Aquatic Invasions (2008) Volume 3, Issue 1: 35-41
doi: 10.3391/ai.2008.1.1.7(Open Access)

Special issue "Invasive species in inland waters of Europe and North America: distribution and impacts"
Sudeep Chandra and Almut Gerhardt (Guest Editors)

Research Article

Distribution and impacts of warm water invasive fish in Lake Tahoe, USA♣

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Received: 6 October 2007 / Accepted: 6 February 2008 / Published online: 23 March 2008

Abstract

In the last 125 years numerous invasive species have been introduced into Lake Tahoe. In recent years there has been an invasion of warm water fishes including largemouth bass [*Micropterus salmoides* (Lacepède, 1802)], and bluegill [*Lepomis macrochirus* (Rafinesque, 1820)]. These species threaten to displace and decrease native fish populations, and reduce nearshore water clarity. It is believed, with the help of climate change increasing lake temperature, these species are spreading to other areas from established populations on the south shore. Our objective was to determine current distribution and the potential impacts of warm water nonnative fishes. Snorkel surveys were conducted bi-weekly from May to November 2006 and electrofishing was conducted four times within the snorkel survey period at locations where warm water species are already established. Snorkel surveys and electro-fishing revealed that 57% of monitored sites contained warm water nonnative fish species. At electro-fish sites, number of native fish decreased with increasing nonnative fish species. Comparing historical and current diet data of natives and nonnatives indicated the latter are consuming the same diet items that native fish consumed historically. As a result, where nonnative and native fish habitats overlap, predation on and competition with native fish is likely. Current distributions of nonnative species found during this study are where the next established populations can be expected if their spread is not controlled.

Key words: aquatic invasion impacts, habitat overlap, invasive fish, native fish declines, warm water fishes

Introduction

Nonnative fish introductions are commonly associated with reduced food web efficiency, extirpation or reduction of native species, and decreased sport fishery production (MacRae and Jackson 2001; Pimentel et al. 2000; Vander Zanden 1999). Lake Tahoe, with an extensive history of nonnative aquatic species introductions, has exemplified all the post invasion impacts mentioned above (Vander Zanden et al. 2003b; Tassell et al. 2000; Goldman et al. 1979). Aquatic species introductions before the 1980's were done intentionally to increase sport fishery production, but the opposite effect resulted when growth rates of top fishery species were reduced (Clarke and Bennett 2002, Tassell et al. 2000). In the late 1980's a suite of warm water fish species were observed in a near shore marina, the Tahoe Keys. These species are thought to have been illegally introduced by anglers (Reuter and Miller 2000).

In Lake Tahoe warm water nonnative fishes, particularly largemouth bass [(*Micropterus*

♣ This paper was presented at the special session "Ecology and Ecotoxicology of Invasive Species in Inland Waters" of the 30th Congress of the International Association of the Theoretical and Applied Limnology (SIL), August 12-18, 2007, Montreal, Canada

salmoides (Lacepède, 1802)] and bluegill [*Lepomis macrochirus* (Rafinesque, 1820)], could reduce food web efficiency and decrease biodiversity of fish assemblages (MacRae and Jackson 2001). Forage fish communities have shifted, declined in abundance, and decreased in biodiversity in lakes after large and smallmouth bass [*Micropterus dolomieu*(Lacepède, 1802)] introductions (Betolli et al. 1992; MacRae and Jackson 2001; Vander Zanden et al. 2003a). Moyle and Nickols (1973) found bluegill presence in Sierra Nevada foothill streams were negatively correlated with percent native fish present. Littoral fish species richness was lower in Adirondack lakes with introduced largemouth bass compared to lakes without (Findlay et al. 2000). Also fish introductions are not without economic cost. It is estimated that non-native fish introductions in the U.S. have caused an annual loss of 1 billion dollars (Pimentel et al. 2000). Thus determining the current distribution of these nonnative fish is important to managers and limnologists.

