Implementation Plan for the
Control of Aquatic Invasive Species within Lake Tahoe

by

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The Lake Tahoe Aquatic Invasive Species Coordination Committee is comprised of representatives from the following organizations:

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Executive Summary

Substantial changes to the economy, water quality, aesthetic value, and recreational pursuits are currently occurring in part due to the unwanted impacts of aquatic invasive species (AIS). In 2009 and again in 2014, the Aquatic Nuisance Species Task Force (ANS Task Force), an inter-governmental organization dedicated to preventing and controlling aquatic nuisance species, approved a Lake Tahoe Region Aquatic Invasive Species Interstate Management Plan (LTAIS Management Plan). The LTAIS Management Plan identifies threats and quantifies economic damages posed by AIS, develops management strategies for AIS in the Tahoe Basin, and supports one of the nation's most rigorous recreational boat inspection programs.

This current document, referred to as "the implementation plan" is intended as an extension of the LTAIS Management Plan and should be used as a guide for resource managers at Lake Tahoe to identify and prioritize species, specific locations and strategies for the implementation of AIS removal and control. The information provided here is intended to guide the prioritization of control strategies and is not intended to be a comprehensive treatment of all issues related to AIS in the Lake Tahoe region. The implementation plan supports the goals of the LTAIS Management plan by providing the following:

1. Identification of AIS that are candidates for control in Lake Tahoe,
2. A comprehensive description of the history of aquatic invasions and control activities in Lake Tahoe or elsewhere. Based on this information, an assessment of feasible control or management options are identified by species group,
3. An ecologically based framework to prioritize (a) species and (b) specific sites for control or removal efforts in Lake Tahoe over 3-5 year period,
4. Efficacy monitoring recommendations,
5. Identification of key knowledge gaps, and
6. Next steps related to research and management of AIS.

This implementation plan was formally reviewed by an external expert panel comprised of individuals with extensive academic, management or regulatory backgrounds concerning AIS. This implementation plan was also reviewed by members of the Lake Tahoe Aquatic Invasive Species Coordination Committee (LTAISCC). The LTAISCC is a bi-state collaborative of local, state and federal agencies, research institutions and stakeholder groups which developed the LTAIS Management Plan and manages AIS issues in the Tahoe Basin.

Through the development of this implementation plan, seven aquatic invasive species groups were determined under guidance from the LTAIS Management Plan and the AISCC. These groups include: warm water fishes (various species), plants (Eurasian watermilfoil, curlyleaf pondweed), invertebrates (Asian clam, mysid shrimp, signal crayfish), and an amphibian (American Bullfrog). A comprehensive history of the invasion of each of these species and the control actions taken to date within the Tahoe Basin and elsewhere was provided. Using this information, as well as information from the peer-reviewed published literature, an assessment of the feasibility of management actions for each of species group was provided. Feasible management actions were qualified into three classifications:

Feasible control actions

- Eurasian watermilfoil
- Curlyleaf pondweed
- Warm water fish

Potential control actions

- Signal crayfish
- American bullfrog

No feasible control options at this time

- Mysid shrimp
- Asian clam

An ecologically-based framework was used to determine a site prioritization for aquatic invasive plants and warm water fish in the Tahoe Basin. The metrics used in the prioritization model included: (1) fish-plant interactions, (2) size of infestation, (3) human use (by recreational boaters), and (4) location of infestation. Other factors of major significance concerning the control of AIS such as suitability of the receiving habitat, proximity to sensitive native species, or potential impact of control actions on the surrounding environment are vital components of site selection, but are not included in this model due to lack of available data.

Sites with the highest prioritization included the Tahoe Keys (East and West). These sites received the highest priority largely as a result of the immensity of nuisance aquatic plant infestations, as well as the intensity or recreational boater visitation. Other highly prioritized sites included Meeks Bay, Ski Run Marina and Channel, and Lakeside Marina and swim area. Emerald Bay was not highly prioritized for immediate control action because of recent successful efforts to remove all Eurasian watermilfoil biomass. This site is indicated as a priority for post-treatment surveillance monitoring.

At present, only non-chemical methods are recommended for the control of all AIS in Lake Tahoe. This is due to the special status designation for Lake Tahoe and States of California and Nevada rules prohibiting the use of chemical additions to the watershed. Suggestions are provided for all AIS considered in this document for immediate implementation actions, the development of future control strategies or technologies, and the consideration of chemical control methods, where appropriate. Major knowledge gaps identified include the need for:

- A consistent lake-wide surveillance program with central data storage,
- Efficacy monitoring associated with each management action taken,
- Development of specific metrics to quantify the success of the overall AIS management/implementation program at Tahoe, and
- As a majority of the AIS considered here are nearshore species, an integration of the Tahoe AIS management program with the Lake Tahoe Nearshore Management plan.

Recommendations for "next steps" include a call for the development of: a nearshore surveillance and monitoring program, metrics to evaluate the progress of AIS control actions carried out in the lake, a research plan to address data gaps, the exploration or development of new strategies or technologies for the control of AIS in Lake Tahoe, and an alignment of available resources with the priorities recommended in this implementation plan.

Background and Aquatic Invasive Species Problem Statement

Lake Tahoe is well known for its remarkable clarity and aesthetic beauty. Since the 1960s, the clarity has declined due to progressive cultural eutrophication and the loading of fine sediments from an increasingly urbanized and developed watershed. As a result of this clarity loss, a significant amount of public and private funding has been utilized to implement conservation programs to improve lake water quality.

Along with changes to Tahoe's clarity, there have been alterations to the lake's biological community over time (Figure 1). Biological organisms can play a very important role in maintaining ecosystem integrity and function. Lake Tahoe's biological organisms can live both in the open water, where clarity has been measured over time, but also in both the lake's deep and nearshore waters where there has been significant degradation measured in recent years (Heyvaert et al. 2013).

In the mid to late 1800s, Lake Tahoe had a relatively simple biological community containing 8 native fish taxa, 6 zooplankton species, 12 benthic invertebrate taxa, and 5-8 plant taxa including higher plants, algae, and mosses. The food web of the lake was relatively simple; the lake's native top fish predator, Lahontan cutthroat trout (*Oncorhynchus clarki henshawi)*, fed mostly in the open water of the lake on zooplankton and fishes. As a result, smaller native fishes (e.g. redside shiner, dace) likely had fewer predators when migrating to the nearshore to spawn during early summer periods.

Over the next 140 years there was a series of species introductions into Lake Tahoe (Figure 1). Some of the early introductions were intentional, sanctioned by federal and state agencies, while more recent introductions may have occurred intentionally or accidentally, but are considered illegal. The sanctioned introductions of fishes from 1880 to 1940s included a number of trout species. Lake trout (*Salvelinus namaycush*), the lake's dominant fish predator today, was first introduced in 1888 and was considered established by 1912. Known to feed on prey half of its length, lake trout likely played a major role in eliminating the lake's native trout, Lahontan cutthroat trout. In the mid 1940s there was the accidental introduction of kokanee salmon (*Oncorhynchus nerka*), an important sport fish in the lake today. And by the mid-1930s the final introduction (of many introduction events) of the signal crayfish (*Pacifasticus leniusculus*) occurred.

By 1960, the food web of Lake Tahoe had changed substantially. In contrast to the native food web, it was comprised of two major fishes, kokanee salmon and lake trout, which are still the dominant sport fishes in the lake today. The lake trout fed on native fishes across habitats in the open, deeper waters similar to the native cutthroat trout but also in the deeper waters of the nearshore habitat. As a result the lake trout were able to further utilize native fishes and crayfish in the nearshore, unlike the native predatory cutthroat trout. Kokanee salmon fed largely on native zooplankton taxa (e.g. *Daphnia*) which are important grazers on algae particles in the open water. In addition, there were other trout species popular with recreational anglers that had established in the lake, rainbow and brown trout.

In the 1960s, resource managers from California and Nevada Fish and Game agencies believed the game fishes in Lake Tahoe were largely limited by food. As a result, the agencies introduced mysid shrimp (*Mysis diluviana*). This was the last sanctioned introduction of species into Lake Tahoe. The introduction of this species had profound changes to the food web and biological composition of Lake Tahoe. Mysids' predatory nature resulted in the decline of two native pelagic taxa (*Daphnia* and *Bosmina* spp.) which are the preferred food resource for kokanee salmon. With the ability for larger mysids to migrate to deeper waters (~400 m), they can evade predation by kokanee salmon, which resulted in a decrease in fish size rather than an increase as intended by the introduction of the shrimp (Morgan 1978). In addition, mysids may be explanatory in the recently observed reduction of native, endemic invertebrate species (Caires et al. 2013, Chandra 2003). After the introduction of *Mysis* shrimp, the food web of Tahoe became increasingly reliant upon pelagic resources. This resulted in the development of two distinct, seasonal food webs; a nearshore food web with fewer top predators and offshore/ deep profundal food web.

After the introduction of mysid shrimp in the 1960s, there was a general understanding by resource managers not to introduce additional species to the lake due to unintended consequences, which may result from the establishment of new species. In addition, evidence had emerged that the lake's clarity was in decline and an agency had been created (e.g. Tahoe Regional Planning Agency) to address the decline in clarity. Existing state of California and Nevada agencies also developed objectives to maintain the lake's water quality, aesthetic beauty, and maintain the lake's "natural" characteristic. With the cultural changes occurring since the 1960s it would be approximately 20 more years before a series of new biological introductions were becoming noticeable in Lake Tahoe.

