the summer months. Two of the nine fish that we detected at the antenna were tagged downstream of the antenna and seven fish were tagged upstream of the antenna. The average downstream movement of suckers tagged in 2009 and detected at the antenna was approximately 2.4 km. In contrast to the results from Honey Creek, suckers tagged in the Twentymile subbasin were detected at the PIT-antenna both nocturnally and during the day.

In the spring of 2010, we recaptured 13 PIT-tagged suckers while electrofishing in the Twentymile Creek drainage. Eleven were tagged in 2008 and two were tagged in 2009. All were tagged in the Twentymile Creek drainage. The average time that these fish were extant was 297 d (range, 240-490 d). The average distance between recapture locations was 1.07 km (range, 0.06-3.75 km). Because these estimates of movement assumed that fish traveled the shortest possible distance between detection locations, the actual extent of movement is likely an underestimate.

In the spring of 2010, we monitored PIT-tag detections at three antennas installed in the Twentymile Creek drainage (**APPENDIX C**). We did not detect any PIT-tags at the antenna installed in the irrigation canal at the Dyke diversion. The ditch was operated sporadically because of abundant precipitation in May. We only detected 11 PIT-tagged suckers at the antenna installed near the USGS gage on Twentymile Creek (Figure 1). Three of these fish apparently resided near the antenna and were detected frequently (15 to 31 detections), four were detected 2 to 6 times, and four were detected on only one occasion. Seven fish moved upstream from their tagging location and four moved downstream. Ten suckers were tagged within 1.5 km of the antenna; one was tagged near the upper antenna (>5 km from lower antenna) (Figure 26). We detected 72 PIT-tagged suckers at the antenna operated at the mouth of the canyon on Twelvemile Creek (Figure 26, **APPENDIX C**). One fish apparently resided near the antenna; it was detected 43 times. Movements of PIT-tagged fish occurred over the entire time period when this antenna was in operation. Peak detections were in June, on the descending limb of the hydrograph when stream temperatures were rising (Figure 27). There were 50 unique suckers that moved upstream across this antenna in June 2010. These 50 fish represent 11.9% of the 421 fish that were PIT-tagged in 2009. Expanding this using our population estimate from 2009, we

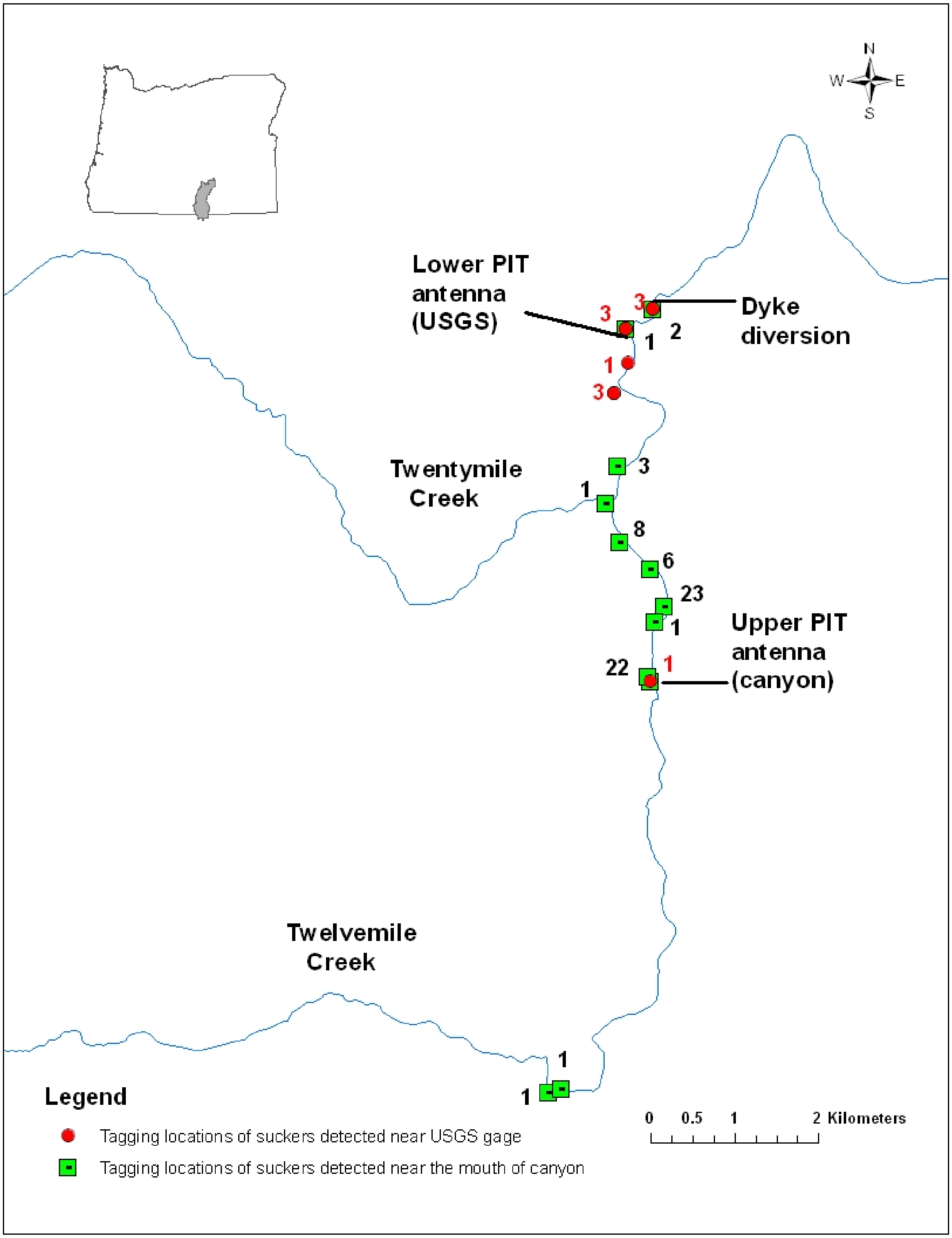

Figure 26. Tagging locations of PIT-tagged Warner suckers detected at antennas in the Twentymile Creek subbasin, 2010. Numbers next to symbols are the number of fish tagged at each location. Colors of the numbers match the colors of the symbols. Note that the tagging location displayed on the map may not represent the location where the fish was residing immediately prior to installation of the PIT antenna.

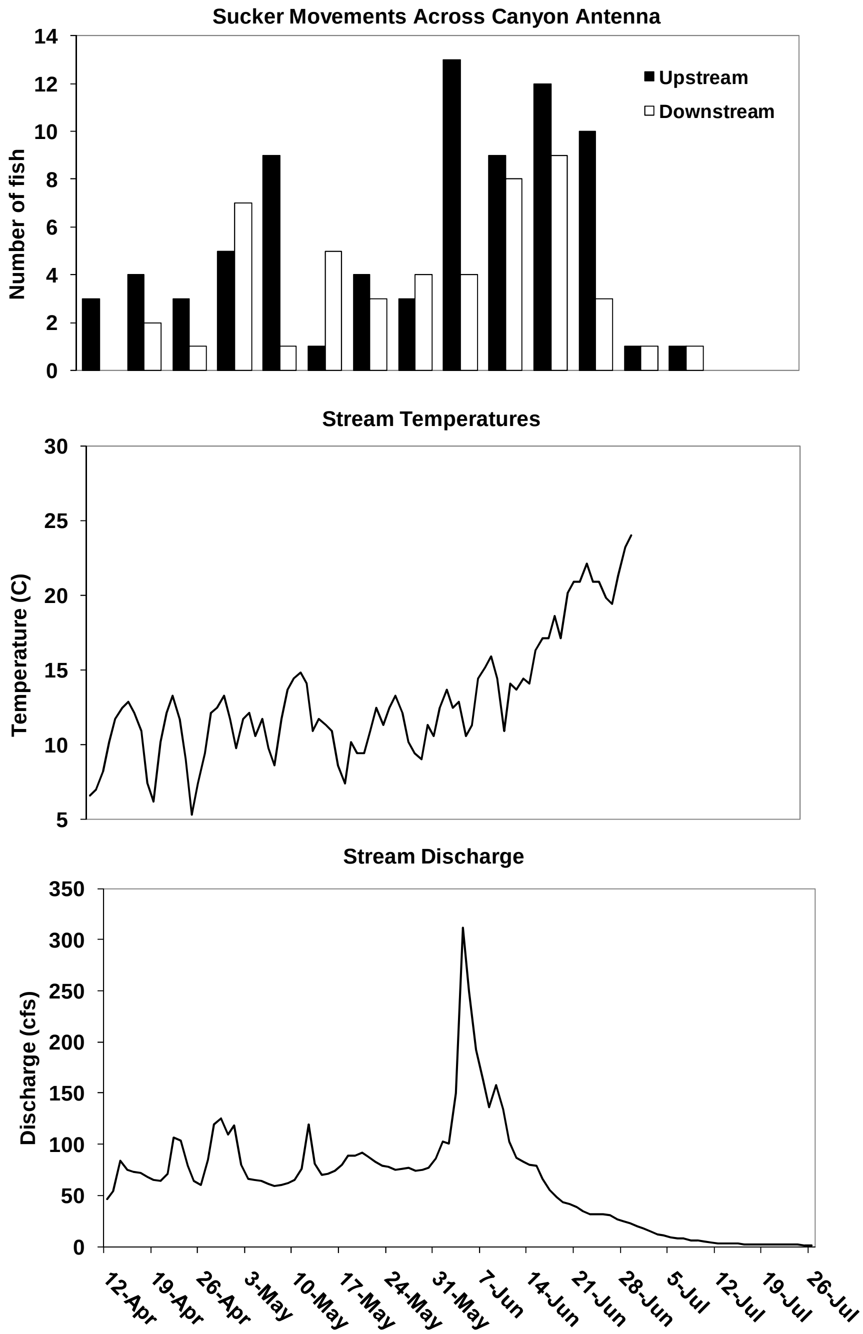

Figure 27. Weekly movements of PIT-tagged Warner suckers (upper panel) across the antenna operated near the mouth of the canyon on Twelvemile Creek in 2010. Also shown are stream temperatures (middle panel) and stream discharge (lower panel).

estimated that 549 fish moved upstream past this point. We estimate ~469 adult suckers crossed the antenna (85.5% of the fish crossing the antenna were adults). Thus, approximately 40% of the adult population (469 of 1,169 adults estimated in 2009) moved upstream across the PIT antenna during June, presumably to spawn. This is a minimum estimate because it assumes 100% detection efficiency at the antenna and no mortality of PIT-tagged fish.

Movements of Radio-tagged Warner Suckers

We radio-tagged a total of 72 Warner suckers from 2006 through 2010 (Table 8). In 2006, we had mixed results tracking the ten Warner suckers radio-tagged in Hart and Crump Lakes. We were frequently unable to locate tagged suckers from the boat or truck and were only able to read the tag codes that identified individual fish when we were within ~50 m. On the two occasions when aerial tracking was conducted (18 May 2006 and 16 June 2006) only six and five of the ten fish were found, respectively. One tagged fish died soon after release (Hart 098). Despite these problems, we were able to document movement of tagged fish from Crump Lake south into Deep Creek, movements offshore in northern Crump Lake, movements of fish along the western shore of Hart Lake, and movements into Honey Creek up to the last irrigation diversion below the road (Figure 28). We did not find any tagged fish that moved between Hart and Crump Lakes, nor were tagged fish detected in the lakes north of Hart Lake.

In 2008, we radio-tagged 32 Warner suckers. Twenty suckers were captured in Hart Lake, tagged, and released back into Hart Lake. Five suckers were captured in Hart Lake, tagged, and released into Honey Creek above the diversion dam at the bridge in Plush. Seven fish were captured in Crump Lake, tagged, and released back into Crump Lake. Originally we had intended to tag more fish in Crump Lake, however most suckers captured in Crump lake were too small for tagging (<225 g; tag was >4% of body weight). In 2009, we experienced some initial equipment problems with our hand held radio receiver antennas and cables, but resolved these by early-May. Consequently, tag detections in April were sparse. In addition, we were unable to obtain codes for individual fish during our aerial tracking flights.

Fish tagged in 2008 in Hart Lake were detected an average of 8.2 times and moved an average of 12.0 km among all locations where they were detected during the period of tracking (range 4.1-19.4 km) (Table 9). Because these estimates of cumulative movement assume that fish traveled the shortest possible distance between detection locations, the actual extent of movement is likely an underestimate. In Hart Lake, we detected the apparent movement of tagged fish towards Honey Creek in early-May. In late-May and June, we detected tagged fish primarily in the northern and eastern portions of Hart Lake, which had deeper water than southern portion of the lake. Detections of radio-tagged fish in Hart Lake were more common near the western shore (Figure 29). Perhaps the high irrigation return from the fields was acting as an attractant flow. Movements of a typical Hart Lake fish (tag code 29) are shown in Figure 30. This fish was tagged 30 April in the northern end of Hart Lake, moved toward and entered Honey Creek on 10 June, and then returned to the northern end of Hart Lake on 16 June. We did not detect any movement of fish between Crump and Hart Lakes in 2008. We detected suckers which were radio-tagged in Hart Lake that moved into lower Honey Creek in early-June and detected unidentified suckers (no codes) during aerial flights in late-May and June in Honey Creek. Most of these detections were from suckers captured in Hart Lake and released into Honey Creek (Figure 31). During aerial flights, we did not detect any tagged fish that moved north of Hart Lake.

Table 9. Numbers of Warner suckers radio-tagged, their mean length, the mean number of observations (detections), and the mean and range of cumulative distance traveled in April-June 2008. One sucker tagged late in June in Crump Lake was not detected.

