NICHES: Nearshore Indicators for Clarity, Habitat and Ecological Sustainability
Development of nearshore fish indicators for Lake Tahoe

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Executive Summary

Lake Tahoe's fishery is among one of the least studied of all the large lakes in the world. Over time there have been a variety of stressors (e.g. introduction of species, eutrophication, nearshore habitat modification), which may have impacted the fishery and only a limited amount of snapshot investigations have been conducted to investigate these impacts or determine the status of a particular species. With little to no information on the status of fishery, in particular the nearshore components where most of the native, littoral fish reside, we have compiled information to determine the status of the nearshore native and non-native fish community and if there are quantifiable indicators and methodologies that can be created to determine the condition of the nearshore fishery. Furthermore, we conducted experiments to determine if ultraviolet radiation (UV) can be used to link nearshore and non-native fish ecology to the physical environment.

Traditional indicators (e.g. species composition, density, growth, condition, and spawning potential) were examined using historical (1960, 1990, etc) and contemporary (2008-2010) data to detect mid and long-term changes in Lake Tahoe nearshore fishery. In 1991-1994 and 2008-2009, the predominant fish species caught in the nearshore minnow traps were Lahontan reside shiners (*Richardsonius egregious*) and speckled dace (*Rhinichthys osculus robustus*). However, current catch of these and other species have declined. Overall, nearshore fish densities have undergone general decrease (58 % of historically sampled sites) between 1988-89 and 2009. In particular, Lahontan redside shiner densities have declined (25-100%) at 42% of the historically sampled sites. No significant change in speckled dace summer condition was observed between 1994 and 2008-09. Lahontan redside shiners summer condition was poorer in recent years than 1994. Tahoe suckers fall condition in 2008 increased when compared to conditions in 1994. Zooplankton, including cladoceran and copepods, and true flies are the most commonly utilized food items by Lahontan reside shiners and speckled dace, both historically and presently. Lahontan reside shiners are consuming a wider range of food types and relying more on surface food sources than before. These changes may be due to nearshore habitat modifications, which alter the food availability or clarity. Alternatively, predation from game fish (e.g. lake trout) may also contribute to the decline when native fishes move offshore in the winter. Changes in spawning activities (spawning behavior and egg presence) and condition

of spawning habitats (substrate types) were observed in 30% (6/20) of the sites when compared to historical data collected by Allen and Reuter (1996). Changes observed can potentially be attributed to changes in substrate types at various spawning sites as a result of decrease in lake water levels.

The potential of using two novel indicators (trophic niche and UV) to measure long- and short-term changes in nearshore fishery was examined. Changes in trophic niche were found. All fish species examined, except Tahoe sucker (*Catostomus tahoensis*) demonstrated greater reliance in pelagic food source and all fish species have reduced trophic position. UV exposure and in situ incubation experiments show that UV transparency of nearshore sites significantly impacts the survival of warmwater fish larvae and influences whether these potentially invasive fish species are able to establish in nearshore Lake Tahoe. Native fish larvae (Lahontan redside shiner) were at least six times more tolerant of UV exposure than non-native warmwater fish larvae (bluegill and largemouth bass). The observed difference in UV tolerance in native versus non-native fish was used to develop a UV attainment threshold (UVAT, i.e. a water clarity threshold based on water transparency to UV) that is lethal to non-native fish larvae with no observed effect on native fish larvae. Measurements of UV transparency around the lake showed that more than half of the sites sampled were in non-attainment of the UVAT, suggesting the potential for widespread warmwater fish establishment.

Previous studies conducted by Cordone (unpublished data 1960) and Thiede (1997) have already shown a sharp decline in nearshore native fish density of nearly 10-fold between the 1960s and late 1990s. Our contemporary assessment also suggests that the health of Lake Tahoe's nearshore native fishery is deteriorating. Given potential expansion of suitable habitat for non-native fishes as a result of increasing spread of invasive plants, elevated lake water temperature, and reduction in UV transparency, as well as other related threats (e.g. nearshore development), the future of Lake Tahoe's nearshore native fishery may be in trouble. We believe that a long-term nearshore monitoring and warmwater fish prevention program utilizing ecologically relevant metrics is necessary to help us better understand Lake Tahoe's nearshore native fishery, and assist stakeholders to more effectively manage and restore the lake's precious native biodiversity.

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Acknowledgements

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I. Introduction

Lake Tahoe aquatic ecosystem is threatened by multiple stressors, including nutrient loading, algae growth, invasive species, and habitat alterations. In particular, the nearshore area is of critical concern since it is heavily influenced by anthropogenic disturbances and is the primary interface with the general public. The nearshore, littoral zone is of critical importance to native fishes (e.g Lahontan redside shiner-*Richardsonius egregious* and Lahontan speckled dace-*Rhinichthys osculus* that utilize cobble and gravel areas for example for different aspects of their life history (spawning and rearing habitat) (Beauchamp et al, 1994; Allen & Reuter, 1996). The presence of vegetation and complex structures in the nearshore zone also provide shelter and invertebrate food sources for juvenile and adult fishes. Recently, local agencies have taken a strong interest in managing the nearshore fishery due to increased distribution of invasive plant (e.g. water milfoil-*Myriophyllum spicatum*, curly leaf pondweed-*Potamogeton crispus*) species. In the mid to late 1970's and again in the late 1980's, a variety of warmwater, non-native fish species (e.g. largemouth bass-*Micropterus salmoides* and bluegill-*Lepomis macrochirus* were found in the nearshore environment (Reuter & Miller, 2000). The warmwater fish introductions were illegal and thought to be the result of anglers eager to catch these fish. At that time, warmwater fish species were rarely found around the lake while native minnows remained abundant (Thiede, 1997). By the end of the decade, non-native largemouth bass and bluegill were common while native Lahontan redside shiner and speckled dace populations declined or were virtually eliminated from Tahoe Keys, an important rearing ground for native fishes (Kamerath et al, 2008). Change in fish species composition was confirmed by fishing guides operating out of Tahoe Keys. Within a decade they could no longer collect minnows commonly used as bait during fishing charters from certain marinas.

The quick reduction in native fish abundance in Lake Tahoe has become an increasing concern to managers at state and federal agencies seeking to maintain and restore the lake's native biodiversity. The expansion of suitable habitat for non-native fishes through increases in invasive plant populations in the nearshore has raised an alarm that existing, native communities may be in trouble. Moreover, recent observation of elevated lake water temperature (Coats et al, 2006) and predicted increase in future surface water temperatures (Ngai, 2008) will encourage further spread of non-native fish species resulting in potential decline of native fish density, and disruption of their spawning habitats (Kamerath et al, 2008; Herold et al, 2007; Thiede, 1997). Water transparency to ultraviolet radiation may be an additional factor that regulates the current and future distribution of non-native fishes. Traditionally the physical and biological characteristics that control the potential for exotic species to invade and establish are viewed as components of an "invasion window" (Johnstone, 1986) that can be altered by disturbance. In freshwater ecosystems most natural and human disturbances that might open an invasion window will also generate changes in water transparency. For example, transparency to visible light decreases with cultural eutrophication (Edmondson, 1991; Seehausen et al, 1997) and with the introduction of planktivorous or predatory fish (Mazumder et al, 1990; Kaufman, 1992). In Lake Tahoe, a variety of disturbances have been associated with a decrease in the average annual Secchi transparency from 31 m in 1968 to 21 m by 1998 (Jassby et al, 1999). During this same time a number of non-native warmwater fish species became established in portions of the lake (Reuter and Miller 2000), suggesting that decreasing water transparency may create a refuge for non-native species that are more sensitive to the optical properties of water such as ultraviolet radiation (discussed below).

The Tahoe Regional Planning Agency does have a threshold for assessing the health of nearshore fishery based on habitat, however, this threshold was recently found to be in non-attainment (Threshold Evaluation Report). Furthermore, there have only been a few and sporadic assessments and documentaries of the nearshore fishery of Lake Tahoe (e.g. Miller, 1951; Byron et al, 1989; and Beauchamp et al, 1991) with no stuides conducted in the last 20 years after the establishment of invasive, warmwater fishes. This knowledge gap stimulated the process of conducting a contemporary assessment and developing ecologically relevant metrics to assess the nearshore fishery (Chandra, 2007).

In this study, we examined the potential of using traditional indicators commonly used in other ecosystem to detect mid and long-term changes in Lake Tahoe nearshore fishery. These traditional indicators (Table 1) typically require a comparison with historical data collected through long-term monitoring programs. We also conducted experiments and field sampling to explore the development of a set of novel indicators that can be used to measure change on a short-term basis. These indicators (Table 1) are based on direct measurements of feeding preference and survival of native versus non-native fishes due to changes in nearshore water clarity.

Our assessment of the nearshore fish communities in Lake Tahoe addressed the following objectives:

1. Conduct a contemporary evaluation of the nearshore fishery
2. Evaluate a variety of traditional indicators that may be used to determine long-term change
3. Determine an efficient capturing method to assess nearshore fish communities
4. Develop novel metrics including UV transparency and trophic niche (stable isotope techniques) to detect shorter term change to the nearshore habitat
5. Provide recommendations and guidance for establishing a long-term monitoring program for nearshore fish communities of Lake Tahoe

Table 1. Metrics that will be evaluated during this study to determine short and long-term changes and metric development for the nearshore fishery.

Metric/ Indicator	Detection Scale	Indicator type	Data comparison to existing data
Density	long-term	Traditional	Yes- 1960, 1990, this study
Composition	long-term	Traditional	Yes- 1960, 1990, this study
Growth rate	long-term	Traditional	Yes- 1960, this study
Spawning habitat/ Recruitment potential	mid-term	Traditional	Yes- 1990, this study
Trophic niche	long- and short- term	Novel	Yes- 1960, this study
Ultraviolet radiation tolerance	short-term	Novel	No- this study

II. Traditional Metrics

Lake Tahoe's community assemblage was relatively simple prior to several large scale intentional and some unintentional introductions of non-native species. There were only 12 orders of zoobenthic taxa, 6 zooplankton species, and 8 fish taxa with Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) as the only native piscivore in the lake (Vander Zanden et al, 2003; Chandra et al, 2005). Started in the end of the 19th century, a series of intentional introductions added several species of salmonids to the lake, which includes rainbow trout (*O. mykiss*), brown trout (*Salmo trutta*), lake trout (*Salvelinus namaycush*), brook trout (*S. fontinalis*) and Kokanee salmon (*O. nerka*). Predatory impacts from lake trout combined with over fishing, hybridization, and siltation of spawning streams contributed to the extirpation of Lahontan cutthroat trout from Lake Tahoe by 1939 (Cordone & Frantz, 1968; Moyle, 2002). In the 1980s and 90s, a series of illegal introductions brought warmwater non-native species, such as largemouth bass and bluegill into the lake. Today, Lake Tahoe's nearshore fish community assemblage is much more complex and is dominated by non-native fishes and a few native forage fishes (Table 2).

Previous studies conducted by Cordone (unpublished data 1960) and Thiede (1997) showed that native forage fish densities have experienced sharp declines of nearly 10-fold between the 1960s and late 1990s. Researchers attributed such observations to disruption of favorable nearshore habitats due to development (Beauchamp et al, 1994) and increased predation from non-native species. However, current status and health of Lake Tahoe's nearshore fishery is unknown due to the lack of contemperary comprehasive study in the last 20 years after large changes in community structure and nutrient concentrations in the lake. Therefore, we conducted extensive literature review (reports and publications) for historical baseline information and collected comparable current data on several traditional metrics commonly used in fishery assessment to try to provide a contemporary assessment of our nearshore fishery. Traditional metrics, such as density, composition, body condition, growth rate, and spawning habitat availability have been used as indicators to identify and evaluate changes due to anthropogenic influences in lake ecosystems (Table 1). These metrics are best at detecting substantial and long-term changes given the availability of baseline information. Our contemporary collections were made in 2008 and 2009 at several locations on the Lake Tahoe shoreline (Figure 1, Table 3).

Table 2. Native and introduced fishes found in the nearshore, littoral zone of Lake Tahoe (Vander Zanden et al, 2003).

Species (Common Name)	Latin Name
Native fishes	*Catostomus tahoensis*
Tahoe sucker	*Rishardsonius egregius*
Lahontan redside shiner	*Rhinichthys oseulus robustus*
Lahontan speckled dace	*Gila bicolor (obesus or*
Tui chub	*pectinifer)*
Paiute sculpin	*Cottus beldingii*
Mountain whitefish	*Proposium williamsoni*
Established non-native salmonids	
Rainbow trout	*Oncorhynchus mykiss*
Brown trout	*Salmo trutta*
Kokanee salmon	*Oncorhynchus nerka*
Non-native fishes with limited distribution	
Goldfish	*Carassius auratus*
Bluegill	*Lepomis macrochirus*
Black crappie	*Pomixis nigromaculatus*
Brown bullhead	*Ictalarus nebulosus*
Carp	*Cyprinus carpio*
Largemouth bass	*Micropterus salmoides*

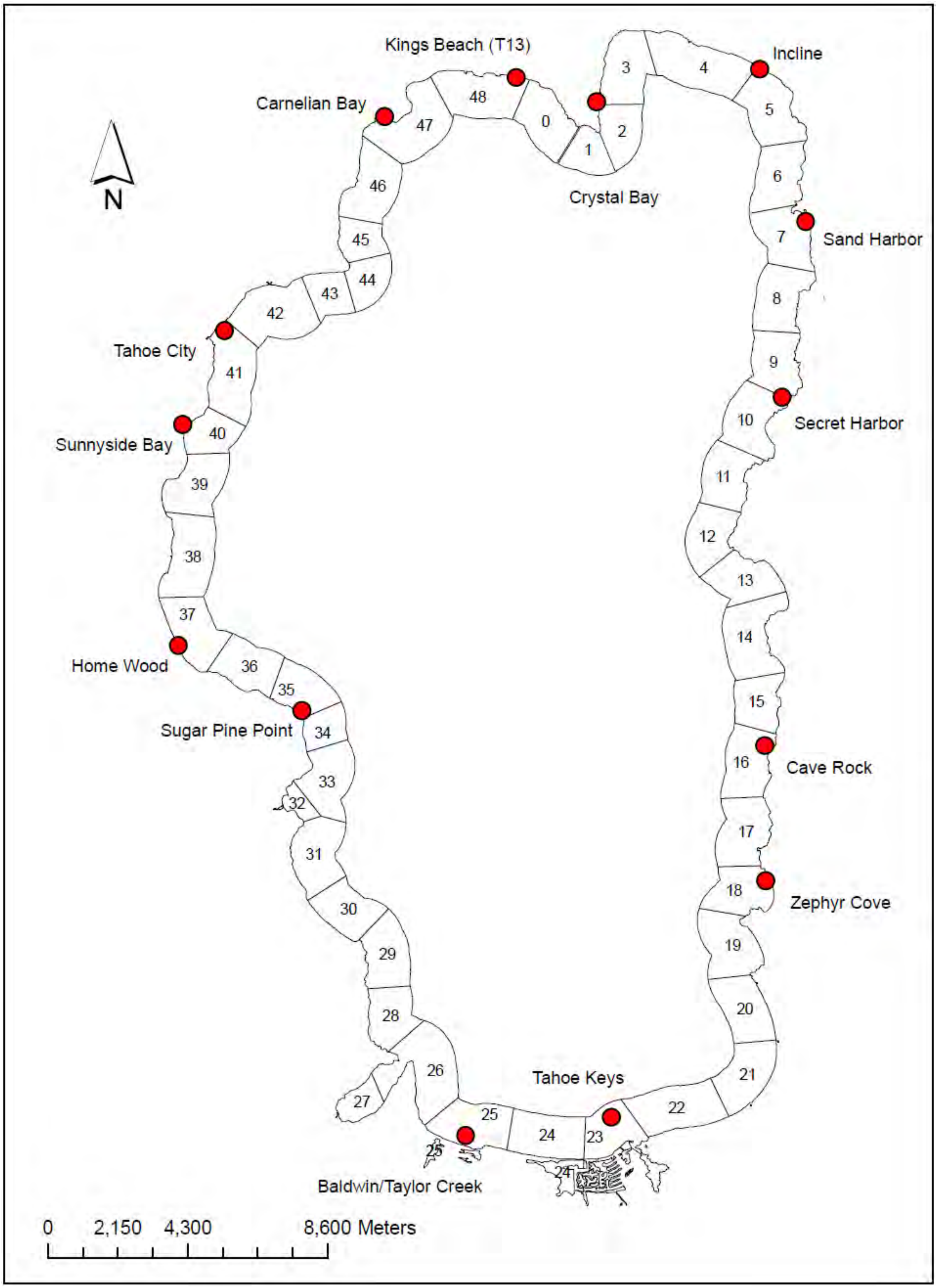


Figure 1. Map of Lake Tahoe with site locations- 49 sites for snorkeling surveys, and 14 transects (●) for minnow trap surveys.

a. Species composition

i. Minnow traps transact methods

Minnow trap transects were conducted at monthly intervals from May to November at 14 locations in 2008 and 2009 (Figure 1, Table 3). Similar to previous study conducted by Thiede (1997), two minnow traps were set at each location at 3, 10, 20, 30, 40, and 50 meters using one cup of dog food as bait. For each traps set, we recorded the following Information: total catch from paired traps over 24 hours, species of fish caught, primary substrate (bedrock, sand, gravel, cobble, and boulder), depth, GPS location, time, and duration of set time. Since historical data used for comparison collected by Thiede (1997) were based on catch from 12 hours overnight sets (e.g. 8pm to next day 8am), whereas our traps were left over-night for 24 hours (e.g. 8am to next day 8am), for proper comparison, we calculated catch per unit effort (CPUE) as total catch from paired traps per 12 hours. A subsample of fishes was processed in the lab for basic life histories characteristics (length, weight, diet and sex). Stomach contents were removed and preserved in 70% ethanol for diet analysis when possible and muscle samples were extracted for stable isotope analysis to determine longer term utilization of energy sources. Dorso-lateral scales were removed from the left side of each fish and stored in a coin envelope for aging and growth rate determination purposes.

Table 3. Sites monitored during monthly minnow traps surveys in 2008 and 2009 with GPS coordinate (Also see Figure 1).

Site	Latitude	Longitude
Tahoe City	N39.16756	W120.13617
Sunnyside Bay	N39.14191	W120.15222
Home Wood	N39.08079	W120.15619
Sugar Pine Point	N39.06163	W120.11304
Baldwin/Taylor Creek	N38.94247	W120.05965
Tahoe Keys (not within the marina)	N38.94618	W120.00776
Zephyr Cove	N39.01028	W119.95029
Cave Rock	N39.04764	W119.94892
Secret Harbor	N39.14408	W119.93850
Sand Harbor	N39.19243	W119.92810
Incline	N39.23504	W119.94270
Carnelian Bay	N39.22537	W120.07692
Kings Beach (T13)	N39.23496	W120.02958
Crystal Bay	N39.22754	W120.00110

ii. Results and discussion

Due to weather and accessibility issues, we were not able to sample all 14 locations every month (between May and November) in both years, resulting in periodic data gaps from certain locations. In order to display a more comprehensive snapshot of lakewide species composition, we chose to present CPUE (total catch from paired traps per ~12h) and species composition data collected in June and November of 2008 and 2009 (Figure 2 and Figure 3) where the most complete set of sites were surveyed. These time periods are ideal for sampling since they represent early summer (June) and late summer/fall (November) conditions. The most common species of native fishes caught from our 14 locations in those two months were Lahontan reside shinner and Lahontan speckled dace (Figure 2 and Figure 3). No non-native warmwater fish species were caught in our minnow traps at the 14 locations sampled. There was large spatial and temporal (inter-annual and seasonal) variability in CUPE were observed between the two years (Figure 2 and Figure 3).

Between 1991 and 1994, Thiede (1997) sampled three locations (North Stateline, Sunnyside and Meeks Pt/Sugar Pine Point) by minnow traps and the predominant species captured were Lahontan redside shiners, speckled dace and Tahoe suckers (Figure 4). Present day data (2008 and 2009) from these three locations did not show the same pattern. Lahontan reside shiners and speckled dace remained the two dominant species, but no Tahoe sucker was captured and CPUE at all three sites are significantly lower than historical sampling (Figure 4). Catch of Tui Chub were low in both historical and current times (except Meek Point in 1992) (Figure 4). Historical data (1991-1994) also show great spatial and temporal (inter-annual) variability in species composition and CPUE (Figure 4). Factors that may contribute to the spatial and temporal (inter-annual) variability observed among and within sites from both the historical and present datasets should also be considered when examining potential changes in abundance and composition of nearshore native fishes. As the data presented are only snapshot captures of the historical and present conditions, short-term variations in seasonality, lake condition (e.g. lake level), habitat and other conditions between sites can confound our results and analysis (Hubert, 1996). In order to better capture and identify changes in composition and abundance among these localized populations and reduce variability, longer-term, continuous and constant sampling with standardized gear, methods, and location is warranted to overcome the spatial and temporal variability introduced by these short-term effects (Hubert, 1996).

Please note that absence of Paiute sculpin in our traps and historical sampling may likely be the result of underrepresentation due to this sampling method because of their preferences for deeper, benthic habitat and cryptic nature.

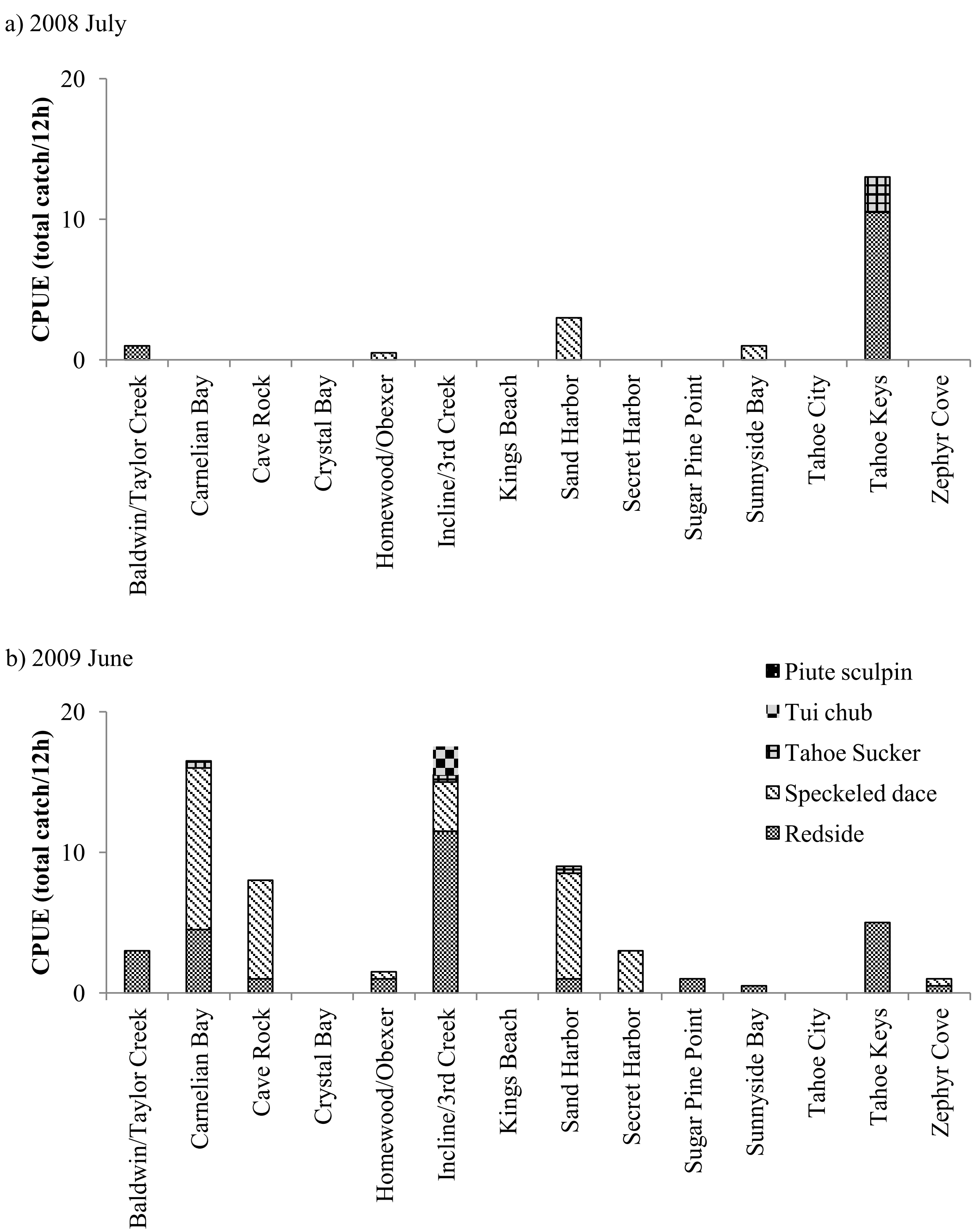


Figure 2. Early summer overnight minnow trap CPUE (Catch per unit effort: total catch per 12 h) of nearshore fishes and species composition of catch summed from 3 sample depth (3, 10 and 20 m) in a) 2008 July and b) 2009 June. Refer to Figure 1 for the locations of the listed sites.