Ongoing studies at Lake Tahoe are testing the hypothesis that climate warming and local land use practices (i.e. marina development) are expanding warm water fish distribution around the lake by increasing the amount of thermally suitable habitat. Coats et al. (2006) report increases in water temperature at deep and shallow depths in Lake Tahoe over the last 33 years. As water temperatures respond to air temperatures with high predictability, increasing air temperatures associated with global climate change could amplify lake warming (King et al. 1999). Locally, marinas and embayments experience elevated water temperatures throughout summer months due to lack of mixing with the main body of the lake. This facilitates growth of aquatic weeds including nonnative Eurasian watermilfoil [*Myriophyllum spicatum* (Linnaeus, 1753)], and curly leaf pondweed [*Potamogeton crispus* (Linnaeus, 1753)]. The combination of these local and global effects is likely to favor proliferation of warm water fish species over time.

The objectives of this paper are to: a) determine current distribution and relative abundance of two warm water nonnative fish species, largemouth bass and bluegill, within Lake Tahoe, b) sample established populations in Tahoe Keys and Taylor creek by electrofishing to determine their abundance compared with native fishes, and c) discuss potential impacts of nonnative fish on native fishes.

Methods

Study Site

Lake Tahoe (N39º W120º) is a sub-alpine oligotrophic lake in the Sierra-Nevada mountain range on the California-Nevada border, USA. Our study was conducted at several locations on the Lake Tahoe shoreline (Figure 1). Boat electrofishing occurred at three locations where established populations of warm water nonnative species are known to exist: Tahoe Keys East, Tahoe Keys West, and Taylor Creek on the 26 May, 15 Jun, 22 Aug, and 26 Oct 2006.

The Tahoe Keys is a housing development on the south shore constructed in the mid-1960's within the Upper Truckee Marsh. The Upper Truckee River once flowed through the Tahoe Keys, but was diverted to prevent flooding. The developed property is over 150 acres in size and contains two separate marinas. The larger marina is residential and contains boating channels for resident boat traffic. The residential marina lies to the west of the smaller inland commercial marina which makes up the other portion of the Tahoe Keys. These marinas are referred to as Tahoe Keys West and Tahoe Keys East respectively (Figure 1). Two boating channels, one for the commercial, and one for the residential section of Tahoe Keys are the only sites for surface water exchange with the main body of the lake. Aquatic vegetation is abundant in the Tahoe Keys where control of nonnative Eurasian watermilfoil can cost up to $150,000 annually (Eiswerth 2000).

Taylor creek is 2.6 km in length and originates 152 m above Lake Tahoe at Fallen Leaf lake dam. Electrofishing occurred in the 6 acre lagoon at the mouth of Taylor creek. The shallow lagoon lies four shoreline km west of Tahoe Keys and is inundated with aquatic vegetation including Eurasian watermilfoil, curly leaf pondweed and native American waterweed (*Elodea canadensis* Michx.). Elevated summer temperatures and abundant aquatic vegetation in the Tahoe Keys and Taylor Creek lagoon provide suitable conditions for establishment of warm water nonnative fish species.

Snorkel Survey

For the purposes of this study, the Tahoe Keys and Taylor creek are referred to as marina or embayment sites. 'Marina/embayment' sites contain constructed walls, or piers, or geographic features (e.g. sand bar) that prevent nearshore-