Release Site	Number of fish	Mean length (mm)	Mean Number of Observations	Distance traveled (km) mean	Distance traveled (km) range
Crump Lake	6	330.8	3.8	6.3	2.7 - 12.4
Hart Lake	20	360.7	8.2	12.0	4.1 - 19.4
Honey Creek	5	348.6	5.8	--	--

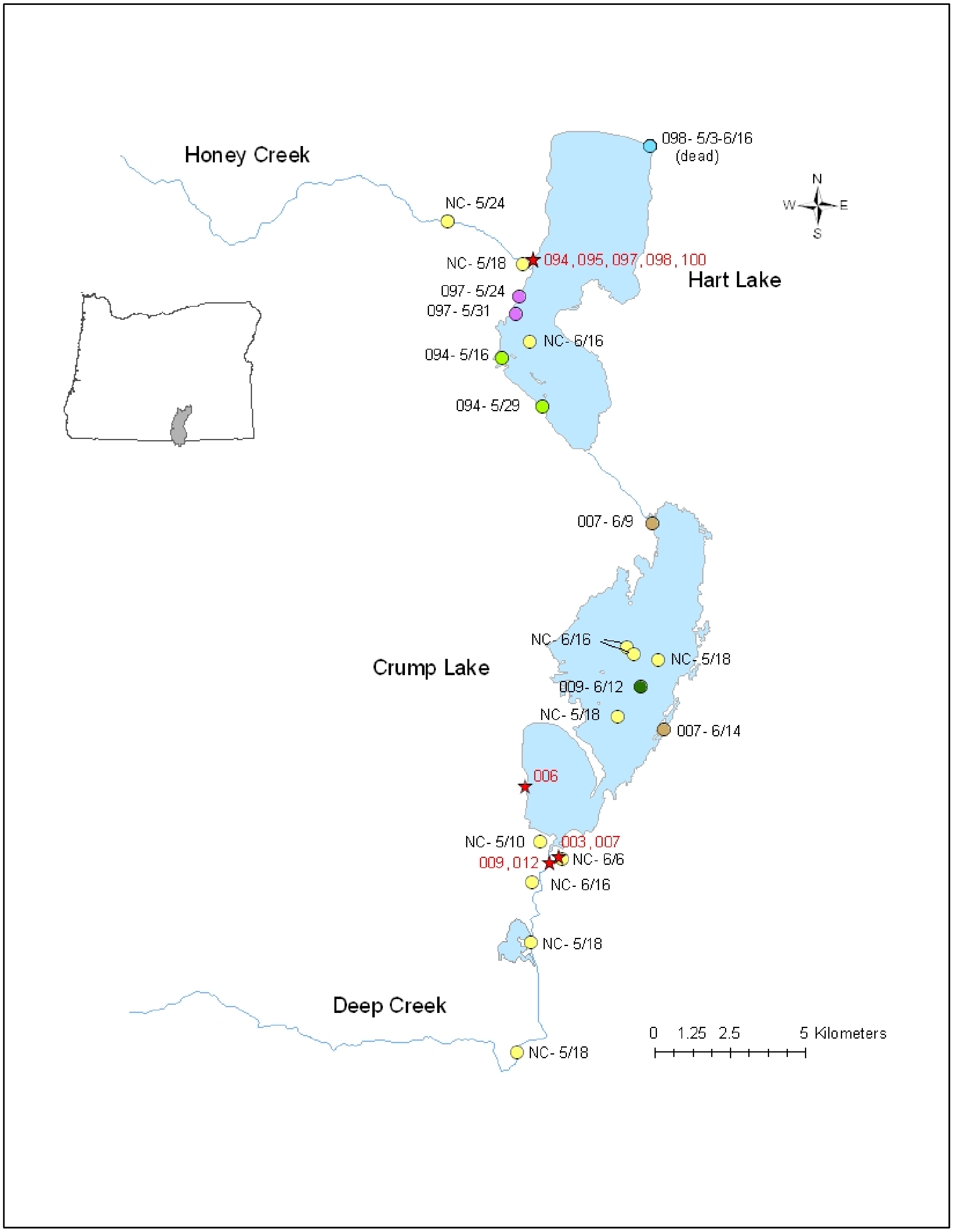

Figure 28. Tagging locations (red stars), tracking locations (circles), and tracking dates of Warner suckers radio-tagged suckers in 2006. Each tracking location is identified with the tag code number and date of tracking. Most codes, labeled as NC, were not identified (yellow circles). Detections of coded tags for the same fish are depicted by circles of the same color. All fish were tagged on 25-26 April 2006.

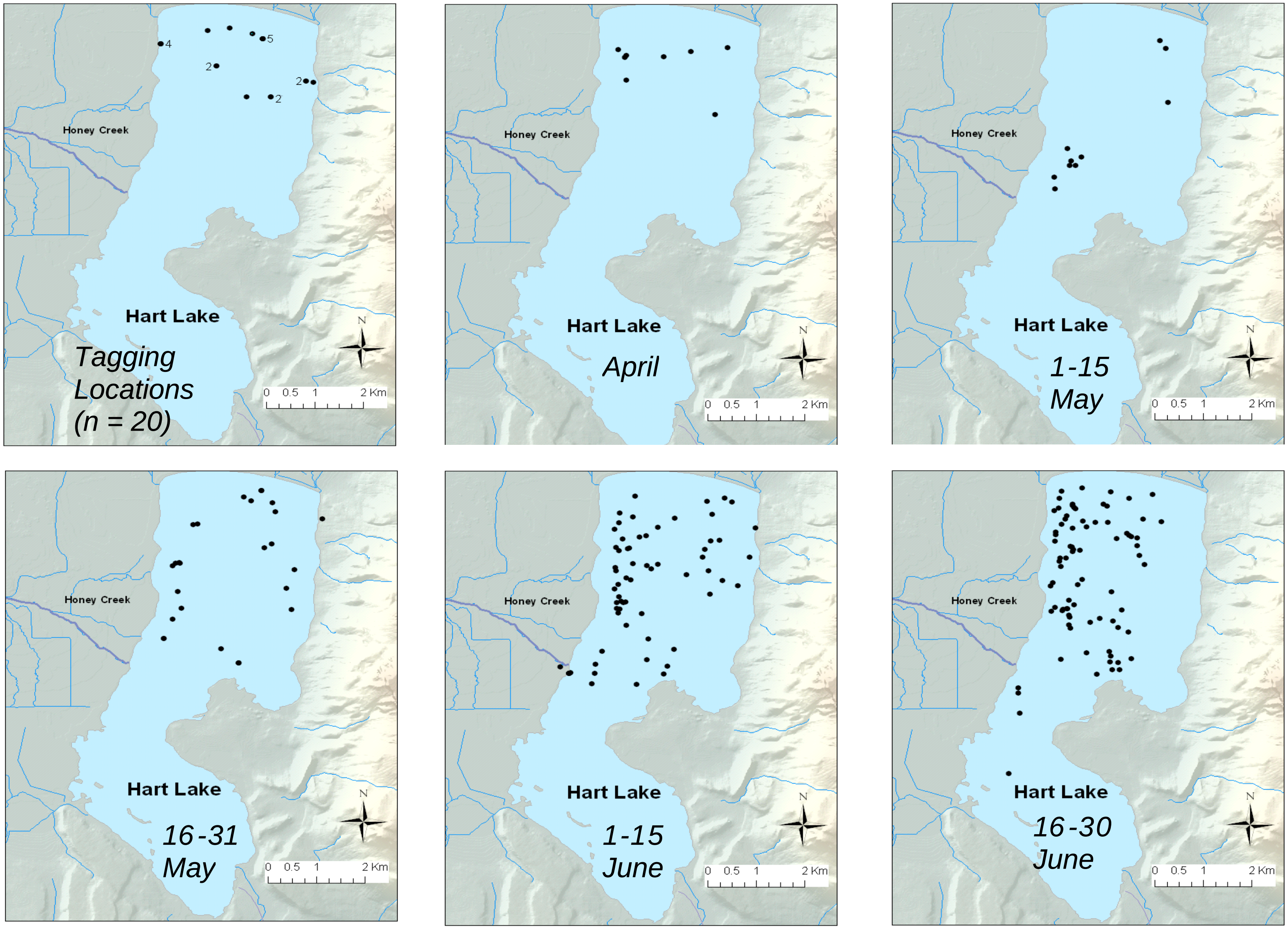

Figure 29. Tagging (upper left panel) and tracking locations (remaining panels) for Warner suckers tagged in Hart Lake, 2008. Numbers are shown next to tagging locations where more than one fish was tagged.

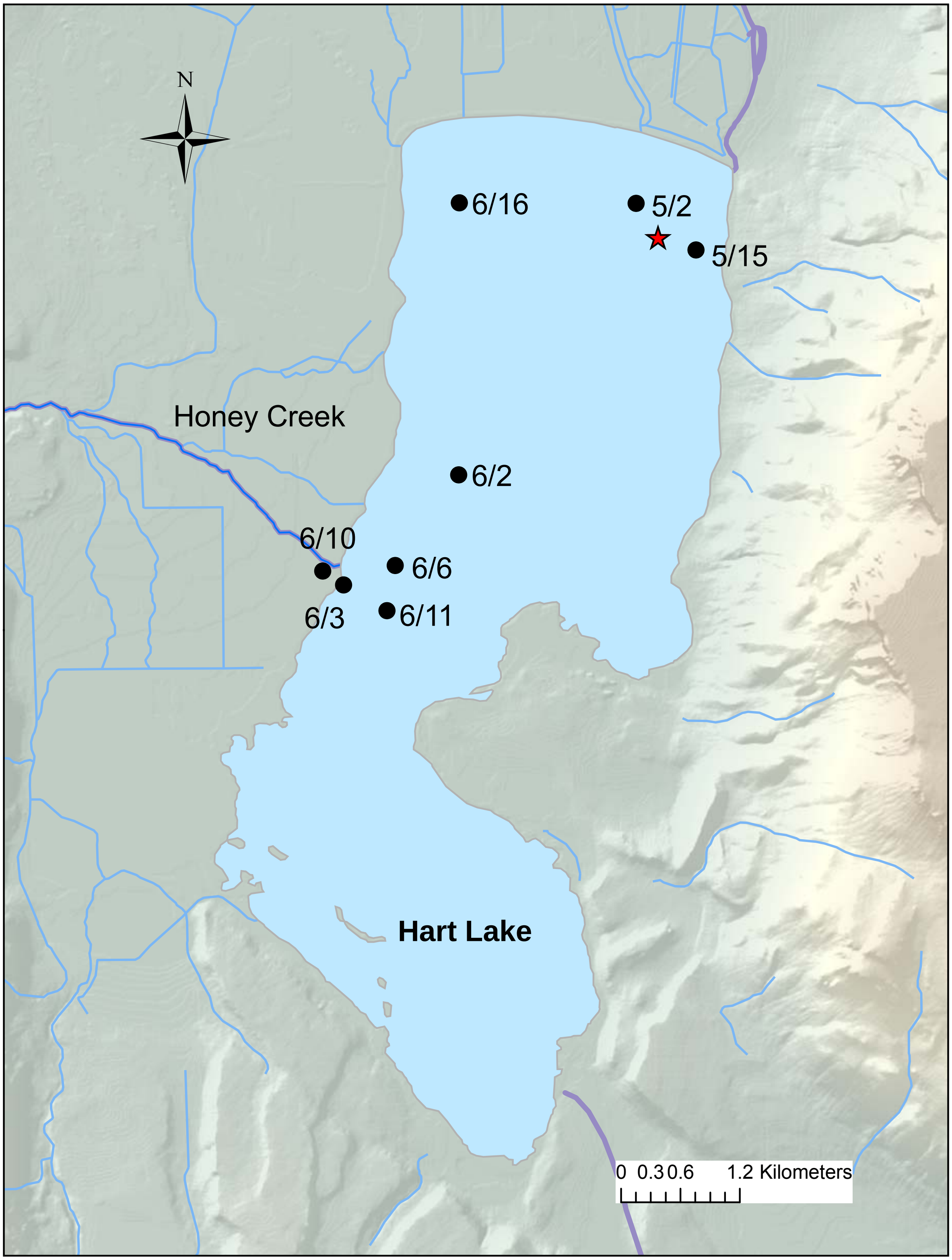

Figure 30. Detection of a radio-tagged Warner sucker (tag code 29) tagged 30 April 2008 in Hart Lake. Dates of tag detections are listed next to each black circle. The tagging location is noted with a red star.

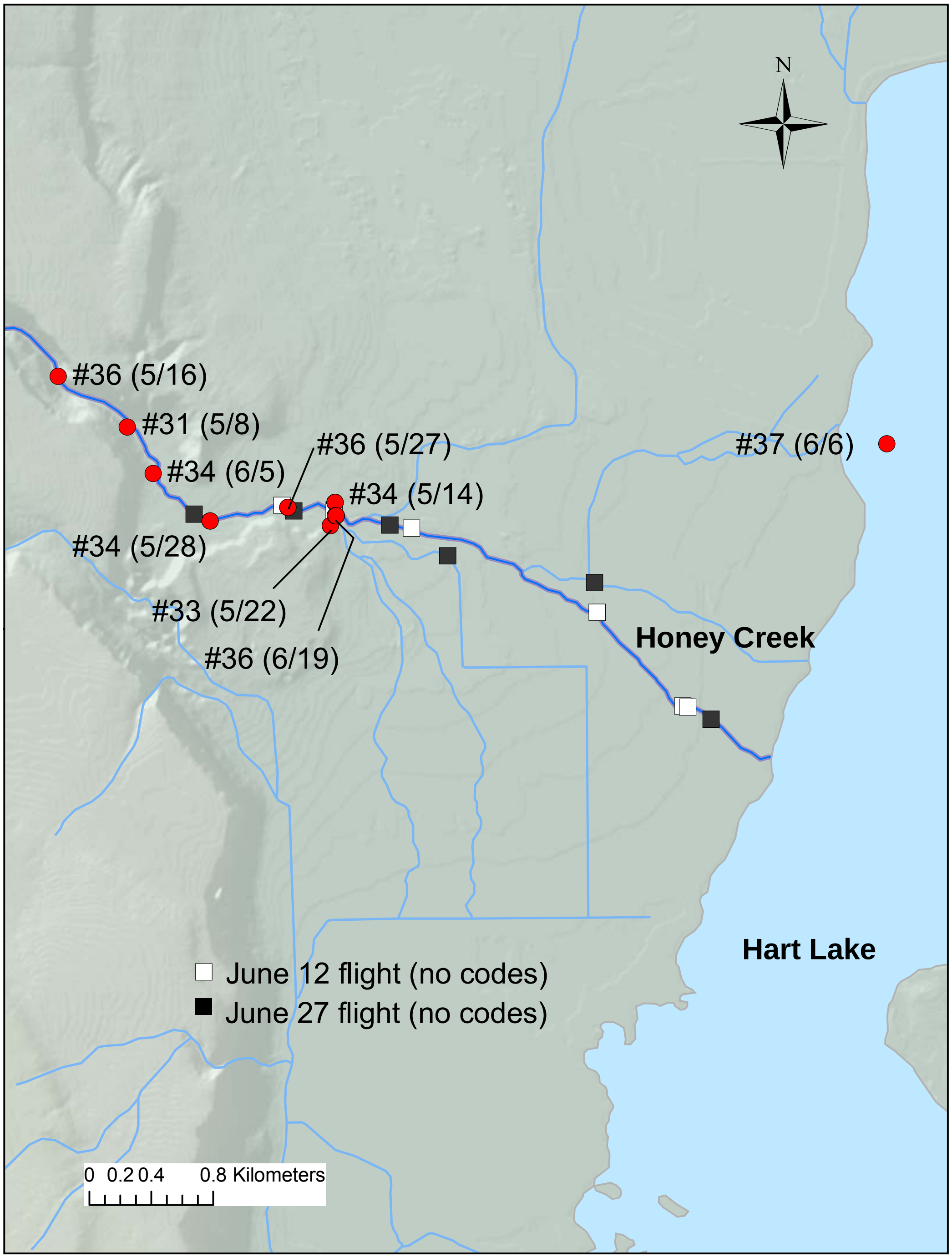

Figure 31. Detections of Warner suckers captured in Hart Lake in 2008, radio-tagged, and released into Honey Creek (red circles for coded detections and black and white squares when codes were not obtained). Tag code and date of detection (in parentheses) are next to each coded detection. Honey Creek (purple line) and irrigation canals (blue lines) are shown. Note: we detected two suckers which appear to be in irrigation canals, although we were unable to ground truth these data (denied access) to assess the accuracy of these locations from our aerial tracking. Also note, one fish (code 37) was preyed upon by a pelican, as this tag moved several times when the pelican moved on 6 June 2008.

Radio-tagged suckers in Crump Lake were detected an average of 3.8 times and moved an average of 6.3 km in 2008 (range 2.7-12.4 km; Table 9. The lower number of tag detections and shorter distances traveled by suckers radio-tagged in Crump Lake are due, in part, to the later tagging dates of these fish compared to fish tagged in Hart Lake (fewer opportunities to track). Most detections of suckers in Crump Lake were from the southern portion of the lake, south of the peninsula (Figure 32). Two tagged suckers moved south into Deep Creek. Movements of a typical Crump Lake fish (tag code 23) are shown in Figure 33. This fish was tagged 22 April in the south end of Crump Lake and was detected primarily south of the peninsula. No radio-tagged suckers moved between Hart and Crump Lakes or into the lakes north of Hart Lake, which were desiccated in 2008.