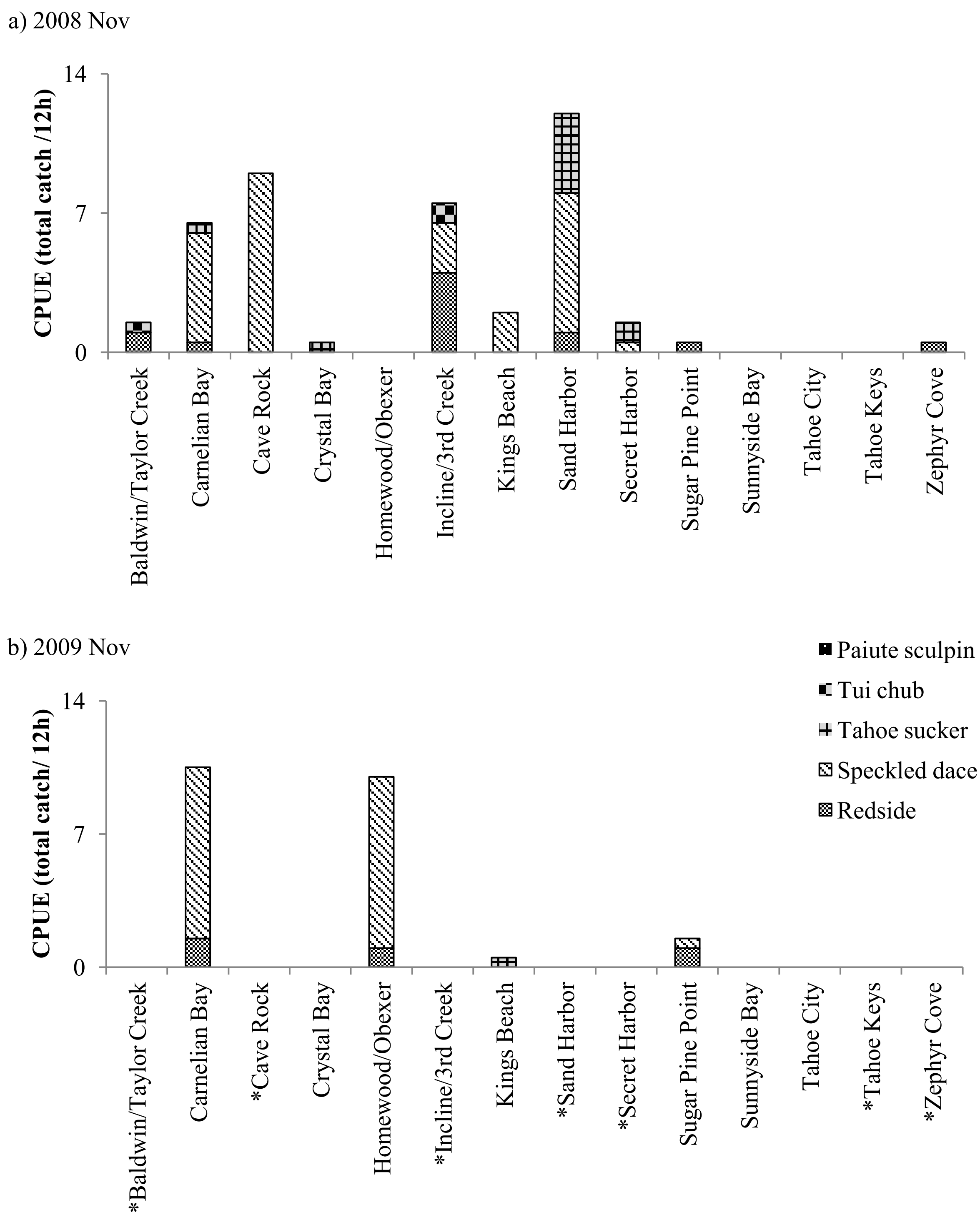


Figure 3. Late fall overnight minnow trap CPUE (Catch per unit effort: total catch per 12h) of nearshore fishes and species composition of catch summed from 3 sample depth (3, 10 and 20 m) in a) 2008 Nov and b) 2009 Nov from overnight minnow traps. Refer to Figure 1 for the locations of the listed sites. * identifies sites not sampled.

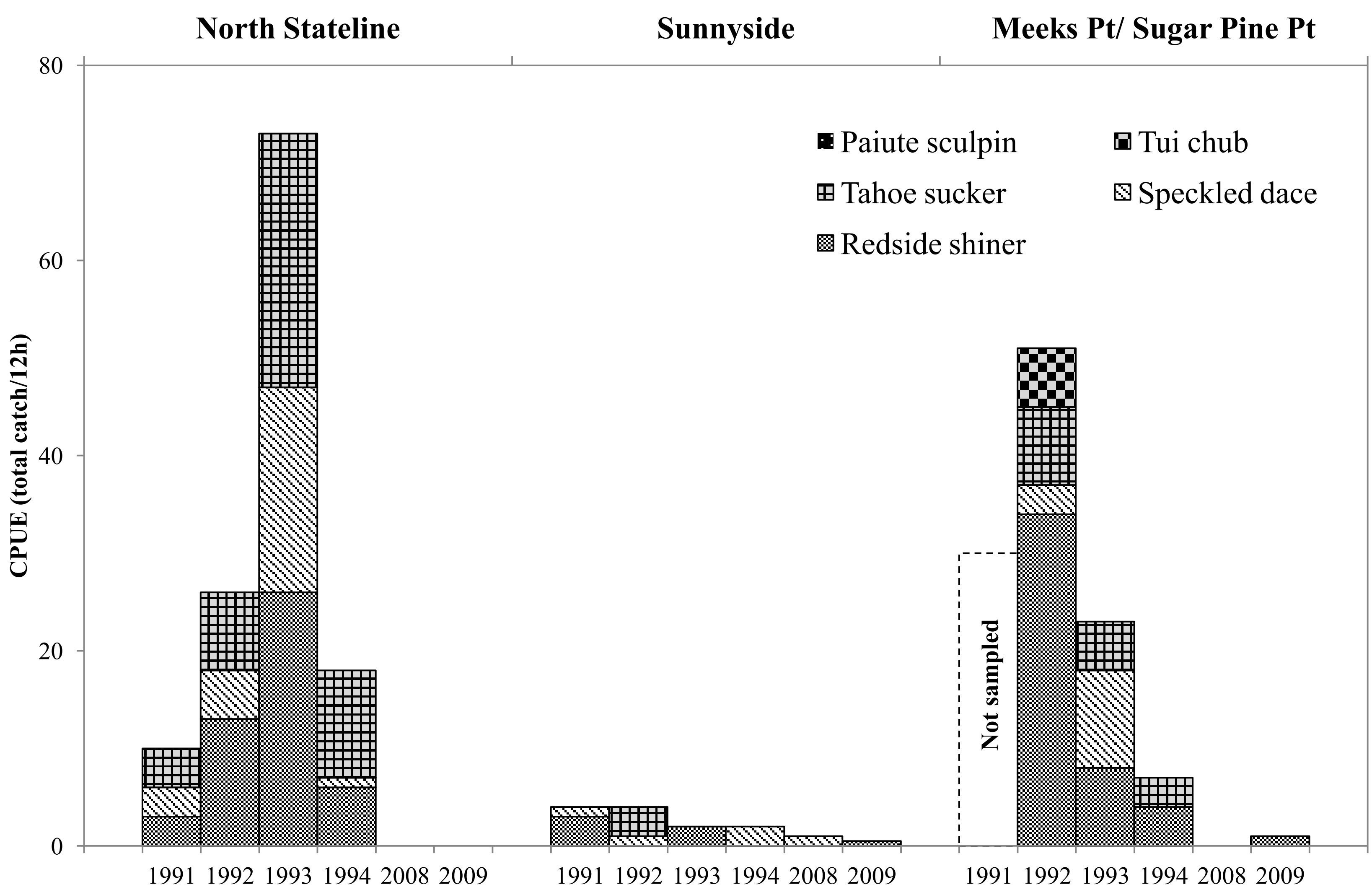


Figure 4. Early summer (June or July) overnight minnow trap CPUE (Catch per unit effort: total catch per 12 h) of nearshore fishes and species composition of catch summed from 3 sample depth (3, 10 and 20 m) at three locations (North Stateline, Sunnyside, and Meeks Point/ Sugar Pine Point). Refer to Figure 1 for the locations of the listed sites.

b. Fish density and substrate preferences

i. Snorkel transact methods

Byron et al. (1989), as well as Beauchamp et al. (1991) and (1994) recorded fish counts in Lake Tahoe at 28 nearshore locations in 1988 and 1989. In order to understand the spatial variability and make a comparison with this historic data, we revisited these locations and utilized similar sampling techniques to collect comparable data in 2009. We also added 21 additional sites to provide a more comprehensive fish density and substrate survey of the nearshore zone of Lake Tahoe. Fish densities were estimated through snorkeling transacts at 49 sites around the lake during daylight in June 2009 (Figure 1). At each site, divers surveyed a 100m long and 4m wide transact parallel to shore at 1m and 3m depths. The diver at the 1 m transect was limited to observation between 0-2m and the diver at the 3m transect was limited to observation between 2-4m. This is to avoid "overlap counting" when the two divers were close to each other at steep sites. Instead of conducting substrate grabs at each site, substrate type and % composition at each transact was identified by divers based on classification as defined by the American Geophysical Union nomenclature (Lane, 1947) (Table 4 and Table 5).

Table 4. Size range classifications for different substrate types defined by the American Geophysical Union nomenclature (Lane, 1947; Re-print from Beauchamp et al, 1994).

Substrate	Size range (mm)
Sand	<2
Gravel	2-64
Cobble	>64-256
Boulders	>256
Bedrock and clay	

Table 5. Composition classifications for different substrate types (Beauchamp et al, 1994).

Substrate type	Composition
Sand	100% sa
Sand-cobble	10-30% co, 70-90% sa
Sand-boulder	10-30% bo, 70-90% sa
Cobble	100% co
Cobble-boulder	30-70% co, 30-70% bo
Boulder	100% bo

Substrate type, % composition of substrates, and slope of each site, as well as number, species, and size class (juvenile and adult) of all fishes observed were recorded on a slate attached to the diver's arm. The size class criteria for different species of fishes are listed in Table 6.

Table 6. Size class criteria for different fish species (Beauchamp et al, 1991).

Species	Size class (juvenile)
cyprinid and sculpin	<40mm
Tahoe sucker	<100mm
Salmonids	<150mm

For comparison, fish counts of adults and juveniles from the 1988-89 survey by Byron et al (1989) and 2009 survey were converted to total weight from species-specific length-weight regressions (Byron et al, 1989; Table 7). Nearshore fish biomass was calculated as total fish weight observed at each transect divided by transect area (0.4 ha). Native biomass was calculated as the sum of observations at 1 and 3m during the summer sampling session.

Table 7. Estimated sizes of fishes observed by SCUBA divers in transects. Adult fish are indicated by "A", juveniles by "J". and larvae by "L". These values were used to estimate the biomass of fish presented in Figure 7. (Re-print from Byron et al, 1989; Appendix: Table A-1)

Taxa	Weight (g)
Lahontan redsides (A)	4.6
Lahontan redsides (J)	0.5
Tahoe suckers (A)	276
Tahoe suckers (J)	11
Tui Chub (A)	12
Speckled dace (A)	1.7
Speckled dace (J)	0.3
Paiute sculpin (A)	1.4
Paiute sculpin (J)	0.4
Rainbow trout (A)	672
Rainbow trout (J)	31
Brown trout (A)	672
Lake Trout (A)	465
Kokanee salmon (A)	151
Mountain whitefish (A)	162
Mountain whitefish (J)	9
Unidentified (A)	3.8
Unidentified (J)	0.1

ii. Results and discussion

The most common species encountered by our divers during the snorkeling surveys were Lahontan reside shiners and speckled dace. Our observations show that native forage fishes such as Lahontan redside shiners and speckled dace generally prefer complex habitats in the summer months (Figure 5 and Figure 6). Similar to results shown in Beauchamp et al (1994), highest densities of nearshore fishes were found near substrates containing boulder (Figure 5 and Figure 6). Speckled dace can also be found near cobble substrate (Figure 6). Distribution of these fishes are also found to be patchy and variable, even at locations with the same substrate (standard deviation of density at different substrates ranges between: redside shiner juvenile 0.7-308; adult 0.3-190, speckled dace juvenile 0.2-19; adult 0.4 -6). For example, high density of juvenile redside shiner at sand-boulder substrate shown in Figure 5a in 2009 and adult redside shiner at boulder substrate shown in Figure 5b are due to high counts at one site (27: Emerald Bay, Figure 1). This site (Emerald Bay) has a great amount of organic material (fallen trees and branches) on top of the sand-boulder substrate that was unique to this location. The extra coverage provided may explain the aggregation and abundance of forage fishes in that location (Mehner et al, 2005). There is a slight increase in densities of juvenile redside shiner at all substrate, but a significant decrease in densities of adult redside shiner between the 1989 survey and recent observation (Figure 5). Densities of both juvenile and adult speckled dace remained similar between the two time periods (Figure 6).

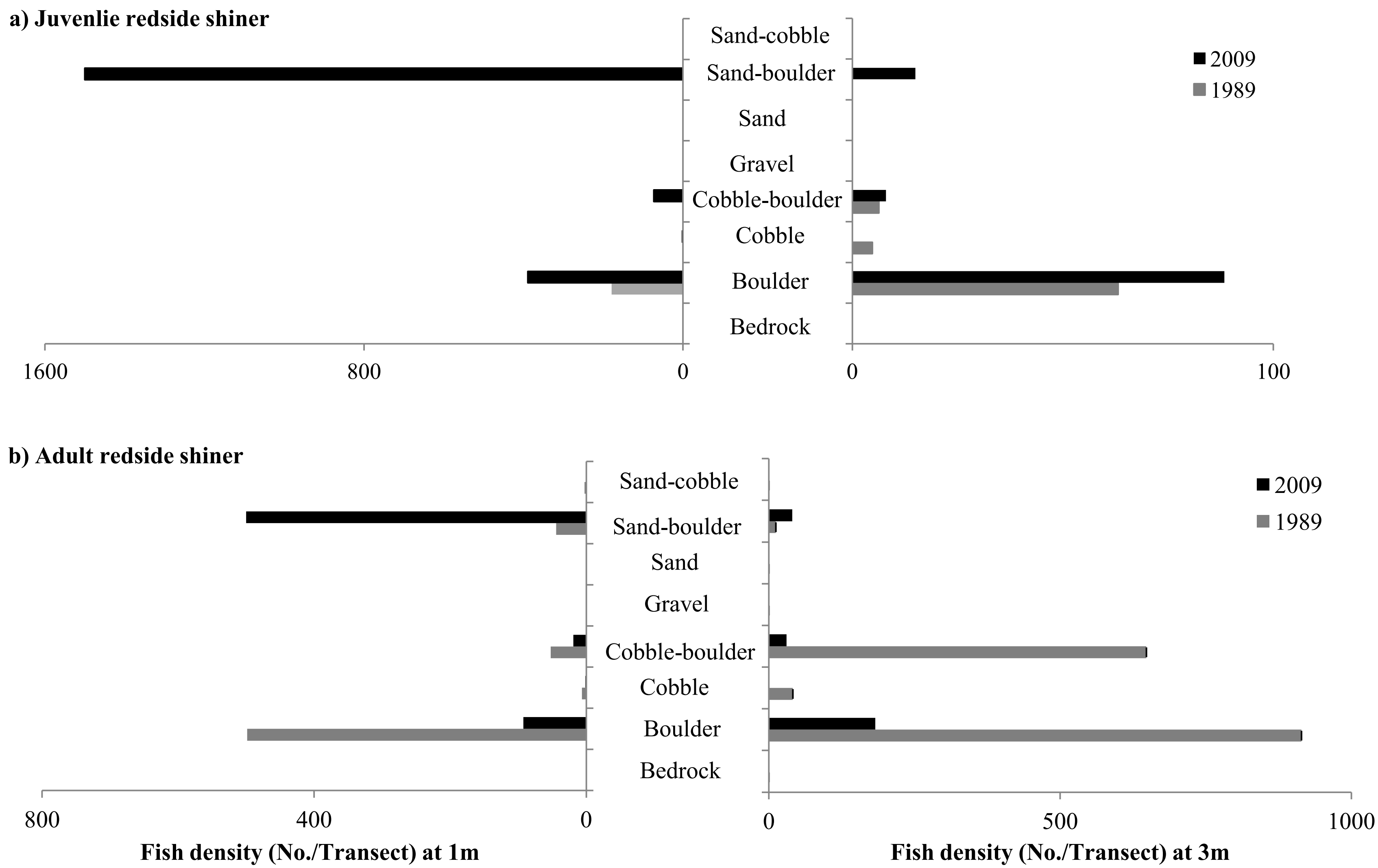


Figure 5. Average summer densities (number/400m^2) of a) Juvenile Lahontan redside shiner and b) Adult Lahontan redside shiner, observed along snorkeling/SCUBA transects by substrate categories defined in Table 4 and Table 5. Note that graph density scales differ.

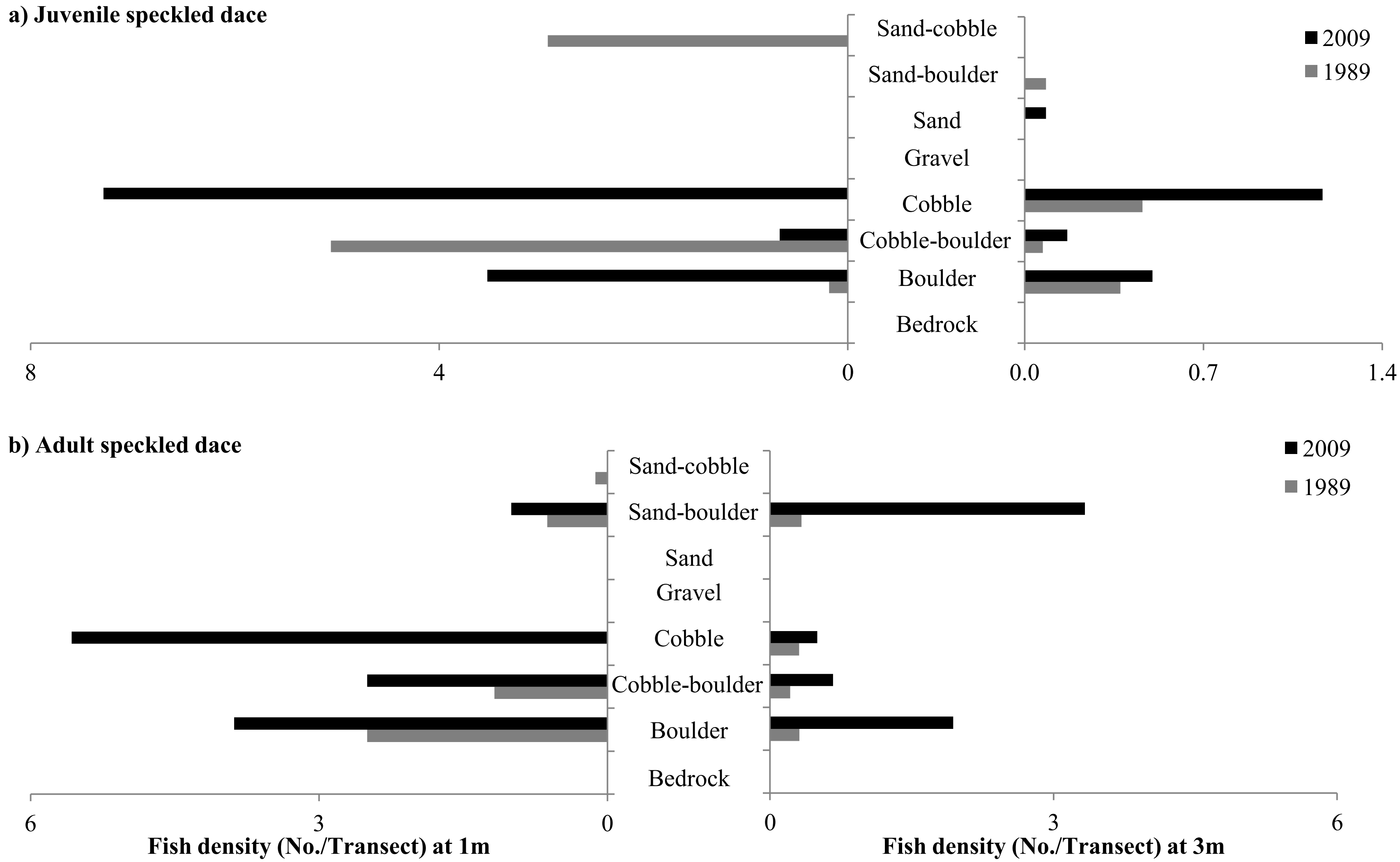


Figure 6. Average summer densities (number/400m^2) of a) Juvenile Lahontan speckled dace and b) Adult Lahontan speckled dace, observed along snorkeling/SCUBA transects by substrate categories defined in Table 4 and Table 5**.** Note that graph density scales differ.

Comparison of native biomass estimates between 1988-89 and 2009 show a general decline in nearshore native fish densities (Figure 7). When compared with current survey data, 15 out of the 26 historically sampled sites (58%) show decline in native fish densities (Figure 7). When examined per species, mountain whitefish, Paiute sculpin and tui chub that were observed in the 1988-89 surveys were not sighted in our June 2009 survey. For Lahontan redside shiner, densities decline (25% to 100% decrease) were observed at 42% (11/26) of the historically sampled sites (Figure 8). Densities of speckled dace and Tahoe sucker were low in both 1988-89 and 2009 surveys, and little changes in speckled dace and Tahoe sucker densities were observed between the two time periods. One should note that the cryptic nature of Paiute sculpin, Lahontan speckled dace, and Tahoe sucker make these species harder to be identified by snorkelers, which may attribute to the low counts of these species even when sighted. The additional 21 new sites had low to zero fish counts (Figure 7). No non-native warmwater fish species were observed during the 1988-89 surveys and during the time of our snorkeling surveys in 2009. However, non-native warmwater fishes have been sighted in some of the sites in snorkeling surveys done in previous year (2006-2008), in particular in embayment and marinas around the nearshore of the lake (Chandra et al, 2009).

As observed in our study, distribution and density of fishes are highly patchy and variable spatially and temporally due to animal behavior and physical complexity in the environment (Brandt, 1996). In addition, the expansive nearshore zone of Lake Tahoe and cool water temperatures can make long-term comprehensive snokeling surveys extremely labor and time-intensive. Other abundance and distribution assessment techniques, such as hydroacoustics should be considered to provide larger scale and coverage of assessment at the nearshore zone (Brandt, 1996). Such technique has been extensively used in fishery surveys from other ecosystems to determine relative abundance of different fish species. The use of transducer transmitting sound to detect fish can provide information of fish sizes, distributions and abundances at a wider range of spatial and temporal scales (Brandt, 1996). Biennial lake-wide snorkeling survey and seasonal minnow trap transects can be used to supplement hydroacoustic assessment with calibration data and verify species composition and density estimates.

Tahoe Keys (Figure 1; site 23 a and b) was not sampled by snorkeling survey due to low visibility. Tahoe Keys is an extensive housing project and inland marina on the south shore constructed in the mid-1960’s on the Upper Truckee Marsh. The Upper Truckee River is thought to be the major rearing area of Lake Tahoe's native fishes (Cordone, personal communication). It once flowed through Tahoe Keys, but was diverted to prevent flooding. Tahoe Keys consists of an inland marina on the northeast portion of the project whose waters are separate from a residential area with boating channels and waterways for residents. The shallow backwaters contain abundant aquatic vegetation including invasive Eurasian water milfoil and the water clarity is general low throughout the year. Warmer, lentic waters with abundant vegetation provides habitat for warmwater non-native fishes including: largemouth bass, bluegill, black crappie, brown bullhead, and goldfish (Chandra et al, 2008). Previous research suggests that the presence of warmwater non-native fishes can threaten the persistence of native littoral fishes through competition and predation (Kamerath et al, 2008). We surveyed the fish community in Tahoe Keys Marina by electrofishing with assistance from California Department of Fish and Game. A list of all species caught in the Tahoe Keys by electrofishing is provided (Table 8). For littoral native species, captures declined by 87 % between July and August from 1999 to 2003 (Figure 9). Thereafter, declines continued to 2008 when only 10 native fishes were captured in Tahoe Keys East. A slight increase in catch of native species was observed in 2009, mainly due to an increase in the number of Tahoe sucker caught (Figure 9). In addition, no Lahontan redside shiner or speckled dace were ever captured in Tahoe Keys Marina after the 1999 sampling.