By the mid 1980s a series of unintentional fish, invertebrate and plant introductions occurred and resulted in another suite of changes to the lake's nearshore ecology. These include the two aquatic plants, Eurasian watermilfoil (*Myriophyllum spicatum*) and curlyleaf pondweed (*Potamogeton crispus*), first observed in South Lake Tahoe and which are now established in more than 20 locations of the Lake Tahoe nearshore zone. These species are considered a nuisance in some locations (e.g. Tahoe Keys) since they foul boat propellers. These nuisance aquatic plants also increase habitat for invasive warm water fishes and have been shown to alter phosphorus cycling in the nearshore zone (Kamerath et al. 2008; Walter 2000). Asian clams (*Corbicula fluminea*) were first observed in the early 2000s in the Southeastern portion of Lake Tahoe at Nevada Beach. These bivalves have now established along most of the south shore, in Emerald Bay and potentially in Sand Harbor in the Northeastern region of the lake. Asian clams have been correlated with nuisance level growth of nearshore algal populations and have impacted the aesthetics of beaches through shell deposition along some locations in the south shore. Warm water fishes such as largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*) and other species were first discovered in Lake Tahoe in the 1970s and 1980s. The population size of these fishes is increasing through time, with the majority of the populations concentrated in the Tahoe Keys area of the lake. Warm water fishes prey on native fishes, and have contributed to the ongoing decline in these native species. Native to eastern North America, the American bullfrog (*Rana catesbeiana*) is established in the Lake Tahoe Basin and is of particular concern in sites that are targeted for restoration efforts such as Taylor Creek.

Today nearly 30 non-native aquatic species are established in the Lake Tahoe watershed, including plants, fish, invertebrates, and an amphibian. An analysis of potential AIS economic impacts to both recreation/ tourism/property values, and increased boat/pier maintenance costs in the Lake Tahoe Region was estimated to be $22.4 and $78 million per year respectively (TRPA 2014). However, these estimates do not, and were not intended to capture the potential economic effects on ecological function for the sensitive and unique biological community in Lake Tahoe. Of particular recent concern, and the result of the development of this implementation plan, is the establishment and within-lake spread of a number of unintentionally introduced species. Lake Tahoe's water quality, aesthetic value, and recreational pursuits are currently threatened by the unwanted effects of non-native aquatic plants, fish, invertebrates, and other species. These non-native aquatic organisms are considered ‘invasive’ when they threaten the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent upon such waters (ANSTF 2012).

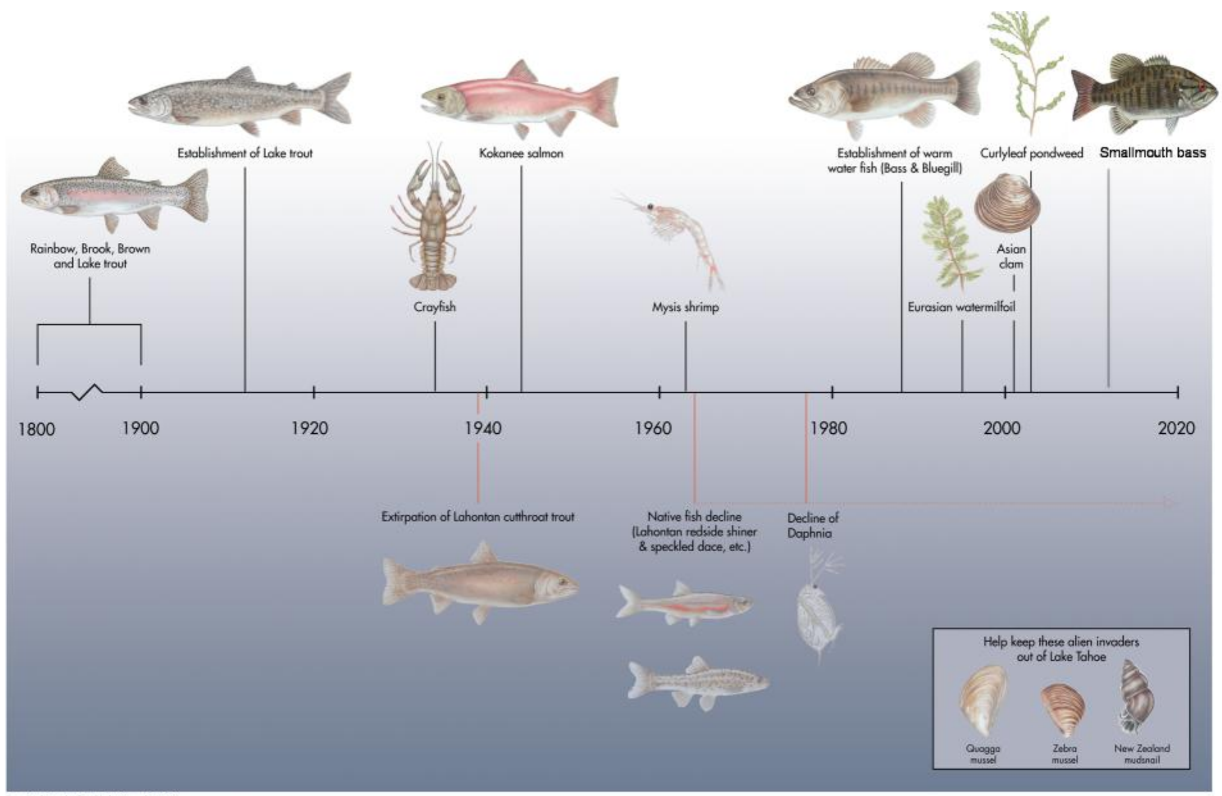

Figure 1. A timeline of species introductions and associated biological declines in Lake Tahoe. Initial introductions until the mid-1960s were sanctioned and legal by federal and state agencies. These introductions resulted in the loss (e.g. Lahontan cutthroat trout) or near elimination (e.g. *Daphnia* and *Bosmina*) of species. Introductions by the mid 1980s were not legal and resulted in the establishment in the lake’s nearshore habitat.

Current Efforts in the Tahoe Basin related to prevention

Regulators, managers and scientists understand the ecological and economic threats posed by AIS in the Tahoe region and have established a formidable prevention program. The AIS prevention program in the Tahoe Basin has been established using regulatory precedents. Namely, the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 (P.L. 101-636) establishes federal authority to prevent the introduction of nuisance aquatic organisms and control their spread through coordinated research, control strategies, priorities, and education efforts. Under guidance provided by NANPCA, the Tahoe Regional Planning Agency (TRPA; a compact regulatory agency) developed a regional Code of Ordinances (Chapter 63.4.1) prohibiting the following actions in the Lake Tahoe region:

- The transport or introduction of aquatic invasive species into the Lake Tahoe region.
- The launching of any watercraft or landing of any seaplane contaminated with AIS into the waters of the Tahoe region.
- The provision of inaccurate or false information to the TRPA or persons designated to conduct inspections.

There are a number of AIS prevention efforts currently in place in the Lake Tahoe Basin which include outreach, education, voluntary action by the boating public, and governmental regulation (TRPA 2014). In addition to the numerous and ongoing outreach and education programs, one of the most significant prevention programs is the motorized and non-motorized watercraft inspection and decontamination program. This program, which began in 2008, is managed by the TRPA and its designee, the Tahoe Resource Conservation District (TRCD). Under this inspection and decontamination program, all motorized watercraft shall be inspected prior to launching into the waters of the Lake Tahoe region. The objective of inspection and decontamination is to completely eliminate all viable AIS life stages, and thereby prevent their introduction into waters of the Lake Tahoe Region. Inspections are mandatory and incur a vessel-size dependent fee to the boater. From 2009-2014, approximately 43,000 watercraft inspections and 17,000 decontaminations were conducted. The federal government has invested more than $3 million each year for the last four years to support the entire AIS program; these funds are scheduled to be eliminated in 2015.

The Lake Tahoe AIS Management Plan: History and Status

The Aquatic Nuisance Species Task Force (ANSTF) is an intergovernmental organization dedicated to preventing and controlling aquatic nuisance species, and implementing the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990. The ANSTF encourages state and interstate planning entities to develop management plans which describe detection and monitoring efforts for aquatic nuisance species, prevention efforts to stop their introduction and spread, and control efforts to reduce their impacts. Management plan approval by the ANSTF is required to obtain funding under Section 1204 of NANPCA.

In 2009, the first Lake Tahoe Interstate AIS Management Plan (hereafter referred to as the LTAIS Management Plan) was approved by the ANSTF. In 2014, the first update of the original

2009 plan was approved by the ANSTF. This update revised the 2009 Plan taking into account developments in the implementation of AIS efforts in the Tahoe Region, and primarily focuses on changes needed to make the LTAIS Management Plan as useful as possible for management, policy and funding decisions related to AIS issues in the region. The Tahoe Regional Planning Agency provides oversight to the implementation of this plan, including acting as the fiscal agent, or pass-through agency for funds associated with its implementation.

Generally, the goals of the LTAIS Management Plan are to: (1) Prevent new introductions of AIS to the Lake Tahoe Region (2) Limit the spread of existing AIS populations in the Lake Tahoe Region, by employing strategies that minimize threats to native species, and extirpate existing AIS populations when possible, (3) and abate harmful ecological, economic, social and public health impacts resulting from AIS (TRPA 2014). Summarized in the LTAIS Management Plan is the background information on the current non-native species in the Lake Tahoe Region, the introduction pathways for existing and potential AIS taxa, information on potential AIS in the Lake Tahoe Region, and a description of the goals and objectives of the plan. Also included (as appendices) is an overview of existing regulations and programs, prevention plans, control and eradication plans, monitoring and response plans, economic information including an estimate of potential monetary impacts AIS may have on the Region, and an overview of existing and potential AIS life histories and distributions.

The need for a Lake Tahoe AIS Implementation Plan

The LTAIS Management Plan provides a strong description of the available AIS detection and monitoring efforts, prevention activities to stop their introduction and spread, and control efforts to reduce their impacts. However, there remains the need to provide information concerning the *implementation* of the control efforts to reduce impacts of AIS in the Tahoe Basin. Specifically, this refers to target species selection, site selection and prioritization of species and sites given the current environmental conditions in the Tahoe Basin.

Objectives and evaluation of the Implementation Plan

The goals of this implementation plan are to:

1. Identify AIS that are candidates for control efforts in Lake Tahoe,
2. Provide a comprehensive description of the history of aquatic invasions and control activities in Lake Tahoe, or elsewhere. Based on this information, an assessment of feasible control or management options are identified by species group, and
3. Provide an ecologically-based framework to prioritize (a) species and (b) specific sites for control or removal efforts in Lake Tahoe over 3-5 year period.

The implementation plan has been formally reviewed by (1) an external expert panel comprised of individuals from academic and management backgrounds with specialties in invasive species management and ecology (Table 1), and (2) the Lake Tahoe Aquatic Invasive Species Coordination Committee.