In 2009, we located 29 of the 32 suckers that we radio-tagged in 2008. Of these 29 fish, only four were presumed to be live fish based on their movement; all four were located in Hart Lake. The remaining 25 fish were presumed to be dead (mortalities, preyed upon, or tag ejected). Fish movements were limited due to the low water levels in Hart Lake during the spring of 2009. These fish moved around the deeper, northern portion of Hart Lake (Figure 34). Locations of the radio-tagged fish that did not move (presumed mortalities) are shown in Figure 35. Note that four tags in Crump Lake and four on the western shore of Hart Lake were found on land. These suckers may have died of natural causes, from predation, or may have been scavenged after death.

In 2010, we radio-tagged 30 Warner suckers in the Twentymile Creek drainage (Figure 36). These fish were subsequently detected an average of 14.7 times (range 2-24 times) and moved an average of 1.7 km (range 0-8.7 km; SD = 2.2 km) among all locations where they were detected during the period of tracking (Table 10). Because these estimates of cumulative movement assume that fish traveled the shortest possible distance between detection locations, they likely underestimate the actual extent of movement. No fish moved downstream past our fixed radio antenna which was located immediately downstream of the Dyke diversion, hence we did not document any movement of tagged suckers into irrigation diversions. We confirmed that five radio-tagged suckers were preyed upon by cormorants (tag numbers 93, 95, 100, 102, and 106) and two tagged suckers disappeared shortly after they were tagged (tag numbers 104 and 112). Either these two tags failed or these suckers were also predated upon. Seven tagged suckers did not move (tag numbers 99, 101, 108, 109, 114, 115, and 120). These fish were either mortalities, the tags were ejected, or they showed very high site fidelity. Movements of all radio-tagged suckers are shown in Figure 37. Four radio-tagged suckers (tag numbers 91, 97, 117, and 118) moved upstream initially, followed by a subsequent downstream movements in late-May through June. An example of movements for the sucker with tag number 91 is shown in Figure 38. Contrary to results from PIT-tagging, there was no apparent difference in overall radio-tag detections in the June-July time period compared to the April-May time period (Figure 39). Four radio-tagged fish (tags 91, 94, 103, and 119), which were also PIT-tagged, were detected at the upper PIT antenna, which is located at river km ~8.8 (see Figure 36).

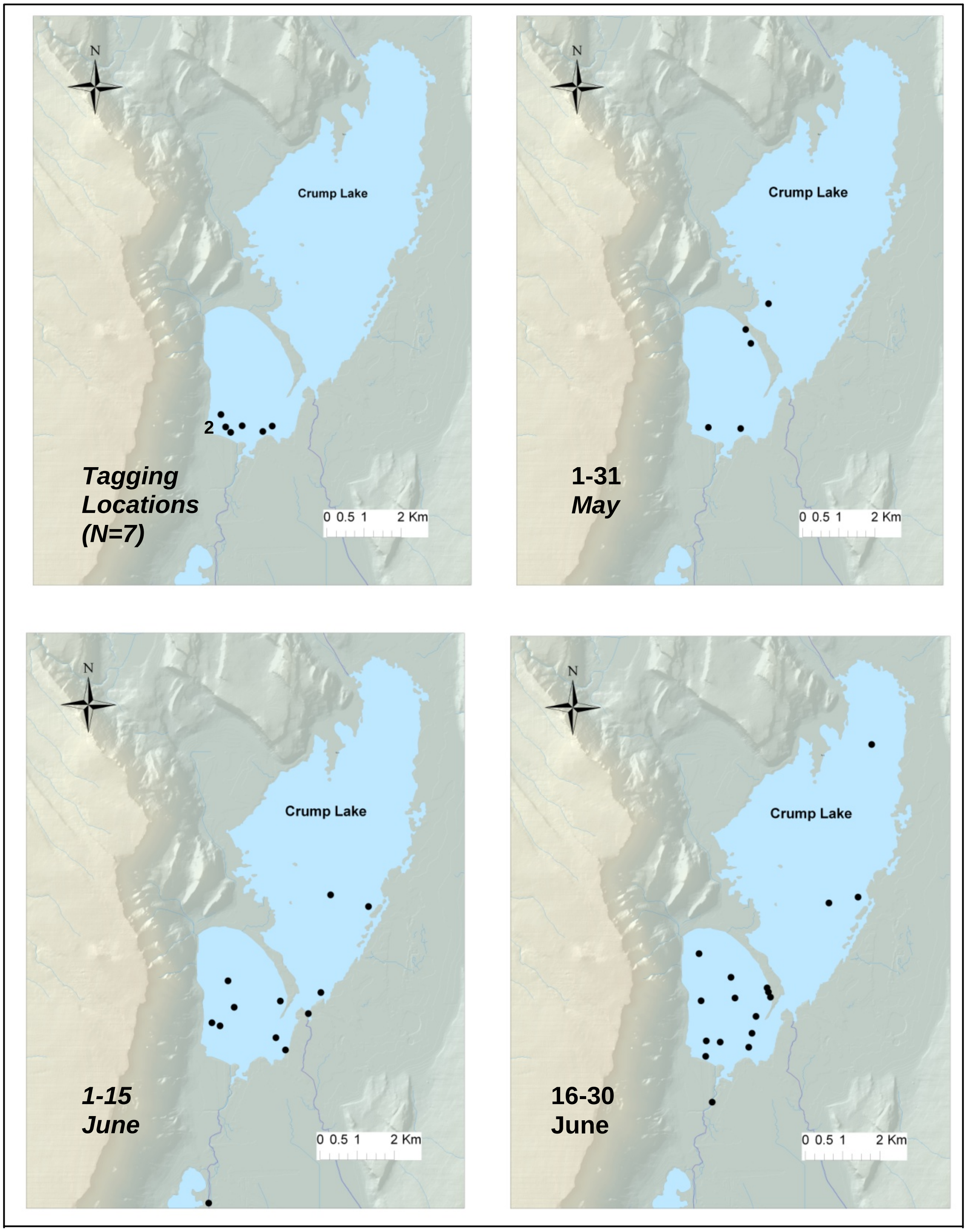

Figure 32. Tagging (upper left panel) and tracking locations (remaining panels) for Warner suckers tagged in Crump Lake, 2008. Note: two fish were tagged at one of the locations.

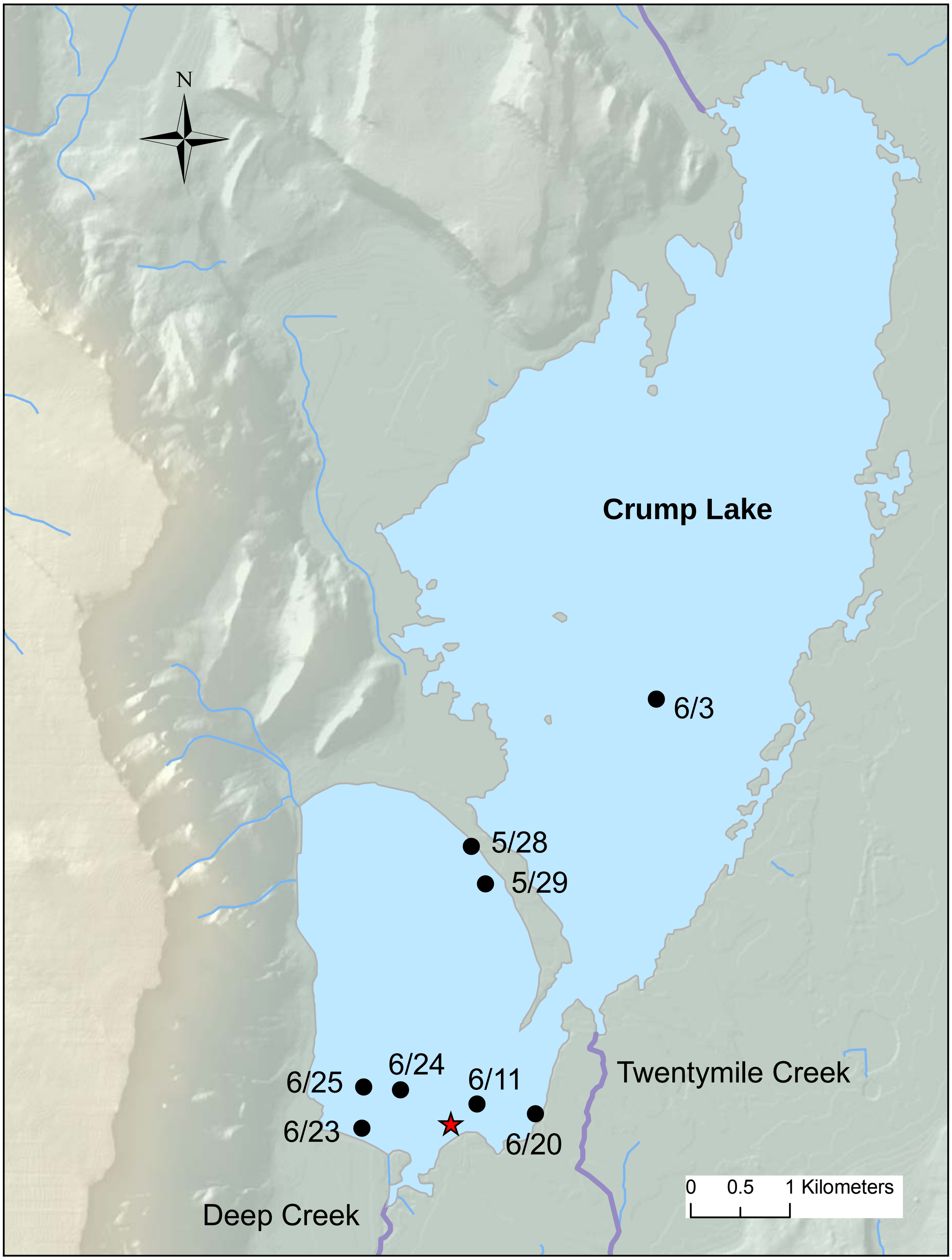

Figure 33. Detections of a radio-tagged Warner sucker (tag code 23) captured in Crump Lake and released on 22 April 2008 (red star). The date of each tag detection is listed next to each symbol.

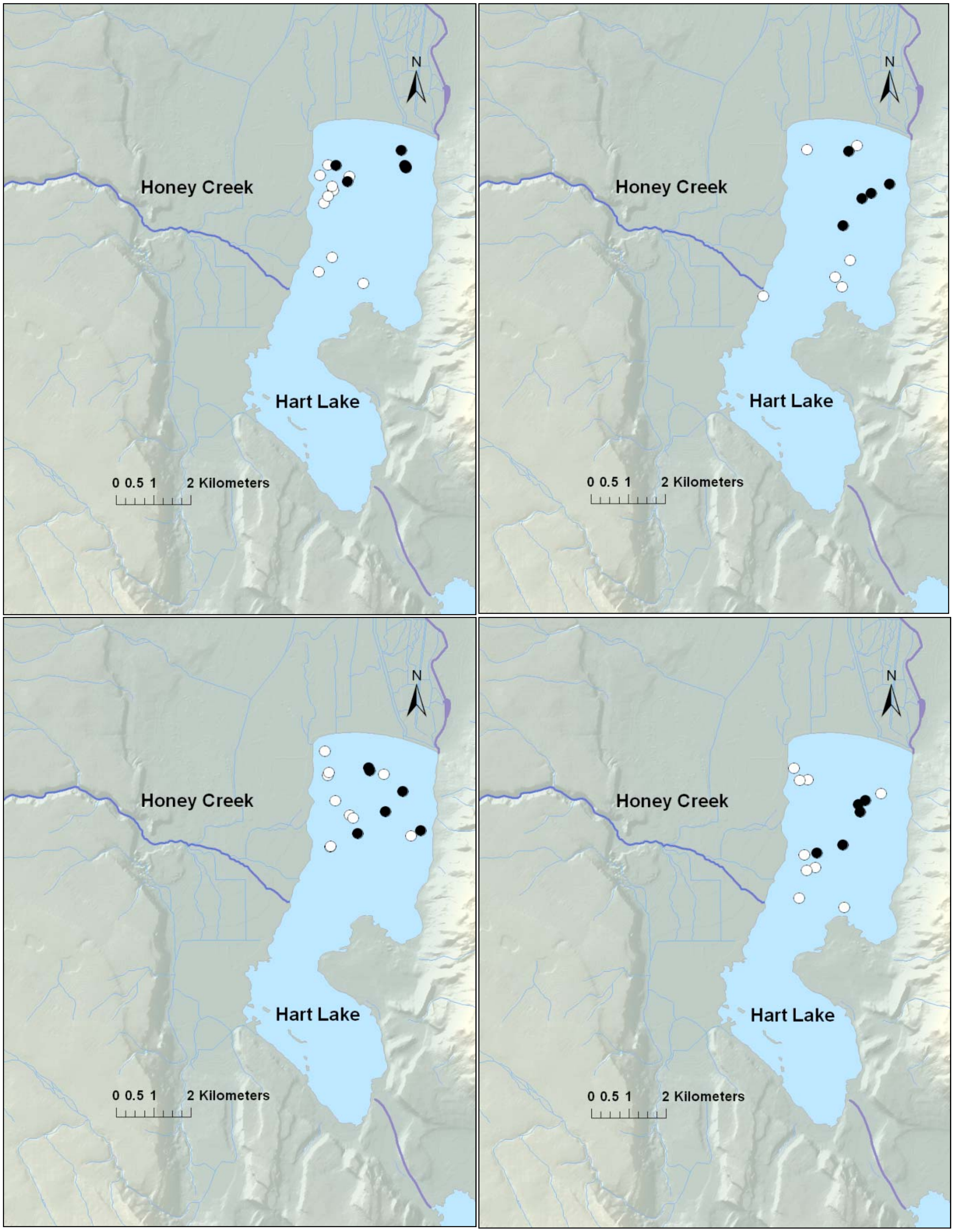

Figure 34. Detections in spring 2008 (white circles) and spring 2009 (black circles) of Warner suckers radio-tagged in Hart Lake in 2008. Starting at the upper left and moving clockwise, these maps represent tracking locations for fish with tag codes 12, 14, 17, and 15, respectively.