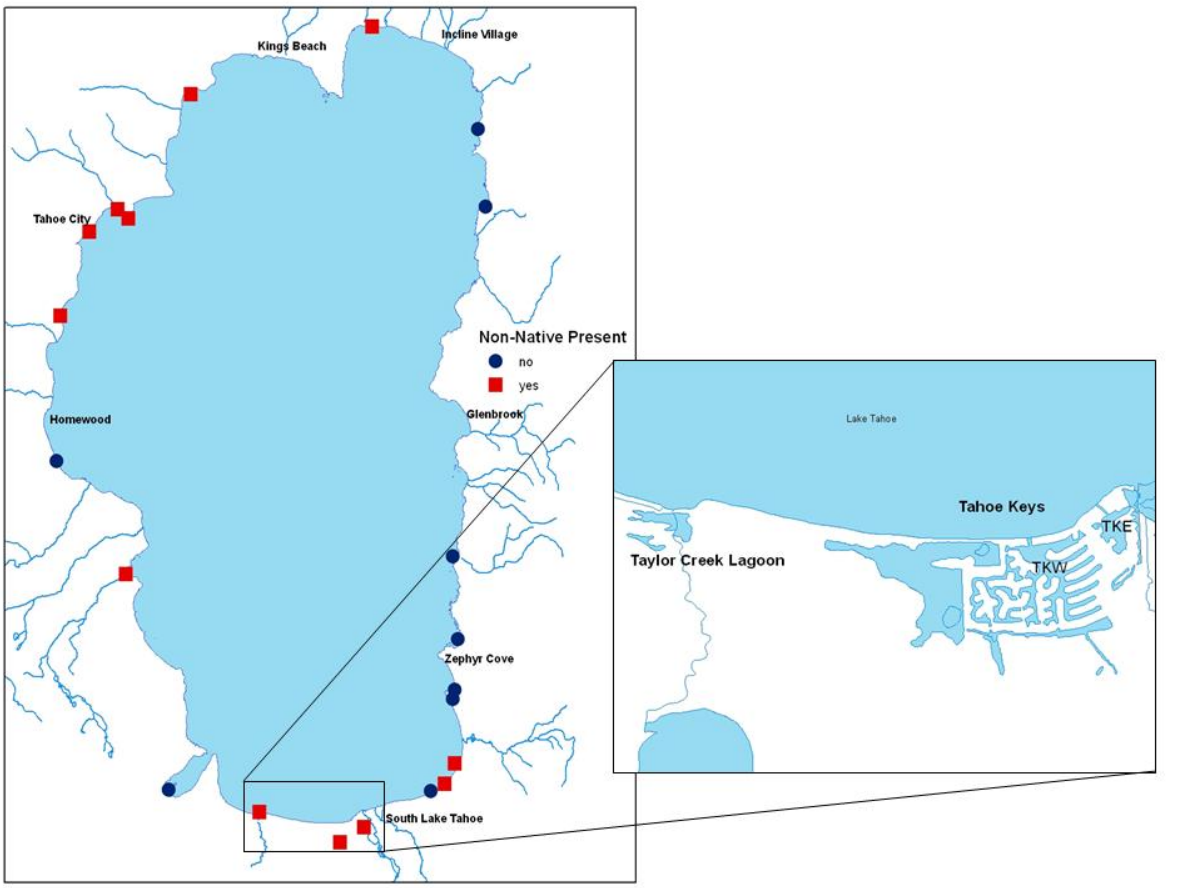

Figure 1. Squares indicate that at least one warm water nonnative species was present during at least one snorkel survey period from May to November 2006. Circles indicate that nonnatives were never detected. The two squares that appear on land are located in Tahoe Keys West (TKW) and Tahoe Keys East (TKE) residential and commercial marinas respectively. Electroshock sampling locations, TKW, TKE, and Taylor Creek, are shown in the inset map.

offshore water mixing 'Non-marina' sites are free of features that would inhibit nearshore-offshore water mixing. 'Non-marina' sites were considered control habitats where nonnative species are not expected. A total of 13 marina sites, and 8 non-marina sites were included in this survey.

All sites in Figure 1 were snorkeled bi-weekly May to November 2006, excluding three non-marina sites on the east shore that were snorkeled three times total. Bi-weekly surveys consisted of up to 45 minute snorkeling and above water observations. During each survey, presence or absence of native fishes and warm water nonnative fishes were recorded. Temperature was taken within a meter of the surface every 3 hours at all survey sites by DS1921Z-F50 i-button thermistors (Embedded Data Systems).

