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Dairy Meadows in autumn, Taylor Creek watershed, South Lake Tahoe, California.

Waterbirds (including ducks, shorebirds, and rails) are special-status species that find their primary habitat in lakeside marshes. Their populations have fallen in response to the loss of much of Pope Marsh to development in the 1960s (Manley et al. 2000). The TRPA has conducted surveys of key marshes around the lake for the past 7 years, and their findings are summarized in the Pathway planning documents.[8]

These issues and uncertainties suggest the following management questions:

- What management actions will contribute to restoring and sustaining desired ecological values and biodiversity in Lake Tahoe's lakeside marsh and beach habitats?
- What ecosystem attributes should be subjected to monitoring to assess the effectiveness of management actions directed at lakeside marsh and beach habitats?

Research Needs

Following are lakeside, beach, and marsh research questions:

(**LM1**) For shoreline plants of concern, does the spatial extent of existing populations support life-history requirements (including access to pollinators, disturbance regimes, seed dispersal)? What environmental factors most affect the persistence,

[8] Kelchlin, E. 2007. Personal communication. Wildlife biologist, Tahoe Regional Planning Agency, 128 Market Street, Stateline, NV 89449.

extent, and reproductive success of populations at a given site? Are there genetic strains of shoreline plants that are more robust to environmental stressors, thus conferring enhanced survival?

(**LM2**) What is the ecological status of marsh habitats in the basin, and what measures can be taken to retain and restore their ecological integrity?

(LM3) What performance measures—including presence and abundance of plants and animals and other ecological metrics—can be used to assess treatment effects and effectiveness in maintaining, restoring, and rehabilitating the biological diversity and ecological function, and to monitor conditions in marsh and beach habitats?

Aquatic Ecosystem Restoration

The ecology of the aquatic ecosystems within the Lake Tahoe watershed has been altered dramatically over the last two centuries. Most of our knowledge of historical change has focused on alterations to Lake Tahoe itself; however, lakes, streams, and meadows within the upper watershed also have been altered resulting in the increased need to manage these ecosystems. In this section, we differentiate Lake Tahoe and other aquatic ecosystems to assist in interpreting the change and research needs for these distinctive ecosystems. We focus specifically on alterations from eutrophication, potential changes owing to atmospheric loading of nitrogen, and the influence of nonnative species (plant and animal) on the restoration or management of native biota.

Lake Tahoe

Prior to large changes in community structure and conditions of nutrient loading brought about by human activities, Lake Tahoe's community assemblage was relatively simple with 12 orders of zoobenthic taxa, 6 zooplankton species, and 8 fish taxa (Chandra 2003, Frantz and Cordone 1996, Juday 1906, Miller 1951, and Vander Zanden et al. 2003). The benthic invertebrate community supported one endemic, wingless form of stonefly. Beginning in the mid to late 1800s, species introductions combined with landscape disturbances started to alter the lake's biology.

The preinvasion food web (circa 1872) was dominated by a single predator, Lahontan cutthroat trout (*Oncorhynchus clarki,* subspecies *henshawi*), which fed primarily on pelagic tui chub (*Siphateles bicolor pectinifer*) and zooplankton (Chandra 2003, Juday 1906, Vander Zanden et al. 2003). Forage fishes obtained energy from a mix of benthic and pelagic primary production sources. By 1939, cutthroat trout were extirpated from Lake Tahoe, and a lake trout (*Salvelinus namaycush*) population replaced them as the top predator (Cordone and Frantz

1966). Three primary reasons for the demise of cutthroat trout were predation from introduced lake trout, the degradation of spawning stream habitat from increased siltation owing to watershed deforestation (Moyle 2002), and the hybridization of cutthroat trout with rainbow trout owing to hatchery propagation.[9] There have been several attempts to reestablish both fluvial (stream form) and lacustrine (lake form) cutthroat populations in the Tahoe basin, all of which failed. As part of the U.S. Fish and Wildlife Service recovery plan for cutthroat trout (Coffin and Cowan 1995) in its native range, efforts have begun to restore cutthroat in Fallen Leaf Lake, located in the southern end of the basin.