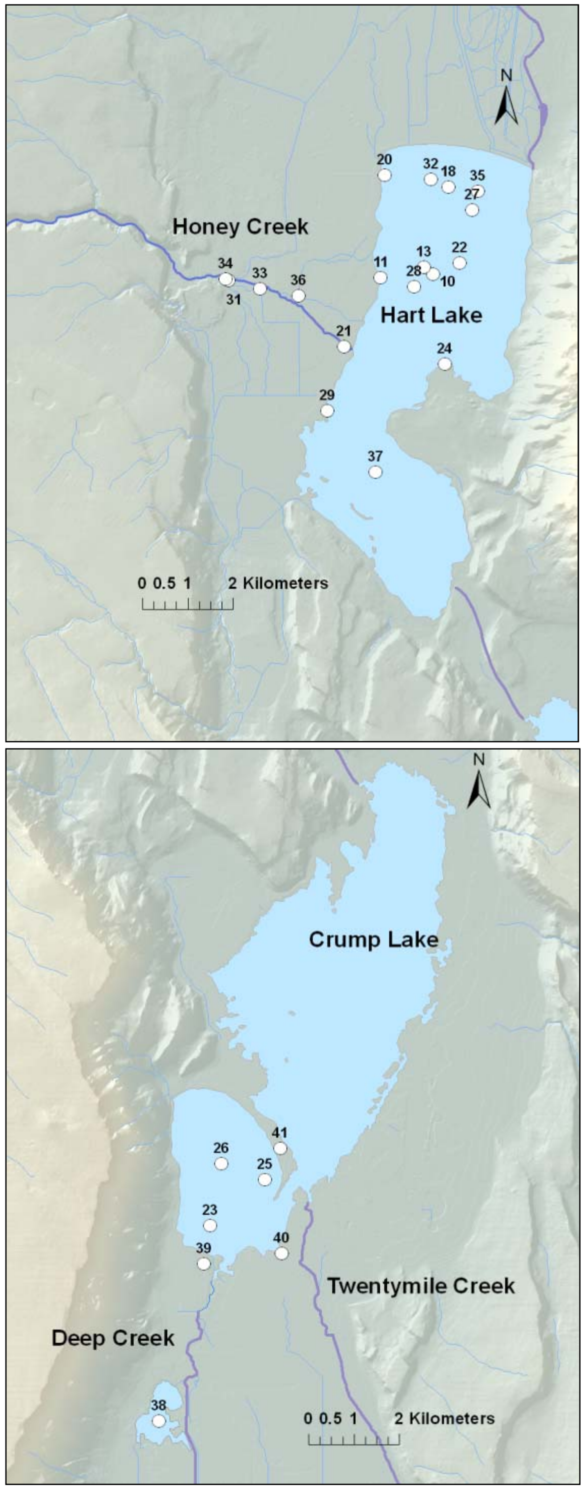

Figure 35. Detections of Warner suckers that were radio-tagged and tracked in Hart and Crump Lakes in 2008 and lost (died or shed tags) prior to tracking in 2009. No suckers tagged in Crump Lake in 2008 were found alive in 2009. Tag numbers are listed next to the white circles. Note that several tags were located on shore, including several on the western shoreline of Hart Lake, which was dry in 2009.

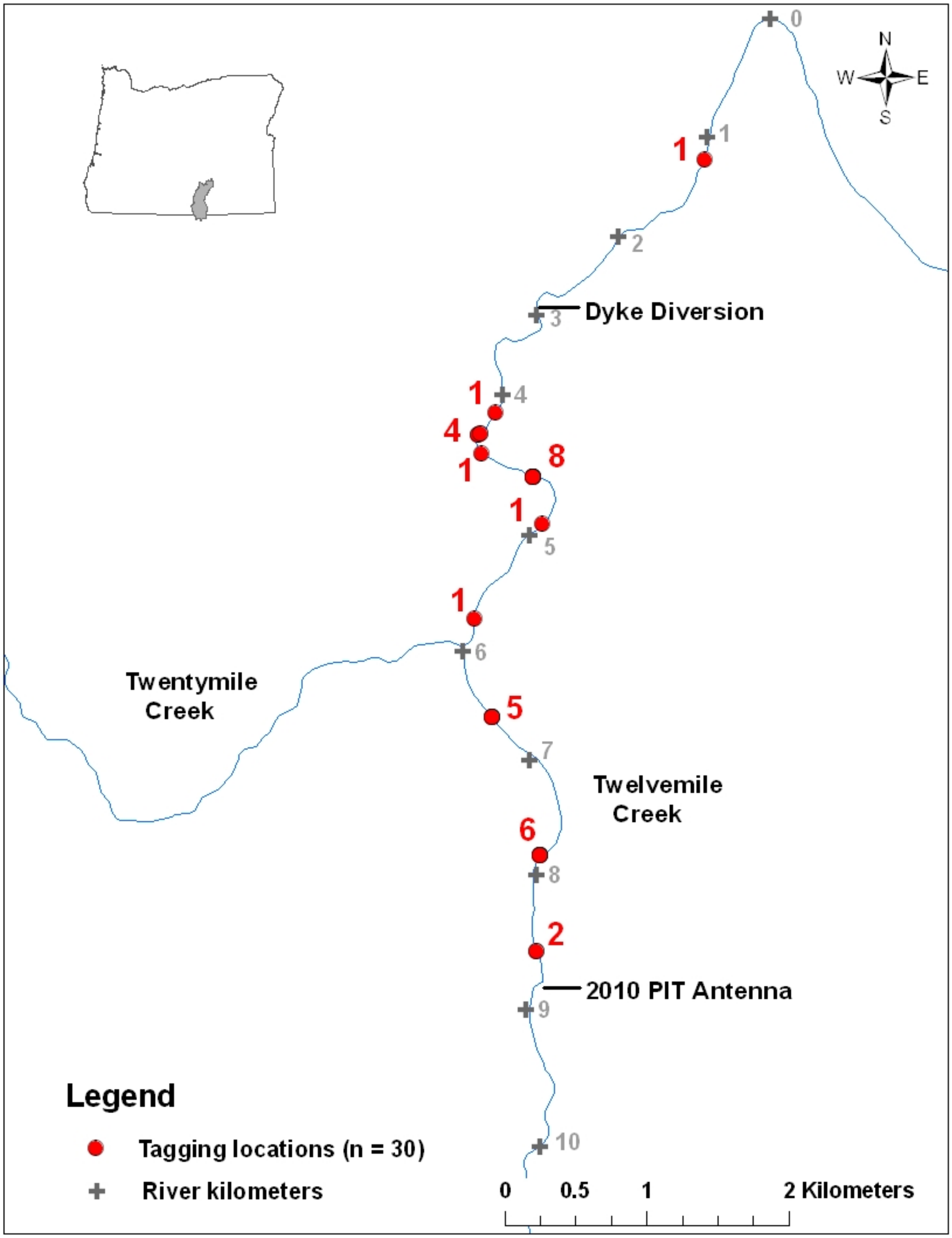

Figure 36. Locations where Warner suckers were captured, radio-tagged, and released in 2010 (red circles) and river kilometers from the downstream boundary of our survey (grey plus signs). Numbers next to circles represent the number of fish captured at each location and numbers next to the plus signs denote the assigned river kilometer.

Table 10. Stream locations of radio-tagged Warner suckers detected in the Twentymile Creek drainage in 2010, showing the furthest downstream (minimum) and upstream (maximum) location and range of river kilometers for each fish, the number of detections, and the minimum movement distance. Note that several fish were confirmed prey for cormorants and others showed no movement. River kilometer locations are shown on Figure 36 for geographic reference.

	Radio tag code																													
Date	91	92	93[a]	94	95[a]	96	97	98	99[b]	100[a]	101[b]	102[a]	103	104[c]	105	106[a]	107	108[b]	109[b]	110	111	112[c]	113	114[b]	115	116	117	118	119	120[b]
14-Apr						7.9		7.9		7.9									7.9			7.9		7.9						
19-Apr						7.9		7.9	4.0	7.9				4.0					7.9		4.2	7.9		7.9						
22-Apr						8.0		7.9	4.0	7.9		4.6		4.0					7.9		4.2			7.9						
26-Apr						8.0		7.9	4.0	8.0	4.6	4.6			4.6		4.6	4.6	7.9		4.2			7.9						
28-Apr						8.0		7.9	4.0		4.6				4.6		4.6	4.6	7.9		4.2			7.9						
4-May	4.6	4.6	4.6		4.0	8.0		8.0	4.0		4.6				4.6	4.0	4.0	4.6	7.9		4.2			7.9						
7-May	5.7	4.6	6.2		4.0	8.0		7.9	4.0		4.6				4.6	4.0	4.0	4.5	7.9		4.2			7.9						1.1
12-May	6.1	4.5			4.0	7.9		7.6	4.0		4.5				4.6	4.0	4.0	4.5	7.9		4.2			7.9						1.2
17-May	7.7	4.5		8.6	3.2	7.9	3.8	7.7	4.0		4.5		8.6		4.6	4.0	4.0	4.5	7.9	5.0	4.2			7.9						1.2
19-May	7.7	4.6		8.6	3.2	7.7	3.8	7.7	4.0		4.6		8.6		5.3	4.0	4.0	4.6	7.9	5.0	4.2		6.7	7.9	6.7	6.7	6.7		6.7	1.2
21-May	7.7	4.6		8.6	3.2	7.7	3.8	7.6	4.0		4.6		8.5		5.3	4.0	4.0	4.6	7.9	5.1	4.2		6.7	7.9	6.4	6.6	6.8	5.9	6.7	1.2
24-May	7.7	4.5		8.6	3.2	7.7	3.2	7.7	4.0		4.5		8.6		5.3	4.0	4.0	4.5	7.9	5.0	4.2		6.6	7.9	6.4	6.6	6.9	5.9	6.6	1.2
27-May	7.7	4.5		8.6	3.2	7.7	3.1	7.6			4.6		8.6		5.3	4.0	4.0	4.6	7.9	5.0	4.2		7.0	7.9	6.4	6.7	6.9	5.9	6.7	1.2
2-Jun	8.9	4.5		8.6	3.2	7.7	3.1	7.6			4.6		8.6		5.1		4.0	4.5	7.9	5.1	4.2		6.9	7.9	6.4	6.7	6.7	6.1	6.7	1.2
3-Jun	8.8	4.5		8.6		7.7	3.2	7.7			4.5		8.6		5.1		4.0	4.5	7.9	5.1	4.2		7.0	7.9	6.4	6.7	6.7	7.1	6.7	1.2
7-Jun	8.8	4.6		8.7		7.7	3.2	7.6			4.6		8.6		5.1		4.0	4.6	7.9	5.1	4.2		6.9	7.9	6.4	6.7	6.7	5.9	6.7	1.2
10-Jun	8.9	4.6		8.6		7.7	3.2	7.7			4.6		8.6		5.1		4.0	4.6	7.9	5.2	4.2		8.1	7.9	6.4	6.7	6.7	5.6	6.7	1.2
15-Jun	8.9	5.1		8.6		7.6	5.3	7.6			4.5		8.6		5.1		4.0	4.5	7.9	5.3	4.2		6.6		6.4	6.7	6.7	5.6	6.8	1.2
17-Jun	6.8	5.2		8.6		7.6	3.8	7.9			4.5		8.6		5.0		4.0	4.5	7.9	5.2	4.2		6.7		6.4	6.7	6.7	5.7	6.6	
21-Jun	8.0	3.9		8.6		7.6	5.4	8.2			4.5		8.9		5.3		4.0	4.5	7.9	5.1	4.2		6.6		6.4	6.8	6.7	5.6	8.6	
23-Jun		5.3		8.6		7.7	5.3	8.2			4.5		8.9		5.3		4.0	4.6	7.9	4.5	4.2		6.6			6.7	6.7	5.6	8.6	
24-Jun		5.6		8.9		7.7	5.6	8.2			4.5		8.9		5.3		4.0	4.5	7.9	4.5	4.2		6.8			6.7	7.9	5.6	8.6	
28-Jun		5.3		8.6		7.7	4.5	8.0			4.5		8.9		5.3		4.0	4.5	7.9	4.5	4.2		6.8			6.7	6.7	5.6	8.9	
30-Jun		5.4		8.6		7.7	4.9	8.0			4.5		8.9		5.3		4.0	4.5	7.9	4.5	3.2		6.8			3.8	6.7	5.6	8.9	
7-Jul				8.6			4.0						8.6				4.0	4.6		4.6	4.2						6.7	5.6		
Minimum	4.6	3.9	4.6	8.6	3.2	7.6	3.1	7.6	4.0	7.9	4.5	4.6	8.5	4.0	4.6	4.0	4.0	4.5	7.9	4.5	3.2	7.9	6.6	7.9	6.4	3.8	6.7	5.6	6.6	1.1
Maximum	8.9	5.6	6.2	8.9	4.0	8.0	5.6	8.2	4.0	8.0	4.6	4.6	8.9	4.0	5.3	4.0	4.6	4.6	7.9	5.3	4.2	7.9	8.1	7.9	6.7	6.8	7.9	7.1	8.9	1.2
Range	4.3	1.8	1.7	0.4	0.8	0.4	2.5	0.6	0.0	0.1	0.1	0.0	0.4	0.0	0.8	0.0	0.6	0.1	0.1	0.8	1.0	0.1	1.5	0.1	0.3	3.0	1.2	1.5	2.3	0.1
Count	15	19	2	17	9	24	17	24	11	4	21	2	17	2	21	8	22	22	24	17	24	2	15	17	11	15	16	15	15	12
Distance travelled	7.8	4.4	1.7	1.2	0.8	0.8	8.7	1.8	0.1	0.1	0.2	0.0	1.0	0.0	1.5	0.1	0.8	0.5	0.3	1.3	2.1	0.0	3.8	0.3	0.3	3.4	3.0	2.8	2.9	0.2

[a]Suckers predated upon by cormorants

[b]Suckers which showed no movements, presumed dead

[c]Suckers with tags that failed or that were predated upon, but not confirmed

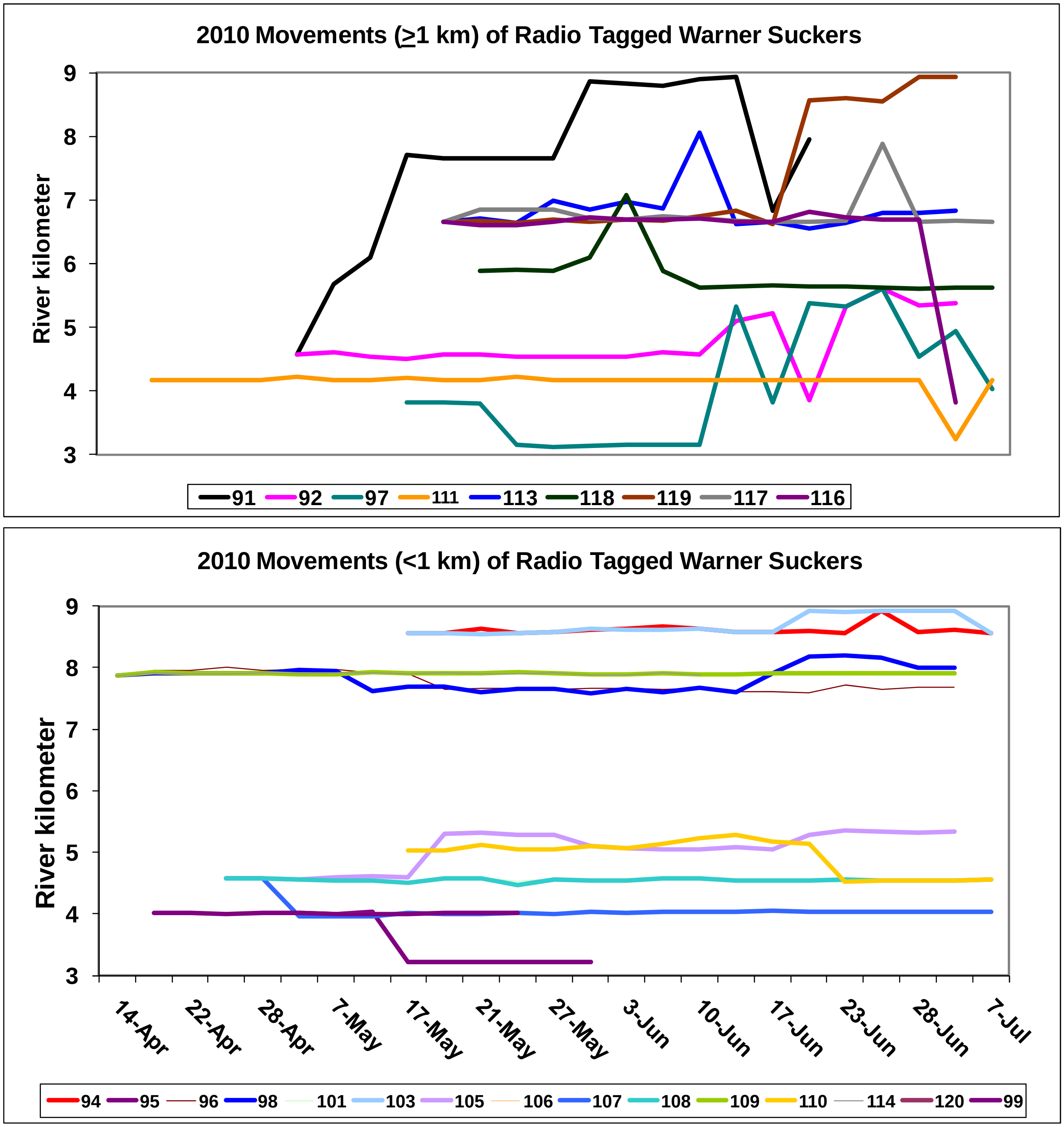

Figure 37. Movements of Warner suckers radio-tagged in 2010 in the Twentymile Creek subbasin where net movements were equal to or exceeded 1 km (top panel) and where net movements were less than 1 km (bottom panel). Each fish is depicted with a different color line. River kilometer locations are shown on Figure 36 for geographic reference. The tagging locations correspond to the river kilometer which matches the point on the left end of each line (see also Figure 36 and Table 10).