Name	Affiliation	Expertise
Lars Anderson, Ph.D.	Waterweed Solutions, USDA Agricultural Research Service (Retired)	Control and eradication of invasive and detrimental aquatic plants, Integral to Bay Delta programs including the successful reduction of *Egeria densa* in over 3,000 acres of the Sacramento-San Joaquin Delta and 800 acres in Discovery Bay, CA
Meghan Brown, Ph.D.	Associate Professor of Biology, Hobart and William Smith Colleges	Biological limnologist with a focus on zooplankton including mysid ecology, ecosystem dynamics, impacts of Asian clam on ecological dynamics
Michael Hoff, M.S.	Regional AIS Coordinator Great Lakes-Big Rivers Region, US Fish and Wildlife Service	Use of risk assessment for regulatory and non-regulatory decision-making, AIS early detection and response planning, specialty in invasive warm water fish, plants, and other species
Nicholas Mandrak, Ph.D.	Associate Professor of Biological Sciences, University of Toronto Scarborough	Invasive species risk assessment, fish biology and ecology, invasion ecology, impacts of invasive species
Michael Marchetti, Ph.D.	Fletcher Jones Professor of Ecology, St Mary's College of California	Invasion ecology, fish ecology, invasive species risk assessment, impacts and establishment on non-native species
Sandra Nierzwicki-Bauer, Ph.D.	Professor of Biology, Director of Darrin Freshwater Institute, Rensselaer Polytechnic Institute	Basic and applied studies of aquatic invasive species (zebra mussels and Asian clam), water resource management
John Rothlisberger, Ph.D.	Aquatic Ecologist, US Forest Service	Invasion ecology, invasive plants, fish and invertebrates, spread of invasive species by recreational boats, impacts of non-native species, risk assessment

Table 1. Names, affiliation and expertise of external expert review panel which evaluated the Lake Tahoe Aquatic Invasive Species Implementation Plan.

Identify invasive species that are candidates for control efforts in Lake Tahoe

The selection of AIS species that qualify as candidates for control under this implementation plan was a result of a two-step process. First, the LTAIS Management Plan was used to identify nonindigenous species perceived to cause significant damage or harm in the Lake Tahoe Watershed and are therefore considered invasive and unwanted[1]. This includes species referenced under Type 2, 3 and 4 (Chapter 3, Table 5) in the LTAIS Management Plan (TRPA 2014). Second, by referencing the LTAIS Management Plan and through discussions with the Lake Tahoe AIS Coordination Committee in 2015, the species of concern were further refined to include those taxa for which control or management is feasible in the Lake Tahoe Basin, and/or those which have significant unwanted effects on restoration goals within the Basin. The following species groups will be considered in this Implementation Plan: (1) Two aquatic plant

[1] In the LTAIS Management Plan, this determination was made through the TRPA Code of Ordinances, Chapter 63.4 which contains regulations relating to the prevention of invasion by AIS. Invasive species are defined in the TRPA Code as:

"…species, both aquatic and terrestrial, that establish and reproduce rapidly outside of their native range and may threaten the diversity or abundance of native species through competition for resources, predation, parasitism, hybridization with native populations, introduction of pathogens, or physical or chemical alteration of the invaded habitat. Through their impacts on natural ecosystems, agricultural and other developed lands, water delivery and flood protection systems, invasive species may also negatively affect human health and/or the economy."

species: Eurasian watermilfoil, curlyleaf pondweed, (2) various warm water fish species, (3) three invertebrate species: signal crayfish, Asian clam, mysid shrimp, and (4) one amphibian, the American Bullfrog.

History of Tahoe invasions, control activities and management conclusions

The following section provides a comprehensive description of the history of aquatic invasions and associated control activities in Lake Tahoe and elsewhere for the species identified in the previous section. At the end of each species-specific invasion and management section, a recommendation concerning management actions to be implemented for each species grouping is provided.

Aquatic Plants

Currently there are two known species of nonindigenous aquatic plants in Lake Tahoe, Eurasian watermilfoil (*Myriophyllum spicatum*) and Curlyleaf pondweed (*Potamogeton crispus*). These species are considered invasive in Lake Tahoe due to their impacts to recreation, navigation and ecosystem dynamics. Additionally, despite its designation as a native plant, coontail (*C. demersum*) is considered a nuisance in some regions of Lake Tahoe (e.g., the Tahoe Keys) due to its excessive growth in these areas.

Prior to the establishment of non-native aquatic plants, Lake Tahoe's benthic zone was dominated by a number of Characeae, mosses, liverworts and filamentous algae species, which have been observed at depths up to 400 m (Frantz & Cordone 1967; Caires et al. 2013).The native macrophytes Andean milfoil (*M. quitense*), Canadian waterweed (*Elodea canadensis*), coontail (*Ceratophyllum demersum*), Richardson's pondweed (*Potamogeton richardsonii*) and leafy pondweed (*Potamogeton foliosus*) are also found in Lake Tahoe. It is important to note that information related to the historic distribution and densities of native plants in Tahoe is limited. This may be important when looking to retain Tahoe's natural setting or the inadvertent removal of native species during invasive species control work.

The following sections provide a brief description of both nonindigenous plant species' establishment history in Tahoe, and control options based on observed accounts in Tahoe and elsewhere. Based on these accounts, a brief recommendation concerning Lake Tahoe-specific management options for each species is provided.

Eurasian watermilfoil

Eurasian watermilfoil is thought to have been introduced to Lake Tahoe in the 1960s or 1970s and was formally identified along the south shore in the late 1980s and 1990s (Loeb & Hackley 1988; Anderson & Spencer 1996; Anderson 2003). In 1995, there were 13 nearshore sites in Tahoe that contained Eurasian watermilfoil. Since this time, the number of sites with Eurasian watermilfoil has increased, with 17 sites observed in 2000, 22 sites in 2003 and 26 sites in 2005 (Figure 2). In 2011, there were 23 sites with Eurasian watermilfoil, and in 2012 the number of occupied sites declined again, to 18, with a total coverage of approximately 500 km^2 (Figure 3). The decrease in number of sites in 2011 and 2012 relative to previous years is potentially a result of changes in surveillance strategies or the extirpation of localized populations due to management actions (K. Boyd pers. comm. 2015). A recently published assessment of the potential spread of Eurasian watermilfoil in Lake Tahoe indicates that a number of sites currently without Eurasian watermilfoil may be designated as high risk for Eurasian watermilfoil establishment in Lake Tahoe (Wittmann et al. 2015). Some of the highest risk sites for future Eurasian watermilfoil establishment include the Lake Forest Boat Launch, Camp Richardson, Carnelian Bay and other areas that are generally protected from high wave action and contain appropriate habitat conditions such as suitable sediment substrates.

Eurasian watermilfoil in Lake Tahoe and in other systems can cause unwanted ecological and economic impacts. In North America, high density populations of Eurasian watermilfoil impact native species (Boylen et al. 1999) and can cause unwanted effects on water quality, recreation and other ecosystem services (Eiswerth et al. 2000; Halstead et al. 2003; CAST 2014). In the nearshore regions of Lake Tahoe, Eurasian milfoil has been found to alter phosphorus cycling in the water column, potentially leading to increased algae production (Walter 2000). In the Tahoe Keys, aquatic macrophytes, including Eurasian milfoil are present in very high abundance and provide habitat and protection from harmful ultra violet (UV) light exposure for invasive warm-water fishes (Kamerath et al. 2008; Tucker et al. 2010). Eurasian milfoil and other aquatic plant species are navigation and aesthetic nuisances to homeowners in the Tahoe Keys, who incur an annual harvesting cost of $400,000 to control species solely within the Tahoe Keys property area (TKPOA 2015).

Control of Eurasian watermilfoil

A variety of mechanical, biological and chemical methods have been used to control Eurasian watermilfoil (Berent et al. 2015). Mechanical means to reduce plant biomass such as harvesting, cutting, hand removal or mowing are often used in localized regions such as marinas or swim areas to clear navigation or recreation use zones (Greenfield et al. 2004). Unfortunately these methods tend to promote the spread of the plant (Crowell et al. 1994) because milfoil can grow from broken-off stems. Other mechanical means include gas permeable or impermeable barriers or blocking/shading light from infestations using dyes or fabric. Water drawdowns are often utilized in reservoir systems and are most effective when the plants are exposed to several weeks of drying and the root crowns are exposed to sub-freezing temperatures (Berent et al. 2015). Water level manipulation is often used conjunction with herbicides and/or shade barriers (Bargeron et al. 2003, Swearingen et al. 2002).

Biocontrol options include a fungus *Mycoleptodiscus terrestris,* a North American weevil (*Euhrychiopsis lecotie*), and a cyprinid fish, the Grass Carp (*Ctenpharyngodon idella*). Grass carp have been widely used as biocontrol agents for aquatic macrophytes including Eurasian watermilfoil. Unfortunately studies have found that Grass Carp will feed on Eurasian watermilfoil only after other macrophytes (including natives) have been consumed by this species. As a result, grass carp are currently not recommended for Eurasian watermilfoil control by some agencies (Washington State Department of Ecology 2013). It is important to note that Grass Carp are not native to the Lake Tahoe region and are considered invasive in many regions of North America.