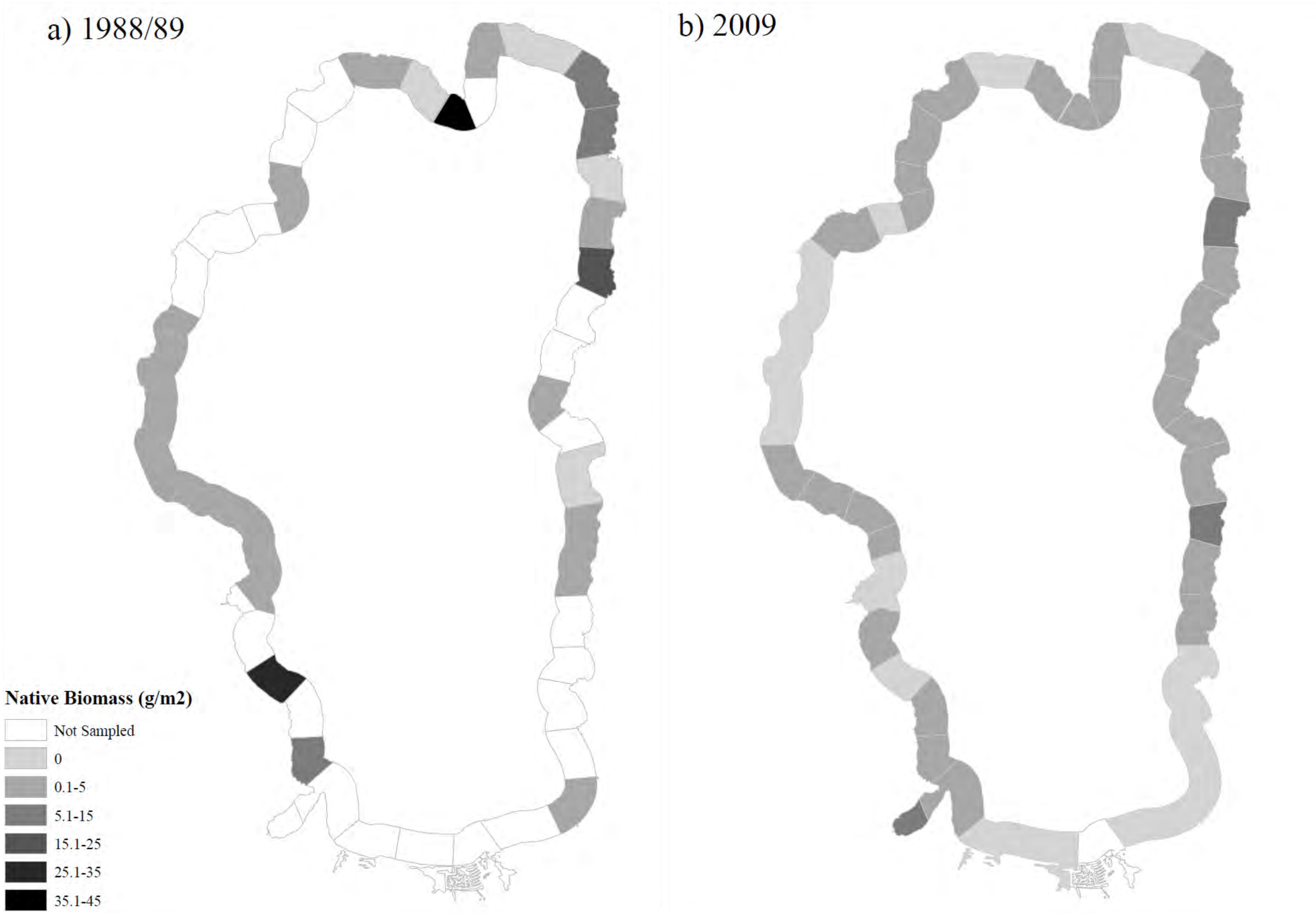


Figure 7. Native biomass estimates derived from fish count data collected from snorkeling surveys conducted in 1988-89 (Byron et al, 1989; Beauchamp et al, 1994) and in 2009.

Figure 8. Lahontan redside shiner biomass estimates derived from fish count data collected from snorkeling surveys conducted in 1988-89 spring-summer (Byron et al, 1989; Beauchamp et al 1994) and in 2009.

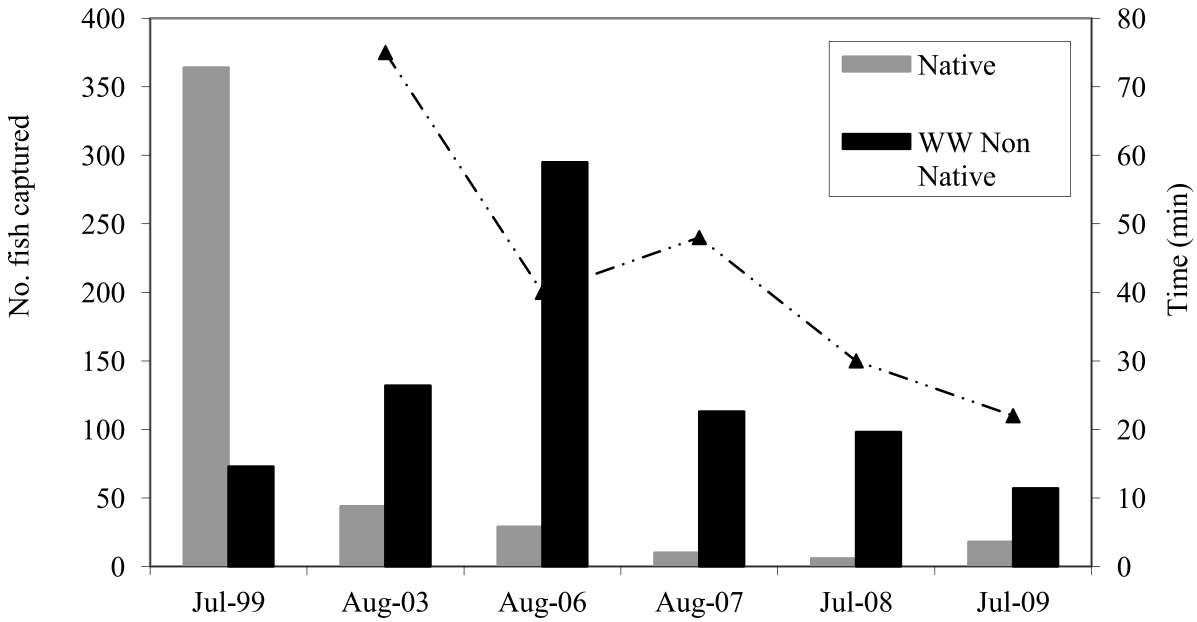


Figure 9. Number of native fishes and warmwater non-native fishes captured during electrofishing sampling at Tahoe Keys East in the summer of 1999, 2003, and 2006-2009.

Table 8. Species list of fishes captured in Tahoe Keys East and West during electroshocking in 2006-2009. Species native to Lake Tahoe are indicated by *. All other species are non-native.

Tahoe Keys Species List 2006-09	
Common Name	**Scientific Name**
Largemouth Bass	*Micropterus salmoides*
Bluegill	*Lepomis macrochirus*
Brown Bullhead catfish	*Ameiurus nebulosus*
Black Crappie	*Pomoxis nigromaculatus*
Goldfish	*Carassius auratus*
Brown trout	*Salmo trutta*
Rainbow trout	*Oncorhynchus mykiss*
*Tahoe Sucker	*Catostomus tahoensis*
*Tui chub	*Gila bicolor*
*Lahontan redside shiner	*Richardsonius egregious*
*Lahontan speckled dace	*Rhinichthys osculus robustus*
*Mountain whitefish	*Prospiu, williamsoni*

c. Diet

i. Short-term minnow traps survey methods

Encountering the problem of bait-filled stomach contents and advance digestion found in native fishes collected from overnight minnow traps in 2008, we conducted supplementary short-term trapping (2-6 hours) in 2009 as a way to collect true "natural food" stomach contents from these nearshore native species. Fishes were collected from nine sites around Lake Tahoe (Figure 10). A lakewide total of 24 speckled dace and 52 redside shiners were collected. Collections were done in late June and early July during daylight hours. Traps were baited with cichlid fish food that was isolated with a perforated glove to prevent ingestion of the food. Collected fishes were preserved on site with 70% ethanol with a small incision to the body cavity to allow for quick preservation of the stomach. Length, weight, and sex of each fish were recorded. Fullness of fish stomach was assessed. For fish with stomach contents, stomachs were removed for later analysis. Each food item found in preserved stomachs was separated and when possible, individuals were identified to order using the Ecology and Classification of North American Freshwater Invertebrates (Thorp & Covich, 1991) and An Introduction to the Aquatic Insects of North America 3rd edition (Merritt & Cummins, 1996). The percent (%) occurrence for each diet item and proportion of diet by weight (g) were calculated for each fish. The percent occurrence was calculated as the number of fish containing a particular diet item divided by the total number of fish examined, regardless of quantities of the diet item. Proportion of diet by weight (also known as percent by weight) was calculated as the summed weight of each individual diet item divided by total weight of all diet items for that fish. Each component of the fish diet was dried for 24 hours at 60º C and weighted using a Sartorius microbalance. All data collected were used to supplement stable isotopes analysis to establish trophic niche metric for nearshore native fishes (see below). Diet data collected by these short-term traps were compared to historical diet data presented in Miller (1951) and Evans (1969) for redside shiners, and Miller (1951) and Tucker (1969) for speckled dace.

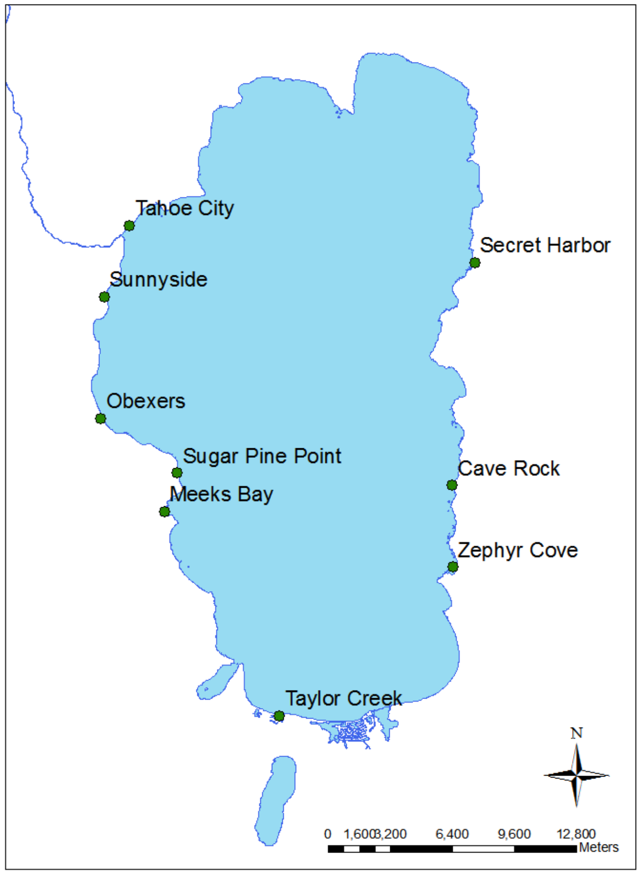


Figure 10. Outline of Lake Tahoe showing nine sampling sites for diet analysis.

ii. Results and discussion

Diptera larvae/pupae, and zooplankton including cladocera and copepoda remained the most common diet items consumed by Lahontan reside shiners (Figure 11). However, a greater variety of food items are consumed by redside shiners sampled in 2009 than in 1969. One should note that high frequency of occurrence does not imply that a given food type is of higher nutritional importance to the consumer. Certain diet items maybe consumed with great regularity by most members of a population but in very small quantities. Frequency of occurrence describes the uniformity with which groups of fish select their diet but should not be used as a reference for nutritional importance of the various diet items selected.

Diet by weight (%) is a better indicator of relative importance of individual food types in the nutrition of the fish, since most of the time food value is proportional to weight. In Miller (1951), diet items were grouped based on the nature of their sources (surface, zooplankton, bottom, and fish) (See Table 9 for classifications). A two time period of diet by weight (%) is compared for Lahontan redside shiners' using Miller (1951) and in 2009 based on these categories (Figure 12). Our data suggest that redside shiners are utilizing more surface food source, in particular terrestrial insects in summer months. Terrestrial insects are typically larger in size than aquatic insects and might contribute to the higher percentage content by weight value observed.

Table 9. Diet items categorized based on Miller (1951) definitions

Categories	Content
Surface	lepidoptera, coleoptera, hymenoptera, other terrestrial insects
Bottom	plecoptera, coleoptera, diptera larvae, chironomid larve, simuliidae, and other aquatic insects
Zooplankton	cladocera, daphnia, copepods, amphipods, gammarus (amphipoda)
Fish	fish eggs of 1mm diameter (potentially Tahoe sucker eggs)

The majority of Lahontan speckled dace consumed zooplankton including cladocera and copepoda and diptera larvae/pupae both historically and at present (Figure 13). However, similar to Lahontan redside shiners, a greater variety of food items were identified in speckled dace sampled in 2009 than 1951 and 1960s. In particular, ostracods (watermites) and plant matters which had either low or no occurrence in historical samples were found in over 40% of present day samples. Unfortunately, no historical percentage by weight data of speckled dace is available to date for comparsion .

Diet analysis from stomach contents is a good supplemental metric for varifying changes in food sources and trophic position detected from stable isotope analysis (See Novel Metrics-Trophic Niches section below). However, diet and energetic can be highly variable over time (within and across years) for fishes, depending not only on their plasticity in selection but food available (Bowen, 1996). Therefore, long-term collection plan using a consistent protocol with standardized sampling time (e.g. summer when nearshore fishes are most active) and measuring parameter (e.g. % Diet by weight) is needed to ensure accurate assessments. This can be extremely time and labor intensive, thus it might best be used only as a supplemental assessment when changes in energy pathways of targeted species are detected through stable isotopes analysis.

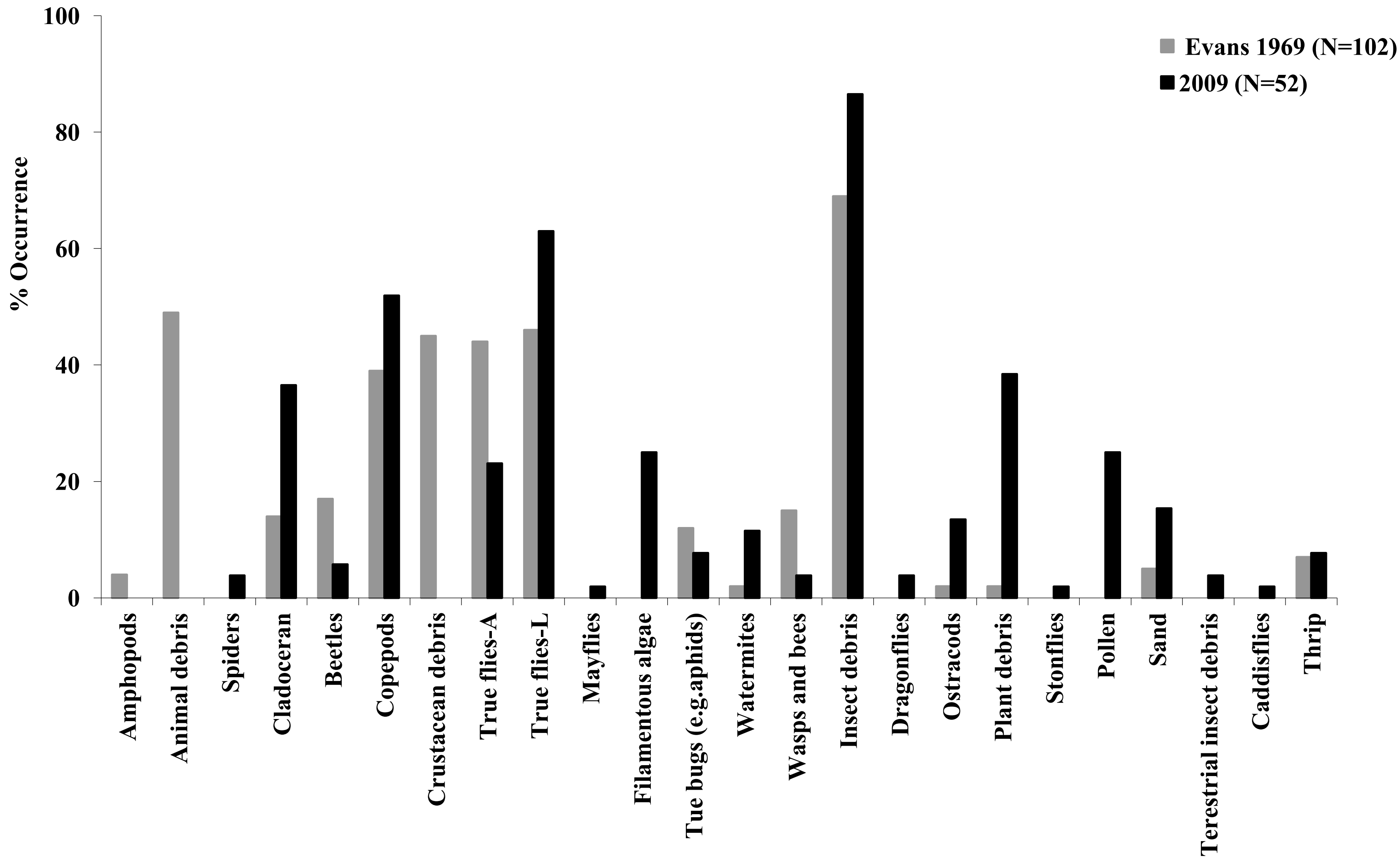


Figure 11. Percentage (%) occurrence (equation) of diet items found in Lahontan redside shiners' stomachs examined by Evans (1969) and in 2009.

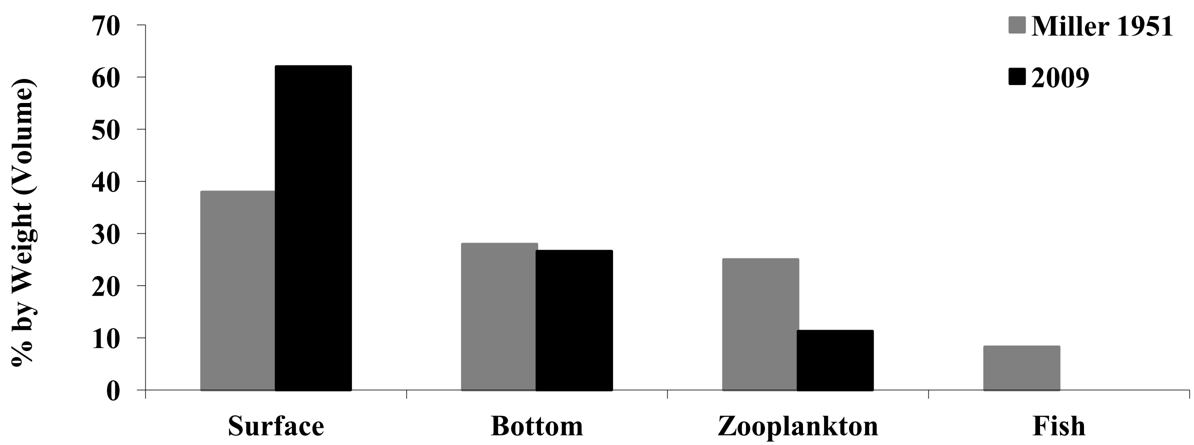


Figure 12. Percentage (%) by weight of diet items in Lahontan redside shiners' stomachs examined by Miller (1951) and in 2009. The diet items were grouped in four categories (Surface, Bottom, Zooplankton, and Fish) based on the nature of the food source (See Table 9 for details categories classifications).

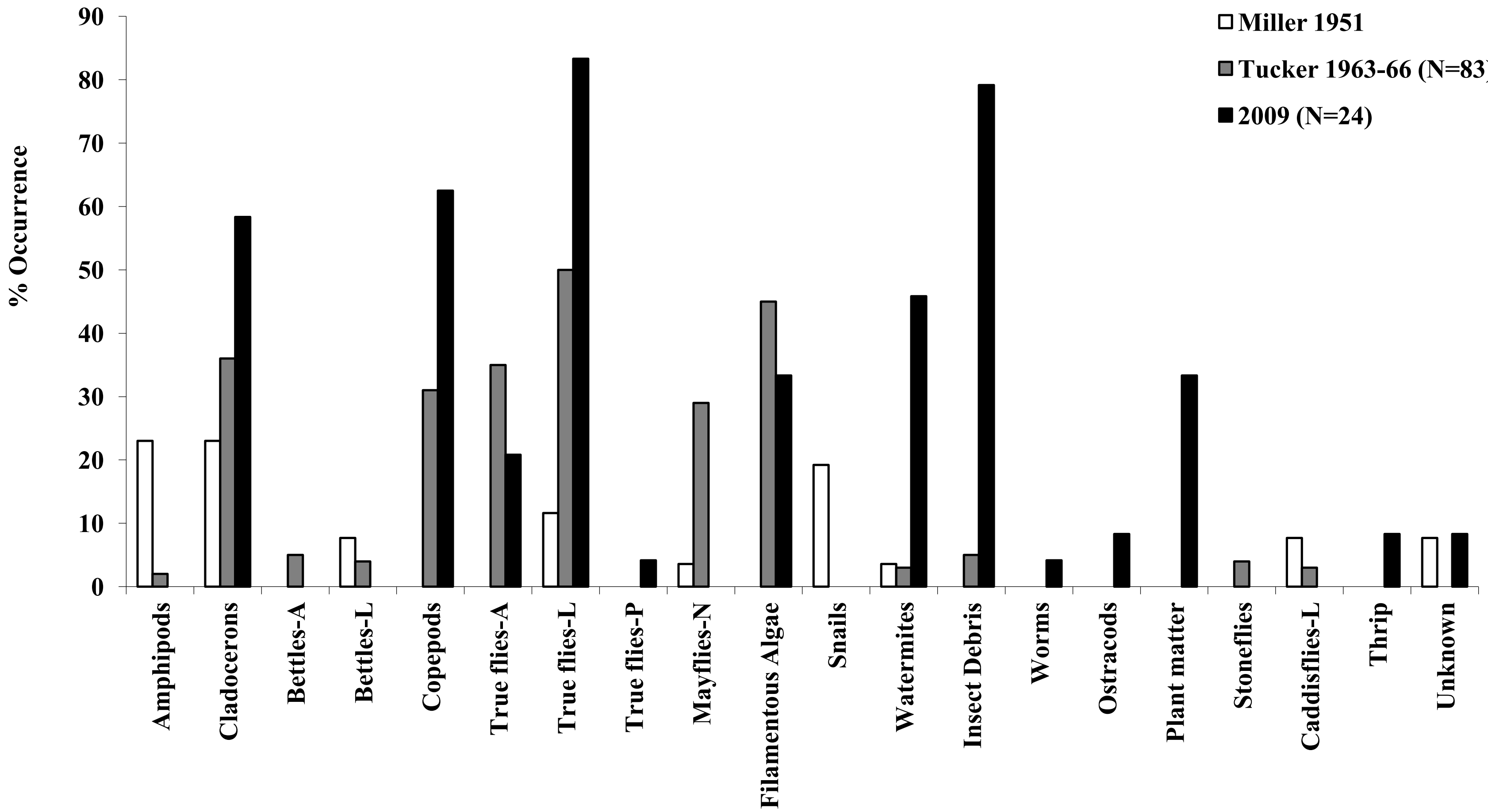


Figure 13. Percentage (%) occurrence (equation) of diet items found in Lahontan speckled dace' stomachs examined by Miller (1951) and Tucker (1969) and in 2009.

d. Body condition and growth

Body conditions of the fishes are quantified using the Fulton's condition factors: K= (W/L^3)*100, where W = weight (g) and L = total length (cm) (Moyle & Cech, 2000) (Figure 14, Figure 15, and Figure 16). Condition factor is commonly used as an indicator of health of a fish. A high K value represents abundant food supplies to support both somatic and gonadal growth (Moyle & Cech, 2000). The value of K can be influenced by a number of factors, (e.g. age, sex, season, stage of maturation) and can be valuable in assessing the status of a population over time (Lagler, 1969). Unfortunately, there is only limited information available from historical collections thus we were not able to calculate K separately based on species, sex, and age. Instead averaged K of all fishes were calculated for Lahontan redside shiners and speckled dace collected in June of 1994, 2008 and 2009 and Tahoe sucker collected in November of 1994 and 2008 (Figure 17, Figure 18, and Figure 19). No significant (ANOVA: $p= 0.12$) changes in speckled dace conditions were observed among years. Condition factors calculated for Lahontan redside shiners (ANOVA: $p<0.001$) were lower in recent years than 1994. Tahoe suckers caught in 2008 November have a higher condition factor (t-test: $p=0.01$) value than in 1994.

As stated above, condition factor is best used to assess the condition of a population over time when data collected can be analyzed by sex, age, and season given how these factors determine life history difference (Lagler, 1969; Moyle & Cech, 2000). Therefore, results presented here should be approach with caution until more detailed and longer-term data can be collected and analyzed.

Age and growth rate of fishes are typically determined by two methods, 1) analysis of hard parts of fish and use of back calculation, and 2) use of length-frequency analysis (DeVries & Frie, 1996). We encountered similar problem as Baker (1967) with annuli identification from minnow fish scales. Age assignments to scales collected were difficult and prevented us from using such method to determine present day age and growth rate estimations. Length-frequency analyses were also not useful in determining age classes and growth rate as no clear length-based cohorts were observed from the length-frequency distributions data, in particular, we do not have a good representation of smaller size class fishes among our samples (Figure 20 and 21). Furthermore, historical age and growth data found were insufficient for comparison (Baker, 1967).