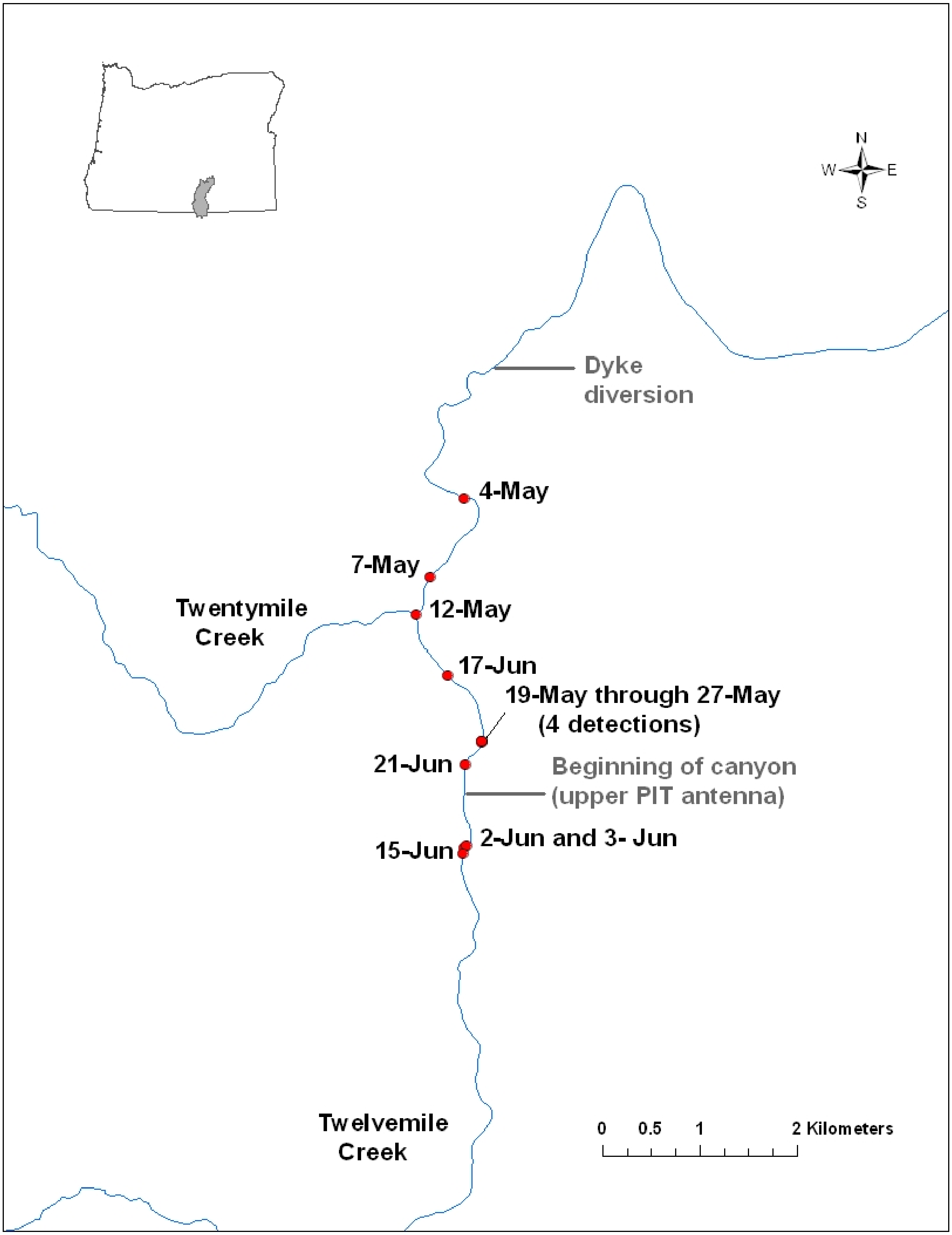

Figure 38. Detections of a radio-tagged Warner sucker (tag code 91) in the Twentymile Creek subbasin in 2010.

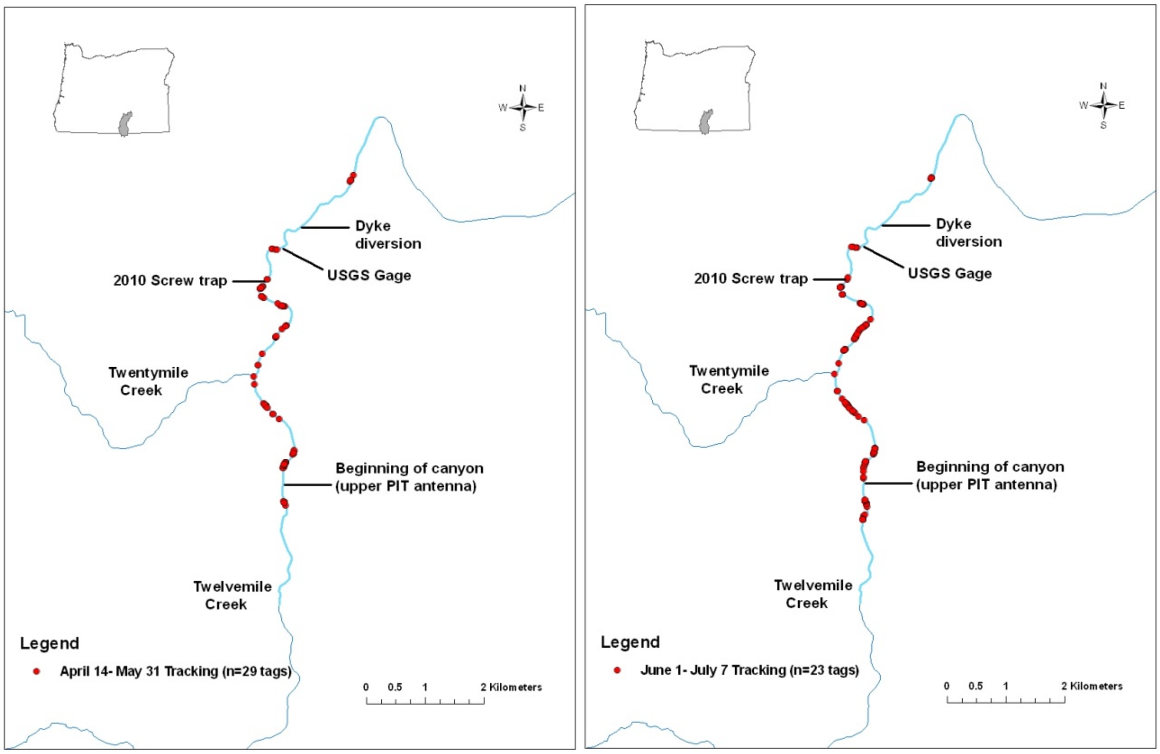

Figure 39. Detections of Warner suckers that were radio-tagged in the Twentymile Creek subbasin in 2010. Detections are shown for two time periods: 14 April- 31 May and 1 June-7 July, 2010.

Movements of Larval Suckers

In 2006, we found that larval fish were first abundant at the mouth of Honey Creek beginning in early-June. Fish were collected on 6 June, 9 June, and 14 June. The majority of these fish were identified as larval Warner suckers (S. Remples, Oregon State University, personal communication). These fish ranged in size from 11 to 16 mm. Sucker eggs incubate for ~2 weeks at 12^{o}C, the larvae are typically 8-9 mm FL at hatch, and swim up in ~2 weeks at 11-12 mm (Dr. Douglas Markle, Oregon State University, personal). Thus, these larvae probably resulted from spawning which occurred in early to mid-May.

In 2010, we sampled larval drift at six locations in the Twentymile Creek drainage. All sampling occurred on the descending limb of the hydrograph, a time when the larvae of other suckers have been found to drift (Cooperman and Markle 2003). We captured our first sucker larvae on 30 June using dip nets. Larvae were abundant on the margins of beds of aquatic vegetation and in vegetated backwater pools in late-June through early-July (Figure 40). However, we never captured larval suckers in drift nets, which we sampled from 15 June through 24 July. The lack of larvae in our drift nets suggests that there was no substantial downstream larval drift during the spring of 2010. These results are consistent with Kennedy and Vinyard (1997), who conducted in situ experiments with Warner suckers to determine how Warner sucker larvae behaved when exposed to high velocity current. They found that even the smallest sucker larvae did not drift far (2.6 m) or for very long (0.97 min) and resisted downstream transport by exploiting cover such as aquatic vegetation.

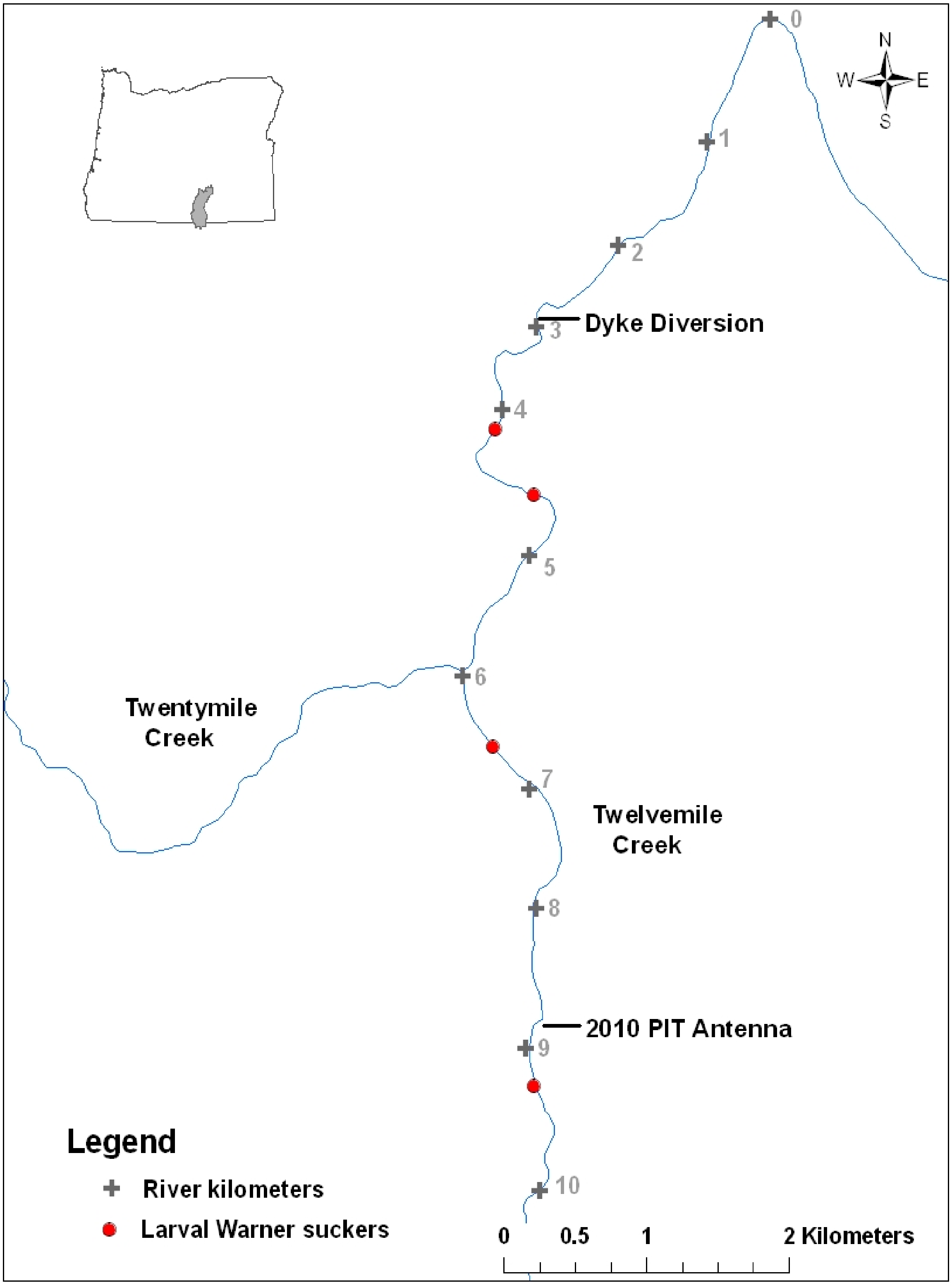

Figure 40. Locations where larval Warner suckers were collected in the Twentymile Creek subbasin in 2010. Note: these locations were the only sites sampled and represent only a minimum distribution of larval suckers in 2010. Because no larval drift was detected, these locations likely represent approximate spawning locations.

Avian Predation on Warner Suckers

In September 2008, biologists studying avian predation on fishes in the Warner Basin recovered one PIT tag from a 215 mm female sucker (75 g) on the Caspian tern (*Hydroprogne caspia)* nesting island constructed in 2007 in Crump Lake. This fish was tagged in Crump Lake on 6 June 2008. In September 2010, they recovered 15 PIT tags from double-crested cormorant (*Phalacrocorax auritus)* and white pelican (*Pelecanus onocrotalus)* nests on Pelican Island (Brad Cramer, Real Time Research Inc., personal communication). Because these island nesting sites are often used by different bird species in different years (e.g., tern, cormorant, great blue heron (*Ardea herodias)*, or great egret *Ardea alba*) and many tags may been on the island for up to five years, it is difficult to determine which species was responsible for the predation (Dr. Daniel Roby, Oregon State University, personal communication). The recovered tags were from suckers tagged on Hart and Crump Lakes (n=6) and in the Twentymile Creek drainage (n=9). These adult suckers ranged in size from 150-305 mm and were tagged in 2006 (n=2), 2008 (n=3), 2009 (n=6), and 2010 (n=4). Two of the fish from 2010 also had radio tags. There were concerns that the FLOY tags we used in the lake surveys might make these fish more vulnerable to avian predation, however only one FLOY-tagged Warner sucker was observed in the tern diet. In addition to the recovered tags, we documented cormorant predation on three other suckers radio-tagged in 2010 during our weekly tracking on Twentymile Creek.