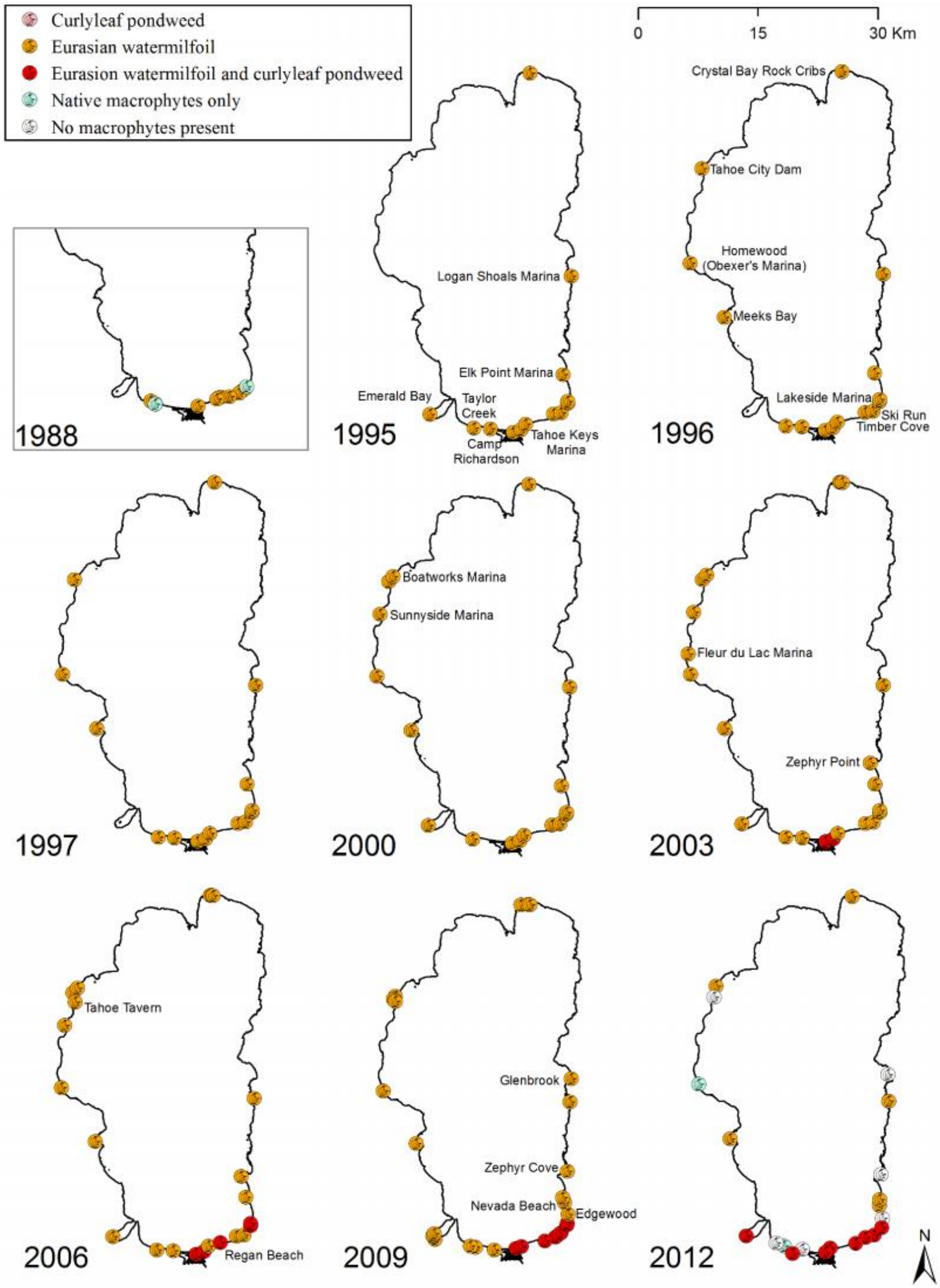

Figure 2. Distribution of Native and non-native aquatic plant presence and absence in Lake Tahoe, 1988 – 2012. Data from 1988 panel after Hackley and Loeb (1988). 1995 – 2006 surveys by L.W.J. Anderson, USDA-ARS, 2009 surveys by P. Caterino, 2012 surveys conducted by SEA, Inc. Note, only 2012 survey data contains native species information and absences, all other surveys only indicate only presence of non-native plant populations.

A number of herbicides are commonly employed to treat Eurasian watermilfoil infestations, including but not limited to triclopyr, 2,4-D, fluridone, imazamox and endothall. Triclopyr, fluridone and 2,4-D have been used in small-plot and whole-lake management programs to control Eurasian watermilfoil and in many instances have shown considerable selectively in removing Eurasian watermilfoil with little to no impact on native plant communities (Petty et al. 2001; Madsen et al. 2002; Siemering et al. 2008). Fluridone applied in the early stages of growth can result in season-long control of Eurasian watermilfoil (USACE 2011; DNR 2012). Disadvantages of chemical control methods include restrictions to swimming, drinking water, and fishing and potential impacts to non-target plants. Additionally, the use of chemical controls may require extensive water quality monitoring that could increase overall program costs (TRPA 2014).

Control of Eurasian watermilfoil in Lake Tahoe

Efforts in Lake Tahoe to remove or control Eurasian milfoil or other aquatic plants began in the 1980s and included mechanical harvesting and raking in the Tahoe Keys as a means to keep navigation pathways clear for boating traffic (Greenfield et al. 2004). In agreement with other published accounts, managers at the Tahoe Keys Property Owners Association (TKPOA) found that this treatment was likely increasing Eurasian watermilfoil biomass (Tischler, pers comm 2002). In an effort to find different solutions, managers in the TKPOA also attempted other experimental efforts such as the unsuccessful use of a water circulator (e.g., "Solar Bee") (Anderson et al. 2005).

The Lake Tahoe Invasive Aquatic Plant Control Program began in 2005 with experimental removal of Eurasian milfoil using diver-assisted suction removal, hand pulling and light impermeable bottom barriers in Emerald Bay in 2005-2007 (Van Way 2005; Gillies & Van Way 2006). While integrated programs using hand pulling and bottom barrier application have been shown to be effective in other systems, it is uncertain whether these 2005-2007 efforts were successful in the lake. This is due to the lack of integration of these three methods as well as the absence of a comprehensive or directed removal program at this location. Further, no follow-up treatments or efficacy surveillance was conducted after these efforts, leaving no quantitative information to evaluate the effectiveness of these actions. Anecdotal evidence suggests that the Emerald Bay Eurasian watermilfoil populations recovered in as little as two years after treatment.

In 2007, several bottom barriers and a pontoon work boat fitted with equipment to assist in invasive plant removal in Lake Tahoe were purchased. In 2008, 46 m^2 of bottom barriers were deployed at Parson's Rock in Emerald Bay. In 2009, 966 m^2 of barriers were placed at Parson's Rock and a 334 m^2 area was treated with diver-assisted suction removal in Emerald Bay in the area of the Vikingsholm Swim Beach and Pier. Transect survey results from these efforts showed that Eurasian watermilfoil began recolonization of bottom barrier treatment sites within 15 months post-treatment and that the use of barriers alone was unlikely to provide an effective strategy for controlling this plant in Emerald Bay (Brockett et al. 2013).

In 2010, a comprehensive removal program using a combination of benthic barriers and diver-assisted suction removal was initiated at three sites in Emerald Bay which has continued through the present (Brockett et al. 2013, Shaw et al. in prep). The results of this effort indicate that by using a combination of methods under a comprehensive framework that allows for rapid response and consistent surveillance efforts, it appears that successful removal of Eurasian watermilfoil can occur. In 2014, 12 Eurasian watermilfoil plants were found and removed from Emerald Bay in spring and no plants were found in a 2014 fall survey. Surveillance efforts are ongoing.

Between 2008 and 2014 a number of Eurasian watermilfoil removal efforts were carried out at other nearshore locations in Lake Tahoe. Removal treatments at Ski Run Marina and Channel first began in 2009. Due to interference with local concessionaires and concerns for diver safety, these control efforts were cut short. Another effort was initiated in 2012 at Ski Run where two removal methods were implemented: 1) gas-permeable, benthic bottom barriers and 2) diver-assisted suction removal. In the Ski Run Channel, 48% of the infestation was treated with bottom barriers and 52% with diver-assisted removal. Results from these experiments indicate that barriers typically need to be in place for 6-10 weeks to achieve plant mortality, and removal of the barriers began in November 2012. Barrier removal was completed in late November and diver-assisted removal continued until December 2012. Complicating the removal efforts in Ski Run Marina was curlyleaf pondweed, which had significantly colonized at Ski Run Marina and Channel. There have been no control actions at Ski Run since 2012, however, mechanical control is planned for 2015.

Prior to 2010, a private-public collaborative aquatic plant removal effort had been initiated with the Lakeside Homeowners Association. This effort carried out at Lakeside utilized a clam-shell dredge and was completely unsuccessful due to the almost complete replacement of Eurasian watermilfoil by curlyleaf pondweed as a result of the clam shell dredge activity. Learning from this experience, the private-public collaboration continued, and in 2010-2012, 3716 m^2 of invasive aquatic plants were treated with diver-assisted suction removal and 3318 m^2 of bottom barriers were deployed at Lakeside Marina and Swim Area. At Lakeside Beach 85% of the treatment was accomplished with bottom barriers and 15% with diver-assisted suction removal.

Conclusions based on Eurasian watermilfoil control research

Successful control of Eurasian watermilfoil at Lake Tahoe requires integration and consistency of removal strategies, as well as post-treatment efficacy monitoring and rapid response capabilities. This recommendation is largely based on the results of the comprehensive and multi-year removal program (relative to a particular site) with post-treatment monitoring and rapid response capability in Emerald Bay, which has resulted in a significant decrease of Eurasian watermilfoil at this location. Further, where control efforts have been haphazard and without monitoring or rapid response capabilities, Eurasian watermilfoil recolonization has occurred. The use of multiple and integrated methods (e.g., bottom barriers, hand pulling, and suction removal) for plant removal is highly recommended, particularly in localized habitats that have variable characteristics. In systems other than Tahoe, chemical control has been successfully used for both seasonal and long-term reductions of Eurasian milfoil. While highly controversial and a number of years away from regulatory permission, herbicide treatments in Lake Tahoe, particularly in marina or other protected nearshore zones, may provide a cost-effective means to reduce local infestation and limit the spread of Eurasian watermilfoil lake-wide.