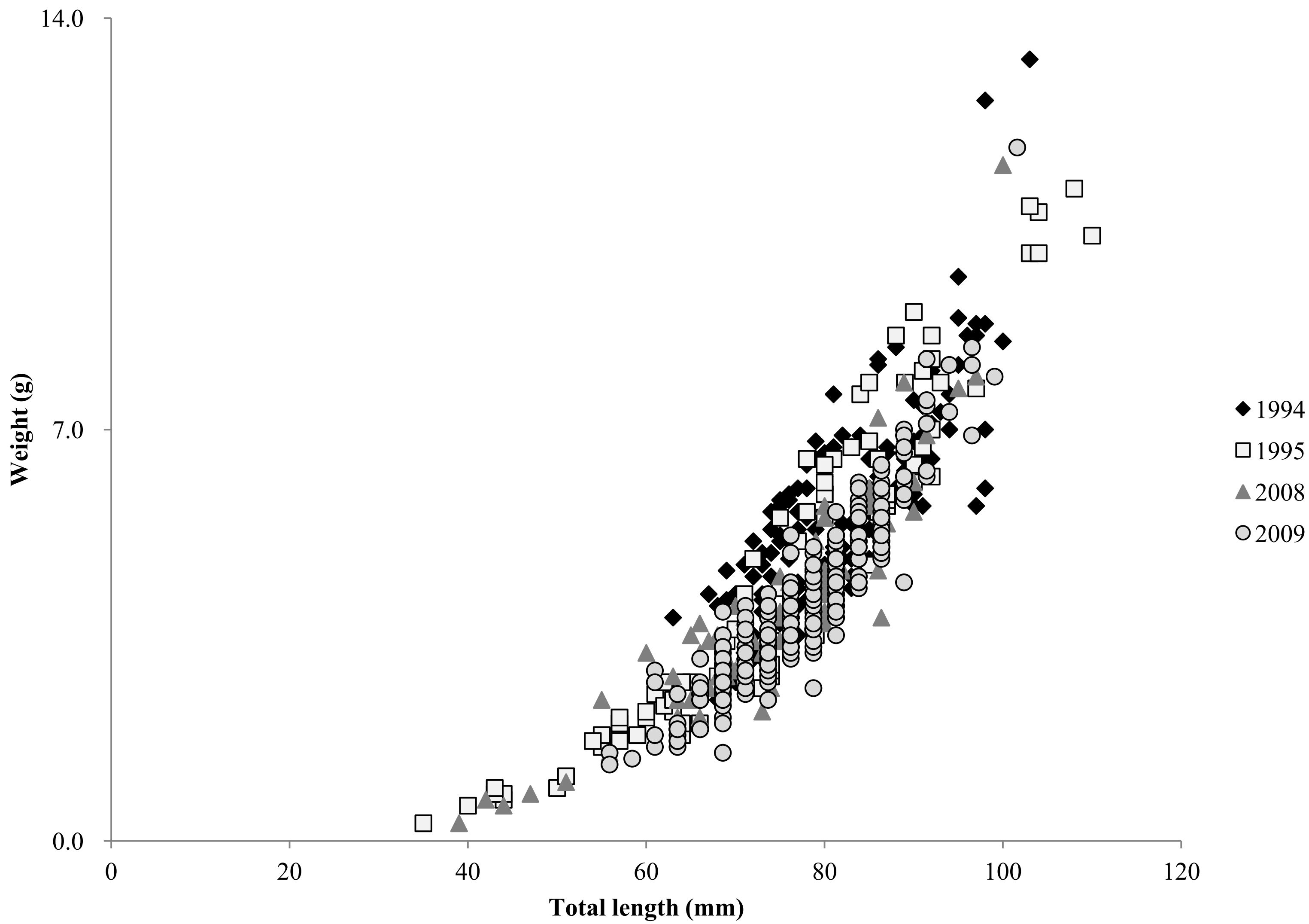


Figure 14. Length-weight relationship of Lahontan redside shiners from Lake Tahoe caught at various locations (Figure 1) in 1994 (N=139), 1995 (N= 90), 2008 (N= 68), and 2009 (N= 356), averaged at 1mm intervals.

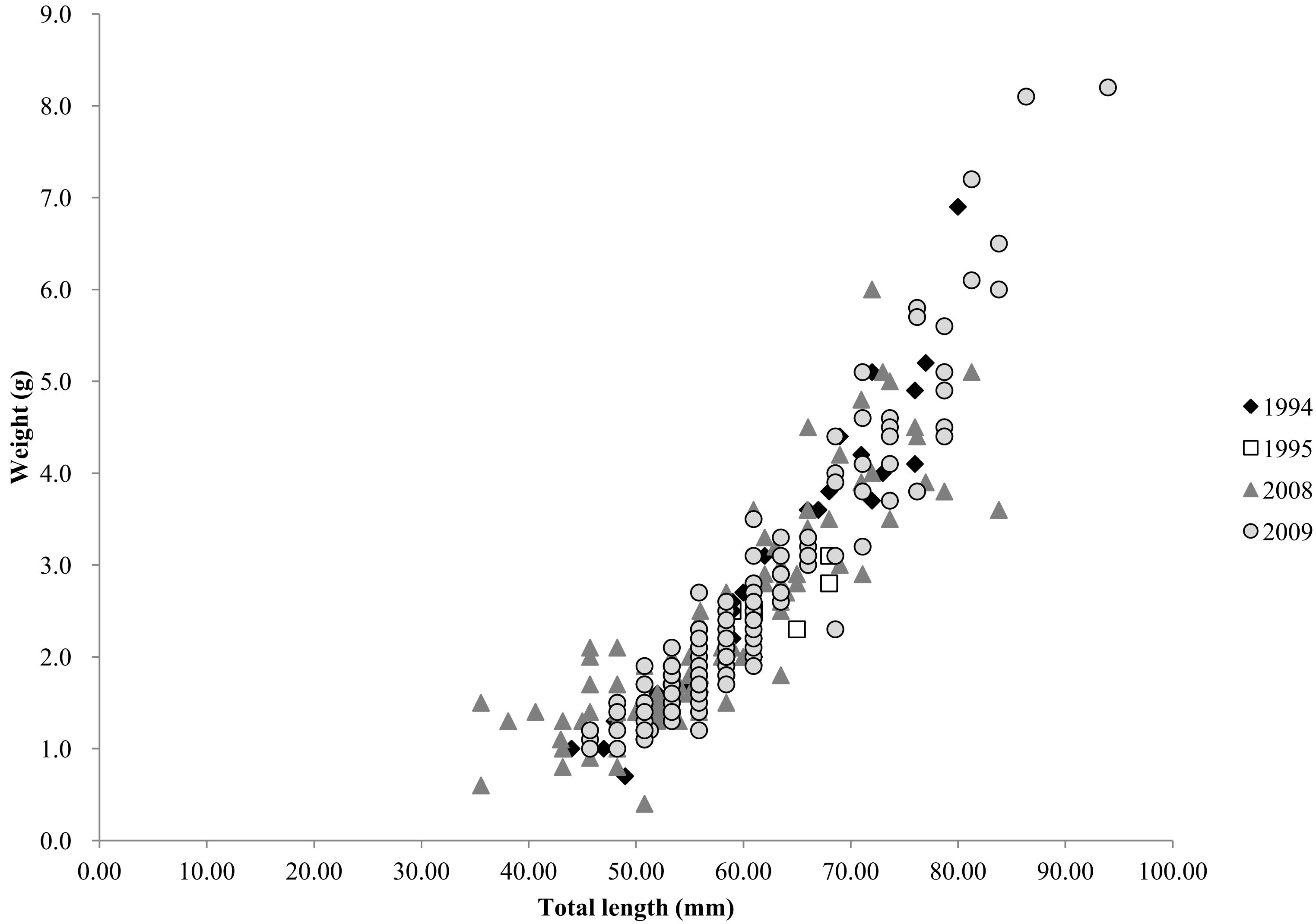


Figure 15. Length-weight relationship of Lahontan speckled dace from Lake Tahoe caught at various locations (Figure 1) in 1994 (N= 27), 1995 (N=5), 2008 (N= 113), and 2009 (N= 152), averaged at 1mm intervals.

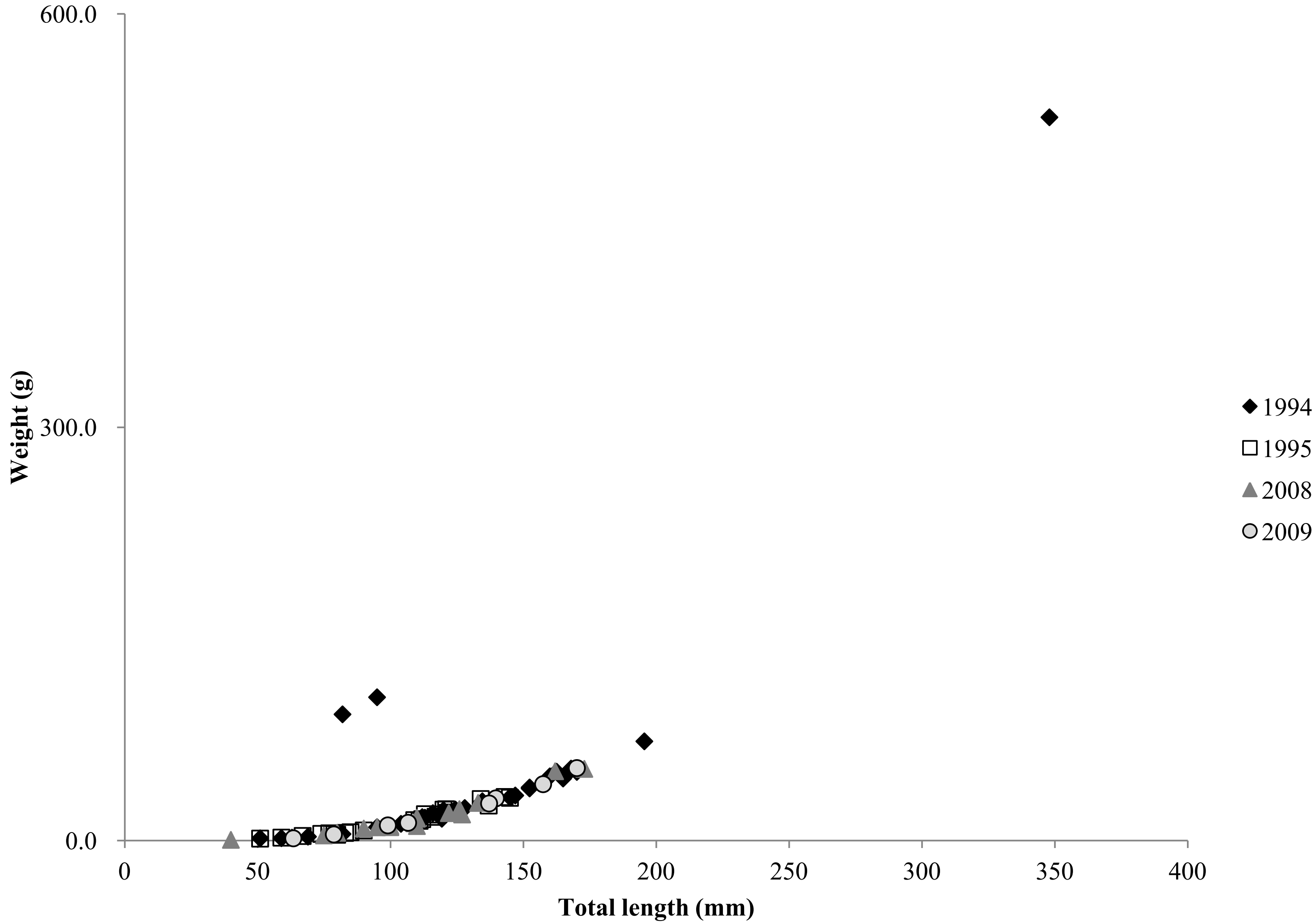


Figure 16. Length-weight relationship of Tahoe sucker from Lake Tahoe caught at various locations (Figure 1) in 1994 (N= 36), 1995 (N= 25), 2008 (N= 17), and 2009 (N= 8), averaged at 1mm intervals.

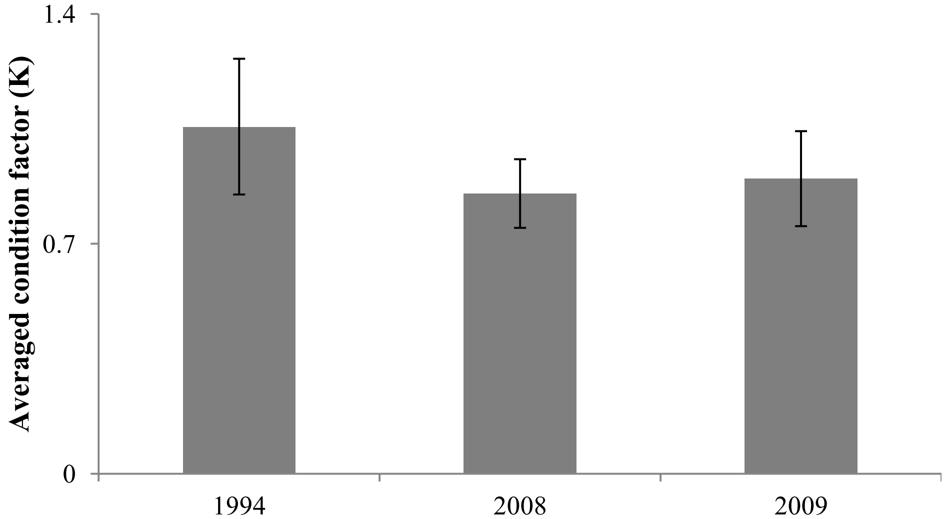


Figure 17. Lahontan redside shiner condition factor (K) for June in 1994, 2008, and 2009. $K=100*W/L^3$, where W = weight (g) and L = total length (cm). K is shown for the average of all redside shiners captured at various locations (Figure 1). Error bars show interval of one standard deviation.

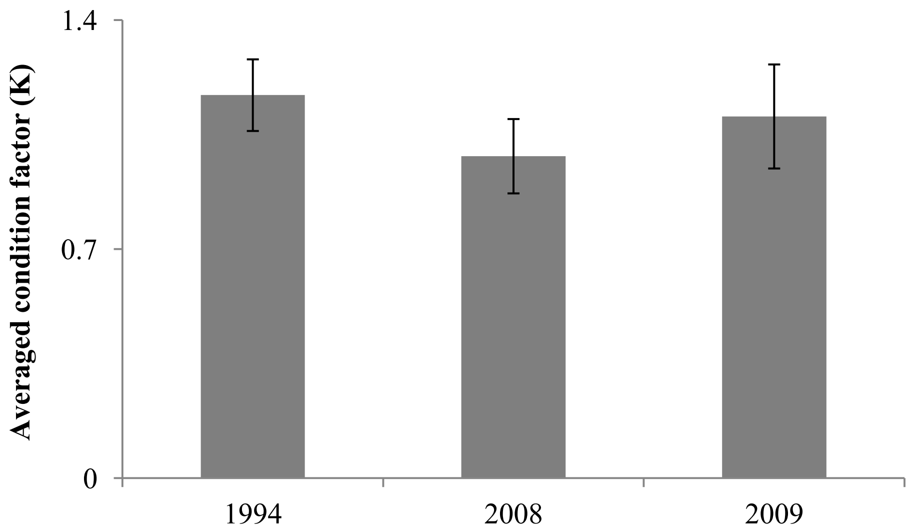


Figure 18. Lahontan speckled dace condition factor (K) for June in 1994, 2008, and 2009. $K=100*W/L^3$, where W = weight (g) and L = total length (cm). K is shown for the average of all speckled dace captured at various locations (Figure 1). Error bars show interval of one standard deviation.

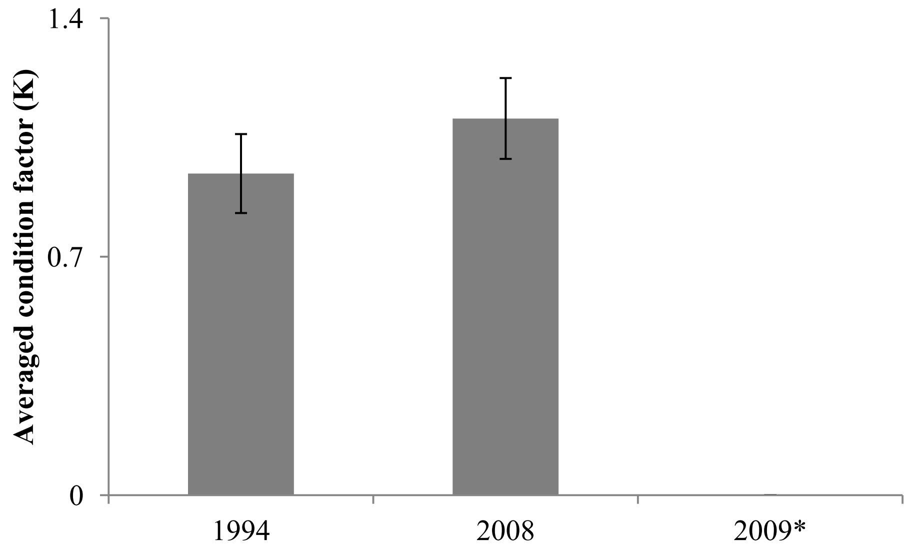


Figure 19. Tahoe sucker condition factor (K) for Nov in 1994 and 2008. $K=100*W/L^3$, where W = weight (g) and L = total length (cm). K is shown for male the average of all suckers captured at various locations (Figure 1). *No Tahoe sucker was collected in 2009. Error bars show interval of one standard deviation.

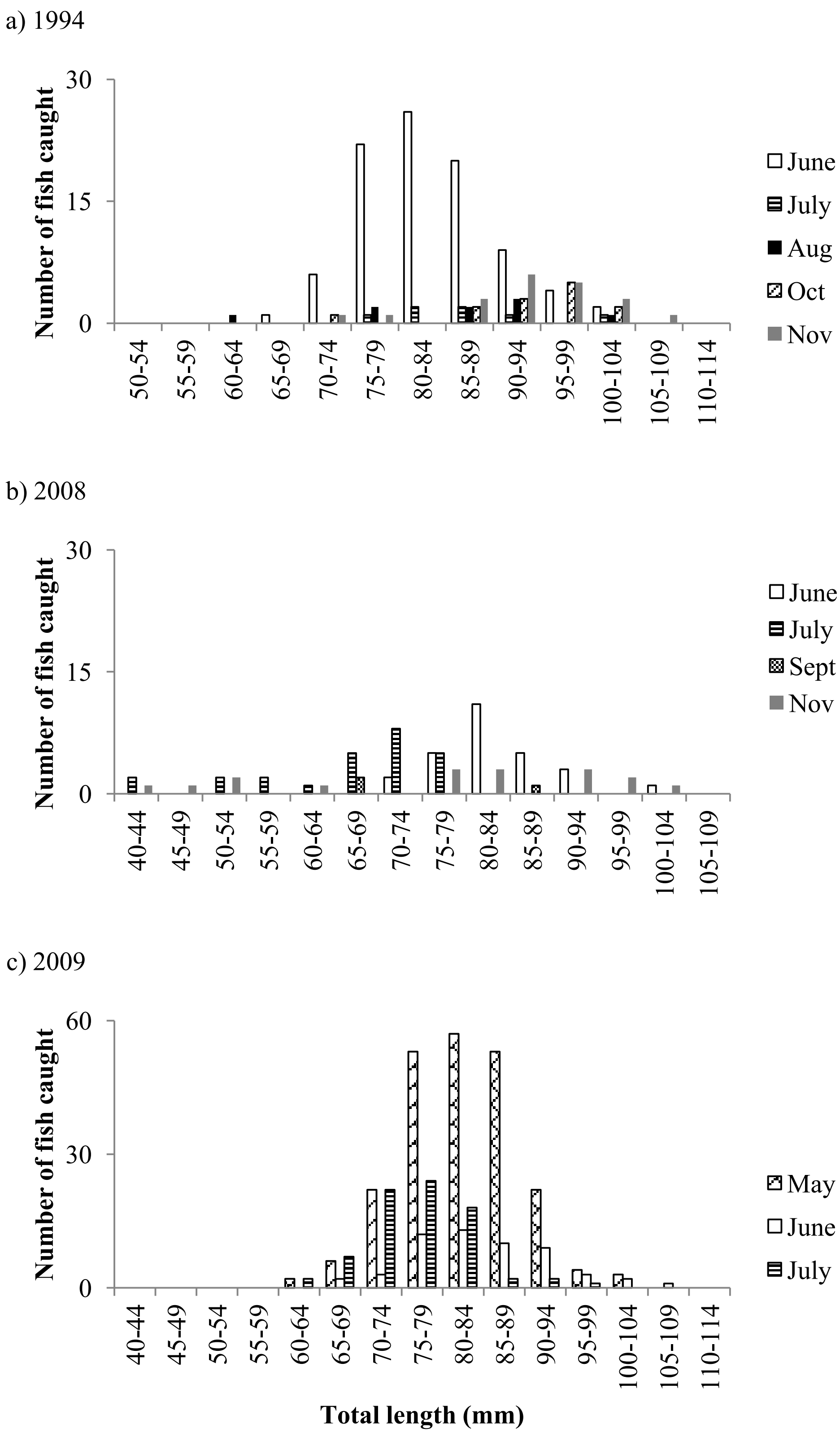


Figure 20. Length-frequency distributions of Lahontan redside shiners captured by minnow traps at various locations (Figure 1) in Lake Tahoe in a)1994, b) 2008, and c) 2009.

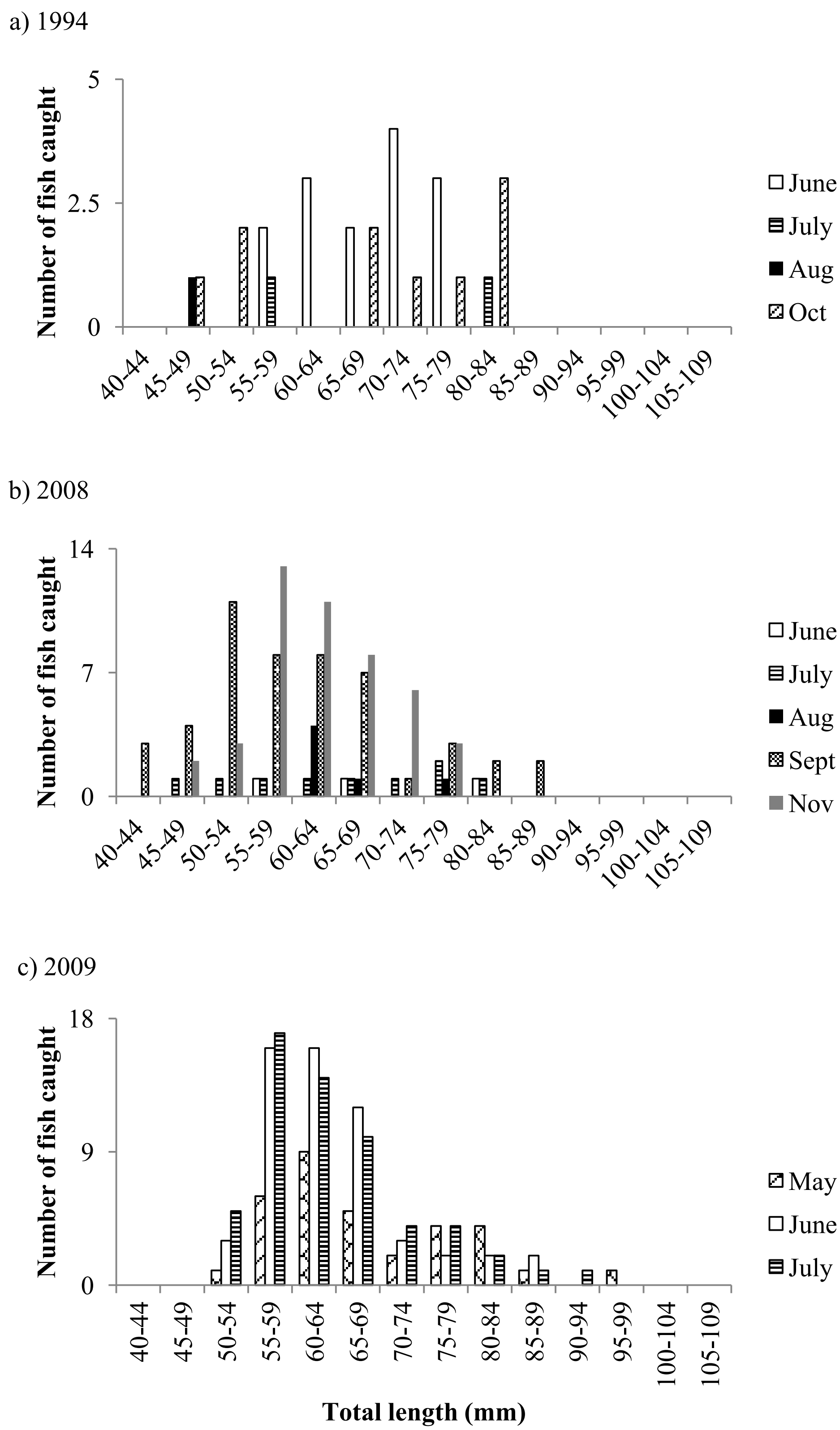


Figure 21. Length-frequency distributions of Lahontan speckled dace captured by minnow traps at various locations (Figure 1) in Lake Tahoe in a) 1994, b) 2008, and c) 2009.

e. Capture method evaluation

i. Evaluation methods

The use of wire minnow traps to survey nearshore fish communities was chosen because these traps were used historically for nearshore fishery sampling in Lake Tahoe (Thiede, 1997), are effective, simple to use, relatively inexpensive, and can be used in a variety of habitats (MacRae, 2006). However, previous use of minnow traps in Lake Tahoe has yielded large numbers of crayfish but few native minnows (Umek et al, unpublished data). This experiment was conducted in order to evaluate an effective method to sample native minnows while minimizing crayfish catch. Two tests were implemented: 1) suspended and non-suspended traps and 2) bait preferences (dog food, dog food in a mesh bag, fish food in a mesh bag, fish food in tights, and glowsticks) between native minnows and crayfish.

Lahontan redside shiners and Lahontan speckled dace are thought to be good indicators of the health of the nearshore fishery in Lake Tahoe because they are the dominant littoral native fish and they are found in a variety of nearshore habitats which make them easy to monitor and most susceptible to human impacts (Beauchamp et al, 1991; Beauchamp et al, 1994). Lahontan speckled dace are primarily found in the benthic zone of rocky areas at depths less than 25 m (Baker, 1967). Lahontan redside shiners tend to aggregate into larger groups than speckled dace and primarily inhabit areas where rocks or piers provide hiding places from predators in depths up to 12m (Evans, 1969).