Crayfish (*Pacifastacus leniusculus*) were introduced multiple times into Lake Tahoe and were established by 1936; they are now found in large numbers (55 million in the late 1960s and 230 million by early 2000 (Abrahamsson and Goldman 1970, Chandra and Allen 2001). Studies suggest that, under low densities (0.16 adult/m^2), the crayfish stimulate periphyton productivity by removing old senescent cells (Flint 1975). Today, crayfish do not contribute to the energetics of nonnative lake trout except for the largest size classes (>50 cm).

Chandra et al. (2005) investigated the effects of cultural eutrophication on the coupling between pelagic primary producers and benthic consumers in Lake Tahoe. At depths where ambient light levels equal 1 percent (which have shifted with time from 50 to 85 m), pelagic primary producer and zoobenthic consumer coupling was positive. Historically, the zoobenthos from this depth zone obtained 32 percent of their energy from phytoplankton sources; after 43 years of eutrophication, they obtained 62 percent of their energy from those sources. A simple model indicated increased pelagic production and resultant export of matter, combined with the loss of benthic primary production, has contributed to the change in zoobenthos energetics. Recent samplings of zoobenthos during 2008–09 suggest there may be a 50 to 80 percent loss in benthic invertebrate density and biomass in Lake Tahoe. Furthermore, there has been a substantial decrease in the density of native, endemic invertebrates such as the blind amphipod and more cosmopolitan invertebrates such as oligochaete worms (Chandra and Caires 2001). Whether this loss is due to a shift in pelagic to benthic coupling or from alterations to Mysid shrimp is unclear (see below).

The establishment of the invertebrate *Mysis relicta*, corresponded with shifts in the trophic niches of forage fishes (chubs) and the top predator lake trout, and a feeding shift of lake trout to pelagic energy sources. The resultant increase in lake trout may have increased predation rates on native forage fishes and decreased

[9] Cordone, A.J. 2007. Personal communication. Fisheries biologist, retired. California Department of Fish and Game, 1416 Ninth Street, Sacramento, CA 95814.

their abundance (Vander Zanden et al. 2003). Growth rates of lake trout before and after mysid introduction do not appear to have changed, except in the smaller size classes. Post *Mysis* invasion studies in Lake Tahoe showed impacts on other biological components of the lake. A strong restructuring of the zooplankton community as a result of *Mysis* predation on native cladocerans occurred, shifting the lake's pelagic environment to a *Mysis* and copepod-dominated system. Furthermore, modeling and empirical measurements suggest mysids may be influencing the carbon dynamics at the sediment-water interface as they feed in the deep part of the lake during the daytime and resuspend sediment particles through excretion during the nighttime as they migrate to the pelagic zone (Chandra 2003). Thus the insertion of *Mysis* into the middle of the food web played a strong determining role in restructuring upper trophic level energetics, and in disrupting community dynamics in the middle and lower parts of the food web. Their role and impact at lower depths is unclear; however they may be playing a role in disrupting carbon dynamics in the deepwater and pumping particles back into the water column.

In the mid to late 1970s, and again in the late 1980s, a variety of nonnative species were discovered in the near-shore environment, primarily driven by the establishment and expansion of nonnative aquatic plants, which provided habitat and refugia for nonnative fishes. The warm-water fish introductions were illegal and thought to be the result of anglers eager to catch these fish. During that period, in the Tahoe Keys, a major rearing area of native fishes, warm-water fish species were rarely found, whereas native minnows remained abundant as evidenced by a snapshot sample obtained in 1999; however, by 2003, largemouth bass (*Micropterus salmoides*) were common, whereas redside shiner (*Richardsonius balteatus*) and speckled dace (*Rhinichthys osculus*) populations declined or were virtually eliminated from the Tahoe Keys (Chandra 2009, Kamerath 2009). The change in fish structure was substantiated by fishing guides operating out of the Tahoe Keys: within a decade they could no longer collect the minnows that were commonly used as bait by fishing charters on the lake.