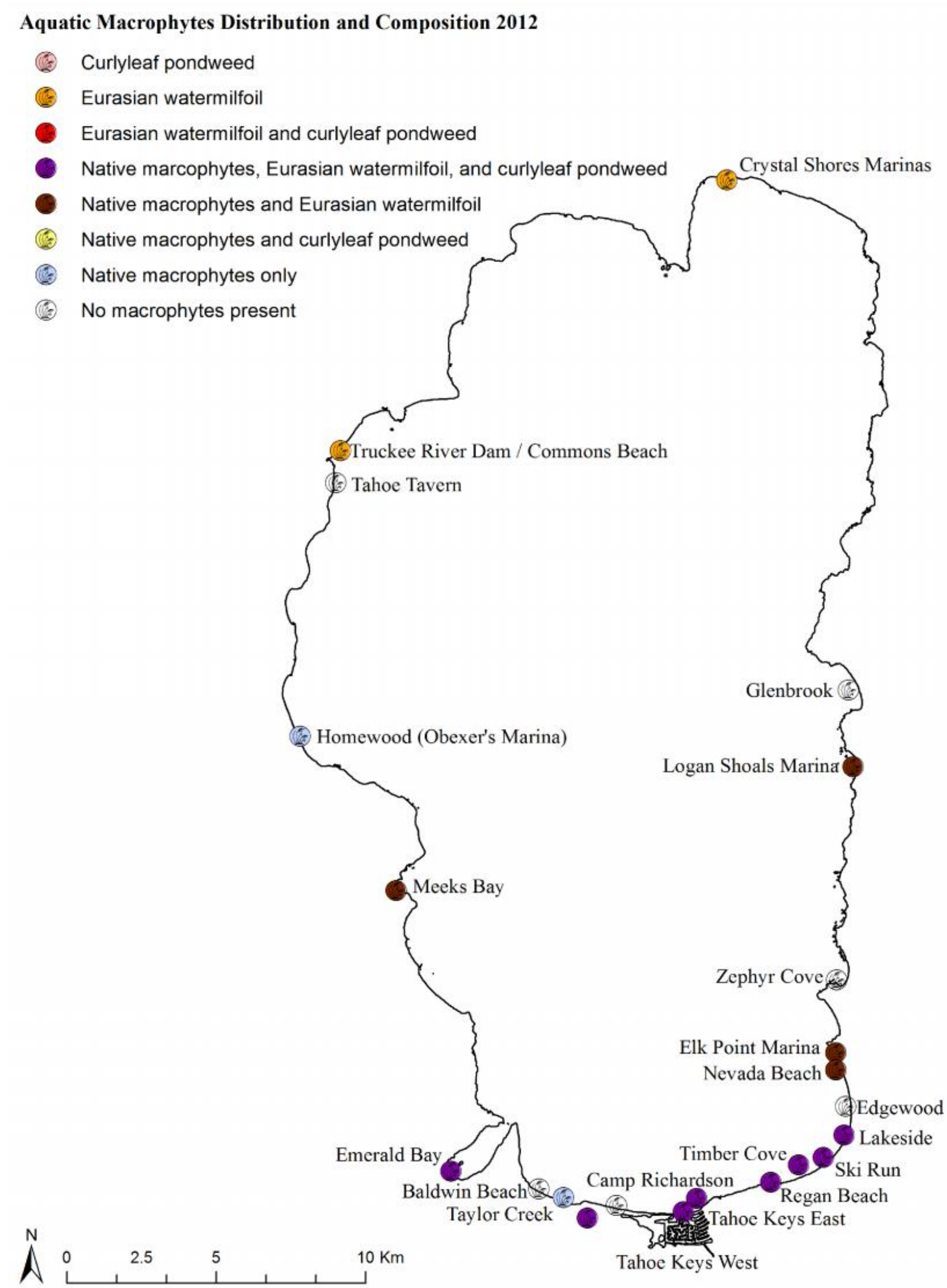

Figure 3. Detailed native and non-native aquatic plant distribution in Lake Tahoe. Data are a compilation of 2012 aquatic plant survey carried out by SEA, and observations made by other Tahoe surveillance efforts.

Curlyleaf pondweed

Curlyleaf pondweed was first identified in the south shore of Lake Tahoe in 2003 (Anderson 2003). Since its discovery, this species has spread along the south shore and in some regions has outcompeted and replaced infestations of Eurasian watermilfoil (Figure 2). Curlyleaf pondweed has been called the most widely dispersed, nuisance invasive aquatic macrophyte in North American lakes. This pondweed can inhibit recreation, increase the phosphorus concentration across the water column and impair water quality (Bolduan et al. 1994, Woolf and Madsen 2003). Curlyleaf pondweed is tolerant of many ecological conditions (low/high nutrients, slow/fast water flow, low/high temperatures, low/high light) and can invade numerous aquatic ecosystems. Its ability to germinate in the fall and overwinter, along with its wide environmental tolerances, allows this species to begin growing in the spring before native plant species. Large infestations of curlyleaf pondweed can impede water flow and can cause excess phosphorus release into the water column as a result of annual die-offs and subsequent decomposition of plant material.

Control of curlyleaf pondweed

Similar to Eurasian watermilfoil, curlyleaf pondweed has a number of mechanical, biological and chemical treatments. Curly-leaf pondweed can be mechanically removed by raking or seining, but will likely reestablish from any remaining roots left behind. Traditional benthic barriers (i.e. gas permeable) have been used on curlyleaf pondweed with variable results. Mayhew and Runkel (1962) and Mayer (1978) reported that covering curlyleaf pondweed populations with benthic barriers (polyethylene and fiber glass coated sheeting) was effective at reducing biomass, but did not report on subsequent recolonization. Madsen and Crowell (2002) suggest that bottom barriers are effective in preventing the growth of rooted curly-leaf pondweed, however, long-term management would require the elimination of vegetative buds (i.e. turions) to fully interrupt the life cycle.

Biocontrol of curlyleaf pondweed can occur using the herbivorous Grass Carp, (*Ctenpharyngodon idella*). However, Grass Carp is not native to the Tahoe Region and is considered invasive in regions of North America (Wittmann et al. 2014).

Herbicide treatment using endothall or fluridone is effective at inhibiting turion production and can substantially reduce curlyleaf pondweed biomass and turion abundance during the initial 2-3 years of treatment. Unfortunately less substantial reductions have been observed in subsequent years (i.e. >3yrs) of treatment (Johnson et al. 2012). In another study, spring treatments of diquat or endothall were effective in reducing curlyleaf pondweed shoot and root biomass, as well as suppressing turion production (Poovey et al. 2002). In both studies, while herbicide treatment reduced turion production, viable turions remained in the sediments up to 5 years post-treatment.

Integrated use of bottom barriers and acetic acid or high temperature treatments

Recent experiments conducted at the bench and mesocosm scale, showed that using a gas impermeable rubber barrier and a 2-week exposure of turions to dilute acetic acid ($C_2H_4O_2$, tapioca starch pearls, which facilitated slow release of the compound) resulted in complete inhibition of sprouting turions at and above acetic acid concentrations of 83.3 mmol (Barr & Ditomaso 2014). Similar results were found with treatments of hot water under bottom barriers (Barr and Ditomaso, *In Press*). These findings demonstrate the potential of acetic acid or hot water combined with impermeable benthic barriers as an effective method for the inhibition of curlyleaf pondweed turion sprouting.

Control of curlyleaf pondweed in Lake Tahoe

Experiments conducted both in the field in Lake Tahoe and in the laboratory between 2011-2013 tested whether bottom barriers could be an effective method to control curlyleaf pondweed (Gamble et al. 2013). Curlyleaf pondweed turions were collected from the Tahoe Keys, placed in mesh bags and placed under jute, polyethylene or rubber barriers that were deployed *in situ*. The results showed that turion sprouting was higher after 8 weeks under the barriers than the control conditions. Yet, benthic barriers were successful in reducing the existing biomass of curlyleaf pondweed populations, with jute being the most cost-effective and easily deployed bottom material. Examination of the test sites six and twelve months after application of the barriers suggests that pondweed populations were not primarily using turions for recolonization, but were instead spreading via rhizomes (Gamble et al. 2013).

Small laboratory experiments (without sediment) showed that using a rubber barrier treatment, 48% of the turions sprouted relative to 100 percent sprouting in the control condition. Turions in the jute and polyethylene treatments had 100% and 97% sprouting respectively. Larger mesocosm scale experiments (with sediment) also showed the rubber barrier treatment had a strong and highly significant effect on turion sprouting: 30% sprouting compared to 98% in the control condition. The jute barrier treatments had a 72% sprouting rate and polyethylene barriers, a 70% sprouting rate. Comparison among treatment means showed that rubber barriers were significantly more effective than either polyethylene or jute and that jute and polyethylene were not significantly different from each other. The authors of this study concluded that benthic barriers alone cannot eradicate 100 percent of the turions on their own, but that benthic barriers could be used in conjunction with other integrated methods for eradication of curlyleaf pondweed turions.

Conclusions based on curlyleaf pondweed control research

Control of curlyleaf pondweed likely requires multiple strategies to reduce plant biomass, destroy turions, and reduce rhizome growth. The integrated use of diver-assisted suction removal and bottom barriers to reduce both vegetative growth and rhizome spread is recommended. Exploration of dredging activities to remove turions from sediments is also warranted. Further, based on results from studies in systems outside of Lake Tahoe, the integration of either acetic acid (e.g., vinegar) or hot water application with the use of bottom barriers or other mechanical removal means may be effective to inhibit turion production and enhance localized eradication efforts for this species. This integrated approach, applied particularly at the early stages of establishment, may provide significant reduction in turion production, vegetative growth and the spread of this species. In order to understand the efficacy of curlyleaf pondweed removal, a better understanding is needed of both the temporal pattern in rhizome growth in Lake Tahoe, and the efficacy of integrative treatments for reducing rhizome and turion spread.

Invertebrates

The first extensive collection of benthic invertebrates from Lake Tahoe occurred in 1962–1963 and revealed the existence of 10 endemic benthic invertebrate species, including 2 species of blind amphipod (*Stygobromus tahoensis* and *Stygobromus lacicolus*), a deepwater stonefly (*Capnia lacustra*), 2 turbellarians (*Phagocata tahoena* and *Dendrocoelopsis hymanae*), and an ostracod (*Candona tahoensis*) (Frantz & Cordone 1967, 1996; Caires et al. 2013). Other common benthic invertebrate species observed at Tahoe include Amphipoda (introduced *Hyalella* sp.), Chironomidae, Oligochaeta, Gastropoda (Planorbidae and Physidae), and the native bivalves, Sphaeriidae (*Pisidium casertanum* and *P. compressum*). Since the 1960s, Tahoe native benthic invertebrates have significantly declined, potentially due to the effects of invasive species, climate change or declines in water transparency (Caires et al. 2013).