For this experiment, simple wire minnow traps with an opening (2 cm diameter) on each end were used to test the effectiveness of different treatments for catching minnows. Minnow trapping was conducted during the first two weeks of July at the Lake Forest Boat Ramp in Tahoe City, CA. We choose this site for a number of reasons, 1) through visual observation it was known that there was a large population of minnows (mainly redside shiners) living in the rocky crib under the pier, 2) the pier also provides a convenient way to suspend traps by ropes so we could set and retrieve them easily, and 3) our laboratory had a good relationship with the manager of the boat ramp and allowed us to use the pier for our research. Each night, six to eight traps were placed in the water, arranged in pairs of suspended and non-suspended traps. All of the traps were set in an area sheltered from waves by the L-shaped the pier and near the rocky crib. The non-suspended traps were set on the bottom of the lake at a depth of approximately 0.9-

1.6 m deep. Suspended traps were set such that the top of the trap was 0.5 m below the surface of the water. The traps were set overnight (13-15 hours), except for the first set, which lasted 22 hours. The first set was a control group of empty traps which were used to compare with the other treatments. The rest of the study nights included six traps of different treatments and usually a pair of empty control traps. Each time traps were set and retrieved, visual observations of weather and a crude density estimate of fished in a 3 m^2 area were also recorded. Once traps were removed, numbers of each species caught in each trap were recorded. The experiment tested 5 different bait treatments: dog food, dog food in a mesh bag, fish food in a mesh bag, fish food in tights, and glowsticks with no food. For the three treatments that involved food contained within a mesh bag or tights, a rock was used as a weight to suspend the food within the middle of the trap. Once data was obtained, the statistical program JMP was used to test the significance of the results using ANOVA.

ii. Results

Data were collected between July 1st and July 13th, 2010 from 41 traps, with a total catch of 435 crayfish, 53 Lahontan redside shiners and 1 Lahontan speckled dace. For the purposes of statistical analysis, data from two of the traps was disregarded due to suspicions that the traps had been tampered with or disturbed. In this case we used the average catch per trap for comparisons rather than an estimate based on time (see above). Density estimates over the course of the two weeks of trapping varied widely between 2.7 and 15 fish per square meter. Fish density was highest on July 7th and lowest on July 13th.

1) Suspended vs. Non-suspended

Data from suspended and non-suspended traps compared across all bait treatments shows that suspended traps have a higher average catch per trap for minnows, but have a lower catch per trap for crayfish (Figure 22 and Figure 23). The ANOVA test (p= 0.0002) demonstrates suspended traps caught significantly less crayfish than non-suspended traps (Figure 23). Although suspended traps had slightly more success in catching minnows than non-suspended traps (Figure 22), the results were not significant (p= 0.137). This can be due to low catch and high variability among traps.

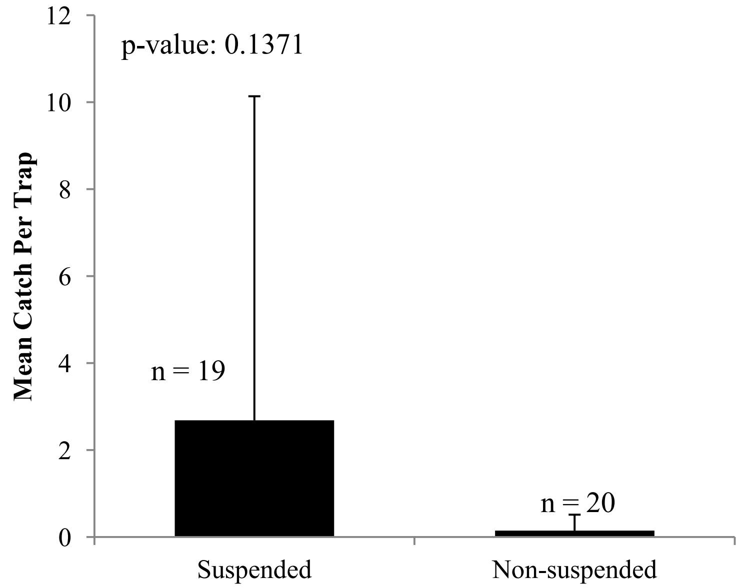


Figure 22. Comparisons of average catch per trap of minnows (± SD) in suspended and non-suspended traps.

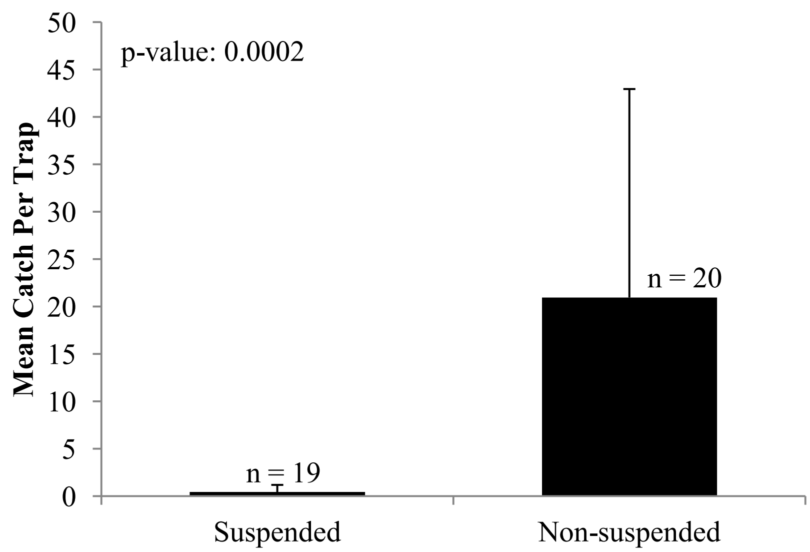


Figure 23. Comparisons of average catch per trap of crayfish (± SD) in suspended and non-suspended traps.

2) Comparison of Baits

As shown above, suspended traps are more effective at catching fewer crayfish and maybe more minnows than non-suspended traps, therefore bait treatments were compared only for suspended traps. Dog food in a mesh bag was the most successful at catching minnows with an average catch per trap of 15 minnows, followed by fish food in mesh, fish food in tights, dog food not contained, and no fish was caught in traps with glowsticks and no food (Figure 24). This implies that baits may be important and food source that is contained within and suspended in the trap may be a better method for minnow trapping. However, given high variability observed within each treatment, small sample sizes, and a 0.05 p-value from our ANOVA test, the differences in catch among different bait types remain inclusive, and perhaps other bait types can be used in replacement of dog food, as long as it is contained and suspended with the traps. We believe that dog food is a good option because it is cheap, consistent, easy to obtain, and is commonly used with minnow traps surveys.

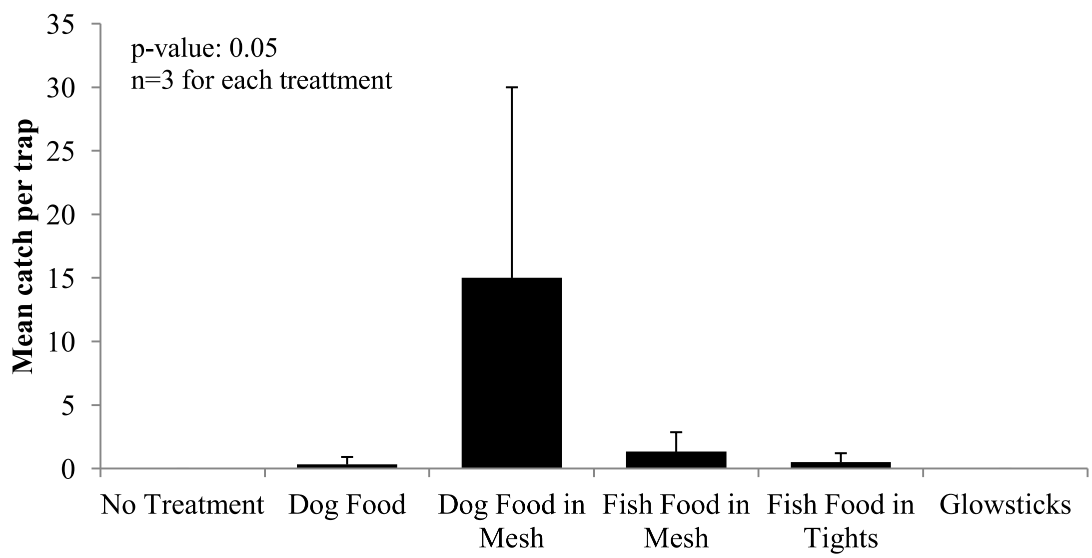


Figure 24. Comparisons of average number of minnow caught per trap (± SD) for each bait treatment. Same number of traps (n=3) were tested with each treatment.

iii. Discussion

Our findings show that traps that are suspended from lake bottom are significantly better at limiting crayfish catch when sampling for minnow, and baits that are contained within and suspended in the trap should be used. However, given the high variability observed within each treatment and small sample size, these results should be considered with caution and more research is necessary to determine the best protocol for obtaining a representative sample of all species of nearshore fishes. This experiment was somewhat limited in scope in terms of scale, species examined, gear tested and time spent. We collected a total of 54 reside shiners but only one speckled dace in the duration of our experiment. This can be a realistic representation of the densities and species composition at the sampled location as visual observations at the Lake Forest pier indicated that there was a large population on redside shiners, few speckled dace and no other fish species. However, it can also be due to gear limitation as it is possible that suspended traps may not be the best method for catching speckled dace since they are benthic feeders and are more likely to be found on the bottom of the lake than redside shiners (Baker 1967).

To better monitor changes in fish species composition and abundance in nearshore zones, Jackson and Harvey (1997) demonstrates that the use of multiple gears and adequate sampling effort are necessary to sufficiently detect changes in species composition and estimate relative abundance as different fish species may have different susceptibility to various sampling gears due to habitat preference, body size, and/or gear limitations. However, effort as suggested can be costly. Therefore, considering the goal of each management project, different approaches should be considered. For sampling abundance of redside shiner and other small-bodied, less cryptic species, baited minnow traps are inexpensive, easy to execute, and has almost no negative effects on the well-being of the fish captured. MacRae and Jackson (2006) suggested that baited minnow traps, in combination with some form of visual sampling should be sufficient in detecting nearshore small-bodied fish species within small sampling area. For comprehensive species composition surveys, other gears, e.g. multimesh gill net, plastic traps, may be used to target various species, such as benthic and cryptic taxa, e.g. speckled dace, Paiute sculpin or larger-bodied species, e.g. mountain whitefish and Tahoe sucker.

f. Spawning habitat availability/ recruitment potential

i. Survey methods

Currently, availability of spawning habitat is the only metric used by the Tahoe Regional Planning Agency to assess the health of nearshore fishery. Previous research found that gravel found in the nearshore zone in Lake Tahoe is the only habitat preferred by littoral native fishes for spawning and is very limited in Lake Tahoe (Byron et al, 1989; Beauchamp et al, 1991; Allen & Reuter, 1996). This threshold was recently found to be in non attainment (Threshold Evaluation Report, 2007). Research using remote sensing data suggests that there may be a decline in these valuable spawning habitats (Herold et al, 2007). The objective for this part of the project was to reassess spawning habitat availability at each location made during the 1990's shorezone study (Allen & Reuter, 1996) to determine if there are a) changes in spawning substrate availability since the last survey and b) changes in site preferences by these littoral native fishes.

Earlier study by Evans (1969) observed no diurnal variation in intensity of spawning activities, but a later study by Allen and Reuter (1996) found that spawning activities were only observed after dark. For our studies, we will conduct both day and night surveys to verify these observations. The shorezone study by Allen and Reuter (1996) was done by snorkeling surveys, however, preliminary observations done earlier in the season by our crew members suggest that it would be difficult for divers to snorkel some sites without generating excessive disturbance to the water column, thus onshore visual inspections were conducted as an alternative where needed. Sampling was conducted at 25 sites around Lake Tahoe beginning in early May and continuing through late July (Figure 25 and Figure 26) with the focus on Lahontan redside shiners and Lahontan speckled dace. In addition to the 20 sites defined in the 1996 shorezone study, additional sites were added to our 2010 study because of observations of large groups of littoral native fishes at the additional sites during a 2009 snorkel study. Sites chosen represent a variety of substrates, from sand to cobble, with heavy emphasis on gravels.

Two methods were used to determine if sites were being used as spawning habitat by redside shiner and speckled dace: 1) visual observations of spawning behavior and 2) egg recruitment. Visual observations of spawning behavior were conducted after dark. Spawning behavior of redside shiner is easily identified by aggregation of large groups of fish, with spawners chasing and crowding each other frequently (Evans, 1969). Unlike redside shiner, dace do not aggregate into large groups, but pairs chasing each other and traveling between rocks can be observed (Miller, 1951). Egg recruitment for both species was determined by use of kick sample method. Sediment that might contain eggs was suspended by kicking and then netted with a small aquarium net to capture potentially suspended eggs in the water column. At least five replicates of kick sampling were conducted at each site in day light. Egg recruitment was recorded as either presence or absence of eggs. Allen and Reuter (1996) shows that the onset of spawning activities happens when nearshore temperature reaches around 11°C. Therefore, in the beginning of the season, six sites, Garwoods restaurant (Figure 25, Figure 26; site 10), Hurricane Bay Beach (site 15), Kings Beach Boat Ramp (site 3), Lake Forest (site 11), Patton each (site 8), and Sunnyside Marina (site 14) were chosen as indicator sites. These sites where consistent observations of spawning activities have been confirmed in previous years were visited twice every week in the beginning of the season when water temperature reaches around 11°C. We assumed that when spawning activities are observed in these sites, then spawning should have begun at the other 19 sites, and then, all 25 sites were visited at least twice for spawning observations.

ii. Results

Changes were observed in 30% (6/20) of the sites when compared to historical data collected by Allen and Reuter (1996) (Figure 25 and Figure 26). The five additional sites chosen for 2010 did not have observations of spawning behavior or presence of eggs (Table 10).

1) Sites with Changes

Garwoods Restaurant (site 10): Spawning activities observed in 2010 but no eggs were found, unlike in 1996 where spawning was not observed but eggs were present. Gravel substrate of 1996 may have changed to a mix of cobble and gravel (Table 10).

Kings Beach Boat Ramp (site 3): Spawning was observed and eggs were present at Kings Beach Boat Ramp in 1996 (Table 10). Aggregation of both species was observed (Table 11) but neither spawning activities nor eggs were observed in 2010. Substrate at Kings Beach Boat Ramp changed from gravel to cobble gravel mix since the 1996 study.

Lake Forest/Burton Creek (site 11): Spawning activities and eggs present in 1996 but not in 2010 (Table 10). Redsides and dace were present during the surveys but did not appear to be spawning. Gravel substrate changed to cobble gravel mix from 1997 to 2010, respectively.

Secline Beach (site 5): No spawning or egg observation in 1997, but one egg was found in 2010. Both species were observed, but neither was observed to be spawning (Table 10 and Table 11). Substrate may have changed from sand in 1996 to a mix of sand and cobble in 2010.

Sugarpine Point and Sugarpine Point North (site 18 and 19): Presence of eggs was observed in 1996 but did not observe spawning and in 2010 neither eggs nor spawning was present (Figure 25 and Figure 26). Substrate may have changed from gravel to cobble gravel at Sugarpine Point, where both redsides and dace were present (Table 10 and Table 11). Substrate at Sugarpine Point north also changed from gravel to cobble boulders and only dace were observed (Table 10).

2) *New Sites as of 2010*

Boatworks Marina (site 12): No observation of spawning or eggs present (Figure 25 and Figure 26). Substrate was composed of gravel and only dace were present (Table 10 and Table 11).

North Stateline Point (site 2): Eggs were not found but there is a possibility of dace spawning, with aggregations of dace chasing each other and hiding under rocks. Redsides were not present at this site (Table 11).

Crystal Shores West (site 1): Substrate is mainly composed of gravel and cobble (Table 10). Both species were present but spawning was not observed and eggs were not present (Table 10; Figure 25 and Figure 26).

Taylor Creek/Baldwin beach (site 21): Neither spawning nor eggs were observed, but both species were present (Table 11; Figure 25 and Figure 26). Substrate at this site was composed of sand (Table 10).

Zephyr Point (site 24): Redsides and dace were present but no spawning or eggs was observed (Table 11; Figure 25 and Figure 26). Substrate was composed of sand (Table 10).

iii. Discussion

We hypothesized that the changes (30%) in spawning activities observed at the sites when compared to historical data collected by Allen and Reuter (1996) may mainly be attributed to changes in substrate types at the sampled sites. Allen and Reuter (1996) found that gravel is the only preferred substrate by littoral native fishes for spawning and most sites where spawning activities were no longer observed have a change in substrate size to small size class such as sand, or larger size classes, such as cobble. A number of reasons can contribute to such changes. Development and structural changes of sites can lead to substrate type change, however, the TRPA has strict restriction on development at protected fish habitats. Another likely cause maybe linked to changes in lake level. Lake level has fluctuated since previous monitoring, Historical spawning studies conducted in 1997 were at full lake level, 6229.1 ft. Current lake level is at 6224 ft. A decrease of 5 feet may have replaced favored spawning gravels with larger gravels and cobbles. This suggest that availiabily of suitable spawning habitat can be variable and perhaps should not be the only metric used to assess the health of nearshore fishery.

Table 10. Spawning behavior observations, egg presence and substrate observation in Allen and Reuter (1996) and 2010

	Spawning observed		**Egg presence**		**Substrate**	
Site	1996	2010	1996	2010	1996	2010
64 acre Beach	No	No	No	No	gravel	gravel
Agatam Beach	No	No	No	No	gravel/sand	sand/boulders
Boatworks Marina	-	No	-	No	-	gravel
Col. Clair's Beach	No	No	No	No	sand	sand
Crystal Shores West	-	No	-	No	-	gravel/cobble
Garwoods restaurant	No	Yes	Yes	No	gravel	cobble/gravel
Grand Ave	No	No	No	No	gravel/sand	gravel/cobble
Hurricane Bay Beach/ Pebble Beach	Yes	No	Yes	Yes	gravel	cobble/gravel
Kings Beach	No	No	No	No	sand	cobble/gravel
Kings Beach Boat Ramp	Yes	No	Yes	No	gravel	cobble/gravel
Kiva Picnic Area	Yes	No	No	No	gravel	gravel/sand
Lake Forest/ Burton Creek	Yes	No	Yes	No	gravel	cobble/gravel
North Stateline Point	-	Maybe	-	No	-	sand
Obexer's Marina	Yes	Yes	Yes	Yes	gravel	gravel
Patton Beach	No	Yes	Yes	Yes	gravel	gravel
Secline Beach	No	Maybe	No	Yes	sand	sand/cobble
Secret Harbor	No	Maybe	No	No	sand	sand/boulders
Sierra Boat Marina/ Carnelian Bay	No	Yes	Yes	Yes	gravel	gravel
Sugarpine Point	No	No	Yes	No	gravel	cobble/gravel
Sugarpine Point North	No	No	Yes	No	gravel	cobble/boulder
Sugarpine Point South	No	No	Yes	Yes	gravel	cobble/gravel
Sunnyside Marina	Yes	Yes	Yes	Yes	gravel	cobble/gravel
Taylor Creek/ Baldwin Beach	-	No	-	No	-	sand
Trout Creek	No	No	No	No	sand	sand
Zephyr Point	-	No	-	No	-	sand

Table 11. Fish species presence in Allen and Reuter (1996) and in 2010 during spawning observations**.**

Site	**Speckled dace**		**Lahontan redside shiner**	
	1996	**2010**	**1996**	**2010**
64 acre Beach	x			
Agatam Beach		x		
Boatworks Marina	-	x	-	
Col. Clair's Beach		x		x
Crystal Shores West	-	x	-	x
Garwoods restaurant		x		x
Grand Ave		x		x
Hurricane Bay Beach/ Pebble Beach	x	x	x	
Kings Beach		x		x
Kings Beach Boat Ramp	x	x		x
Kiva Picnic Area		x	x	
Lake Forest/ Burton Creek	x	x	x	x
North Stateline Point	-	x	-	
Obexer's Marina	x	x	x	x
Patton Beach		x		x
Secline Beach		x		x
Secret Harbor	-	x	-	x
Sierra Boat Marina/ Carnelian Bay		x		x
Sugarpine Point		x		x
Sugarpine Point North		x		
Sugarpine Point South		x		x
Sunnyside Marina	x	x	x	x
Taylor Creek/ Baldwin Beach	-	x	-	x
Trout Creek		x		
Zephyr Point	-	x	-	x

a) Spawning observed 1996

b) 2010

Figure 25. Spawning observations shown in Allen and Reuter **(1996)** and in 2010.

a) Egg Presence 1996 b) 2010

Figure 26. Eggs presence observations in Allen and Reuter (1996) and in 2010.

III. Novel Metrics

a. Trophic niche

Fundamental niche, a concept developed by G.E. Hutchinson (1957), describes the overall potentialities of a species to occur and persist at a location in the absence of predators and competitors given the environmental conditions and resources available. However, in a community, interactions with other species (e.g. predators, competitors, and prey) do occur and when taken into consideration, the range of conditions in which a species can live becomes more limited. Realized niche defines such concept (Begon et al, 1996; Moyle & Cech, 2000). The niche concept describes that species assemblages/composition and diversity in a community is shaped by n- niche dimensions of environmental conditions, resources availability, and inter and intra-species interactions (Begon et al, 1996; Moyle & Cech, 2000). Trophic niche, assessed using diet information is a great tool for examining how energy (food) is utilized among species in a community for growth and reproduction. Diet analysis through examination of stomach contents is conventionally used for quantifying trophic niches, however, such method is not only time and labor intensive, it is also limited in temporal scale as stomach contents are only 'snapshots' of consumers' dietary information (Bearhop et al, 2004). Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes analyses have been used increasingly as an alternative method for assessing trophic niche. Unlike conventional diet analysis, examining consumer tissues using the isotopic approach can provide time-integrated dietary information preserved in the consumers' tissues (Vander Zanden et al, 1999; Schmidt et al, 2007). It also allows for comparative and retrospective studies of food web changes across different systems and timescales, thus making it a much preferable tool for studying tropic niche (Vander Zanden et al, 1999; Schmidt et al, 2007).

i. Stable isotopes analysis methods

Isotopic $\delta^{13}C$ can be used to determine the flow of organic matter through food webs (Gu et al, 1999). Typically, $\delta^{13}C$ of benthic food source is isotopically more enriched than pelagic food source. Minimal enrichment (± .47 ‰) from lower to high trophic levels allows for the differentiation of littoral and pelagic primary production sources among consumers since their carbon isotope ratios should be similar to that of their food (Hecky & Hesslein, 1995; Vander Zanden & Rasmussen, 2001). Thus, spatial variability in $\delta^{13}C$ of the food sources can help distinguish the relative importance of different carbon pools to the consumers. With predictable enrichment (between 3-4 ‰) in $\delta^{15}N$ from prey to predator, biotic trophic position can be determined using isotopic $\delta^{15}N$ (Minagawa & Wada, 1984; Vander Zanden & Rasmussen, 2001). Based on these unique qualities, isotopic $\delta^{13}C$ and $\delta^{15}N$ signatures measured over different time periods can be used to determine if diet shifts and change of trophic niche have occurred in nearshore fishes over time (Chandra et al, 2005; Vander Zanden et al, 2003). Trophic niches of fish can be used as an indicator for identifying short and long-term changes in food web and community structures of our nearshore fishery.

Utilizing similar methods that have been used for previous isotope studies at Lake Tahoe, carbon and nitrogen stable isotopes of native fishes (Tahoe sucker, Lahontan redside shiner, Lahontan speckled dace, Tui chub- benthic *Gila bicolor obese*, and Tui chub-pelagic *Gila bicolor pectinifer* collected in spring-fall 2008 and 2009 were analyzed and compared with historical data (1872-94, 1904-19, 1927-42, 1959-66, and 1998-2000; Vander Zanden et al, 2003). Approximately 1g of dorsal muscle tissue was removed from a subsample of fishes collected by our minnow traps surveys (See *Minnow traps transact methods*, pg. 17) for stable isotope analysis. Samples were dried at 60°C for at least 24- 48 hours, ground with a mortar and pestle to a fine powder, and a subsample of the powder (1.0-1.2 mg) were packed into acid-washed 5 x 9 mm tin capsules for isotope analysis (Saito et al, 2007; Vander Zanden et al, 2003). Stable carbon and nitrogen isotope analyses were performed on the same sample using Micromass IsoPrime stable isotope ration mass spectrometer at the Nevada Stable Isotope Laboratory (Department of Geological Sciences, University of Nevada- Reno).

Trophic niche of each species is determined by measuring their 1) benthic carbon reliance and 2) trophic position.

1) *Benthic carbon reliance:*

Carbon stable isotopes values can be used to estimate contributions of littoral and pelagic resources to higher trophic levels consumers.

$$\text{Benthic reliance (\%)} = [(\delta^{13}C_{fish} - \delta^{13}C_{pelagic}) / (\delta^{13}C_{benthic} - \delta^{13}C_{pelagic})] * 100 \qquad (1)$$

Where $\delta^{13}C_{fish}$ = individual $\delta^{13}C$ value for fish; $\delta^{13}C_{pelagic}$ the pelagic endpoint = $\delta^{13}C$ mean of all zooplankton, represents the pelagic primary production signal; $\delta^{13}C_{benthic}$ the benthic endpoint =

$\delta^{13}C$ mean of littoral amphipod, crayfish, mayfly, snail, and fingernail clam samples, represents the benthic primary production signal.