Until 1994, no lakewide surveys for rooted aquatic macrophytes had been conducted in efforts to document the presence of nonnative species. Early reports (1975) of water milfoil species near Taylor Creek did not identify the species of *Myriophyllum*, nor were vouchers or photographic records made. However, severe impacts from aquatic plants were observed in the Tahoe Keys by the end of the 1970s and early 1980s, during which time mechanical harvesting was begun. Recent studies have documented the role of some of the invasion pathways and vectors (boats and boat trailers) for aquatic plants that are transported both to and away from Lake Tahoe (Wittmann 2008). These vectors contribute to issues of continued reinfestation and potential new infestations of nonnative aquatic plant species.

In 2008, established populations of the nonnative bivalve species, the Asian clam (*Corbicula fluminea*), were discovered in the southeastern portion of Lake Tahoe by University of California, Davis researchers during regular near-shore periphyton surveys. Asian clams were first detected in Lake Tahoe in very low numbers at Timber Cove in 2002 (3 to 20 clams/m^2—Hackley et al. 2008), and at Nevada Beach in 2003.[10] Extensive field surveys during summer 2008 revealed much higher densities of Asian clams (50 to 3,000 clams/m^2), suggesting evidence for local population growth and possible reintroduction from external populations. Asian clams in Lake Tahoe compete with other local native molluscan species, such as the montane pea clam (*Pisidium* spp.) and the ramshorn snail (Planorbidae). Its current known distribution (area ~1 million m^2) is patchy along the southeast shore of the lake from Zephyr Cove to El Dorado Beach, and is rapidly expanding and colonizing a variety of physical circumstances.

Knowledge Gaps

Lake Tahoe's ecological community has changed through the elimination of native trout, restructuring of food web energy flow, and introduction of species that occur in both the limnetic and littoral zones. It is unclear, however, how some of these introduced species are impacting near-shore and offshore water quality as well as native fish biomass and production. In addition, three special status species are primary participants in the Lake Tahoe food web—Lahonton cutthroat trout, osprey (*Pandion haliaetus*) and bald eagle. Populations of osprey and bald eagle are likely to be affected by changes in the relative and absolute abundance of fishes in Lake Tahoe.

Mysis shrimp are the lake's dominant macrozooplankton, exhibiting a large (up to 400 m) diel vertical migration to the lake bottom (Rybock 1978). While on the bottom, mysids feed on sediment detritus and may actively pump detritus and nutrients into the lake's limnetic zone (Chandra 2003). Research from other ecosystems suggesting mysids are supported by benthic detrital energy sources is supported by a number of studies (Lasenby and Lanford 1973, Lasenby and Vanduyn 1992, Lester and Mcintosh 1994, Song and Breslin 1999, Viherluoto et al. 2000). Many ecotoxicological studies have determined that *Mysis* ingest heavy metals and organochlorines directly from sediment (Lasenby and Vanduyn 1992, Lester

[10] Herbst, D. 2003. Personal communication. Aquatic invertebrate ecologist, University of California Sierra Nevada Aquatic Research Laboratory, HCR 79, P.O. Box 198, Mammoth Lakes, CA 93546.

and Mcintosh 1994, Song and Breslin 1999), and serve as a vector for contaminant transport to the pelagic zone. Gut content information also suggests mysids may derive a substantial amount of their energy from benthic resources, including zoobenthos and organic-rich sediment particles (Lasenby and Lanford 1973).