Here we consider three established non-native invertebrate species: one unintentionally introduced bivalve, the Asian clam (*Corbicula fluminea*), and two species intentionally introduced to Lake Tahoe to support game fish, signal crayfish (*Pacifastacus leniusculus*) and mysid shrimp (*Mysis diluviana*).

Asian clam

The invasive, Asian clam is established and spreading in Lake Tahoe (Figure 4). In 2002, low density populations (2-20 individuals m^{-2}) were first observed in the south eastern portion of the lake, and by 2009 densities up to 5000 individuals/m^{-2} had been measured (Wittmann et al. 2012a). Its distribution was regionally confined to the southeastern quadrant of the lake, until 2009 when a population was discovered in Emerald Bay. The Asian clam was generally found in the nearshore zone at depths of 2 - 10 m, but low-density populations were also located at depths between 10 and 50 m. One individual was recovered from 70 meters; deeper than the scientific literature has previously described or studied. Where it is established, the Asian clam comprises the majority of the benthic community biomass, and has been associated with, (but not necessarily the cause of) filamentous algal blooms (Forrest et al. 2012). Through shell deposition, the Asian clam has had a negative impact on the aesthetic qualities of the nearshore environment in the Lake (TRPA 2014).

A recent experiment indicated that passive transport of adult Asian clams is a potential dispersal mechanism in Tahoe, particularly in the movement of adults and juveniles from shallow depths to deeper zones (Wittmann et al. 2013, Forrest et al., *in preparation*). A simulation model indicates that water currents in Lake Tahoe have a 7% probability of transporting juvenile Asian clams multiple kilometers from an origination point (Hoyer et al. 2014). However, the likelihood of establishment is dependent on the characteristics of the receiving habitat (Hoyer et al. 2014).

2014 Observations of Asian clam at Sand Harbor

In August 2014 at Sand Harbor, one half of an Asian clam shell was found on the beach about 50m south of the boat ramp. Scuba surveillance crews returned in September 2014 to do an exploratory survey off of the boat ramp and found one small live Asian clam. During Spring 2015 all suitable habitat within Sand Harbor State Park was surveyed for Asian clam and the shell from one recently deceased Asian clam was recovered at approximate 5 m water depth off the boat ramp. There was no evidence of Asian clams in Divers Cove or along the main swim beach (K. Webb, pers. comm. 2015). Sand Harbor is over 20 kilometers away from the nearest established Asian clam population.

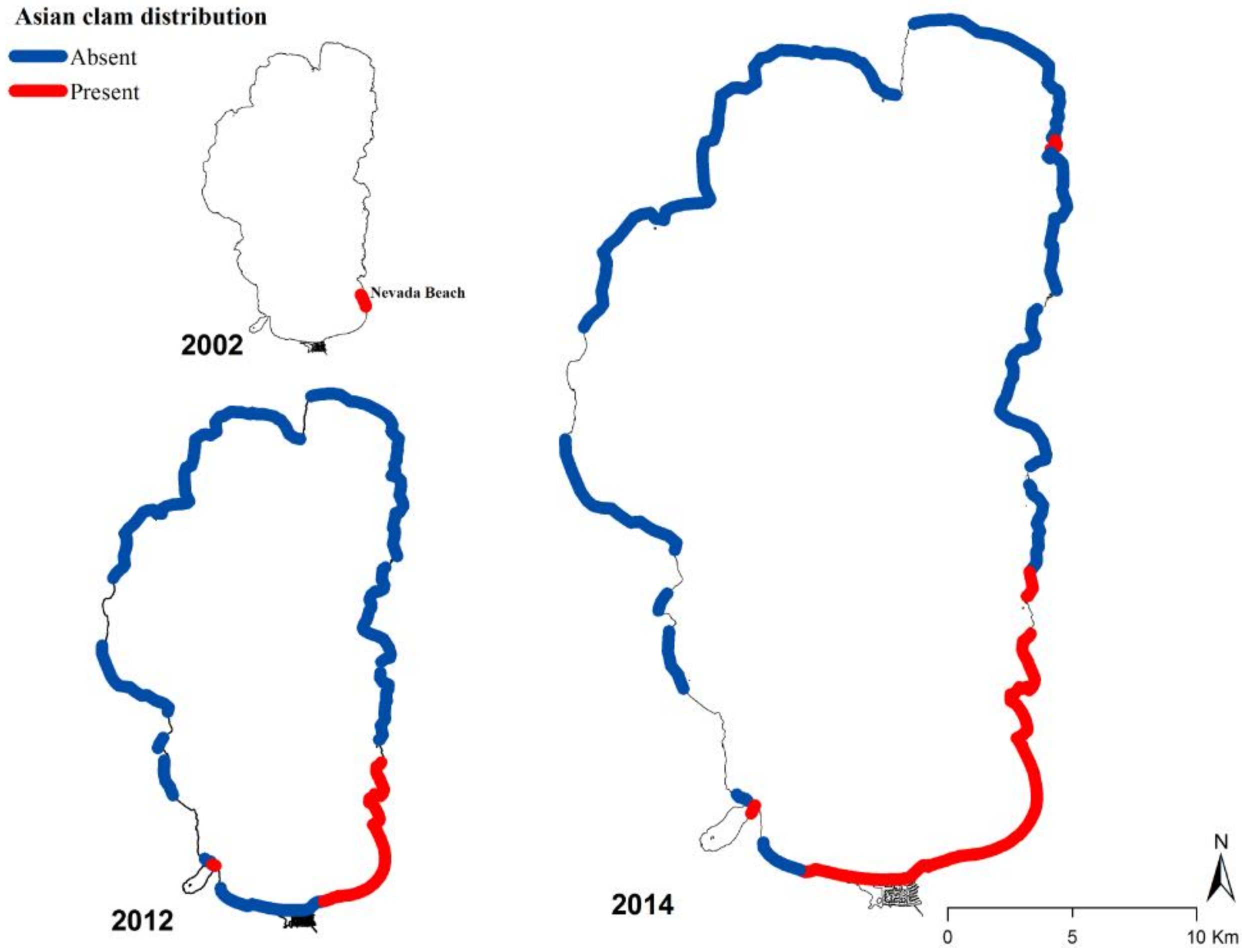

Figure 4. Asian clam (*Corbicula fluminea*) distribution in Lake Tahoe, 2002–2014. Asian clam were discovered in 2002 at Nevada Beach, the rest of the Tahoe nearshore zone was not surveyed. Information in the 2012 panel is after Forrest et al. (2012) and other observations (Wittmann, Unpublished Data). The 2014 panel includes current observations such as the Emerald Bay population (discovered 2009) and the recently observed (2014) Sand Harbor individuals.

Control of Asian clam

Most treatments for the control of the Asian clam were developed specifically to reduce biofouling at electric or nuclear power plants. These methods incorporate both mechanical and chemical options and include the use of screens, strainers, filters, physical removal (vacuuming clams from floors or horizontal surfaces of intake bays), thermal control, paints and coating, metals (copper and zinc), oxidizing compounds such as chlorine, bromine, ozone, and halogenation (Isom et al. 1986). Chlorination is the most widespread chemical treatment used for Asian clam, but is often ineffective due to regulatory limitations in application concentrations (Mattice et al. 1982). Other physical control methods include emersion induced mortality through manual water draw-down (White & White 1977) or unintended die-offs as a result of natural water level fluctuations (Baumgärtner et al. 2008). In general, most treatments are targeting the removal of biofouling clams (i.e., those accumulated on commercial structures, intakes, etc.) and are not appropriate for use in open waters, particularly in locations where state or federal policies limit the use of pesticides. In 2014, the US Geological Survey indicated that the eradication of Asian clams from infested open waters is unlikely and placed management emphasis on preventing further spread (Foster et al. 2015).

Experimental control of Asian clam in Lake Tahoe

Two non-chemical management strategies (i.e., physical harvest through diver-assisted suction removal and application of gas impermeable bottom barriers) had been tested in both small (~8 m^2)- and large (~2000 m^2 and ~20,000 m^2) scale pilot projects in Lake Tahoe (Wittmann et al. 2012a, 2012b, UNR 2015).

Suction Removal

In 2009, physical harvest of Asian clams was conducted using a suction dredge in small experimental plots (~8 m^2) in Marla Bay, in the southeastern region of Lake Tahoe. This treatment resulted in short-term reductions (1500 individuals m^{-2} before treatment to 60 individuals m^{-2} 14 days after treatment) but caused significant disruption to the benthic macroinvertebrate (BMI) community (Wittmann et al. 2012a). The impact to the Asian clam population was present up to 450 days after treatment and the BMI community diversity was not recovered after 365 days. Certain non-target macroinvertebrate taxa (Chironomidae and native clam (*Pisidium spp.*)) increased in the dredged plots to levels higher than before treatment. Sites were only monitored for 450 days after dredging and Asian clams fully recolonized the areas after 2 years. The cost of suction removal was significant: labor and materials associated with the implementation of diver-assisted suction removal were \$265/m^{-2} and included the purchase of dredge equipment, high altitude commercial diver labor, sediment disposal, and permitting fees. A major logistical difficulty associated with suction removal included the inability to separate juvenile clams from similarly sized sediments. This potentially increased overall population growth rates of Asian clam populations within treatment plots relative to control plots due to the reduction of intra-specific density dependence.

Bottom barrier treatments

An experimental, large scale treatment (two half-acre plots) of gas impermeable (EPDM) bottom barriers was implemented between 2009 and 2010 in Marla Bay and near Lakeside Marina in southeastern Lake Tahoe (Figure 4) (Wittmann et al. 2012b). It was found that Asian clam populations were significantly reduced during these applications, with up to 95 - 99% mortality observed. The combination of anoxic conditions and increased toxicity of water due to elevated ammonia conditions under the barriers may have been a key mechanism in the mortality of Asian clams (Wittmann et al. 2012b).Unfortunately native BMI communities were also significantly reduced, but after a one year period, both Asian clams and BMI communities demonstrated rapid recolonization in the treatment plots (Wittmann et al. 2012b). Asian clam abundances in the treatment plots were not different than those observed in control plots 22 months after bottom barrier removal (Wittmann et al. 2013). In an attempt to scale up this treatment, a hypothetical analysis was done by Wittmann et al. (2013) with a 100-acre area. This analysis indicated that the total cost of treatment would range between \$2 and \$26 million. Unfortunately due to the observed recolonization rates for the bivalve in Lake Tahoe, eradication or even significant reduction to low density with this treatment option was not likely (Wittmann et al. 2013). This outcome agrees with some work from similar benthic barrier treatments in Lake George, NY. In 2013, 7 acres of barriers were used to successfully kill populations of Asian clams in Lake George, however, a recent lake wide survey revealed that the invasive clams continue to appear in new locations as well as spreading beyond the treated areas. Managers at Lake George indicated that bottom barriers can cause Asian clam mortality, but are "generally not sufficient to contain them" (www.stoptheasianclam.info).