2) Trophic position

Fish trophic position is estimated from fish $\delta^{15}N$ values. Individual fish signatures will be corrected for baseline variation using invertebrate primary consumer $\delta^{15}N$ similar to Vander Zanden and Rasmussen (1999).

$$\text{Trophic position} = ((\delta^{15}N_{fish} - \delta^{15}N_{baseline})/3.4) + 2 \tag{2}$$

where $\delta^{15}N_{fish}$ = individual$\delta^{15}N$ value for fish; 3.4 = trophic level enrichment factor (Minagawa & Wada, 1984; Vander Zanden & Rasmussen, 2001); 2 = trophic position of organism used to estimate $\delta^{15}N_{baseline}$ (In this case, a primary consumer is used; trophic level = 2). $\delta^{15}N_{baseline}$ = baseline $\delta^{15}N$, estimated using a pooled baseline linear regression equation derived from previous Tahoe studies (Vander Zanden, Chandra, Allen, Reuter, & Goldman, 2003).

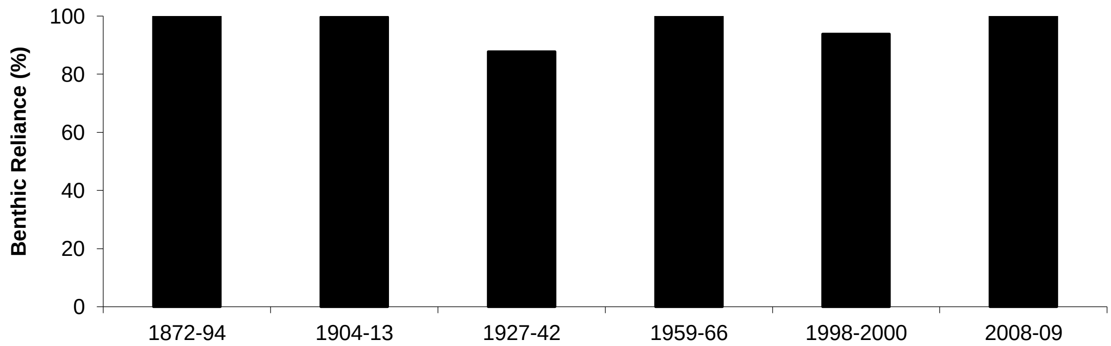
$$\delta^{15}N_{baseline} = -0.094 * \delta^{13}C_{consumer} + 0.898 \tag{3}$$

This equation is used for all time period because previous research demonstrated that there is no significant difference in baseline relationships for samples between years (Vander Zanden, Chandra, Allen, Reuter, & Goldman, 2003).

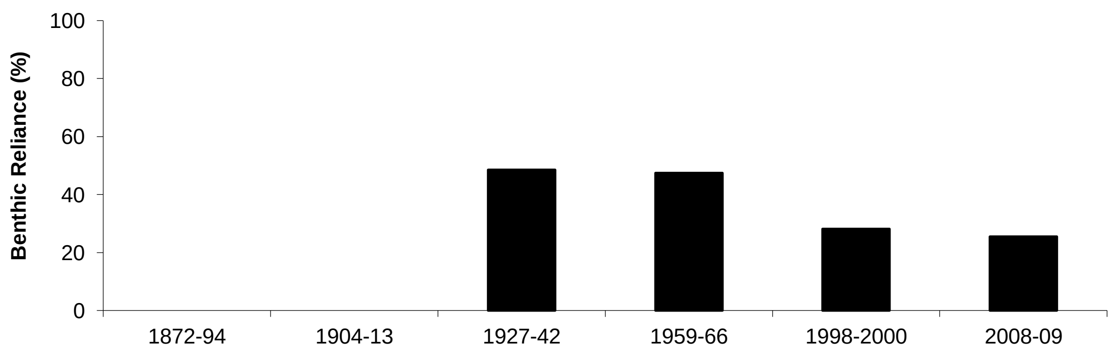
ii. Benthic reliance (carbon stable isotopes $\delta^{13}C$)

We found an overall decrease in benthic reliance with all fish species examined, except Tahoe sucker which is an exclusive benthic feeder due to morphological limitation (Figure 27). Schmidt et al (2007) which analyzed the same set of stable isotopes data (1872-2000) using a difference type of statistical analysis found the same trend among sampled fish species and attributed that to the introduction of non-native *Mysis relicta* and onset of cultural eutrophication.

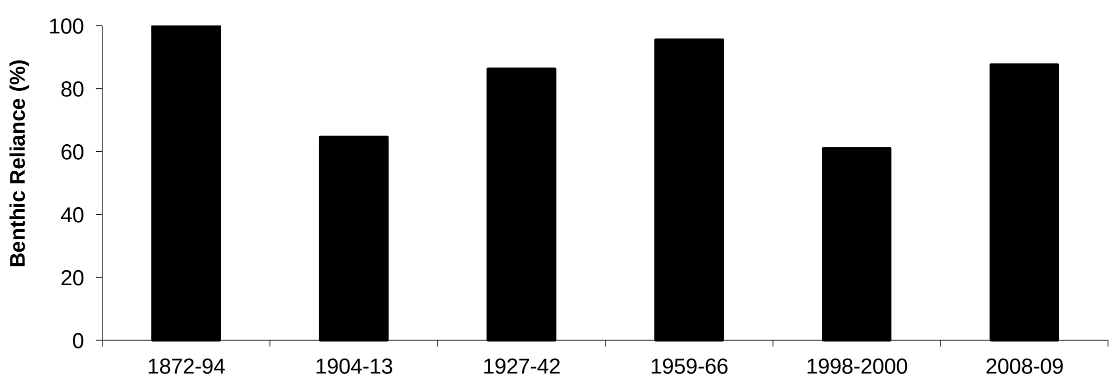
a) Tahoe sucker

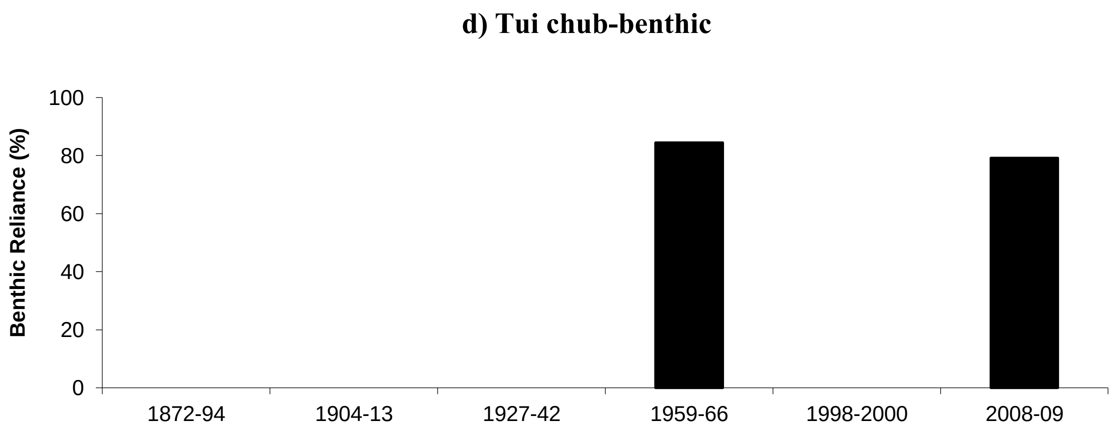


b) Lahontan redside shiner



c) Lahontan speckled dace





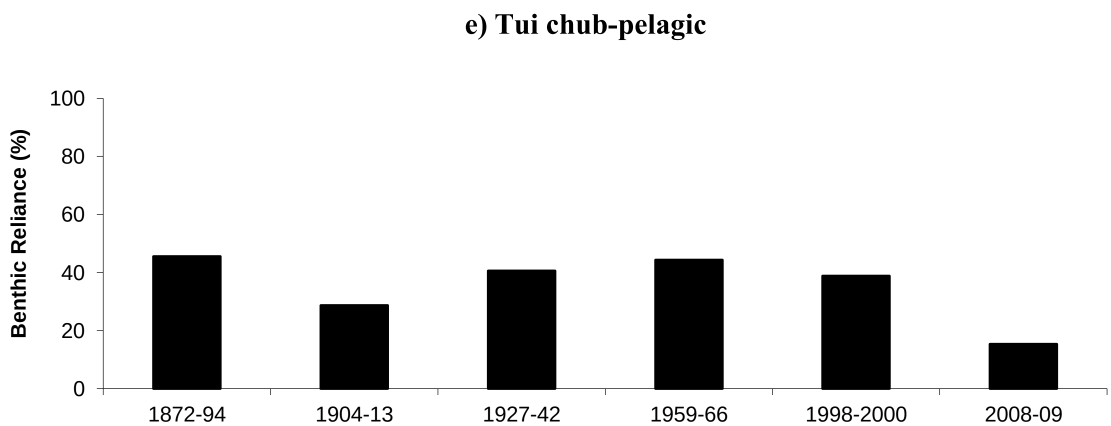
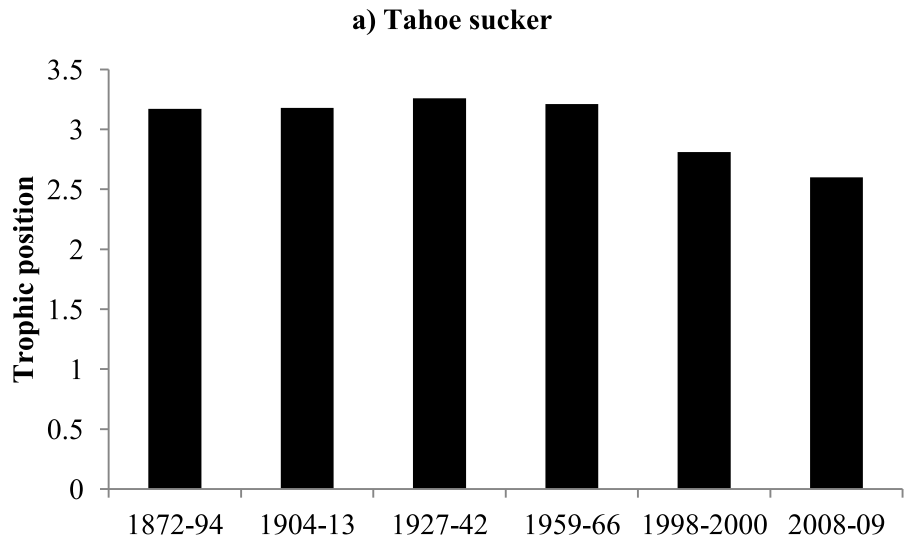
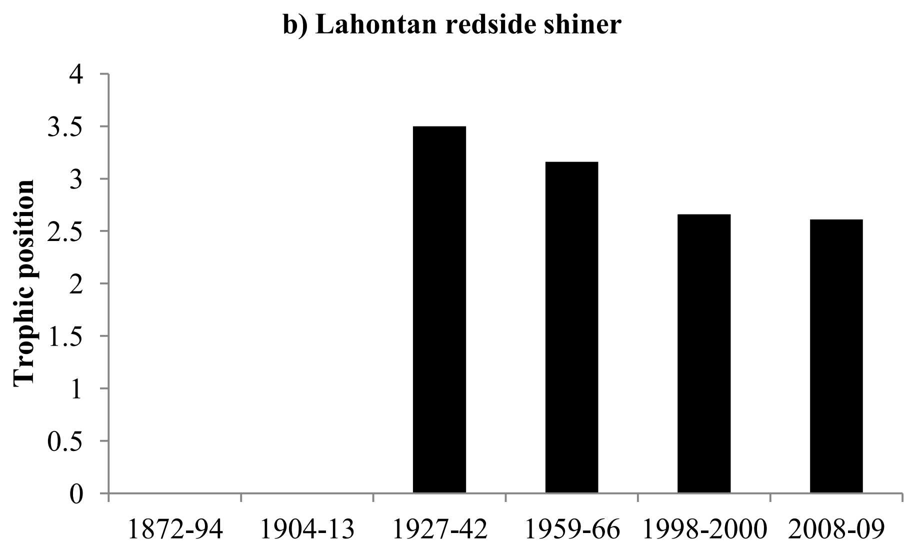


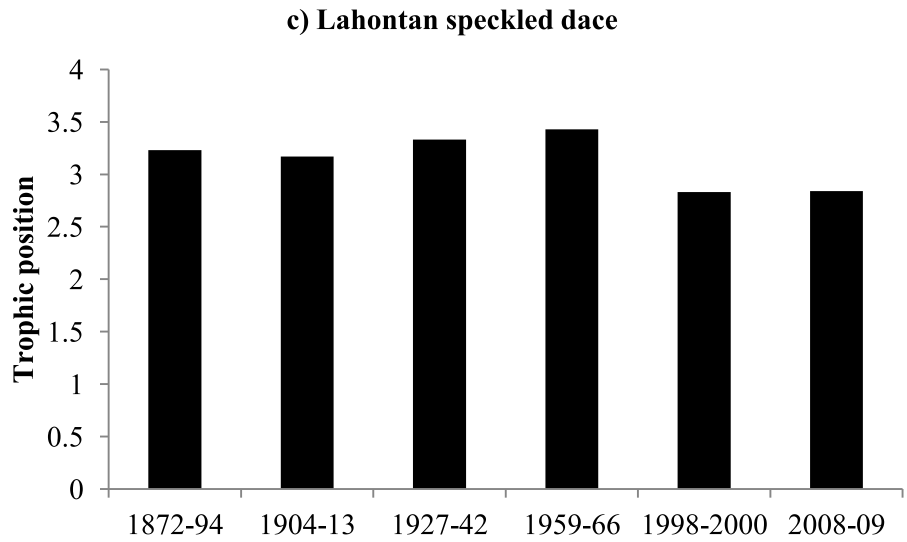
Figure 27. Mean benthic reliance estimates derived from $\delta^{13}C$ of various native nearshore fish species collected from Lake Tahoe, a) Tahoe sucker, b) Lahontan redside shiner, c) Lahontan speckled dace, d) tui chub-benthic, and e) tui chub-pelagic, at six distinct time period (1872-94, 1904-13, 1927-42, 1959-66, 1998-2000, and 2008-09).

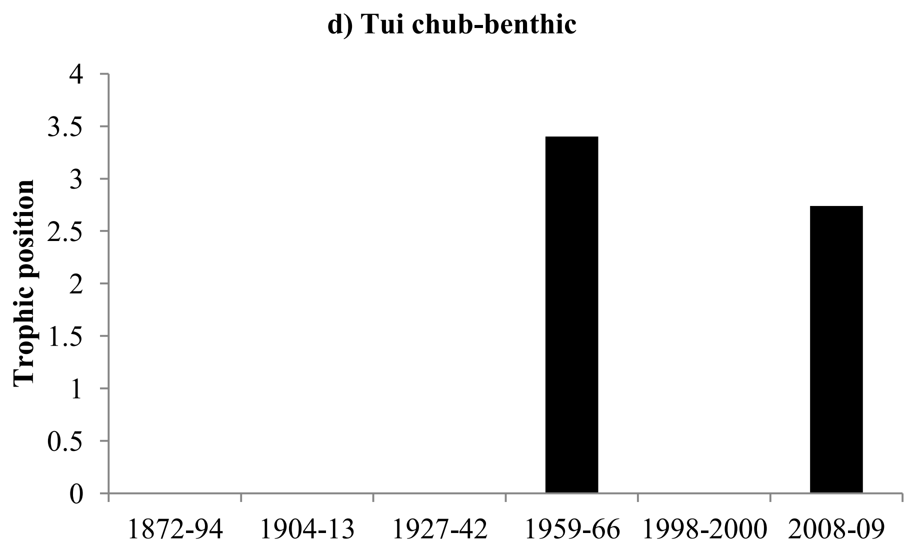
iii. Trophic position (nitrogen stable isotopes $\delta^{15}N$)

We found an overall decrease in trophic position in all the species examined (Figure 28). Schmidt et al (2007) which analyzed the same set of stable isotopes data (1872-2000) using a difference type of statistical analysis found the same trend among sampled fish species and attributed that to the onset of cultural eutrophication which may have shifted productivity to the pelagic zone.


a) Tahoe sucker
Trophic position
3.5
3
2.5
2
1.5
1
0.5
0
1872-94
1904-13
1927-42
1959-66
1998-2000
2008-09


b) Lahontan redside shiner
Trophic position
4
3.5
3
2.5
2
1.5
1
0.5
0
1872-94
1904-13
1927-42
1959-66
1998-2000
2008-09


c) Lahontan speckled dace
Trophic position
4
3.5
3
2.5
2
1.5
1
0.5
0
1872-94
1904-13
1927-42
1959-66
1998-2000
2008-09


d) Tui chub-benthic
Trophic position
4
3.5
3
2.5
2
1.5
1
0.5
0
1872-94
1904-13
1927-42
1959-66
1998-2000
2008-09

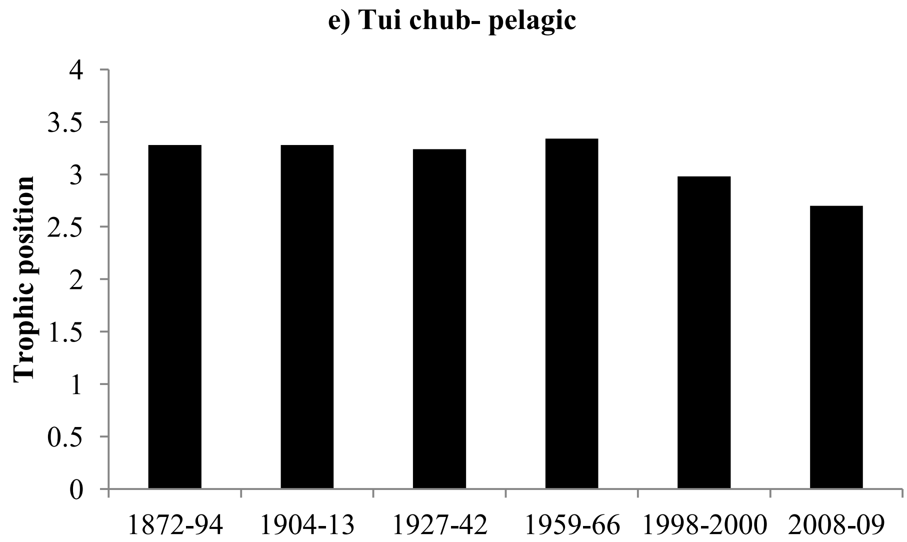


Figure 28. Trophic position derived from $\delta^{15}N$ of various native nearshore fish species collected from Lake Tahoe, a) Tahoe sucker, b) Lahontan redside shiner, c) Lahontan speckled dace, d) tui chub-benthic, and e) tui chub-pelagic, at six distinct time period (1872-94, 1904-13, 1927-42, 1959-66, 1998-2000, and 2008-09).

b. Ultraviolet radiation tolerance

Our previous experiments and the work of others in eastern USA lakes have demonstrated that high UV transparency reduces the reproductive success of warmwater fish in shallow waters (Williamson et al, 1997; Huff et al, 2004; Olson et al, 2006). Lake Tahoe is much more transparent than these lakes. However, reductions in nearshore UV transparency may create a refuge for these warmwater fish to successfully nest and to establish self-sustaining populations in Lake Tahoe. Data from nearhore-to-offshore UV profiling transects in Lake Tahoe demonstrate that shallow environments nearshore to some of the major inflows are far less UV transparent than offshore (Rose et al, 2009) and that patterns of UV transparency change from month to month. This is important because nearshore habitats that are suitable for spawning must be present during summer months that provide both the warm temperatures and low UV conditions that favor spawning by exotic species such as largemouth bass (Carlander, 1977). In Lake Tahoe, native minnow species and introduced warmwater fish both inhabit the nearshore environment. Currently, the only well established non-native fish populations are limited to sites in the southern end of the lake characterized by extensive development and in close proximity to some of the lake's largest tributaries (Kamerath et al, 2008). Water transparency at these sites tends to be lower than elsewhere in the lake and may explain the suitability of such sites for the non-native fish. Native minnows occur widely and in habitats with high levels of UV.

In our original proposal (SNPLMA NICHES Rnd 8) we highlighted previous field and laboratory experiments that indicated strong species related differences in UV-induced stress in fish (Oris et al, 1990; McCloskey & Oris, 1991). From these experiments we predicted that exotic centrarchid fish would be much less tolerant of high levels of UV exposure than native and resident Tahoe fishes. We proposed that this differential UV sensitivity could be used to develop a "UV Threshold" that could be attained to minimize susceptibility to exotic centrarchid fish species establishment in nearshore Lake Tahoe. Here we present the results from experiments comparing UV tolerance of native minnow (Lahontan redside shiner) versus non-native warmwater fish (bluegill and largemouth bass) larvae. We also present data from field surveys of UV and temperature in nearshore Lake Tahoe. From these data we develop UV attainment thresholds (**UVAT**) for 11 nearshore locations in Lake Tahoe. The UVAT is a target value for water clarity based on, 1) surface UV exposure during peak spawning season, and 2) experimentally derived UV exposure levels lethal to larval warmwater fish. For our purposes we present the ***UVAT as the % of incident 305 nm surface UV exposure that must penetrate to any given depth in order to prevent largemouth bass reproduction*** within a site. The UVAT emphasizes largemouth bass because they were the more UV tolerant of the two warmwater fish tested so that water clarity improvements that prevent bass survival will also likely prevent bluegill reproduction. We suggest that this value can be easily measured and monitored with a profiling UV radiometer or modeled from water samples analyzed for transparency in the lab with a spectrophotometer, and used to manage nearshore waters in an effort to minimize invasion by warmwater fish species.

i. Methods

1) UV and temperature profiling

UV and temperature profiles at each nearshore site were taken in June and July 2007, 2008 and 2010, and monthly (except September) from May through October 2009 with a BIC profiling UV-PAR radiometer (Biospherical Instruments Inc.) Nearshore sites included: Tahoe Keys East, Crystal Bay, Sand Harbor, Star Harbor, Cave Rock, Emerald Bay and Emerald Bay at Eagle Falls Creek, Sunnyside Marina, Round Hill Pines, Meeks Bay, and Taylor Creek (Figure

29). Sites were selected to represent a cross-section of the heterogeneity in UV transparency and temperature conditions for nearshore habitats in Lake Tahoe.

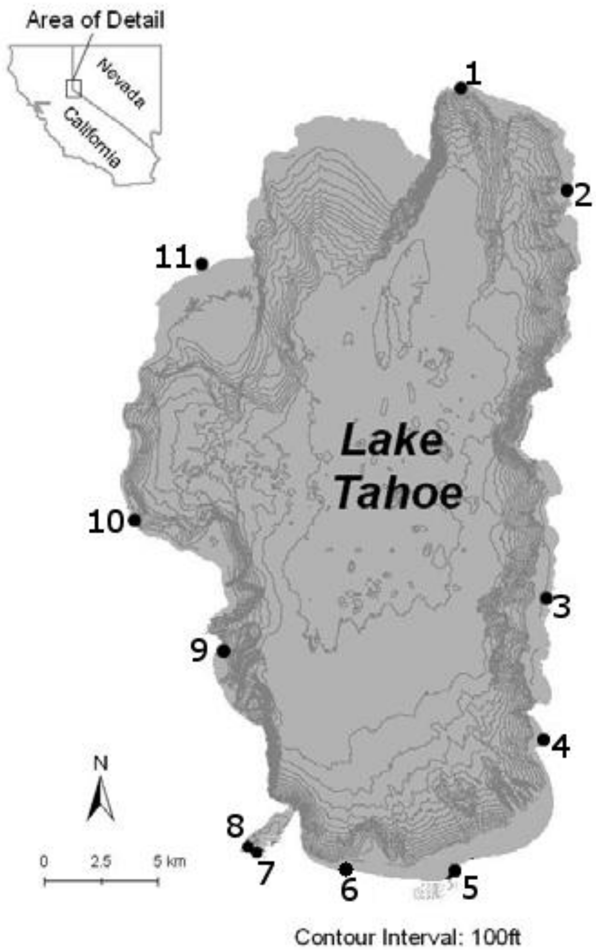


Figure 29. Map of Lake Tahoe indicating location of sample sites and corresponding UV transparency as percent 305 nm surface irradiance present at 1 meter depth. Percent surface irradiance is derived from mean k_{d305} value from once monthly June sampling 2007-2010, except sites 2 and 9 (2008-2010) and site 6 (2009-2010).

Site #	% Surface Irradiance
1- Crystal Bay	61
2- Sand Harbor	78
3- Cave Rock	73
4- RHP	57
5- Tahoe Keys	0
6- Taylor Creek	5
7- Emerald Bay	16
8- Emerald @ Eagle Falls	2
9- Meeks Bay	0
10- Sunnyside	61
11- Star Harbor	0

2) UV exposure experiments: establishing larval UV tolerance

For largemouth bass, bluegill, and Lahontan redside shiners larvae dose-response relationships of UV-induced mortality were established from outdoor exposure experiments in a temperature controlled environment. Here we present methods for largemouth bass and redside shiner experiments from which the UVAT values were determined. Methods for larval bluegill were very similar.

Largemouth bass were collected as eggs from a single nest in the Tahoe Keys on June 20, 2009 and hatched in the lab on or before June 23, 2009. On the evening of June 26, 2009., 5 yolk-sac bass larvae were added across treatments to each of 12 treatment dishes (1750ml Pyrex crystallizing dishes filled with 1.5 L of 48 um filtered lake water). Larvae were also added to each of 3 control dishes (1200 ml plastic bowls filled with 48 um filtered water). Control dishes were maintained in a temperature controlled environment at 18° C under low artificial light conditions. Neutral density stainless steel mesh screens (McMaster Carr) were applied to dishes on the morning of June 27 to provide a range of UV exposure levels (100%, 78%, 57%, and 45% of ambient solar UV). Treatment dishes were then placed in an outdoor water bath and larval survival was monitored every 2 hours for 34 hours. Mortality was recorded as the cessation of a heartbeat observed under a dissecting microscope. Ambient UV exposure for the duration of the experiment was recorded with a BIC-logging radiometer (Biospherical Instruments Inc.).