Electrofish

Shock time was measured by a timer on the electrofish boat. When the timer was inoperable, shock time was kept with a watch. Shock time was complete when the site appeared exhausted of fish in designated shock areas determined on the first sampling date. Taylor Creek was electrofished an average of 1513±427 seconds during all months. Tahoe Keys East was electrofished an average of 1750±312 seconds, and Tahoe Keys West 1508±207 seconds. Lengths

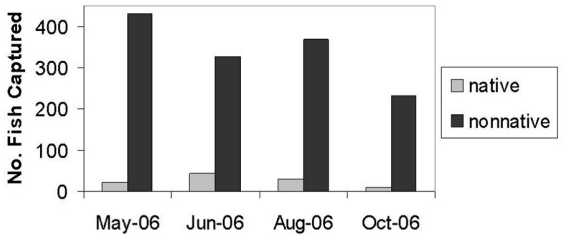

Figure 2. Nonnative fish captured are shown by black bars. Gray bars indicate number of native fish captured. Average shock time May, June, August and October was 1590 ± 319 seconds.

Table 1. Species list of fishes captured in Tahoe Keys East and West during electrofishing in May through October 2006. Species indicated by * are native. All other species are nonnative. Largemouth bass and bluegill were the most abundant species captured.

Common Name	Scientific Name
Largemouth Bass	*Micropterus salmoides* (Lacepede, 1802)
Bluegill	*Lepomis macrochirus* (Rafinesque, 1820)
Brown Bullhead Catfish	*Ameiurus nebulosus* (Lesueur, 1819)
Black Crappie	*Pomoxis nigromaculatus* (Lesueur, 1829)
Goldfish	*Carassius auratus* (Linnaeus, 1758)
Brown trout	*Salmo trutta* (Linnaeus, 1758)
Rainbow trout	*Oncorhynchus mykiss* (Walbaum, 1792)
*Tahoe Sucker	*Catostomus tahoensis* (Gill and Jordan 1878)
*Tui chub	*Gila bicolor* (Girard 1856)
*Lahontan shiner	*Richardsonius egregious* (Girard, 1858)
*Lahontan speckled dace	*Rhinichthys osculus robustus* (Girard, 1856)

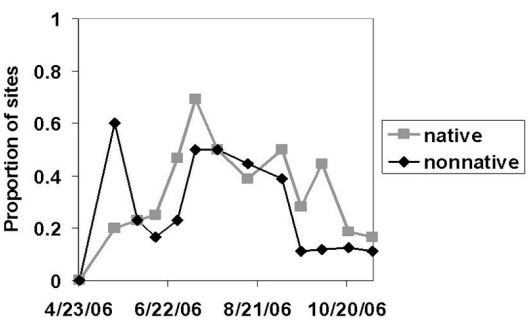

Figure 3. Proportion of marina and embayment snorkel sites that were occupied by nonnative and native fish during May to November 2006.

and weights of native fish were taken on site when possible and then released. Warm water nonnative species were asphyxiated, kept on ice, and processed in the lab the next day.

Diet analysis

Diets of 684 nonnative fish were analyzed (394 bluegill, and 290 largemouth bass). Invertebrates were sorted to taxonomic order, fish and plant were identified to species when possible. All diet items were dried in a vacuum oven for 24 hours at 89°C, and then weighed on a micro-balance. Bluegill were separated into size classes with 40 mm intervals but classes were pooled in this analysis. Largemouth bass were separated into small (0-119 mm), medium (120-239 mm), and large (+240mm) size classes. Percent frequency occurrence was calculated as the quotient of the number of times an item appeared in a stomach divided by the number of stomachs analyzed in a given size class.

Results and discussion

A total of 11 species were captured by electrofishing in the Tahoe Keys in 2006 (Table 1) with largemouth bass and bluegill in highest abundance. Numbers of nonnative fish captured were consistently higher than native fish (Figure 2) in May, June, August, and October. The numbers captured from the Tahoe Keys reinforce previous hypotheses (Chandra et al., unpublished data, 1999) that when warm water nonnative fishes were present, native populations were depressed due to predation and competition from warm water nonnative fish. In the early 1990's warm water fish species were rarely found around the lake while native minnows remained abundant. By the end of the decade largemouth bass and bluegill were common while Lahontan redsides [(*Richardsonius egregius* (Girard, 1858)] and speckled dace [*Rhinichthys osculus robustus* (Girard, 1856)] populations declined or were virtually eliminated from the Tahoe Keys, an important rearing ground for native fishes (CDFG, unpublished data).