A second Tahoe application of gas-impermeable barriers was deployed across a 5-acre region near the mouth of Emerald Bay in 2012. In October of that year, prior to barrier application, 485 petite-Ponar grab samples were collected to characterize the population and live Asian clams were identified in 63% of the samples. The average density in Emerald Bay was approximately 60 ± 3 individuals/m^2. Relative to the Marla Bay and Lakeside populations, this was a relatively low-density population.

After the barriers were installed in Emerald Bay (this application included a layer of "curlex," a biodegradable fiber intended to increase biochemical oxygen demand (BOD) under the barriers), Asian clam populations both under the barriers and outside of the barriers were examined to determine the effectiveness of the barriers. Asian clam mortality increased underneath the barriers over time while the small populations outside the mats appeared to be unaffected; mortality rates for these clams remained at approximately 10-15%, representing the natural mortality rates. The barriers increased mortality most during the summer months (Jul, Aug, Sept) achieving 100% mortality in several, but not all, locations. This mortality is thought to be related to warm water temperatures and less frequent storm events which can potentially cause water to flow underneath the mats and impair barrier integrity (Chandra unpublished data, 2015).

Asian clam population densities after the barrier removal in Emerald Bay decreased by an average of 88% (average Asian clam density: 7 ± 1 individuals m^{-2}). In addition, the density of native clams (*Pisidium sp.*) decreased significantly from 8 ± 1 to 1 ± <1 individuals/m^{-2}. Upwelling and high wind/wave activity was observed during the Emerald Bay treatment. These variables together with increased porosity of the sediment due to composition of the substrate may have caused water to flow underneath the barriers causing dissolved oxygen levels to increase (as opposed to remaining at 0 mg/L as was observed in the Marla Bay and Lakeside treatments). In general, the treatment significantly reduced the Asian clam population in Emerald Bay. Unfortunately the treatment was less effective than the Marla Bay and Lakeside treatments and took considerably longer (2 years compared to 3 months). Planning for post-treatment monitoring to quantify Asian clam recolonization rates in Emerald Bay is currently underway.

Conclusions based on Asian clam control research

While both bottom barriers and suction dredging may be useful to reduce Asian clam populations in the short term, the species' observed rapid recolonization rates likely pre-empts any potential for effective widespread removal and control of Asian clam in Lake Tahoe with these methodologies. This is supported by evidence from technical reports and peer-reviewed studies of Asian clam control experiments in both Lake Tahoe and Lake George and from suggestions put forth in the USGS Non-indigenous Aquatic Species database (e.g., Foster et al. 2015). Further, treatment of Asian clams with pesticides is likely not feasible in Lake Tahoe due to difficulties associated with exposure time in open water conditions. However, the potential for pesticide treatment applied in combination with bottom barriers may provide a means for effective pesticide contact times and containment.

In scenarios where there may be an exceptional need to manage clams, such as where infestations may negatively affect water clarity, recreation, survival of native taxa or other important attributes of the lake, further investigation into various removal strategies over small scales to mitigate some of the potential damages that Asian clam may cause is recommended.

Signal crayfish

Signal crayfish (*Pacifastacus leniusculus*) have been introduced to Lake Tahoe four times between the late 1880s - 1930s. This species is widely distributed in Tahoe with highest densities observed in Northern and Western regions of the lake (Figure 5). Crayfish comprise the bulk of the benthic biomass in the littoral zone and show seasonal movement and migration across depths. Long-term monitoring in Lake Tahoe has indicated that at one transect location (i.e. Sunnyside – on the west shore), crayfish population densities have steadily increased between 1991 - 2010 (Figure 6). In 2011, crayfish populations decreased around the lake due to unknown causes, but in the years since, their numbers have steadily increased.

Signal crayfish are well known for their aggressive behavior and ability to significantly impact all levels of aquatic food webs. Crayfish are "poly-trophic" feeders, meaning they will eat everything and can dominate the benthic community. These characteristics suggest that their role in lake food webs may be significant (Light 2003). In Lake Tahoe, Flint (1975) showed that at low densities, crayfish can stimulate periphyton production by feeding upon old senescent periphyton biomass. In turn, at higher densities (1.05 individuals m^{-2}) crayfish can reduce periphyton, thereby potentially reducing food for the benthic macroinvertebrate community. Crayfish excretion experiments by Flint (1975) indicated that crayfish are a source of nitrogen and can increase periphyton production. Recent studies suggest there have been drastic declines in all invertebrates (besides crayfish) in Tahoe (Caires et al. 2013). A number of endemic aquatic invertebrates have been particularly impacted by crayfish presence including, the Tahoe stonefly (*Capnia lacustra*), the Tahoe blind amphipod (*Stygobromus spp.*), and the Tahoe flatworm (*Phagocata tahoena*), among others (Caires et al. 2013). The interaction between crayfish abundance and the decline of these sensitive endemic species is unknown.

Further, Kamerath et al (2008) suggest that crayfish have subsidized the populations of predatory invasive warm water fishes in Lake Tahoe.

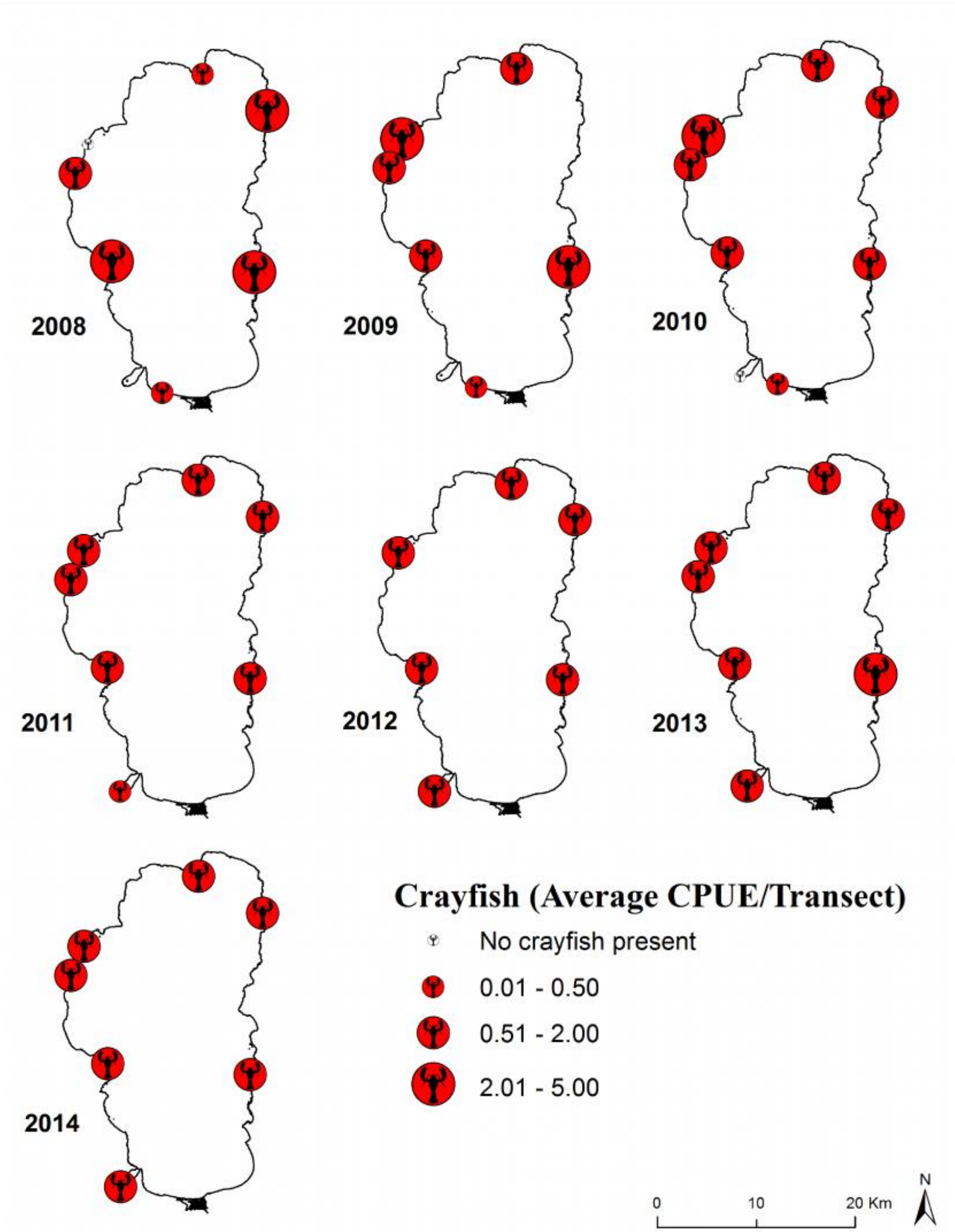

Figure 5. Signal crayfish (*Pacifastacus leniusculus*) distribution in Lake Tahoe 2008 – 2014. Each symbol represents the average catch per unit effort (CPUE) over a regional transect.

Control of Signal Crayfish

Crayfish are harvested globally as a food resource; however whether crayfish populations can be significantly reduced or eradicated is unknown. Manual removal of signal crayfish using traps and pond experiments with biocides have met with only moderate success in the UK (Freeman et al. 2010). Research in the Midwestern US suggests that crayfish invaders in lakes and streams can be significantly reduced in the short term by harvesting individuals through trapping. Qualitative information suggests that crayfish abundance in these situations remained low following removals (Vander Zanden pers. comm., 2015). The success of a trapping program will depend on growth rates and reproductive life histories of the crayfish (Hein et al. 2006, 2007).