The effect of warm-water invasive species on the native fish community and the potential for recycling nutrients in the near-shore habitat are important uncertainties. Recent surveys suggest warm-water fish such as bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and catfish (*Ameiurus nebulosus*) are found around the lake. Recent assessment of their distribution indicated the densities are still very low compared to other ecosystems and can be variable over time. Overall the densities were low around most of the lake with higher densities in some locations such as Meek's Marina and intermediate densities in the Tahoe Keys. Anecdotal observations indicated that bass may be in open water areas of the lake; however, it is unclear the extent to which bass have established in these areas or if they were moving through migration zones before they reach more enclosed sites such as marinas and embayments (Chandra et al. 2009). Although preliminary research suggests these fish are competing and/or preying upon native fishes in the near shore (Kamerath 2009), the role that nonnative crayfish and other physical factors may play in controlling warmwater fish establishment as well as recruitment around the lake remains unclear. Crayfish are a preferred food source for bass in their native habitats. Currently, the invasive crayfish in Lake Tahoe seem to have expanded in population since estimates were first made in the 1970s, with over 230 million individuals in the lake estimated in 2001 (Chandra and Allen 2001). Current models that predict warmwater fish distribution (Chandra et al. 2009, Kamerath 2009) do not account for crayfish as a food resource in the lake and how they may contribute to bass growth and maintenance. Furthermore, using Lake Tahoe fishes researchers have found that ultraviolet light penetration may control recruitment of nonnative fishes and allow the persistence of native fishes.[11] Thus, there may be direct ties between the lake's clarity and the distribution of warmwater fishes. These two resource controls of food availability and physical light constrains should be incorporated into existing models predicting warmwater fish establishment in the lake to refine areas for monitoring as well as management.

The recent invasion of the near-shore area by warm-water species such as bass species could lead to the remobilization of nutrients in this habitat. Examination of seasonal nutrient availability is recommended, particularly during low flow periods, to determine the biological contribution of nutrients to near-shore

[11] Williamson, C. 2009. Personal communication. Professor in ecology, Miami University, Department of Zoology, Pearson Hall 158, Oxford, OH 45056.

production and lake clarity. The interactions between native and nonnative plants also are poorly understood. With the continued expansion of Eurasian water milfoil (*Myriophyllum spicatum*), and the newly expanded populations of curly leaf pondweed (*Potamogeton crispus*), the uncertainties of fish/plant interactions are even more complex.

Eutrophication of Lake Tahoe has led to a shift in energy flowing to the bottom of the lake (Chandra et al. 2005). It is unclear, however, if increased coupling between pelagic to benthic energy flows along with carbon alteration due to *mysid* shrimp are altering benthic invertebrate community structure and production—an issue of particular importance when trying to manage native, benthic biodiversity such as the endemic, wingless stonefly (*Capnia lacustra*) or blind amphipod (*Stygobromus* sp.) and in evaluating the potential for the reintroduction of native species.

Environmental impacts resulting from Asian clam establishment in Lake Tahoe related to water quality, benthic community structure and production, and the potential for the facilitation of invasion of other near-shore invasive species through habitat disturbance and localized increases in nutrient concentrations are uncertain. In particular, the Asian clam (1) excretes elevated levels of nitrogen and phosphorus into the water column and sediment substrate (Wittmann et al. 2008)—which can promote increased algal growth; (2) is able to filter extremely high volumes of water (Vaughn and Hakenkamp 2001)—potentially impacting both water quality and pelagic communities including Lake Tahoe sports fisheries; and (3) can increase levels of calcium through the concentration of dead shell matter—providing potential substrate and appropriate biochemical conditions for the establishment of other nonnative bivalve species such as the quagga (*Dreissena rostriformis bugensis*) and zebra mussel (*Dreissena polymorpha*). Current knowledge about the Asian clam in Lake Tahoe is limited because of the short time since its discovery. Continued efforts to assess the life history, environmental impact, and distribution, and to identify possible control and management actions in Lake Tahoe are underway.

Finally, little is known about the ecology and nutrient dynamics of Emerald Bay. This bay is an important destination for recreational boaters from various parts of the lake and particularly the Tahoe Keys, where most of Lake Tahoe's nonnative species issues currently reside. At least 8 nonnative species have been observed in Emerald Bay including but not limited to Eurasion watermilfoil, largemouth bass, catfish, Mysid shrimp, lake trout, crayfish, Asian clam, and kokanee salmon. Efforts to integrate and assess the limnology and food web ecology of this bay are recommended as it is likely that future invaders will establish in this location owing to the amount of propagule pressure occurring through boat traffic, Peter Goin

Kokanee spawning, Taylor Creek, South Lake Tahoe.

warmer temperatures, and increased productivity. Furthermore, due to its isolated nature and increased productivity compared with Lake Tahoe, this may be an important area for restoring the native Lahontan cutthroat trout.