Lahontan redside were collected as eggs on July 15, 2009 and hatched in the lab at 22° C on 19 and 20 July. On the morning of 22 July 10, yolk-sac larvae were added across treatments to each of 12 treatment dishes (250 ml Pyrex crystallizing dishes filled with 250 mL of 48 um filtered lake water). Larvae were also added to each of 3 control dishes. Control dishes were placed in the water bath with treatment dishes but completely covered in courtgard (CP Films, Martinsville, VA USA). Courtgard is a long-wave pass plastic that transmits no UV-B. Neutral density mesh screens were applied to the treatment dishes to provide a range of UV exposure levels (as above for largemouth bass). After being placed in the outdoor water bath, mortality was recorded every 2 hours for approximately 150 hours. Mortality was recorded as the cessation of a heartbeat. Ambient UV exposure was recorded with a BIC-logger.

Logistic regression of the mortality data for larvae was performed to determine the probability of death for a given UV exposure (SAS v.9.2).

3) Determining the UV attainment threshold (UVAT)

The development of the UVAT proceeded as follows:

(1) Exposure-response relationships of UV-induced mortality were established from outdoor exposure experiments and used to determine the effective exposure of UVB to achieve the target amount of bass mortality. Based on a typical approach for determining efficacy of a pesticide (Ritz & Cedergreen, 2006) we selected a UV-exposure level that caused a high amount of mortality (99%) in bass, but a low amount of mortality in native species (<1%).

(2) Cumulative surface UV-radiant exposure was determined for 4 day incubation periods from a frequency distribution of radiant surface exposure for the month of June, as measured with a ground based GUV- radiometer (Biospherical Instruments Inc.).

(3) The UVAT was then calculated simply as the percent of surface UV radiant exposure that must penetrate to any given depth to prevent larval bass survival (i.e. result in mortality of 99% of the population):

$$UVAT = (LE_{99} / E_0)*100$$

where: LE_{99} = effective UV exposure selected to target bass mortality (kJ*m^{-2})

$E_0 = UV_{305}$ exposure at surface over a 4 day period (kJ*m^{-2})

4) In situ incubation experiments: Corroborating the UVAT

In situ incubation experiments were conducted to test the validity of the UVAT. Yolk sac larvae were selected for these experiments because their high transparency and lack of mobility are likely to make them the life history stage that is most sensitive to UV. For each experiment larval yolk sac largemouth bass were collected from a single nest at approximately 1 m depth in the Tahoe Keys. Larvae (n= 5) were placed in Whirl-Pak bags (Nasco, Fort Atkinson, Wisconsin, USA) filled with 100 mL of 48-µm filtered lake water to exclude most zooplankton. To isolate the effect of UVR between incubation sites, the Whirl-Pak bags were either shielded from incident UVR in Courtgard (CP Films, Martinsville, Virginia, USA) sleeves or exposed to incident UVR in Aclar (Honeywell International, Morristown, New Jersey, USA) sleeves. Courtgard is a long-wave-pass plastic that transmits photosynthetically active radiation (PAR; 95% 400–800 nm in water) but blocks most UVR (transmits no UV-B 295–319 nm, and only 9% of UV-A 320–400 nm with a sharp wavelength cutoff and 50% transmittance at 400 nm). Aclar is a long-wave-pass plastic that in water transmits both PAR (100% 400–800 nm) and most UVR (98% of UV-B 295–319 nm, 99% UV-A 320–399 nm, with a sharp wavelength cutoff and 50% transmittance at 212 nm). Four replicates of each of the UVR shielded and unshielded treatments were deployed at one meter depth at a given site for four days. After collection, larvae were examined under a dissecting microscope and scored as live if a heartbeat was observed. All procedures involving animals were in accordance with the policies set forth by Miami University's Institutional Animal Care and Use Committee (IACUC protocol #683).

ii. Results

UV transparency of nearshore Lake Tahoe varies considerably (Figure 29). For the most transparent sites, on average more than 70% of 305 nm UV radiation present at the surface penetrates to a depth of 1m. In the least transparent sites all of the 305 nm UV radiation is attenuated by 1 meter. There is also some variation in incident surface exposure over time (Figure 30). For the month of June 2009, incident surface 305 nm UV exposure for all possible consecutive four day periods ranged from 2.7 to 6.2 kJ/m^2. The majority of these 4 day windows of time indicated surface exposure somewhere between 4 and 6 kJ/m^2. The disparity in UV tolerance of native (Lahontan redside shiner) versus non-native (bluegill and largemouth bass) larvae is striking (Figure 31). The native minnow is almost six times as UV tolerant as the largemouth bass and more than 9 times as UV tolerant as the non-native bluegill. Approximately 2 kJ/m^2 305 nm UV exposure is lethal to at least 99% of non-native fish larvae with little or no effect on the native minnows. A combination of UV transparency, UV exposure, and UV tolerance data indicate that, assuming June spawning at 1 m depth (typical for Lake Tahoe largemouth bass), largemouth bass larvae could survive (i.e. successful reproduction could occur) at 6 of 11 sample sites (Table 12).

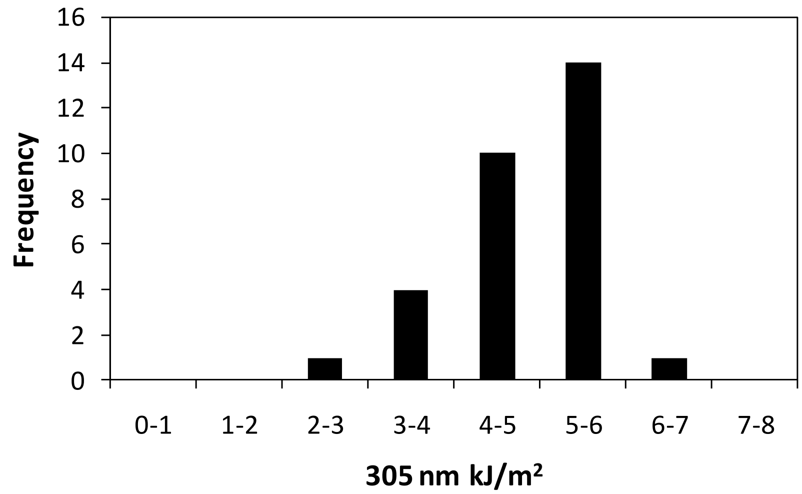


Figure 30. Frequency plot of 305 nm UV surface exposure for 4 day windows of time in June 2009 (e.g. of all consecutive 4 day periods in the month of June, 305 nm UV surface exposure was between three and four kJ/m^2 four times). Surface exposure was measured with a logging ground-based UV radiometer (GUV, Biospherical Instruments). The 4 day window represents a typical (though conservative) incubation period for yolk-sac largemouth bass larvae. The median value from this frequency distribution was used in calculating the UVAT values presented in Table 1 below (E_o = 4.99 kJ/m^2).

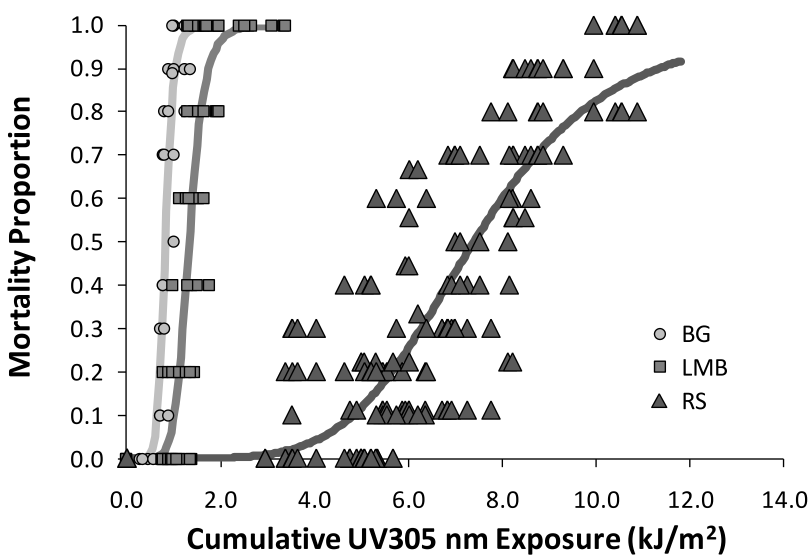


Figure 31. 'Exposure-response' curves from rooftop exposure experiments for bluegill (BG), largemouth bass (LMB) and Lahontan redside shiner minnow (RS) larvae. Calculated LE_{99} values for: bluegill = 1.38 kJ/m^2, largemouth bass = 2.08 kJ/m^2, Lahontan redside shiner = 12.2 kJ/m^2 (SAS v 9.2 proc logistic). The LE_{99} value for largemouth bass was selected as the effective

UVB exposure used to achieve the target amount of bass mortality. This UV-exposure level (i.e. 2.08 kJ/m^2) caused a high amount of mortality (≥99%) in bass and bluegill larvae, but a low amount of mortality in the native Lahontan redside shiner larvae (<1%).

Table 12. UVAT values for the prevention of largemouth bass in 11 nearshore sites. UVAT = (2.08 kJ/m^2/ 4.99 kJ/m^2) * 100, where 4.99 kJ/m^2 is the median surface irradiance for June 2009 measured from GUV data (see Figure 30), and 2.08 kJ/m^2 is the LE_{99} value from logistic regression of the rooftop exposure experiment (see Figure 31). We assume a standard spawning depth of 1 meter for all sites. Sites with greater than 42% of surface UV 305 nm exposure still present at 1 m depth are considered to be in attainment and susceptibility to largemouth bass establishment is reduced. In situ experiments show survival of largemouth bass larvae in a subset of the sample sites for a 4-day incubation at 1 m depth.

SITE	% surface UV @ 1m †	UVAT (%) ¶	ATTAINMENT	IN SITU ± SE *
Crystal Bay	61.0	42.0	Y	0
Sand Harbor	78.0	42.0	Y	0
Cave Rock	73.0	42.0	Y	
Round Hill Pines	57.0	42.0	Y	
Tahoe Keys	0.0	42.0	N	93.75 (6.25)
Taylor Creek	5.0	42.0	N	85 (5)
Emerald Bay	16.0	42.0	N	85 (9.6)
Emerald @ Eagle Falls Crk	2.0	42.0	N	
Meeks Bay	9.0	42.0	N	
Sunnyside	61.0	42.0	Y	
Star Harbor	0.0	42.0	N	

† based on mean value for June K_d from 2007-2010, except Sand Harbor and Meeks Bay (2008-2010) and Taylor Creek (2009-2010)
¶ UVAT= (2.08 kJ/m^2/ 4.99 kJ/m^2) * 100
* percent survival from in situ incubation experiments (2009,2010)

iii. Discussion

Our results suggest that UV transparency of nearshore sites significantly impacts the survival of warm-water fish larvae and could influence whether or not these potentially invasive fish species are able to establish successful spawning grounds in nearshore Lake Tahoe. Here we present three strategic recommendations based on our findings and discuss the relevance of each in the context of some of the key objectives put forward in the Lake Tahoe Region Aquatic Invasive Species Management Plan (USACE 2009; Appendix A-3).

1. ***Implement a program to more broadly identify priority non-attainment sites with warm water temperatures and low UV transparency (Tahoe AIS management objectives D.2.c, E.3.f, F.2.c)***

The development of a detailed study to identify sites at risk of invasion is a key objective of the Tahoe AIS management plan. We have identified UV transparency of nearshore sites as a critical metric for predicting short-term changes in the nearshore fishery and have provided a template for assessing attainment of UV thresholds (See attached spreadsheet.). An important next step is to couple this metric with additional metrics for bass success that have been identified by Chandra et al. (2009) and in this report (e.g. substrate availability, food resources, and adult presence or absence). This approach will assist in increasing the cost effectiveness of eradication efforts by identifying 'priority at risk' sites that, based on multiple metrics, are most likely to support reproduction of invasive warmwater species.

Chandra et al (2009) assessed habitat suitability for warmwater fish in 48 sites based on temperature and availability of aquatic plants coverage. Of those 48 sites, all sites were considered suitable for warmwater fish establishment. The UVAT attainment status of each of these sites should be measured. In short, a UV and water temperature profile should be taken at least once in June to a maximum depth of 10 m (see Appendix A-2). Based on site morphometry and water temperature, a depth for UV attainment should be selected (i.e. the maximum depth where water temperature is greater than 12.7° C). If less than 42% of 305 nm surface UV is present at the UV attainment depth the site is considered 'at risk' and a monitoring program, as described below should be implemented. See Appendix A-1 and the supplemental spreadsheet provided 'Estimating UVAT depth.xls' for information regarding the assessment of attainment/non-attainment status. This multiple-metric approach should be employed to assess the habitat suitability of additional nearshore locations that have not been monitored as part of this report.

2. ***Regularly monitor non-attainment sites (see Table 12) for the presence of largemouth bass and other centrarchid nests (Tahoe AIS management objectives D.2.c, E.3.f)***

Two important goals of the Tahoe AIS management plan are 1) to identify habitats that are predicted to support all life stages of warmwater fish and 2) develop a plan that includes long-term monitoring, prevention, and rapid response. We have identified at least six "at risk" sites that could support all life stages of warmwater fish and that can be targeted immediately for systematic monitoring and early detection. "At risk" sites represent locations in the nearshore environment where water temperature and water clarity are conducive to reproduction of non-native warmwater fish, more specifically largemouth bass. From our analysis "at risk" sites are those sites where, for the month of June, water temperature is greater than the lower limit for bass spawning and less than 42% of surface 305 nm UV is present at 1 meter depth. Our analysis is based on observations that suggest June spawning at 1 meter depth is typical for largemouth bass in Lake Tahoe. We assume a lower thermal limit of 12.7 ° C for bass spawning (Wallus & Simon, 2008). Water temperature at 1 m depth in June exceeded 12.7° C for all sample sites (see Appendix A-4). In calculating the UVAT of 42% we assumed normal UV conditions (i.e. median June 305 nm surface exposure, see Figure 30). Based on these criteria ***six of our eleven sample sites are "at risk" of bass establishment***, assuming the presence of reproductive adults. Regular monitoring of these "at risk" sites increases the likelihood of early detection and the potential for successful implementation of control measures. Note that largemouth bass may in some cases spawn at depths deeper than 1 m, and the UVAT may need to be adjusted accordingly. This can be done in the spreadsheet included with this report.

A monitoring program for the presence of warmwater fish nests in these 6 sites should at the very least include plans to sample during the months of possible warmwater fish spawning and at depths where nest establishment is most likely. Our nearshore survey data suggest that in most years water temperature is suitable for spawning in these 6 sites beginning in June. Consequently, monitoring efforts should begin no later than June 1 each year. In some sites (e.g. Tahoe Keys) water temperature exceeds 12.7° C beginning in May. Therefore, a more comprehensive monitoring program might take into account site specific temperature data and initiate monitoring accordingly. The frequency of these monitoring efforts should be no less than bi-weekly. Less frequent sampling might allow for the fish to construct a nest, spawn, and safely usher larvae through development to swim-up before detection, especially in sites or at depths where water temperature is warm. Underwater surveys of the entire shoreline for each site at a fixed depth are recommended to ensure nest detection. Alternatively, transects could be systematically selected and sampled at a fixed depth, although this presents the possibility that some nests may not be observed.

Our observations suggest that the majority of largemouth bass spawning in Lake Tahoe occurs at less than 1 meter. This is consistent with descriptions from the literature that report typical nest depths of 15 cm to 2 m (Carlander 1977 and references therein). However, there are records of bass nesting as deep as 8.2 m and in some of our non-attainment sites (e.g. Emerald Bay) lake morphometry and water temperature may allow bass to spawn at these greater depths. Whereas monitoring efforts should focus on shallower depths (< 2m), comprehensive monitoring may require surveys up to 10 meters in depth. We have not observed bass spawning after July in Lake Tahoe, but temperatures are still suitable for spawning well into summer, and in some locations water temperature is still above the minimum spawning threshold into October (see Appendix A-4). However, age-0 bass survival is known to be largely dependent on size at overwintering and recruitment to age 1 favors fish spawned earlier in the season (Miranda & Hubbard, 1994; Ludsin & DeVries, 1997; Garvey et al, 1998). Also, for temperate latitudes bass are not known to have an especially protracted spawning season and generally reproduce over a period of one to two months (Wallus and Simon 2008). Therefore, we recommend that monitoring efforts continue through July, but suggest that monitoring beyond this time is unnecessary.

3. a. Assess what factors are reducing UV transparency in non-attainment sites. Tahoe AIS management objective F.2.b)

The Tahoe AIS management plan calls for research to identify limiting factors for AIS survival. In this report we have identified UV radiation as a critical limiting factor for warmwater fish survival. However, additional research on the underlying cause(s) of variability in nearshore UV transparency (and thus levels of this important factor) is required to help lake managers implement a program to successfully meet UV attainment thresholds that will prevent warmwater fish spread.

The decline in visible light transparency in Lake Tahoe has traditionally been attributed to increases in both organic (i.e., phytoplankton and detritus) and inorganic (i.e., terrestrial sediment) particulate matter (Swift et al, 2006) resulting largely from human impacts in and around the basin related to eutrophication (Goldman, 1988) and stream bank erosion (Byron & Goldman, 1989). In highly transparent lakes like Lake Tahoe, phytoplankton may also be an important regulator of UV transparency (Laurion et al, 2000; Sommaruga & Augustin, 2006) Concentrations of dissolved organic carbon (DOC) are also an important regulator of UV transparency and thus underwater UV exposure (Morris et al, 1995; Williamson et al, 1996). DOC may be especially important in nearshore habitats where fish spawning occurs, since DOC inputs are likely to be concentrated in those areas. For example, in Lake Tahoe stream water inputs of DOC are approximately 10 times higher than DOC levels offshore where most of the long-term transparency monitoring has been conducted (Swift, 2004). Water quality analysis of nearshore sites in Tahoe also shows that UV transparency in the nearshore is strongly dependent on DOC concentration (Tucker et al. 2010). However, this same analysis also suggested that the best model for predicting UV transparency included both DOC and chlorophyll, and contributions from inorganic particulate matter were not assessed in the study. An analysis that quantifies the relative importance of each of these factors in controlling UV attenuation and that emphasizes seasonal patterns in these light attenuating components relevant to warmwater fish spawning times should be initiated. The analysis should emphasize UV attenuation in non-attainment sites.

b. Implement measures to meet UV attainment thresholds in non-attainment sites

A program to evaluate the effectiveness of BMPs and other water clarity improvement measures in terms of their ability to move sites toward UV attainment thresholds that would prevent warmwater fish invasion should be initiated. BMPs and water clarity improvements in Lake Tahoe have focused largely on reducing levels of organic and inorganic particulate matter (Schuster & Grismer, 2004). Where these efforts are effective in improving water clarity they are also likely increasing underwater UV exposure and therefore moving sites toward UVAT attainment levels that could prevent warmwater fish invasion. However, practices that are tailored to increase underwater UV levels in particular may be a more cost-effective means of both increasing water clarity and preventing warmwater fish spread. For example, in a report for the Western Australia Department of Water, Wendling et al. (2009) identified a few key mineral based industrial by-products that served as effective adsorbents for reducing DOC concentrations, namely neutralized used acid and calcined magnesia. The authors suggested that these materials could be incorporated into drain liners or constructed wetlands (i.e. DOC retentive structures) to reduce DOC concentrations in surface water (although they noted that these adsorbents would require additional optimization to validate the performance of the materials in the field). In the event that an analysis of UV attenuation in non-attainment sites identified DOC as the primary cause of low underwater UV levels a program to test and implement the use of these kinds of 'designer contaminant adsorbents' should be pursued. A management approach that targets the factor most responsible for UV attenuation in non-attainment sites could prove to be more effective than current broad spectrum BMPs in moving sites toward UV attainment thresholds (though see Appendix A-5).

IV. Recommendation

The primary goal of this project was to 1) evaluate the utility of traditional metrics and novel metrics for assessing the current and future status of native and non-native fishes in the nearshore, and 2) provide recommendations and guidance for implementing the best metrics as part of a long-term nearshore monitoring and warmwater fish prevention program. We believe that a long-term monitoring program is critical for providing necessary information to scientifically manage and protect the nearshore fishery resources of the lake.

Multimetric Refinement:

1. Determine interannual variability of fish nutrition, growth, recruitment, habitat variables (e.g. temperature), density/catch and composition of nearshore fishery.

   a. *Long-term density/catch and composition assessment*

   Application of hydroacoustic fish assessment techniques can be used to provide larger scale assessment of the distribution and density of nearshore fish. Such technique has been extensively used in fishery surveys from other ecosystems to determine relative abundance of different fish species (Brandt, 1996). Biennial lake-wide snorkeling survey and seasonal minnow trap transects can be used to supplement hydroacoustic assessment to confirm species composition and density estimates.

   Seasonal minnow trap transects with sampling effort focused in early summer and fall can be conducted at a selection of 6-8 sites (sampling effort: 3-4 days max) along the shoreline to collect basic information, such as catch per unit effort (CPUE), composition, length and weight, growth, and diet data. To better capture and identify temporal changes in composition and abundance among localized populations and reduce sampling variability, a rigid sampling regimes with standardize protocol, gear, location and time should be established. For comprehensive species composition surveys, multiple gear types should be used with adequate sampling effort to sufficiently detect changes in species composition. Criteria to be considered for site selection should include: 1) Historically sampled sites; 2) sites with high and low fish density (based on data collected in 2008-2010); 3) At least one site at each of the seven sections of the lake (see Beauchamp et al 1994).

b. Spawning habitat and recruitment assessment

The use of snapshot capture of the availability of spawning habitat to assess the health of nearshore fishery can potentially be confounded by factors, such as changes in water level. Thus, we do not recommend using this metric as the only threshold for assessment of nearshore fishery. To understand how spawning potential may be affected over time, assessment of the actual recruitment of larval fish should be considered. In addition, knowledge of the life history of these nearshore native fish are lacking and better understanding of these information under different conditions should help us determine why changes in composition and density are detected.

Growth rate and the condition of these nearshore forage fishes were hard to determine using scales and other hard materials from the fishes thus should not be used as an indicator for assessment of fish conditions in Lake Tahoe.

2. Trophic niche: Measure isotopic levels in fish across species

Isotopic analysis of carbon and nitrogen from fish tissues can provide information regarding the trophic niche for each species and used to couple with local nutrient levels and algal production conducted by other monitoring programs. It can be used to elucidate short and long-term changes in food web structure and energy flow pathways among different species that can indicate why the catch of these species is changing over time. This approach also allows for retrospective examination of historical conditions with relative ease (e.g. use of preserved museum samples, see Vander Zanden et al, 2003). In this study, certain native species shifted their feeding behavior based on historical condition while some species remain consistent in their feeding strategies (e.g. Tahoe sucker). Since there is long term information on the trophic niche of each species, we recommend that samples from selected locations where catch is monitored be collected and archived for isotopic analysis. This laboratory analysis from preserved samples can be conducted when funds are available. Seasonal stomach content analysis can be used to supplement isotopic analysis to provide information on the actual food items being consumed by these fishes and validate changes demonstrated by trophic niche measurements. Thus the same fish caught during the composition survey should be preserved for stomach content analysis. Contents can be analyzed when funds are available.

3. UV transparency: Assess controlling factors, UVAT for juveniles, refine species UV tolerance distributions at all life stages and implement UV transparency control.

Our results suggest that UV transparency of nearshore sites significantly impacts the survival of warmwater fish larvae and influences whether these potentially invasive fish species are able to establish in nearshore Lake Tahoe. By quantifying the effect of UV exposure on the earliest life history stage of warmwater fish and measuring levels of this important abiotic factor in nearshore Lake Tahoe our research provides critical new insights that will increase the cost effectiveness of warmwater fish control and management efforts. We used the difference in UV tolerance of native and non-native larval fishes to develop an UV Attainment Threshold (UVAT), a water clarity threshold based on UV that is lethal to non-native fishes. The UVAT allows managers to identify 'at risk' sites based on larval fish survival. Therefore, prevention and control efforts can be focused in both space and time (by focusing on sites during the spawning season where UV conditions might allow non-native larval fish to survive). Our approach also provides a framework for managing water clarity to prevent further warmwater fish spread in the basin. Here we present briefly *three strategic recommendations*. In a later section (III. b. iii) we provide a more detailed treatment of the recommendations and discuss the relevance of each in the context of some of the key objectives put forward in the Lake Tahoe Region Aquatic Invasive Species Management Plan (USACE 2009; Appendix A-3).

a. Implement a program to more broadly identify priority non-attainment sites

We have identified UV transparency of nearshore sites as a critical metric for predicting short-term changes in the nearshore fishery and have provided a template for assessing attainment of UV thresholds (see attached spreadsheet). An important next step is to couple this metric with additional metrics for bass success that have been identified by Chandra et al (2009) and in this report (e.g. substrate availability, food resources, and adult presence or absence). This approach will assist in increasing the cost effectiveness of control and management efforts by identifying 'priority at risk' sites that, based on multiple metrics, are most likely to support reproduction of invasive warmwater species.