The impact of bird predation on Warner suckers may be substantial; the proportion of tagged suckers that we documented was consumed in a given year ranged from 0.0 to 16.7% (Table 11). For example, by multiplying the proportion of suckers tagged in 2009 in the Twentymile Creek drainage whose tags were recovered in 2010 (1.4%) by the 2009 abundance estimate (4,612; 95% CI: 3,820-5,567) and adjusting for estimated on-colony detection efficiencies (Roby et al. 2010) for cormorants (mean: 68.7%) and pelicans (mean: 72.5%) in the Columbia River basin for 2007-2009, we estimate that a minimum of $\underset{\sim}{}$92 suckers (95% CI: 76-111) were consumed in 2009 and 2010. Note that detection efficiencies are lower for tags that have been on the nesting island longer, thus we likely underestimated the consumption rates for 2006 through 2009 presented in Table 11.

Table 11. Numbers and percentages of Warner suckers tagged in the Warner basin that we documented were consumed by avian predators, 2006-2010. All totals were for PIT tags, except for those listed in 2010 for Twentymile Creek, which were radio tags.

Year	Location tagged	Number of tags recovered	Total number PIT-tagged	Proportion
2006	Hart Lake	1	54	1.9%
2006	Crump Lake	1	60	1.7%
2007	Twentymile Creek	0	27	0.0%
2007	Honey Creek	0	33	0.0%
2008	Hart Lake	1	74	1.4%
2008	Crump Lake	3	27	11.1%
2008	Twentymile Creek	1	28	3.6%
2009	Twentymile Creek	6	421	1.4%
2010	Twentymile Creek	5	30	16.7%
2010	Crump Lake	2	30	6.7%
		20	754	2.7%

Comparison of Ageing Techniques

Lapilli were the easiest structure to read; 68% of the time we assigned the same age for all three reads (Table 12). Also, 58% and 51% of the time we assigned the same age all three times for pectoral and pelvic fin rays, respectively, indicating that fin rays were also relatively easy to read. Both opercles and scales were relatively difficult to age, due to the presence of false growth marks and tightly packed growth marks on the edge of the structures.

Table 12. Percent agreement among three reads for each structure aged in the study.

Structure	Percent agreement
Lapillus	68%
Pectoral fin ray	58%
Pelvic fin ray	51%
Opercle	38%
Scale	44%

Age-bias plots showed the best age correlations among hard structures occurred between otoliths and pectoral fin rays (Figure 41). Pectoral rays tended to underestimate ages compared to otoliths in fish older than 15 years and became difficult to read as growth marks became tightly packed along the leading edge of the ray. At younger ages ($\leq$15 years), there was 79% agreement between pectoral rays and lapilli (27 out of 33 fish) and when ages differed between the two structures, there was typically only a one year difference. False rings were present on pectoral fin rays, but were easily distinguishable from true growth marks, due to their poorer contrast and ephemeral appearance. Pelvic fin rays underestimated ages, compared to otoliths, for fishes older than ten years and the deviation of the assigned age increased as fish age increased. Pelvic rays from older fish contained many false rings, had tightly packed growth marks on the edge, and several were deemed unreadable. Opercles also tended to underestimate age, compared to otolith age, for older fish due to tightly packed growth marks along the edge. Smaller opercles had false growth marks that caused overestimation of age in younger fish. Finally, scales were the poorest choice of an ageing structure, as they highly underestimated age, compared to otolith age, for all age groups. Growth marks on scales were extremely difficult to count, even on relatively young fish.

For pectoral fin rays, an assessment of the loss of growth marks with distance from the fin ray base was inconclusive. The three fin ray sections taken closest to the base displayed similar growth marks; however, sections that were 2-2.5 mm away from the base of the ray showed loss of the innermost growth mark. This trend was more pronounced in smaller, younger fish than in larger, older fish. Further, the loss of the innermost growth marks was visually obvious and resulted in an abnormally indistinct translucent area that would have contained the two innermost growth marks.

Warner Sucker Abundance Estimate at Summer Lake WMA

In 2007 and 2009, we obtained population estimates for Warner suckers at the Summer Lake Wildlife Management Area. This population is the result of natural production of adult suckers that were moved to the refuge when the Warner Lakes desiccated during

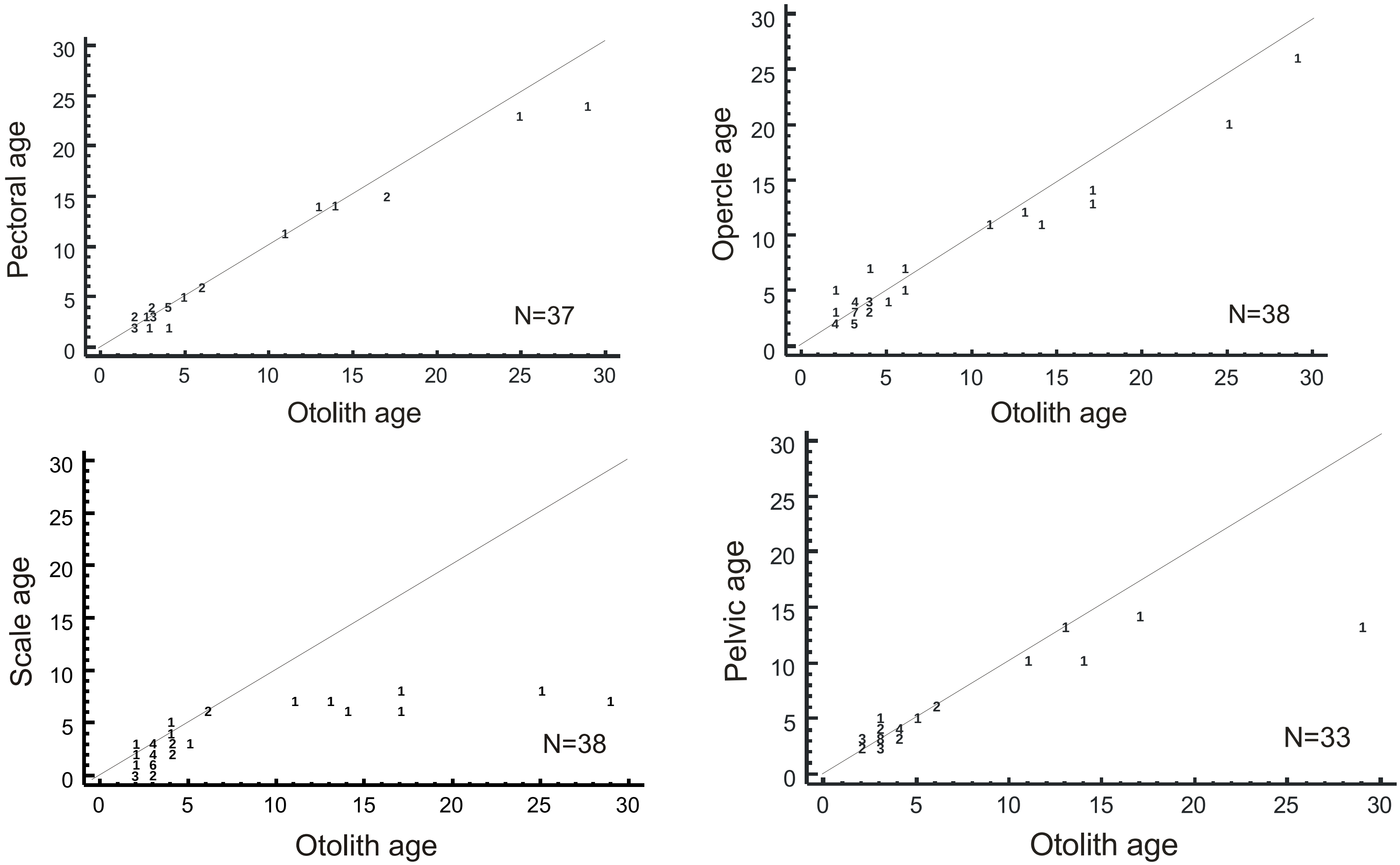

Figure 41. Age bias plots comparing ages from lapilli (otoliths) with other hard structures. Points that fall along the 45° line represent no ageing bias. Sample sizes varied between comparisons due to our inability to read all structures from all fish. Numbers on the plots represent multiple, overlapping points.

the 1992 drought. The 2009 estimate was 660 fish (95% CI: 421-1,024). This estimate was significantly larger than the 2007 estimate of 142 fish (95% CI: 91-218). These estimates are for suckers in the ditch fed by the artesian well. Only three suckers were collected in 2007 from the sinuous channel between the ditch and the wetland and no suckers were captured in 2007 from the wetland or in 2009 from Lower Sulfur Well Pond. The size distribution for suckers collected in 2009 was broader and contained smaller fish than in 2007 (Figure 42), indicating recent successful recruitment at this location. We did not observe any difference in the amount or quality of available habitat in 2009, compared to 2007.

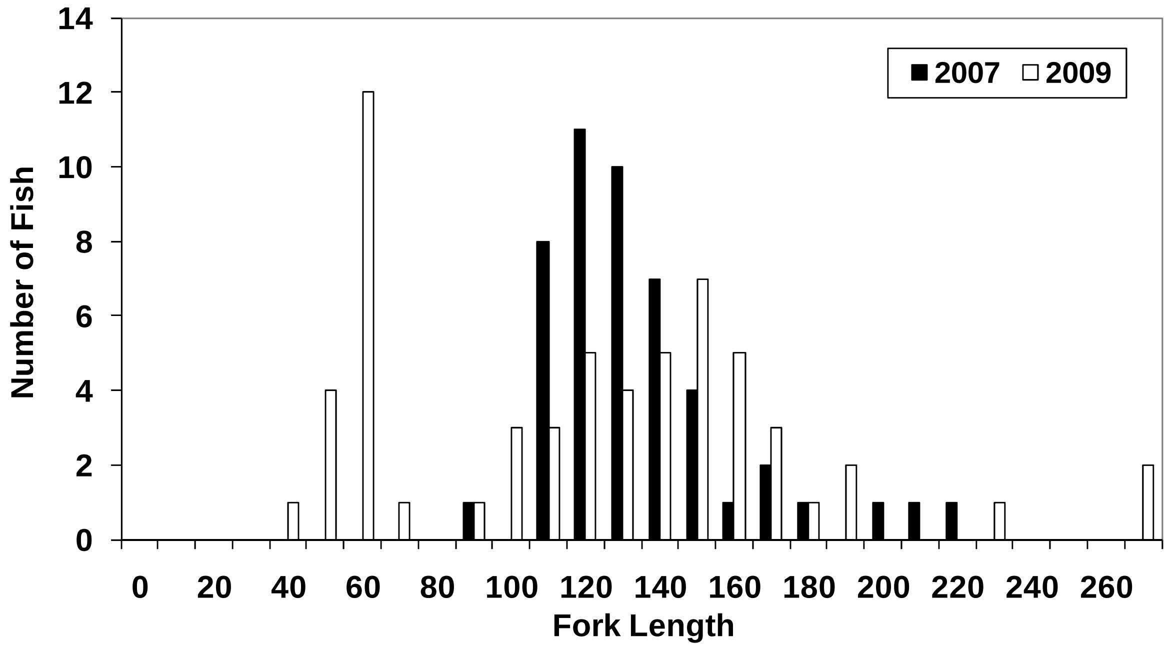

Figure 42. Length-frequency histograms for Warner suckers at Summer Lake Wildlife Management Area in 2007 and 2009.

DISCUSSION

The Warner sucker was federally listed as threatened in 1985. The reasons for the listing, which include watershed degradation, irrigation diversion practices, and predation and competition from introduced fishes (U.S. Fish and Wildlife Service 1998), have shown only minor improvements in the 26 years since listing. Habitat fragmentation resulting from impassable irrigation dams and diversions limits movements and genetic exchange between lake and stream suckers by blocking both the upstream spawning migrations from the lakes into the streams and the downstream migration of young fish to the lakes. The objectives of our investigations were to answer basic questions regarding the current distribution, abundance, life history, and connectivity of the Warner sucker metapopulation that inhabits the lake and stream environments in the Warner subbasin.

Our investigations indicate that the Warner sucker populations in Crump and Hart Lakes are depressed compared to levels in the mid-1990's (Allen et al. 1994; Allen et al. 1995; Allen et al. 1996; Scheerer et al. 2006; 2008a; this study). We obtained indices of abundance (CPUE) in

Hart and Crump Lakes and found they were some of the lowest on record. Compared to peak sucker CPUE's in the 1990s, the recent CPUE's had declined more than 90%.

The distribution of Warner suckers in 2006, 2008, and 2010 in the Warner Lakes was determined, in part, by lake water elevations. In 2006, precipitation and stream discharge were high (Figure 2), both Hart and Crump Lakes were full, and water flowed into the ephemeral lakes north of Hart Lake. Since 2006, annual precipitation has been below average (Oregon Climate Service 2010), Hart and Crump Lakes have not filled, portions have dried completely, and the lakes north of Hart Lake have desiccated. We found that suckers were distributed throughout the wetted portions of Hart and Crump Lakes, but were most common along the western shore of Hart Lake and south of the peninsula in Crump Lake. During wetter cycles, suckers have been documented to use the ephemeral lakes north of Hart Lake (White et al. 1990; Allen et al. 1996) and the spillway channel north of the Hart Lake (Coombs et al. 1979; Williams et al. 1990). During the drought in 1991, a winter kill of suckers occurred when lake elevations were low (White et al. 1991). The low catch rates in 2010 may be the result of similar, undocumented winter kill events in recent years, and/or due to harsh conditions during the summer months.

Nonnative fish dominated the catch in Hart and Crump Lakes and the proportion of nonnative fish in the catch was substantially higher in recent years, compared to the mid-1990's. After the lakes desiccated in 1992, native fish recolonized in the mid-1990's and dominated the catch for several years. However, by 2001 the nonnative fishes once again dominated the catch, as they did prior to the desiccation of the lakes in the early 1990's (Hartzell et al. 2001). In addition, we noticed shifts in the proportional contribution of nonnative species in the catch since 1990.

Current drought conditions appeared to affect the health of Warner suckers, as evidenced by the apparent mortality of larger lake suckers in Crump Lake, following the near desiccation of the lake in the winter of 2007, and the high proportion of suckers captured in Crump Lake with poor body condition and high parasite infection rates. In addition, harsh drought conditions likely caused the substantial decline in the catch of nonnative fishes in Crump Lake from 2008 and 2010. However, we observed no apparent decline in the catch of native tui chubs and suckers in Crump Lake. Perhaps native fish species were able to withstand the harsh, drought conditions better than the nonnatives.

We did not find evidence of substantial recruitment of suckers into the lake populations or movements of stream suckers into the lakes. In Hart and Crump Lakes, the sucker size distributions were dominated by large, presumably older aged fish. We documented an increase in the average sucker length since the lakes were recolonized in 1993, following desiccation in 1992. We did not document substantial downstream movement of suckers in the tributaries during the spring months. We only captured small numbers of suckers in the rotary screw traps that we operated during the spring months of 2006, 2008, and 2010. We documented only small numbers of suckers moving downstream across the PIT antennas we operated in lower Twentymile Creek in the summer of 2009 and the spring of 2010. We did not capture any suckers in the lakes that were PIT-tagged in the tributaries nor did we detect in the lakes any suckers that were radio-tagged in the tributaries.

We sampled larval drift and did not document movement of larval suckers in the Twentymile Creek drainage in the spring of 2010, despite large aggregations of larval suckers present in shallow, backwater pools and along vegetated stream margins which were located immediately upstream from where we fished our larval drift nets. Also, we did not capture larval suckers in drift nets or light traps fished near the mouth of Honey Creek in the spring of 2009. These observations are consistent with those of Coombs and Bond (1980), who described the distribution of larval Warner suckers in shallow backwater pools and along the stream margins where there was no current. Kennedy and Vinyard (1997) reported that Warner sucker larvae resisted downstream transport by seeking cover in aquatic macrophytes and other structure. Our data and that of Kennedy and Vinyard (1997) suggest that larval drift is not a major dispersal mechanism for Warner suckers. It is important to note that in 2006, we collected larval suckers from the weed beds in Hart Lake, near the mouth of Honey Creek. We are uncertain whether these were the offspring of suckers that spawned in the lake (the lake was full and aquatic vegetation was available at the lake margins) or from suckers that spawned in lower Honey Creek.