These issues and uncertainties suggest the following key management questions:

- What management actions are necessary to restore and sustain a desired food web in Lake Tahoe, and will those actions be consistent with efforts to reverse declines in the lake's clarity?
- What are the appropriate measures of management and restoration program actions to assess their effectiveness in meeting ecosystem objectives?

Research Needs

Following are Lake Tahoe aquatic ecosystem research questions:

(**LT1**) What is the interaction between nonnative and native species in the basin, and how does this affect our ability to manage native biodiversity?

(LT2) What is the linkage between habitats (i.e., profundal-pelagic, littoral-pelagic) for carbon, phosphorus, and sediment transport particularly with the introduction of nonnative species? How does this affect Lake Tahoe water quality and clarity and native benthic invertebrate biodiversity?

(LT3) What is the seasonal role of mysid shrimp in controlling native plankton and benthic invertebrate populations and reducing water clarity through the transport of benthic nutrients and sediment particles into the water column? Ideally, research would focus on understanding the life cycle, contemporary feeding behavior, and the role mysid shrimp may play in reducing water clarity in Lake Tahoe.

(LT4) Can we predict future invaders (plant or animal) and the potential impacts to the lake's water clarity or biodiversity?

(LT5) Will current limnological characteristics support the establishment of non-native species or the potential recovery of native fish populations in Emerald Bay?

(**LT6**) What is the variability of benthic algal production and does this affect near-shore production and clarity? Will nonnative species alter this production? Future research is recommended to examine the production of benthic algae and invertebrates such as invasive crayfish to determine if eutrophication is affecting ecological community structure.

(LT7) What is the status of osprey and bald eagle populations in the basin, and how do their distribution, abundance, and productivity track changes in fish populations in Lake Tahoe?

(LT8) How can we best ensure the survival of native fish and other desired aquatic vertebrates? What stressors are affecting native species, and what can be done to lessen negative impacts?

(**LT9**) How can we restore native fishes and other aquatic vertebrates to the lake? What portions of Lake Tahoe are best suited to reintroduction efforts for native species? How will established nonnative species likely affect the success of restoration efforts?

(LT10) How can water quality and water clarity be protected from the effects of introduced species and human activities? What aspects of water quality and clarity are at most risk? What management actions might contribute to minimizing negative impacts from those sources?

(**LT11**) What is the current distribution of the Asian clam in Lake Tahoe, and what are its ecosystem-level impacts? How does it impact near-shore quality and the potential facilitation of the invasion of other nonnative aquatic species?

Other Aquatic Ecosystems in the Lake Tahoe Basin

Much of the research carried out in the Lake Tahoe basin has focused on understanding the impacts of watershed development, nutrient loading, water quality, and aquatic ecology in Lake Tahoe itself. Very little effort has been placed on evaluating the response of other lakes, streams, and other aquatic habitat types to the array of human disturbances affecting them, including ground disturbance, increased inputs from atmospheric pollution, and the impacts of nonnative species (fish, amphibians, plants) introductions.

The aquatic ecosystems research that has been conducted has been short term (seasonal or one-time assessments), primarily owing to funding constraints. For example, Marlette, Cascade, Fallen Leaf, Echo, and Spooner Lakes all have been evaluated for one or all of the following constituents: nutrient status (e.g., phosphorus, and nitrogen), basic physical and chemical measurements (e.g., dissolved oxygen, temperature, and pH), pelagic primary production, and zooplankton composition and biomass (e.g., Lico 2004, Reuter et al. 1996; University of California, Davis and University of Nevada, Reno 2003, 2006). In 2006, an effort was made to assess the nutrient concentrations via depth profiles and limitation (nitrogen, phosphorus, or co-limitation) for Upper and Lower Echo, Upper and Lower Angora, Fallen Leaf, Tahoe, Eagle, Spooner, and Marlette Lakes. Results showed the pelagic primary production in five lakes (Tahoe, Marlette, Fallen Leaf, Lower Echo, Lower Angora) was co-limited; Spooner Lake exhibited possible nitrogen limitation, and data from Eagle Lake were inconclusive (Chandra and Rost 2008).