Chandra et al (2009) assessed habitat suitability for warmwater fish in 48 sites based on temperature and availability of aquatic plants coverage. Of those 48 sites, all sites were considered suitable for warmwater fish establishment. The UVAT attainment status of each of these sites should be measured (see detailed instructions in "Ultraviolet radiation" section below). This multiple-metric approach should be employed to assess the habitat suitability of additional nearshore locations that have not been monitored as part of this report.

b. *Regularly monitor non-attainment sites for the presence of largemouth bass, other centrarchid nests, and other invasive species of interest*

Based on the UVAT, we have identified at least six "at risk" sites (see Table 12) that could support all life stages of warmwater fishes and that can be targeted immediately for systematic monitoring and early detection of warmwater fish nests. Underwater snorkel or SCUBA surveys of the entire shoreline for each site at fixed depths from 0-10 meters at bi-weekly intervals in June and July are recommended to ensure nest detection.

c. *Assess what factors are reducing UV transparency in non-attainment sites. Implement measures to meet UV attainment thresholds in non-attainment sites*

We have identified UV radiation as a critical limiting factor for warmwater fish survival. However, additional research on the underlying cause(s) of variability in nearshore UV transparency (and thus levels of this important factor) is required to help lake managers implement a program to successfully meet UV attainment thresholds that will prevent warmwater fish spread.

Preliminary water quality analysis of nearshore sites in Tahoe showed that UV transparency in the nearshore is strongly dependent on dissolved organic carbon (DOC) concentrations (Tucker, et al., 2010). However, this analysis did not consider contributions from inorganic particulate matter, which have played a strong role in controlling transparency to visible light in Lake Tahoe. An analysis that quantifies the relative importance of each of these factors in controlling UV attenuation and that emphasizes seasonal patterns in these light attenuating components relevant to warmwater fish spawning times should be initiated. The analysis should emphasize UV attenuation in non-attainment sites.

Likewise, a program to evaluate the effectiveness of BMPs and other water clarity improvement measures in terms of their ability to move sites toward UV attainment thresholds that would prevent warmwater fish invasion should be initiated. BMPs that are tailored to increase underwater UV levels may be the most cost-effective means of both increasing water clarity and preventing warmwater fish spread.

Synthesis and Integration:

Extend to other lakes and streams in watershed and use this as a model for change in the Sierra Nevada

We hope that our recommendations will assist in preserving nearshore native fish populations, increasing the cost effectiveness of eradication efforts of invasive warmwater species, and inform mitigation efforts to increase water clarity at compromised sites around Lake Tahoe. In a biological invasion context "an ounce of prevention is worth a pound of cure" (Leung et al, 2002) and given the potentially high cost of a full scale warmwater fish invasion any expense to implement these largely preventative measures is money well spent. Our approach and the outcomes from this research could also be useful for other management concerns. The development of a risk map based on knowledge of the condition of nearshore native and non-native fish (e.g. nutrient, recruitment, density, and composition) and UV transparency could aid managers in the development of cost effective management strategies. Therefore, research on the role of these indicators in preserving native fishes and controlling warmwater fish invasion can serve as a useful model for controlling other AIS of concern to lake managers and would therefore be a crucial component of a data base to guide future management strategies.

V. References

Allen, B., & Reuter, J. (1996). *Shorezone spawning in Lake Tahoe: the effect of shorezone structures and associated activities on the spawning success of native minnows. Report to the Tahoe Regional Planning Agency.* Stateline, NV: Tahoe Regional Planning Agency.

Baker, P. (1967). Distribution, size composition, and relative abundance of the Lahontan speckled dace, Rhinichthys osculus robustus (Rutter), in Lake Tahoe. *California Fish and Game* , 53:165-173.

Bearhop, S., Adams, C., Waldron, S., Fuller, R., & Macleod, H. (2004). Determining trophic nich width: a novel approach using stable isotope analysis. *Journal of Animal Ecology* , 73: 1007-1012.

Beauchamp, D., Byron, E., & Wurtsbaugh, W. (1994). Summer habitat use by littoral-zone fishes in Lake Tahoe and the effects of shoreline structures. *North American Journal of Fisheries Management* , 14:385-394.

Beauchamp, D., Wurtsbaugh, W., Allen, B., Budy, P., Richards, R., & Reuter, J. (1991). *Tahoe fish community structure investigations: Phase III Report.* Logan, Davis Calif: Department of Fisheries and Wildlife, Utah State University, and Institute of Ecology, Division of Environmental Studies, University of California Davis.

Begon, M., Harper, J., & Townsend, C. (1996). Chapter 2 Conditions. In M. Begon, J. Harper, & C. Townsend, *Ecology: individual, populations, and communities* (pp. 48-89). Oxford: Blackwell Science Ltd.

Bowen, S. (1996). Quantitative description of the diet. In B. Murphy, & D. Willis, *Fisheries Techniques* (pp. 513-532). Maryland, USA: American Fisheries Society.

Brandt, S. (1996). Acoustic Assessment of Fish abundance and Distribution. In B. Murphy, & D. Willis, *Fisheries Techniques* (pp. 385-432). Bethesda, Maryland: American Fisheries Society.

Byron, E., & Goldman, C. (1989). Land-use and water quality in tributary streams of Lake Tahoe, California-Nevada. *Journal of Environmental Quality* , 18:84-88.

Byron, E., Allen, B., Wurtsbaugh, W., & Kuzis, K. (1989). *Final report: littoral structure and its effects on the fish community of Lake Tahoe.* Davis: Institute of Ecology, Division of Environmental Studies, University of California.

Carlander, K. (1977). Life history data on centrarchid fishes of the United States and Canada. In K. Carlander, *Handbook of Freshwater Fishery Biology Volume 2.* Ames, Iowa: THe Iowa State University Press.

Chandra, S. (2007). *Determination of the methods needs to examine the health of the nearshore fishery in Lake Tahoe.* Tahoe Regional Planning Agency.

Chandra, S., Ngai, K., Kamerath, K., & Allen, B. (2009). *Warm-water Non-native Fishes in Lake Tahoe. Report to Nevada Divison of State Lands.* Reno: University of Nevada.

Chandra, S., Ngai, K., Kamerath, M., & Allen, B. (2008). *Warmwater nonnative fishes in Lake Tahoe.* Carson City, NV: Technical report prepared for Nevada Division of State Lands.

Chandra, S., Vander Zanden, M., Heyvaert, A., Allen, B., & C.R., G. (2005). The effects of cultural eutrophication on the energetics of lake benthos. *Limnology and Oceanography* , 50: 1368-1376.

Chandre, S., Ngai, K. L., Kamerath, M., & Allen, B. (2009). *Warm-water Non-native Fishes in Lake Tahoe* . University of Nevada, Reno: Final Report prepared for Nevada Division of State Lands.

Coats, R., Perez-losada, j., Schladow, G., Richards, R., & Goldman, C. (2006). The warming of Lake Tahoe. *Climatic Change* , 76:121-148.

Cordone, A., & Frantz, T. (1968). An evaluation of trout planting in Lake Tahoe. *California Department of Fish and Game* , 54:68-69.

DeVries, D., & Frie, R. (1996). Determination of Age and Growth. In B. Murphy, & D. Willis, *Fisheries Techniques* (pp. 483-512). Bethesda, Maryland: American Fisheries Society.

Edmondson, W. (1991). *The Uses of Ecology: Lake Washington and Beyond.* Seattle, Washington: University of Washington Press.

Evans, D. (1969). Life history studies of the Lahontan redside, Richardsonius egregius, in Lake Tahoe. *California Fish and Game* , 55: 197-212.

Garvey, J., Wright, R., & Stein, R. (1998). Overwinter growth and survival of age-0 largemouth bass (Micropterus salmoides): Revisiting the role of body size. *Canadian Journal of Fisheries and Aquatic Sciences* , 55:2414-2424.

Goldman, C. (1988). Primary productivity, nutrients, and transparency during the early onset of eutrophication in ultra-oligotrophic Lake Tahoe, California-Nevada. *Limnology and Oceanography* , 33:1321-1333.

Gorman, O., & Moore, S. (2006). *Inventory of nearshore fish population densities and community structures at Apostle Islands National Lakeshore and Isle Royale National Park.* Great Lakes Inventory and Monitory Network Report GLKN/2006/05.

Gu, B., Schell, D., & Alexander, V. (1994). Stable carbon and nitrogen isotopic analysis of the plankton food web in a subarctic lake. *Canadian Journal of fisheries and Aquatic Sciences* , 51: 1338-1344.

Hecky, R., & Hesslein, R. (1995). Contributions of benthic algae to lake food webs as revealed by stable isotope analysis. *Journal of the North American Benthological Society* , 14: 631-653.

Herold, M., Metz, J., & Romsos, J. (2007). Inderring littoral substrates, fish habitats, and fish dynamics of Lake Tahoe using IKONOS data. *Canadian Journal of Remote Sensing* , 33:445-456.

Hubert, W. (1996). Passive Capture Techniques. In B. Murphy, & D. Willis, *Fisheries Techniques* (pp. 157-192). Bethesda, Maryland: American Fisheries Society.

Huff, D., Grad, G., & Williamson, C. (2004). Environmental constraints on spawning depth of yellow perch: The roles of low temperatures and high solar ultraviolet radiation. *Transactions of the American Fisheries Society* , 133: 718-726.

Hutchinson, G. (1957). Concluding remarks. *Cold Spring Harbour Symposium on Quantitative Biology* , 22: 415-427.

Jackson, D., & Harvey, H. (1997). Qualitative and quantitative sampling og lake fish communities. *Canadian Journal of Fisheries and Aquatic Sciences* , 54:2807-2813.

Jassby, A., Goldman, C., Reuter, J., & Richards, R. (1999). Origins and scale dependence of temporal variability in the transparency of Lake Tahoe, California-Nevada. *Limnology and Oceanography* , 44:282-292.

Johnstone, I. (1986). Plant invasion windows: A time-based classification of invasion potential. *Biological Reviews* , 61:361-394.

Kamerath, M., Chandra, S., & Allen, B. (2008). Distribution and impacts of warm water invasive fish in Lake Tahoe, CA-NV, USA. *Aquatic Invasions* , 3:35-41.

Kaufman, L. (1992). Catastrophic cahnge in species-rich freahwater ecosystems: the lessons of Lake Victoria. *Bioscience* , 42:846-858.

Lagler, K. (1969). Chapter XI: Length-weight relationship and condition. In K. Lagler, *Freshwater Fishery Biology* (pp. 159-166). Dubuque, Iowa: WM. C. Brown Company Publishers.

Lane, E. (1947). Report of the subcommittee on sediment terminology. *Transactions of American Geophysical Union* , 28: 936-938.

Laurion, I., Ventura, M., Catalan, J., Psener, R., & Sommaruga, R. (2000). Attenuation of ultraviolet radiation in mountain lakes: Factors controlling the among- and within-lake variability. *Limnology and Oceanography* , 45:1274-1288.

Leung, B., Lodge, D., Finnoff, D., Shogren, J., Lewis, M., & Lamberti, G. (2002). An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. *Proceedings of the Royal Society B* , 269:2407-2413.

Ludsin, S., & DeVries, D. (1997). First-year recruitment of largemonth bass: The inter-dependency of early life stages. *Ecological Applications* , 7:1024-1038.

MacRae, P. J. (2006). Characterizing north temperate lake littoral fish assemblages: A comparison between distance sampling and minnow traps. *Canadian Journal of Fisheries and Aquatic Sciences* , 63:558-568.

Mazumder, A., Taylor, W., McQueen, D., & Lean, D. (1990). Effects of fish and plankton on lake temperature and mixing depth. *Science* , 247:312-315.

McCloskey, J., & Oris, J. (1991). Effect of water temperature and dissolved-oxygen concentration on the photoinduced toxicity of anthracene to juvenile bluegill sunfish (lepomis macrochirus). *Aquatic Toxicology* , 21:145-156.

Mehner, T., Diekmann, M., Bramick, U., & Lemke, R. (2005). Composition of fish communities in German lakes as related to lake morphology, trophic state, shore structure and human-use intensity. *Freshwater Biology* , 50:70-85.

Merritt, R., & Cummins, K. (1996). *An Introduction to the Aquatic Insects of North America 3rd Edition.* Iowa: Kendall/ Hunt Publishing Company.

Miller, R. (1951). *The natural history of Lake Tahoe fishes.* Palo Alto, CA: Doctoral dissertation. Stanford University.

Minagawa, M., & Wada, E. (1984). Stepwise enrichment of N-15 along food chains- futher evidence and the relation between delta N-15 and animal age. *Geochimica Et Cosmochimica Acta* , 48: 1135-1140.

Miranda, L., & Hubbard, W. (1994). Winter survival of Age-0 largemouth bass relative to size, predators, and shelter. *North American Journal of Fisheries Management* , 14:790-796.

Morris, D., Zagarese, H., Williamson, C., Balseiro, E., Hargreaves, B., & Modenutti, B. (1995). The attenuation of solar UV radiation in lakes and the role of dissolved organic carbon. *Limnology and Oceanography* , 40:1381-1391.

Moyle, P. (2002). *Inland Fishes of California.* Berkeley: University of California Press.

Moyle, P., & Cech, J. (2000). *Fishes: an introduction to ichthyology.* Upper Saddel River, New Jersey: Prentice Hall.

Ngai, K. (2008). *Potential effects of climate change on the invasion of largemouth bass (Micropterus salmoides) in Lake Tahoe, California-Nevada.* Toronto: University of Toronto.

Olson, M., Colip, M., Gerlach, J., & Mitchell, D. (2006). Quantifying ultraviolet radiation mortality risk in bluegill larvae: Effects of nest location. *Ecological Applications* , 16: 328-338.

Oris, J., Hall, A., & Tylka, J. (1990). Humic acids reduce the photoinduced tocisity of anthracene to fish and daphnia. *Environmental Toxicology and Chemistry* , 9:575-583.

Reuter, J., & Miller, W. (2000). *Aquatic resources, water quality and limnology of Lake Tahoe and its upland watershed. Lake Tahoe Watershed Assessment.* USA: Department of the Interior.

Ritz, C., & Cedergreen, N. (2006). Relative potency in nonsimilar dose-response curves. *Weed Science* , 54:407-412.

Rose, K., Williamson, C., Schladow, S., Winder, M., & Oris, J. (2009). Patterns of spatial and temporal variability of UV transparency in Lake Tahoe, California-Nevada. *Journal of Geophysical Research-Biogeosciences* , 114.

Saito, L., Redd, C., Chandra, S., Atwell, L., Fritsen, C., & Rosen, M. (2007). Quantifying foodweb interactions with simultaneous linear equations: stable isotope models of the Truckee River, USA. *Journal of the North American Benthological Society* , 26: 624-662.

Schmidt, S., Olden, J., Solomon, C., & Vander Zanden, M. (2007). Quantitative approaches to the analysis of stable isotope food web data. *Ecology* , 88:2793-2802.

Schuster, S., & Grismer, M. (2004). Evaluation of water quality projects in the Lake Tahoe Basin. *Environmental Monitoring and Assessment* , 90:225-242.

Seehausen, O., Van Alphen, J., & Witte, F. (1997). Cichlid fish diversity threatened by eutrophication that curbs sexual selection. *Science* , 277:1808-1811.

Sommaruga, R., & Augustin, G. (2006). Seasonality in UV transparency of an alpine lake is associated to changes in phytoplankton biomass. *Aquatic Sciences* , 68:129-141.

Swift, T. (2004). *Thesis: The Aquatic Optics of Lake Tahoe, CA-NV.* University of California, Davis.

Swift, T., Perez-Losada, J., Schladow, S., Reuter, J., Jassby, A., & Goldman, C. (2006). Water clarity modeling in Lake Tahoe: Linking suspended matter characteristics to secchi depth. *Aquatic Sciences* , 68:1-15.

Tahoe Regional Planning Agency. (2007). *2006 Threshold Evaluation Report.* South Lake Tahoe, CA: Tahoe Regional Planning Agency.

Thiede, G. (1997). Impact of lake Trout predation on prey populations in Lake Tahoe: A bioenergetics assessment. Thesis. Utah State University.

Thorp, J., & Covich, A. (1991). *Ecology and Classification of North American Freshwater Invertebrates.* London: Academic Press, Inc.

Tucker, A., Williamson, C., Rose, K., Oris, J., Connelly, S., Olson, M., et al. (2010). Ultraviolet radiation affects invasibility of lake ecosystems by warmwater fish. *Ecology* , 91:882-890.

Tucker, T. (1969). *Diet of Lake Tahoe speckled dace (Rhinichthys osculus robustus).* San Francisco: Thesis. San Francisco State College.

Vander Zanden, M., & Rasmussen, J. (1999). Variation in delta 13 C and delta 15 N and the trophic position of aquatic consumers. *Ecology* , 80: 1395-1404.

Vander Zanden, M., & Rasmussen, J. (2001). Variation in delta N-15 and delta C-13 trophic fractionation: Implications for aquatic food web studies. *Limnology and Oceanography* , 46: 2061-2066.

Vander Zanden, M., Chandra, S., Allen, B., Reuter, J., & Goldman, C. (2003). Historical food web structure and restoration of native aquatic communities in the Lake Tahoe (California-Nevada) Basin. *Ecosystems* , 6:274-288.

Vander Zanden, M., Shuter, B., Lester, N., & Rasmussen, J. (1999). Patterns of food chain length in lakes: A stable isotope study. *The American Naturalist* , 154:406-416.

Wallus, R., & Simon, T. (2008). *Reproductive biology and early life history of fishes in the Ohio River Drainage.* Boca Raton, Florida: CRC Press.

Wendling, L., Douglas, G., & Petrone, K. C. (2009). *Best management practices: Investigation of mineral-based by-products for the attenuation of nutrients and DOC in surface waters from the Swan coastal plain. Report for the Water Foundation.* Western Australia Department of Water: CSIRO: Water for a Healthy Country National Research Flagship.

Williamson, C., Metzgar, S., Lovera, P., & Moeller, R. (1997). Solar ultraviolet radiation and the spawning habitat of yellow perch, perca flavescens. *Ecological Applications* , 7:1017-1023.

Williamson, C., Stemberger, R., Morris, D., Frost, T., & Paulsen, S. (1996). Ultraviolet radiation in North American lakes: Attenuation estimates from DOC measurements and implications for plankton communities. *Limnology and Oceanography* , 41:1024-1034.

VI. Appendix

A-1: Using the Diffuse attenuation coefficient (K_{d305}) to calculate UVAT

The diffuse attenuation coefficient (K_d) is a measure of the extent to which light intensity is reduced as it passes through water. Light attenuation in water follows the Beer-Lambert law, $E= E_0 e^{-K_d z}$, where: E_0 is light exposure at the water surface, K_d is the diffuse attenuation coefficient, and z is depth. Therefore, a large attenuation coefficient indicates that light is quickly attenuated as it passes through water, whereas a small coefficient means that the water is more transparent and light can penetrate rather deeply. The coefficient is measured by conducting a UV profile (see A-2- 'Sampling underwater UV levels' below) and calculating the slope of the line derived by plotting the log of UV intensity at 305 nm versus depth (Fig. A-1). The K_d has units of reciprocal meters (1/m).

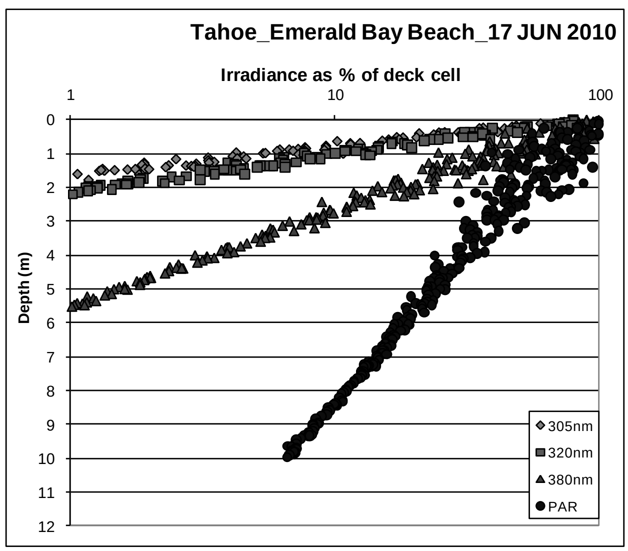


Fig A-1. Semi-log plot of UV exposure used to calculate K_d.

In this report the K_d was used to determine site attainment/non-attainment based on a UVAT of 42% (i.e. at any given depth 42% of 305 nm surface UV exposure prevents bass survival). See the supplement 'Estimating UVAT depth.xls' for additional information.

A-2: Sampling Underwater UV levels

Determining UV attainment thresholds in nearshore sites for the prevention of warmwater fish survival and establishing a monitoring program to assess the realization of these target water clarity thresholds is a key recommendation of this report. Successful implementation of this recommendation will require that lake managers be able to sample underwater UV levels (used to calculate K_d values and convert to UVAT as in A-1 above). Underwater UV levels are easily measured with a BIC profiling UVR-PAR radiometer (Biospherical Instruments, San Diego, California, USA). This instrument quantifies incident solar irradiance at three different UVR wavelengths (305, 320, and 380 nm) as well as visible wavelengths of photosynthetically active radiation (PAR, 400–700 nm). The submersible BIC is paired with a deck cell radiometer to provide the user with surface reference values that allow calculation of subsurface UV relative to surface UV levels. The total time necessary for equipment setup and taking of the UV profile is approximately 20-30 minutes per site, and faster if the equipment is left set up and multiple sites are sampled on the same day (for example, taking multiple nearshore profiles from a boat) The BIC connects to a laptop computer for data-acquisition through Windows-based LoggerLight software. A Microsoft Excel template can be used to estimate K_d values from BIC profiles.

To operate the BIC with LoggerLight follow the instructions below:

1) Plug BIC surface and underwater sensors into Digital Signal Manifold (small gray box); plug 9 pin serial cable to USB-serial converter, and converter into laptop.

2) Click on LoggerLight Icon to start program.

3) **Go to EDIT OPTIONS menu and be sure box is checked for "rapid sampling**, maximum rate, no statistics" to permit sampling data at maximal rate during profile (or set selected time interval to log ambient UV with no profiling).

4) **Take a "dark" reading for 2 minutes each day that you sample**. Put the black covers on the deck cell and submersible sensors and record data for 2 minutes. Be sure to insert a comment that says that this is a dark reading. This will help determine if there is sensor drift.

5) **Reset the field offset value to zero the depth sensor before sampling each day:**

a) Put the BIC submersible sensor in the water with the top at the water surface.
b) From EDIT menu, select DARK CORRECTION, check the **depth box only.**
c) Click on the "Correct Selected" and then "Save" to use these values.

This will give you a depth offset that is close to zero and easier to see and work with where barometric pressure varies with elevation or weather.

6) **Take the light profile.** Collect 10 seconds of data above the surface (sensor entirely out of the water) and 10 seconds of data just below the surface (sensor entirely submerged, but as near to surface as possible). Go very slowly in high DOC sites because UV attenuates very rapidly. You can go faster in low DOC where UV penetrates more deeply.

7) For both light and dark profiles, to start data collection depress "recording" button in upper left of screen. The button will be black when off and red when it is recording.

8) **Once recording has started press the comments button** and record the following comments for each file (including the dark reading):

a) **User names(s)** – enter who is operating the computer and any assistants.

b) **Name of lake profiled**, with **note that says "DARK" for the dark reading**.

c) **Weather** (percent sun/cloud, wind) and any other relevant notes.

Record the comment at the end of the profile to avoid corrupting the data stream. The best way to do this is write the comment and leave it covering the record button. Then when the profile is done, press the RECORD button in the comment box and then immediately press the RECORDING button to stop the profile.

9) After you have finished profiling, close Logger Light. Data files will be automatically saved to a designated folder.

IMPORTANT NOTE: UV profiles should be taken between 10 AM and 4 PM, preferably on clear calm days.

A-3- Lake Tahoe Region Aquatic Invasive Species Management Plan key objectives (USACE 2009)

- Identify habitats that are predicted to support all life stages of warmwater fish (Objective D.2.c)
- Develop a plan that includes long-term monitoring, prevention, and rapid response (Obj. E.3.f)
- Understand life histories and environmental requirements of current and potential AIS (Obj. F)
- Identify limiting factors for survival (Obj. F.2.b)
- Develop a detailed matrix to identify at risk sites (Obj. F.2.c)

A-4- Table of water temperature at 1 m for all sites May-Oct 2009

Table A-4. Temperature (°C) at 1 m depth (or max depth as indicated in parentheses) for all sample sites from BIC profiles. Sampling dates were from 2009 as follows: May 12-13, June 18-20, July 16-18, Aug 27-29, Oct 1-2.

SITE	MAY	JUNE	JULY	AUG	OCT
CRYSTAL BAY	11.0	16.8	18.8	21.3	18.1
SAND HARBOR	11.1	15.2	18.1	20.7	18.7
CAVE ROCK		15.4	17.7	19.6	17.8
ROUND HILL PINES		16.0	19.6	19.5	17.2
TAHOE KEYS	17.3	19.8	22.7	20.9	16.4
TAYLOR CREEK		20.6 (0.72)	23.7 (0.47)	17.9 (0.91)	12.7 (0.42)
EMERALD BAY BEACH	11.5	16.4	19.9	20.1	17.7
EMERALD BAY RIVER	7.3 (0.74)	13.0 (0.44)	18.3 (0.72)		16.4 (0.35)
MEEKS BAY		16.0 (0.8)	18.7 (0.7)	18.2 (0.7)	11.8 (0.86)
SUNNYSIDE	9.4	14.0	17.1	20.0	17.3
STAR HARBOR		14.3 (0.83)	17.0 (0.81)	18.9	8.2 (0.83)

A-5- 'Natural' DOC signals

In some sites low underwater UV levels may result primarily from 'natural' DOC fluxes (e.g. increased DOC during spring snowmelt). In these areas, 'management' towards UVAT attainment goals may not be practical. For sites where underwater UV is low primarily as a consequence of 'natural' (often seasonal) DOC concentrations management efforts should center on nest monitoring during periods of high DOC. For example, nearshore sites at the mouth of tributaries like Emerald Bay at Eagle Falls and Meeks Bay showed seasonal DOC signals that reduced UV transparency in mid-June.