Our surveys indicate that the Warner suckers in the Warner tributaries are faring better than the lake populations. Our surveys were more comprehensive than the previous surveys (Tait et al. 1995) and consequently allowed us to document a broader and more detailed distribution of Warner suckers in both the Honey and Twentymile Creek drainages, and to document both adult and juvenile suckers in lower Deep Creek (not part of prior sampling frames). In 2007, we found the sucker distribution in Warner tributaries was patchy and densities were typically low (Scheerer et al. 2008b), which may be due, in part, to the drought conditions in the summer of 2007; 21% of our samples sites were dry. Nonetheless, we estimated 6,852 adult suckers in Warner tributaries, however the estimate had low precision (±93%), due to the high levels of variability in fish densities between sample locations. We found the highest sucker density in Twelvemile Creek (237 fish/km), an intermediate density in Honey Creek (59 fish/km), and the lowest density in Deep Creek (8 fish/km). Because access was denied to large portions of lower Deep, lower Honey, and Snyder Creeks, we were limited in our ability to assess the actual sucker distribution in the tributaries and were not able to confidently estimate the density of suckers in these areas.

In 2009, we modified our approach for estimating stream sucker abundance, due to the low precision of our 2007 estimate, and chose to conduct a comprehensive mark-recapture survey, rather than estimate abundance by extrapolating from estimates obtained at randomly chosen sampling locations using the GRTS design. Our 2009 estimate of sucker abundance (4,612) was similar to that obtained in 2007 (4,746), though with markedly improved precision (95% CI: 3,820-5,567). Approximately 25% of these suckers in 2009 were adults (1,169; 95% CI: 969-1,412) (Richardson et al. 2009). Taken together, these results indicate that the Twentymile Creek subbasin supports a robust population of stream suckers. Because of the vastly improved precision of our estimate, we plan to use this same protocol to obtain an abundance estimate for Warner suckers in Honey Creek in 2011. It is interesting to note that the abundance estimate for redband trout in the Twentymile subbasin in 2007 exceeded 25,000 fish (ODFW 2007), which was substantially (6 times) higher than our sucker estimate. We are uncertain whether the abundance of Warner suckers (and redband trout) in this subbasin was greater historically, and/or whether their relative proportions vary over time.

In addition to the improved precision of our 2009 estimate, we were better able to describe the distribution of suckers in the Twentymile subbasin and infer associations with habitat conditions (Richardson et al. 2009). We found that suckers were distributed throughout the subbasin, but were most abundant between the Dyke diversion and the Twelvemile Creek canyon. This area was characterized by deep pools, numerous backwater pools, abundant aquatic macrophytes, and warmer stream temperatures. We found suckers were typically more abundant in deep pools (including beaver ponds) and backwater habitats and were more common in areas with low velocities, abundant aquatic macrophytes, and fine substrates. We found a positive correlation between maximum recorded temperature and sucker abundance (i.e., suckers were more common in areas where water temperatures were higher). However, because warmer water temperatures were common in the slower, wider downstream areas, suckers may have been primarily keying in to the habitats, rather than the temperature of these habitats. Using multiple regression analysis, we found that water temperature and depth were important variables that may influence sucker distribution and abundance. This is consistent with prior studies that identified depth and temperature as primary variables explaining sucker abundance (Tait and Mulkey 1993a; 1993b; Tait et al. 1995).

We noted a high incidence (64%) of external parasites, lesions and/or deformities on the stream suckers from the Twentymile Creek subbasin in 2009. In contrast, fewer than 10% of the suckers had external parasites, lesions, and/or deformities in 2010. The most common parasite observed on both the lake and stream suckers was *Lernaea* sp. This parasitic copepod, commonly called fish lice, has no intermediate host and can easily spread among fishes. As water levels drop, available habitat is reduced and water temperatures increase, which may result in increased fish densities in suitable, available habitats. A combination of crowding and higher temperatures may increase the levels of infection (Craig Banner, ODFW Fish Pathology, personal communication). The lower stream temperatures in 2010 may have resulted in the lower incidence of infection and lesions observed.

Irrigation diversion dams on the Warner basin tributaries may limit the ability of Warner suckers to move freely between the lakes and the spawning tributaries. We found little evidence of substantial upstream movement of lake suckers into lower Honey Creek and none into Twentymile Creek. We did not recapture any PIT-tagged lake suckers in any of the tributaries. In 2006 and 2008, we documented movement of a few radio-tagged lake suckers from Hart Lake into lower Honey Creek. In 2006, during high stream flows, one of these suckers moved past six of the seven lower irrigation dams, perhaps before the boards were installed. We located this fish downstream of the seventh diversion dam, which is situated immediately below the county road bridge to the north of Plush, OR. Swenson (1978) also found suckers were able to pass the lower six diversion dams under certain flows, but not the seventh and highest dam (1.5 m). None of the suckers radio-tagged in the lakes was captured in the Twentymile drainage, nor did we detect movement of radio-tagged suckers between Hart and Crump Lakes. However, we did document movement of radio-tagged Crump Lake suckers into lower Deep Creek. It is possible that lower Deep and Honey Creeks, downstream of the irrigation diversions, are currently important spawning areas that contribute to the limited, periodic recruitment that occurs in the lakes. We found no evidence of successful downstream movement of stream suckers into the lakes. Few PIT-tagged suckers crossed the antennas in lower Twentymile Creek and no PIT-tagged stream suckers were captured in the lakes. In 2008, after we moved five radio-tagged lake suckers above the lower Honey Creek diversions, several moved several kilometers upstream, presumably to spawn. In 2010, we did not detect any PIT or radio-tagged suckers moving downstream of the Dyke diversion on Twentymile Creek.

Within the stream environments, most suckers we tracked did not move long distances and there was no apparent relationship between movement patterns and fish length. During the summer of 2009 in Twentymile Creek, most PIT-tagged suckers we recaptured were within the same 500 m reach where they were tagged. During the spring of 2010, the suckers we radio-tagged in the Twentymile Creek drainage moved an average total distance of 1.7 km (range 0-8.7 km), but most showed minimal net movement (Figure 37). There was no apparent difference in habitat quality between the locations from which suckers moved and the locations where suckers stayed put. This is consistent with the low numbers of suckers we captured in our downstream migrant traps. However, we documented a few suckers that moved relatively long distances. Two suckers that were PIT-tagged in the Nevada reach of Twelvemile Creek were detected at the PIT antenna at the lower end of the canyon (~6.5 km downstream), one that was PIT-tagged near the lower end of the canyon was detected at the PIT antenna near the USGS gage (~6.0 km downstream), and three PIT-tagged suckers moved from just above the Dyke Diversion to the lower end of the canyon (~5.5 km upstream) (Figure 26). These data indicate that there is some degree of mixing of suckers within the Twentymile Creek subbasin.

We documented a mass movement of PIT-tagged suckers across the upper PIT antenna on Twentymile Creek in June 2010, apparently to spawn. When expanded by the total number of fish tagged, we estimate that approximately 469 adult suckers or ~40% of the 2009 adult population moved crossed the antenna during June. These data are consistent with observations of other stream suckers that migrate upstream in large aggregations to spawn. For example, thousands of white suckers (*C. commersoni)* in the Midwestern U.S. and Sacramento suckers (*C. occidentalis)* in California have been found ascending suitable spawning streams during the spawning season, and large schools of largescale suckers *C. macrocheilus* have been observed along river margins during the spawning season in the northwestern U.S. (Scott and Crossman 1979; Wydoski and Whitney 2003).

We documented a broad size structure of suckers in the Warner tributaries. Length frequency histograms for the Twentymile Creek drainage were bimodal with an initial peak at ~80 mm FL and a second peak at ~190 mm, indicating at least two age groups. Large numbers of ~80 mm suckers, presumably age 1 fish, are an indication of recent successful recruitment in this drainage. We found substantial variation in annual sucker growth (average: 23 mm/yr; range -3 to 76 mm/yr) and that the rate of growth was asymptotic. Slow and variable growth rates can result in substantial overlap of lengths-at-age, particularly for larger sized suckers, and make it nearly impossible to use length-frequency histograms to infer age structure. Past data on age structure was collected by Coombs et al. (1979), using scales, and White et al. (1991), using opercles. Scale ageing has been shown to underestimate the true ages of western suckers and otolith ageing is the most reliable method (Mark Terwilliger, Oregon State University, personal communication). The only disadvantage of otolith ageing is that the technique requires sacrificing the fish. Recent studies indicate that ageing pectoral rays is an accurate, non-lethal alternative to otolith ageing (Sylvester and Berry 2006; Koch and Quist 2007; Sweet et al. 2009; Albrecht et al. 2008). In 2009, we evaluated the use of fin rays as a non-lethal means to assess the age structure of Warner suckers and concluded that pectoral fin ray sections can be used as a non-lethal means to age threatened Warner suckers. Growth marks on these structures were visually distinct and were relatively easy to count, especially for younger fish. Pectoral fin ray ages matched otolith ages, for suckers ≤15 years old, 79% of the time, and all were aged with 1 yr of the otolith age.

Age-at-maturity and age-class distribution are relatively unexplored aspects of the life history of stream suckers. Ageing pectoral rays may allow us to track year-class strength and identify those environmental factors that favor or limit successful sucker recruitment in the lake suckers. In 2010, we collected pectoral fin rays from suckers captured in Crump Lake (n=30) and Twentymile Creek (n=56). In addition, we will collect fin rays from suckers captured in Honey Creek in 2011, and will use this aging technique to describe the population age structure for these population segments. In addition, we initiated an ageing validation study to confirm the annual periodicity of annulus formation by marking 26 PIT-tagged Warner suckers in Twentymile Creek by injection with oxytetracycline (OTC). Fish injected with OTC show visible fluorescent marks on their hard structures (Brown et al. 2004) and increment counts outside the

OTC mark will be examined on fish recaptured in 2011 to examine agreement with time of release.

We documented direct avian predation on Warner suckers, including radio-tagged suckers that were consumed by cormorants and pelicans. In addition, the avian biologists studying the tern colony nesting in Crump Lake found one PIT tag from a Warner sucker on the Capsian tern nesting island construted by the US Army Corps of Engineers in 2007 and 15 PIT tags from Warner suckers on Pelican Island. We estimated that avian predation accounted for a minimum of 0-16.7% of the suckers we tagged in any one year, or as many as 92 suckers in 2009-2010. We also noted that several of the radio tags that we inserted in lake suckers in 2008 were found in 2009 on the dry shore of Hart Lake (n=5) and Crump Lake (n=4), which may be a result of predation or scavenging. White et al. (1990; 1991) and Coombs et al. (1979) also noted evidence of bird predation on Warner suckers. White et al. (1990) described the significance of low water conditions, i.e. as the lake levels dropped during the drought in the late-1980's and early-1990's, sucker mortality due to bird predation increased. We documented avian predation on stream suckers, thus the impact of avian predators on the remaining stream suckers during periods of drought may be even larger. Because sucker survival during droughts may be further impacted by low stream flows, it is prudent to protect and enhance these stream habitats, which are so important to the long-term survival of the species.

We monitored the population of Warner suckers that was established in the 1990's at the Summer Lake Wildlife Management Area and found that the population was abundant with evidence of recent successful reproduction and recruitment. We propose genetic analysis of this population to determine the level of genetic diversity and look for evidence of genetic drift that may have been caused by a population bottleneck. It is critical to determine whether this population is suitable for use in repopulating the Warner Lakes following future drought events that result in lake desiccation in the Warner basin.

In summary, we conclude that Warner suckers warrant listing as a threatened species is warranted. Lake populations are depressed and recruitment of suckers in the lake populations is limited by the abundance of predatory game fishes, and possibly predatory birds, in the lakes. Lake suckers are also apparently limited by the lack of suitable upstream passage to access stream spawning habitats. We were challenged by our inability to capture sufficient numbers of suckers to obtain mark-recapture estimates for lake suckers. In addition, drought conditions resulted in low lake levels during 2008 and 2010, further limiting our ability to capture lake suckers, and limiting access by suckers to certain habitats, including the ephemeral northern lakes.

The stream population in the Twentymile Creek subbasin is robust with nearly 1,200 adults, but connectivity between the lakes and other tributaries is restricted by unscreened and mostly un-laddered irrigation diversions. The numerous diversion dams and unscreened irrigation canals act to fragment the habitat of Warner suckers (and redband trout) in the basin and are a major obstacle to meeting recovery criteria. We were limited in our ability to assess the status of the Honey Creek and Deep Creek populations because we were denied access to large portions of these drainages (e.g., lower Honey Creek below the canyon, lower Deep Creek, and Snyder Creek) and due to the low precision of our abundance estimates. In our opinion, the stream populations are the stronghold for suckers in the Warner basin and after suckers arrive in the lakes, it is unlikely that they are able to successfully mix with stream suckers and function as a true metapopulation.

Future studies to identify the source of lake recruits, to determine which irrigation diversions impede upstream migration, to assess the success of planned future passage improvements (e.g., Dyke and lower Honey Creek diversions), and to determine when and at what life stage suckers migrate to the lakes will provide information that will allow managers to prioritize funding (e.g., Ruby Pipeline Mitigation funds) to assist local landowners in restoring passage both upstream and downstream of irrigation diversions. A recent increase in landowner interest in partnering to improve stream passage is encouraging. In addition, results from the ongoing ageing study and a 2011 genetics study will provide critical information on species demographics that is needed to manage and recover the species.

Finally, over the past five years we have gained the cooperation of many landowners in the Warner basin and are grateful for their sincere interest and support. It is crucial that we are able to enlist and engage the support of the landowners, whose livelihoods depend on the limited water in the desert, to recover this species that not only bears the name of the valley where they live, but also represents the strong survival spirit that is essential for both to thrive in the desert environment.