Other research has focused on the ecology of some of the small lakes in the Tahoe basin. For example, Cascade Lake has a biological assemblage that closely resembles that of Lake Tahoe prior to the introduction of the two nonnative species (*Mysis relicta* and lake trout, *Salvelinus namaycush*). Vander Zanden et al. (2003) presented a food web structure for this lake in 2001, finding that hybridized cutthroat trout are a dominant predator feeding on pelagic energy sources (e.g., zooplankton). Since 2001, researchers from the Universities of California-Davis, Nevada-Reno, Wisconsin-Madison have been monitoring the biology and general limnology (nutrients, chlorophyll a) during spring, summer, and fall in Fallen Leaf Lake. This lake experienced the reintroduction of native Lahontan cutthroat trout (information on the bioenergetics, historical changes to the lake's fishery, and limnology can be found in Allen et al. 2006). The California Fish and Game and U.S. Forest Service have also attempted to control nonnative brook trout populations on an annual basis to promote the persistence of cutthroat trout in the Upper Truckee River and Meiss Meadows watershed. This effort of more than 10 years has promoted the recovery of native trout; however, the effect of removal of book trout on life history characteristics of cutthroat trout (including growth, survival, and condition) has not been evaluated on a regular basis. Limited food web and genetic information has been obtained for Stony Ridge and Gilmore Lakes.

Most amphibian species in the basin are primarily associated with standing water bodies. Pacific treefrog (*Hyla regilla*), long-toed salamander (*Ambystoma macrodactyla*), and western toad (*Bufo boreas*) are all primarily associated with standing water, although the two frogs are also found in streams. Stocking non-native fish creates large populations of predators that prey on larval amphibians. The U.S. Forest Service has conducted surveys of lakes throughout the watershed to determine the presence of fishes, amphibians, snakes, and waterbirds over the last decade. The limited distribution of most amphibian species has led to an analysis of genetic diversity by University of California, Davis, University of Nevada, Reno and U.S. Forest Service researchers[12] of three species: long-toed salamander, western toad, and mountain yellow-legged frog. These data are being analyzed to better inform restoration efforts and promote amphibian populations that have been shown to be in decline in the Sierra Nevada.

Based on research to date in and near the Lake Tahoe basin, nonnative trout are likely to be a primary factor limiting the distribution and population size of native amphibians there (Knapp and Matthews 2000, Manley and Lind 2005). Although fish stocking has been discontinued on the California side of the basin, it continues on the Nevada side. Some streams in the California side of the basin have been designated "Wild Trout Areas" and are not (officially) stocked with nonnative fishes. It is not clear to what degree this management response benefits amphibians and stream-associated reptiles. Studies in the Sierra Nevada have shown that, without intervention, decades are required for trout populations to decline once stocking has ceased (see Knapp et al. 2001). Fish stocking could potentially benefit garter snake populations, as they can prey on fry. Bullfrogs (*Lithobates catesbeianus*) are also a potential threat to amphibian populations in the basin; however, they currently have a limited distribution, primarily in the mouths of streams in the southern basin. The number of sites occupied is fairly low, but where they exist, their populations are large and affect the native fauna (Manley and Lind 2005).

Stream channel restoration is an active pursuit in the Lake Tahoe basin. Stream restoration and surveys are commonly conducted by the U.S. Forest Service as part of managing the national forest. Surveys have been conducted for most streams

[12] Manley, P., and Lind, A., research wildlife biologists, USDA Forest Service, Pacific Southwest Research Station, Sierra Nevada Research Center, Davis, CA; Shaffer, H.B., professor, University of California-Davis, Davis, CA; Peacock, M., assistant professor, University of Nevada-Reno, Reno, NV; and Vredenburg, V., research associate, University of California-Berkeley, Berkeley, CA.

in the basin over the past 10 years by the U.S. Forest Service; stream habitat types are mapped as are occurrences of fish and amphibian species. Stream restoration has been actively pursued by the U.S. Forest Service and the California Tahoe Conservancy for the past 5 years; in many cases, that work includes before and after measurements of responses of plant and animal species, including aquatic, riparian, and upland associates.[13] The geomorphologic and water quality elements of these efforts are addressed in chapter 4, "Water Quality."