Only largemouth bass and bluegill had widespread distributions outside of the Tahoe Keys and Taylor Creek. Both nonnative species were present in 57% of snorkel sites for a minimum of one survey period (Figure 1). Nonnative species were present at 84.6% of marina sites and 12.5% of non marina sites. Bluegill were present at one

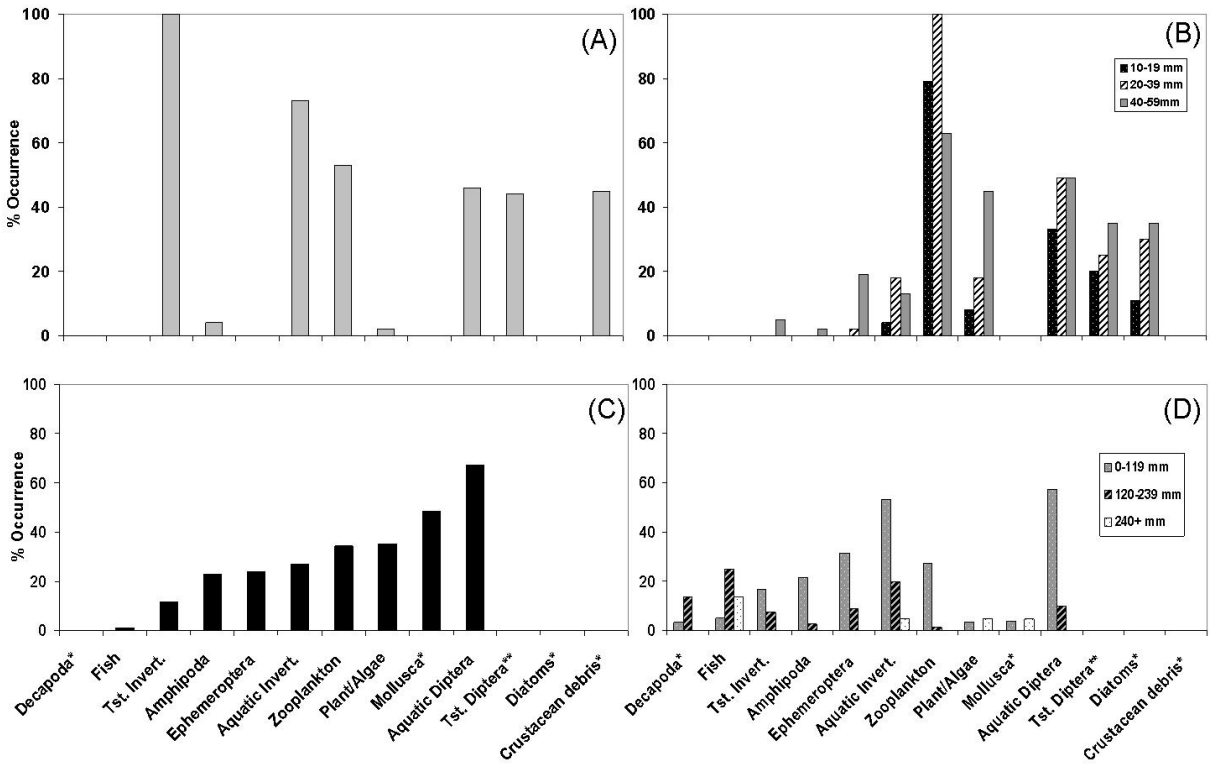

Figure 4a-d. Percent frequency occurrence for: (A) Lahontan redsides (n=102) Evans 1969); (B) Speckled dace (n=221). Data are shown for three size classes originally reported in Tucker 1969; (C) Bluegill (n=394) this study); and (D) largemouth bass (n=290) (this study) for three size classes of fish, small (0-119 mm), medium (120-239 mm), and large (>239 mm). Data are pooled for species where size class data are unavailable, or if species do not exhibit ontogenetic diet shifts. *These are unique diet items reported in only one study; where these values are blank this does not infer a 0% occurrence, rather data for such category were not reported or were categorized elsewhere. **Terrestrial Diptera were included in the terrestrial invertebrate category for bluegill and largemouth bass (Figure 4c-d).