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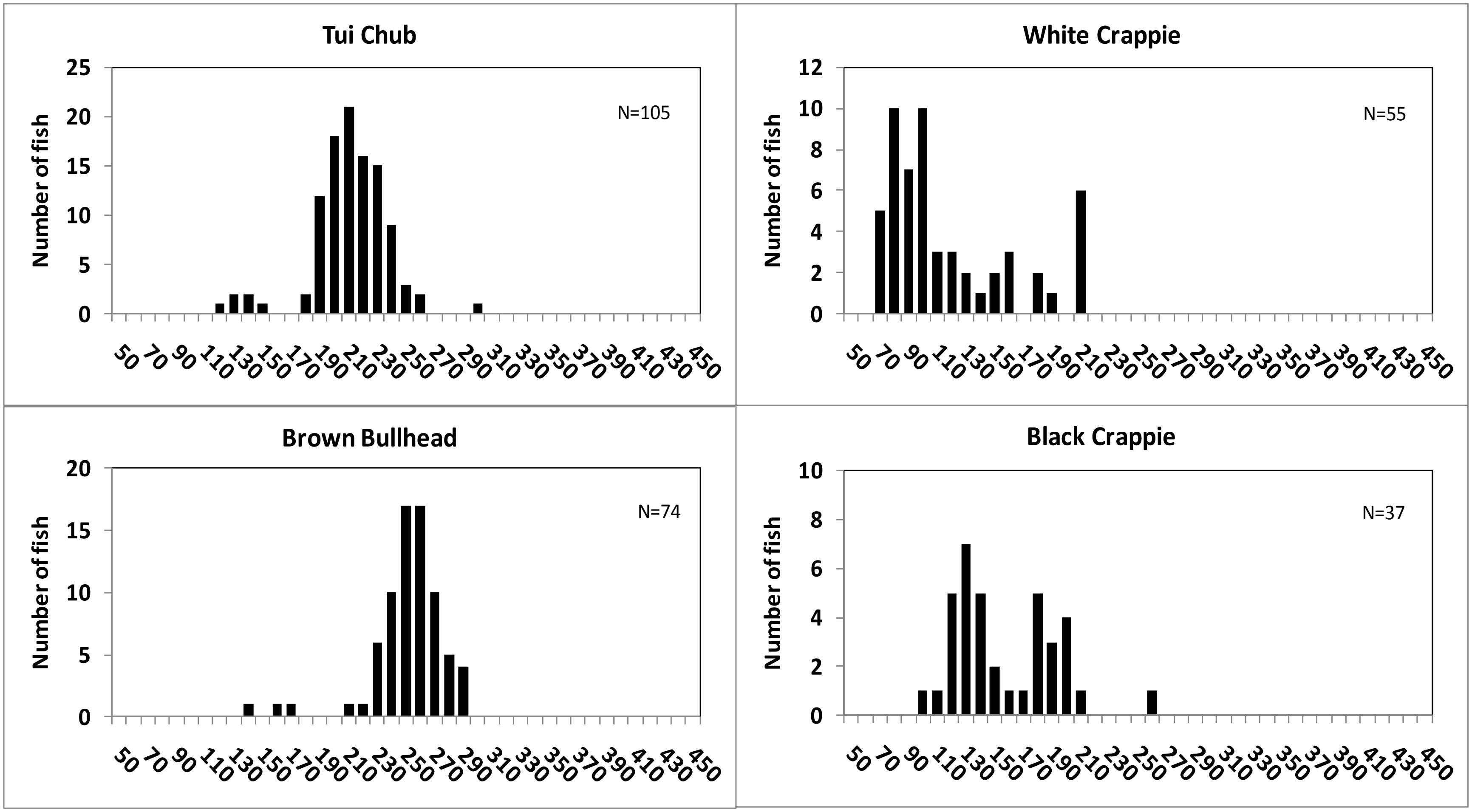
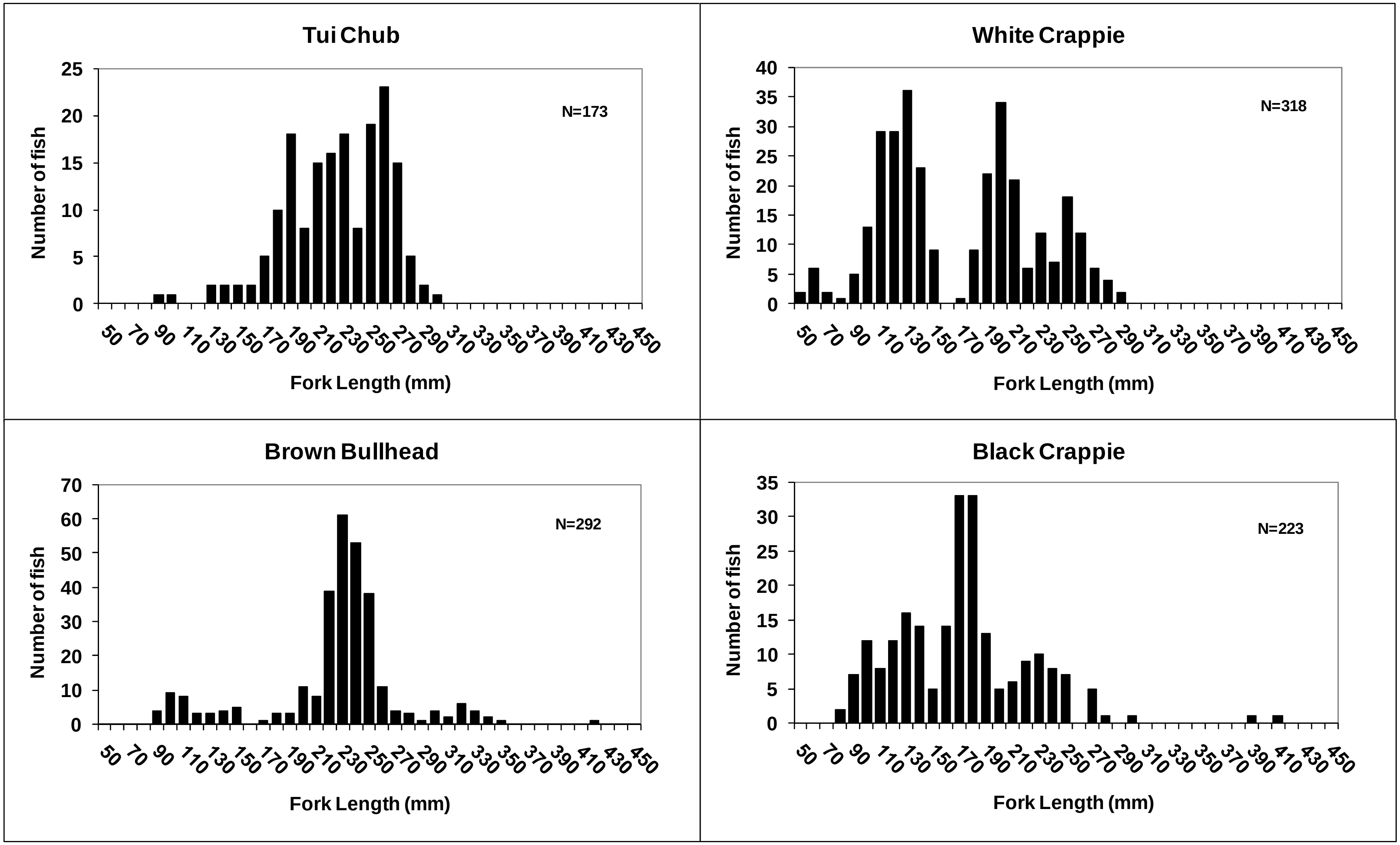
APPENDIX A. Length-frequency histograms for brown bullhead, black crappie, white crappie, and tui chub collected from Crump Lake, 2010 and 2008.

2010

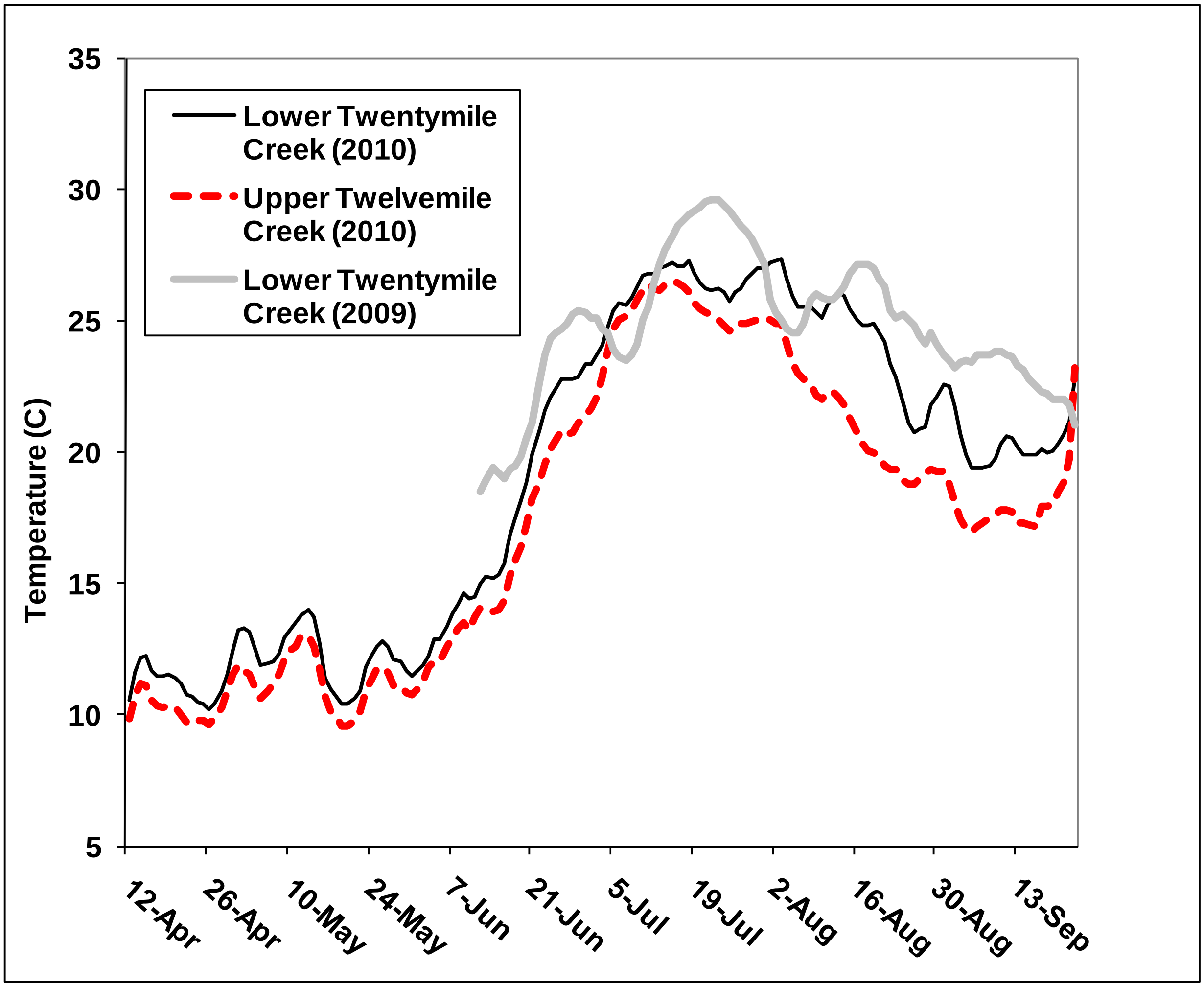


APPENDIX A. Continued.

2008



APPENDIX B. Seven-day running average stream temperatures recorded in the Twentymile Creek drainage in 2009 and 2010. Temperatures were recorded in lower Twentymile Creek near the USGS gage in 2009 and 2010. Temperatures were recorded in upper Twelvemile Creek near the mouth of the canyon.



APPENDIX C. Details of PIT-tagged Warner suckers detected at the antennas in the Twentymile Creek drainage, 2010. The letter or symbol listed after the date detected indicates direction of movement- upstream (u), downstream (d), and unknown (*).

		Location Detected			
Length	Sex	Easting	Northing	Comments	Dates detected
164	?	254941	4857897		5/11*
121	?	254941	4857897	tagged at screw trap 2008	5/4d
164	M	254941	4857897		5/29u
218	M	254941	4857897		4/25u
196	F	254941	4857897		5/31d
193	F	254941	4857897		5/3u,5d,6/5ud,21u,22d,24u,25du,26d,27u
180	F	254841	4661767	tagged at screw trap 2008	5/15u, 6/5d
180	F	254941	4857897		4/27-28d, 5/3u,4d,6u,8d
146	?	254841	4661767		5/29, 6/12d, 6/29u
146	?	254941	4857897		4/19u
148	F	254941	4857897		6/13u, 6/14d, 6/17u
177	M	254941	4857897		5/15u
200	F	254941	4857897	radio tag # 119	6/21u
178	F	254941	4857897		6/21u,22-23d
175	?	254941	4857897		6/13u, 6/15d
150	?	254941	4857897		5/29d, 6/14-15u
133	M	254941	4857897		5/15u
138	?	254941	4857897		6/14u,15d
189	F	254941	4857897		6/13u,7/16d
181	M	254941	4857897		6/13u.21d,24u,27d
193	F	254941	4857897		5/19d
186	M	254941	4857897		5/7d
195	M	254941	4857897		6/22d,7/2u
174	M	254941	4857897		6/29u
169	M	254941	4857897		6/12u, 6/14d
162	F	254941	4857897		4/22*
240	M	254941	4857897		4/15u,20d,25u,5/3d
					4/12,20,21,22,23,24,27,28,29,30,5/2,4,5,6,7,8,9,10,13,14,15,
					16,17,18,19,20,21,22,23,24,25,26,27,29,30,31,
202	F	254941	4857897		6/1,2,7,8,11,21,22
228	F	254941	4857897		4/26u
194	M	254941	4857897		5/14u,5/18d,7/3u
190	F	254941	4857897		6/20u
243	M	254941	4857897	radio tag #91	5/30u, 6/15d, 6/20u
220	F	254941	4857897		5/23*
177	M	254941	4857897		5/7u, 6/9d, 6/22u,23*
176	M	254941	4857897		5/15u,6/7d
150	?	254941	4857897		6/13u, 6/17*
225	M	254941	4857897		6/13u, 7/2d,3u,7d
251	M	254841	4661767		4/14,15,16,17,18,19,23,24,25,5/3,4,5,7,8,9,12,13,15, 5/3-13,15
149	F	254941	4857897		7/17u

APPENDIX C (continued).

		Location Detected			
Length	Sex	Easting	Northing	Comments	Dates detected
184	F	254941	4857897		5/16u
176	F	254941	4857897		5/13u, 6/1d,28u
201	?	254941	4857897		5/14u,21d, 6/12u
164	M	254841	4661767		5/26u
164	M	254941	4857897		5/7u,8d,13u
225	F	254841	4661767		6/12u,18d,19*
183	M	254941	4857897		6/23u,24d,26u
227	F	254941	4857897		4/14u
246	F	254841	4661767		5/4,5,7,8,12,13,14,15,18,23,24,26,27,29,30
232	M	254941	4857897		6/4u,6d,8u,15*
151	M	254941	4857897		6/29u
168	M	254941	4857897		7/2u,3d
214	F	254941	4857897		6/17u, 6/18d
240	M	254841	4661767		4/22*
183	?	254941	4857897		5/3u
187	F	254941	4857897		6/13u,19d,27u
158	?	254941	4857897		6/24u
174	?	254941	4857897		6/22u,23d, 7/1u
172	M	254941	4857897		5/16u,21d
175	F	254941	4857897		6/25u,26d
219	M	254941	4857897		4/20u
189	F	254941	4857897		6/24u
143	M	254941	4857897		7/8u
180	?	254941	4857897		5/30-31u, 6/9d, 6/18u
172	M	254941	4857897		5/22*
172	M	254941	4857897		4/15u,20d,26u
166	M	254941	4857897		6/7u,29d
165	?	254941	4857897		7/3u
198	F	254941	4857897		6/11*,6/14u
183	F	254941	4857897		6/13u
182	?	254941	4857897		6/14u,15d,16u,19d, 7/3u
235	M	254941	4857897		6/24u
213	F	254941	4857897		5/2u
185	F	254941	4857897		4/26*
201	M	254941	4857897		6/7u, 6/8d
165	F	254941	4857897		5/2*
184	F	254941	4857897		5/25-26u,27d
199	M	254941	4857897		6/27d
203	?	254841	4661767		4/14,15,16,17,18,19,21,24,25,26,27,5/4,12,13,14,15,16,17,18, 19,21,23,24,27,28
168	?	254941	4857897		5/15u,6/25d
262	F	254841	4661767	EF recap 4/21/10, radio tag #104	4/22u
160	?	254841	4661767		5/7d,16*
185	M	254841	4661767	2010 radio tag # 97	6/13u
178	F	254941	4857897		4/25*

3406 Cherry Ave. NE
Salem, Oregon 97303