In addition to biological threats, lakes and streams face physical degradation as well. Firefighting often involves the collection of water from lakes to deposit on the fire; associated siphoning activities can potentially directly affect amphibian populations. An evaluation of the ecological value and sensitivity of various water bodies in the basin has not been conducted; thus activities such as siphoning may occur in areas where impacts could be high (e.g., Watson Lake).

Development has been responsible for the loss and fragmentation of marshes in the southern portion of the basin, specifically the Tahoe Keys development in the Upper Truckee Marsh. Surveys are being conducted to assess how development of this marsh has affected water birds and to evaluate the potential to restore affected species. Impacts to the physical condition of lakes, ponds, and marshes also are occurring in the basin, such as shoreline compaction and pollution from human uses. Anglers and hikers appear to have the greatest impact on the shoreline and nearby upland areas around existing lakes and ponds. The most common impacts include compaction of soil and removal of vegetation around the shoreline; however, some paved and dirt roads exist extremely close to shorelines creating the potential for erosion and conveyance of polluted runoff. Research has shown that degraded shoreline conditions can have a negative effect on the presence or abundance of aquatic species that occupy a site (Manley and Lind 2006).

Knowledge Gaps

In the last decade a watershed management approach to restoration activities in the Lake Tahoe basin has dominated. Although nutrient limitations and their shifts have been studied in Lake Tahoe (Jassby et al. 1994), it is unknown how atmospheric nitrogen loading has shifted nutrient limitation in the other lakes in the basin watershed (see chapter 3, "Air Quality"). Understanding the nutrient limitation is critical if we are going to promote the persistence of native fish or amphibian species in these ecosystems. It also is important for us to understand the degree to which nonnative fish are limiting amphibian populations in small lakes, and what

[13] Romos, S. 2008. Personal communication. Science and evaluation program manager, Tahoe Regional Planning Agency, 128 Market Street, Stateline, NV 89449.

options exist for effective reductions in these negative interactions. Understanding the movement patterns of nonnative trout, including barriers and distribution mechanisms, would greatly inform effective options for conservation and restoration of native species. We still lack information on the habitat associations and population dynamics of Pacific treefrog and the two aquatic-system-associated garter snakes. Population models and spatially explicit landscape evaluations of habitat conditions and values have not been developed for any amphibian or aquatic snake species. Management agencies are considering attempting to reintroduce the mountain yellow-legged frog into multiple locations in the basin; additional assessment and evaluation are recommended to establish an information-rich foundation for a reintroduction plan.

Uncertainties and concerns exist for native fish populations, as well. Restoration of native trout has been initiated at Fallen Leaf Lake. It is important to follow the effect of this restoration effort on all aspects of the lake's ecology and limnology. In particular, measurements are recommended to determine the lake's responses—nutrient, primary and secondary production—to the reintroduction. Overstocking of native trout in the lake, for example, could lead to trophic cascades and either increase or decrease the lake's clarity. Most appropriately, this study effort would occur throughout the life cycle of the trout or until they are extirpated from the lake. Beyond the Lahonton cutthroat trout, little information exists about the status of native fishes (e.g., sculpin or redside-shiner).

These issues and uncertainties suggest the following key management questions:

- Which lakes and other aquatic systems should receive priority management attention, and what actions should be undertaken to restore desired ecosystem values to each?
- What spatial and temporal strategy of restoration and management actions can be employed to maximize learning to inform future management decisions in aquatic systems with like conservation needs?
- What monitoring targets and sample techniques will best support adaptive management of Lake Tahoe's aquatics systems and their biota?

Research Needs

Following are other aquatic ecosystem research questions:

(**OE1**) What are the limiting factors of production for other lakes in the Tahoe basin? Do variations in limitation affect secondary production and the ability to support fish and amphibians?