non-marina site on the north shore from 10 July to 14 August. Largemouth bass and bluegill were present at the highest number of sites on 10 July 06. After 10 July the number of sites with nonnatives present decreased, and by 19 September nonnative species were absent for the remainder of the survey period with the exception of two marina sites on the south and east shore. Native fishes were also present in highest proportion of surveyed sites on 10 July 06. Snorkel observations indicated the greatest period of overlap between native and nonnative species began on or near 10 July and lasted through August 06 (Figure 3).

Lahontan redsides typically begin spawning in early June, and young of the year are abundant by mid August (Evans 1969). Largemouth bass and bluegill were present in marinas adjacent to spawning habitat and streams used by native fishes for spawning, feeding, and cover (Metz et al. 2007). Largemouth bass and bluegill were also found in complex habitats where native fish densities are high (Beauchamp et al. 1994). Consequently, the period of greatest overlap between native and nonnative fish is during critical spawning and rearing periods of Lahontan redsides and speckled dace (Evans 1969; Tucker 1969; Miller 1951). From these data alone we cannot infer that native fish species are decreasing because nonnative fish are present. However, because habitat overlap between native and nonnatives is highest during

spawning and rearing of the former, predation and competition is likely to have a negative effect on the native fishery.

Diet analysis of largemouth bass and bluegill from this study were compared to historical diet data for Lahontan redsides and speckled dace (Evans 1969; Tucker 1969). Percent of frequency occurrence for each diet item was compared among all species (Figure 4a-d). Zooplankton, and aquatic invertebrates, particularly diptera were prominent in diets of all four species. Zooplankton occurred in at least 50% of native fish diets, including 100% occurrence in medium sized speckled dace, while zooplankton occurred in over 60% of nonnative diets. Together zooplankton and aquatic invertebrates occurred in nearly 100% of native and nonnative diets indicating they are major dietary components for all species. Our comparison is limited by using historical data, but indicates potential competition for food is high if current native fish diets resemble those reported by Evans (1969) and Tucker (1969).

Current nonnative diet data show that largemouth bass and bluegill are piscivorous and could place increasing stress on native fish populations. Both native and nonnative fish occurred in 43.1% of all largemouth bass specimens. Predation pressure, coupled with potential dietary competition, will likely threaten an already declining native fishery (Thiede 1997) if warm water nonnative fish species become well established in Lake Tahoe.

Warm water fishes appear well established in only the Tahoe Keys and Taylor Creek. Although nonnatives were present in 57% of snorkel sites, only one to 16 largemouth bass and bluegill fishes were present at the remaining snorkel sites. As water temperatures continue to increase, areas currently with small nonnative populations will become increasingly susceptible to establishment. We know from the current distribution of warm water nonnative fish reported here where establishment of warm water nonnatives and the effects that follow are expected next.

Acknowledgements

Funding was provided by Barak Shemai (the US Forest Service Lake Tahoe Basin Management Unit), Elizabeth Harrison (Nevada Statelands: Nevada License Plate Fund), and the University of Nevada. Kyle Murphy, Jay Rowan, and Stafford Lehr (California Department of Fish and Game) assisted in field collection. The Tahoe Keys Homeowner's Association, Tahoe Keys marina management, and other marina operators acted as cooperators in this study. M. Jake Vander Zanden, Brian Shuter, and Christine Ngai provided thoughtful insight during the develop-ment of this project. Laboratory staff (Kyle Ranyak, Annie Lassaline, and Chase Korsmo) in the Limnology Laboratory at the University of Nevada assisted in lab and field sample processing.

References

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, http://dx.doi.org/10.1577/1548-8675(1994)014<0385:SHUBLZ>2.3.CO;2

Betolli PW, Maceina MJ, Noble RL, Betsill RK (1992) Piscivory in largemouth bass as a function of aquatic vegetation abundance. *North American Journal of Fisheries Management* 12: 509-516, http://dx.doi.org/10.1577/1548-8675(1992)012<0509:PILBAA>2.3.CO;2

Clarke LR, Bennett DH (2002) Newly emerged kokanee growth and survival in an oligotrohpic lake with *Mysis relicta*. *Transactions of American Fisheries Society* 131: 176-185

Coats R, Perez-Losada J, Schladow G, Richards R, Goldman CR (2006) Lake Tahoe is getting warmer. *WMC Networker Spring* 2006: 17-21

Eiswerth ME, Donaldson SG, Johnson WS (2000) Potential Environmental Impacts and Economic Damages of Eurasian Watermilfoil (*Myriophyllum spicatum*) in Western Nevada and Northeastern California. *Weed Technology* 14: 511-518

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

Findlay CS, Berg DG, Zheng L (2000) Effect of introduced piscivores on native minnow communities in Adirondack lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 570-580, http://dx.doi.org/10.1139/f99-276

Goldman CR, Mogran MD, Threlkeld ST, Angeli N (1979) Population dynamics analysis of the cladoceran disappearance from Lake Tahoe, California-Nevada. *Limnology and Oceanography* 24: 7-26, http://dx.doi.org/10.4319/lo.1979.24.2.0289

King JR, Shuter BJ, Zimmerman AP (1999) Empirical links between thermal habitat, fish growth, and climate change. *Transactions of the American Fisheries Society* 128: 656-665, http://dx.doi.org/10.1577/1548-8659(1999)128<0656:ELBTHF>2.0.CO;2

MacRae PSD, Jackson DA (2001) The influence of smallmouth bass (*Micropterus dolomieu*) predation and habitat complexity on the structure of littoral zone fish assemblages. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 342-351

Metz J, Herold M, Romosos JS (2006) Mapping fish habitats in Lake Tahoe for planning and management, Donald Bren School of Environmental Science and Management, University of California- Santa Barbara, Santa Barbara, 17 pp

Moyle PB, Nickols RD (1973) Ecology of some native and introduced fishes of the Sierra Nevada foothills in central California. *Copeia* 3: 478-490, http://dx.doi.org/10.2307/1443113

Pimentel D, Lach L, Zuniga R, Morrison D (2000) Environmental and economic costs of nonindigenous species in the United States. *Bioscience* 53: 53-65, http://dx.doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2

Reuter JE, Miller WW (2000) Aquatic resources, water quality and limnology of Lake Tahoe and its upland watershed. pp 150-166, Department of the Interior, US

Tassell JJV, Beauchamp DA, Thiede GP, Gemperle CK, Richards RC, Goldman CR (2000) Kokanee and Mysids influence on zooplankton dynamics and nutrients recycling in Lake Tahoe. Annual Progress Report: Tahoe Research Group, University of California-Davis, Davis

Thiede G, Beauchamp D, Kershner M (1997) Impact of lake trout predation on prey populations in Lake Tahoe: a bioenergetics assessment, Department of Fisheries and Wildlife, University of Utah, Logan, 40 pp

Tucker T (1969) Diet of Lake Tahoe Speckled dace (*Rhinichthys osculus robustus*), San Francisco State College, 42 pp

Vander Zanden JM, Casselman JM, Rasmussen JB (1999) Stable isotopoe evidence for the food web consequences of species invasions in lakes. *Nature* 401: 462-467, http://dx.doi.org/10.1038/46762

Vander Zanden JM, Chandra S, Allen BC, Reuter JE, Goldman CR (2003b) Historical Food Web Structure and Restoration of Native Aquatic Communities in the Lake Tahoe (California-Nevada) Basin. *Ecosystems* 6: 274-288, http://dx.doi.org/10.1007/s10021-002-0204-7

Vander Zanden JM, Olden JD, Thorne JH, Mandrak NE (2003a) Predicting occurrences and impacts of smallmouth bass introductions in north temperate lakes. *Ecological Applications* 14: 132-148, http://dx.doi.org/10.1890/02-5036