In the last 3 years, the states of NV and CA have passed legislation or amended regulations that allow for the commercial harvest of crayfish in Lake Tahoe. In 2014, licensed operators finished their third season of harvesting crayfish from Lake Tahoe, a program that began in 2011. It is not clear if commercial harvest can successfully reduce crayfish populations in Lake Tahoe; however, it is recommended that harvester activity should be coordinated and/or centralized in order to more efficiently reduce populations across different regions of the lake.

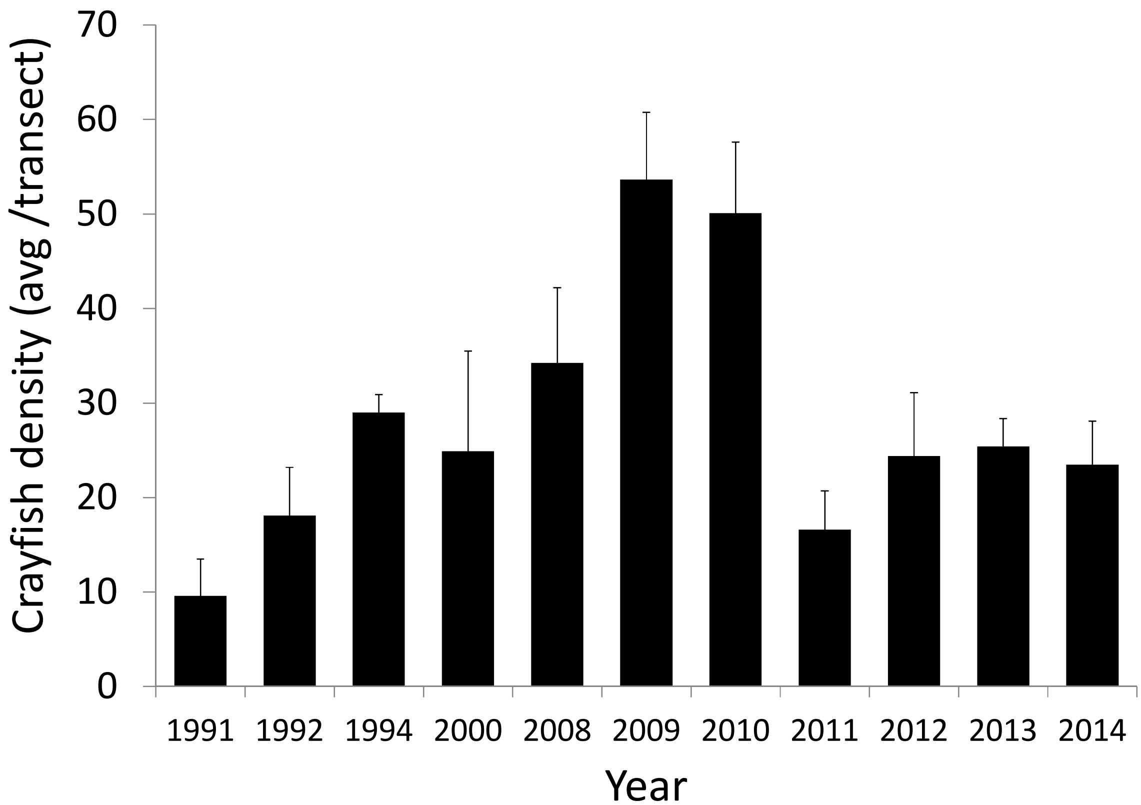

Figure 6. Average summer/fall signal crayfish density, 1991 – 2014. Data were collected at the “Sunnyside” transect, located on the west shore of Lake Tahoe. Data presented from Chandra et al., 1991, 1992, and 1994 and 2008 - 2010 from Umek et al. unpublished.

Conclusions based on Signal Crayfish control research

The unwanted effects of signal crayfish are significant, in Lake Tahoe and elsewhere. Continued monitoring of crayfish populations is important for understanding the long-term dynamics of the nearshore communities and the potential impacts they may have on native species in Lake

Tahoe, as well as other synergistic effects they may be having on other non-native species. In addition, monitoring can inform managers of crayfish population changes across the current harvest areas. Harvesting of crayfish has significantly reduced populations in other systems over short time periods (1-3 years), and potentially over longer time intervals (e.g., 10 years) (Vander Zanden pers. comm., 2015). Continued exploration into the use of commercial or non-commercial harvest as a means to reduce both the population density and the associated impacts of crayfish on native taxa, water clarity or other aspects of the Lake's ecosystem is recommended. Further, investigations evaluating the amount of effort and harvest needed to control this relatively long-lived species of crayfish, which can live up to 9 years, is warranted.

Mysid shrimp

Mysis diluviana (previously *Mysis relicta*), is an important invertebrate ominivore in many aquatic ecosystems. In the past, fisheries managers have introduced Mysid shrimp to lakes across the North American Pacific Northwest and Scandinavia with the intent to increase fish production (Lasenby et al. 1986; Northcote 1991). Although some introductions to support fisheries were successful (e.g., Sparrow et al. 1964), a great number resulted in the collapse of fisheries and significant changes to food webs (Rieman and Falter 1981; Beattie and Clancey 1991; Bowles et al. 1991; Richards et al. 1991; Ellis et al. 2011). Perhaps one of the most well-known failures of mysid shrimp introduction occurred in the Flathead River-Lake ecosystem. Owing to predation by the shrimp, cladoceran zooplankton declined dramatically, contributing to the collapse of kokanee salmon, an important planktivorous fish in that system. Loss of this formerly abundant forage fish caused displacement of mammals and birds (eagles) that had fed on them in an upstream tributary within Glacier National Park (Spencer et al. 1991).

Mysid shrimp were introduced into Lake Tahoe in the mid 1960s as forage for introduced gamefish, kokanee salmon and lake trout. Mysids were not recorded in the lake until 1968, when they were found only in lake trout stomachs (Morgan et al. 1978). Prior to *Mysis* invasion, Lake Tahoe's zooplankton community was comprised of two copepod (*Epishura nevadensis*, *Diaptomus tyrelli*) and three cladoceran (*Daphnia rosea, D. pulicaria*, *Bosmina longirostris*) species. Following the establishment of *Mysis*, cladocerans (both *Bosmina* and *Daphnia*) were virtually eliminated from the lake. As a result of competition for cladoceran food sources, kokanee salmon population and body size decreased (Morgan et al. 1978). From 1971-1975, mysids established high densities in the lake (>300 m^{-2}) and continue today to be one of the dominant zooplankton taxa. Similar to the situation in the Flathead Lake system, mysids in Lake Tahoe have the potential to seriously impact the food web of the greater Tahoe ecosystem and potentially hamper future efforts with native cutthroat trout reintroduction.

Control of Mysid Shrimp

Management options are extremely limited for mysid shrimp. Some research has indicated that biological controls such as large-scale introductions of amphipods or fish (deepwater sculpin, Arctic Char) appear feasible, however no research successfully demonstrated this (Martinez & Bergersen 1989; Olsen 2014).

Conclusions based on Mysid shrimp control research

In Lake Tahoe, it appears that management options for *Mysis* are also extremely limited. The harvest of mysid shrimp in the lake does not appear feasible, based on general life history characteristics, their high population growth rate, and the widespread distribution of the taxon throughout the lake. Further monitoring of mysid densities to understand their role in controlling phytoplankton, sediment particle delivery from the lake bottom to open water, and impacts on organisms such as endemic invertebrates, which have declined, is recommended to understand whether restoration actions or the promotion of other species reintroductions in Lake Tahoe is feasible.

Warm water fish

Beginning in the mid-late 1970s through the late 1980s, a variety of warm water fish species were found in the nearshore zone of Lake Tahoe (Reuter & Miller 2000). These illegal introductions are thought to be the result of angler introduction (e.g., largemouth bass, (*Micropterus salmoides*)), aquarium releases (e.g., goldfish, (*Carassius auratus auratus*)) or other unintentional introduction activities. Prior to the 1970s, native minnows were abundant in the lake; however, by the late 1980s largemouth bass and bluegill (*Lepomis macrochirus*) were common in the Tahoe Keys region of the lake. By the 1990s, recreational fishing guides were unable to collect native bait minnows at certain marinas. This rapid reduction in native fish abundance raised concerns, while at the same time nearshore habitat for non-native fishes increased with the expansion of aquatic weed beds (Kamerath et al. 2008). Until 2006, the distribution of warm water fishes beyond the Tahoe Keys was largely unknown. 2006 surveys by Kamerath et al. (2008) found non-native fishes, including bluegill, largemouth bass, goldfish, brown bullhead (*Ameiurus nebulosus*), and black crappie (*Pomoxis nigromaculatus*), at 12 of 19 sites (not including the Tahoe Keys) around Lake Tahoe (Figure 7). Most sites outside of the Tahoe Keys were characterized by very low abundances (observations of 1-10 individuals per snorkel survey), and the highest densities have always been observed in the Tahoe Keys. Since 2011, a number of non-native warm water fish discoveries (e.g., first sightings) occurred. The first voucher specimen of a small mouth bass (*Micropterus dolomieu*, a 15.5 inch, 2.3lb, gravid female) was collected from the Tahoe Keys in June of 2011. The first voucher specimen of common carp (*Cyprinus carpio*) (Total length 28.5 inches, 10.6 lbs, gravid female) was collected in the Tahoe Keys in September 2012.

At this time, the extent to which warm water fishes have established in areas outside of the Tahoe Keys is unclear. Nearshore temperature data suggest that all of the monitored sites are thermally suitable for spawning by largemouth bass, bluegill, and other warm water fishes (Kamerath et al. 2008). However, not all monitored sites are currently thermally suitable for the over-winter survival of warm water fishes. A study by Chandra et al. (2009) suggests that bass migrate out of the Tahoe Keys in early to mid-summer. This and other research also suggests that suitable habitat for nonnative warm water fishes in the nearshore has increased with the expansion of aquatic weed beds and increased nearshore water temperatures (Kamerath et al. 2008; Chandra et al. 2009; Ngai et al. 2013).

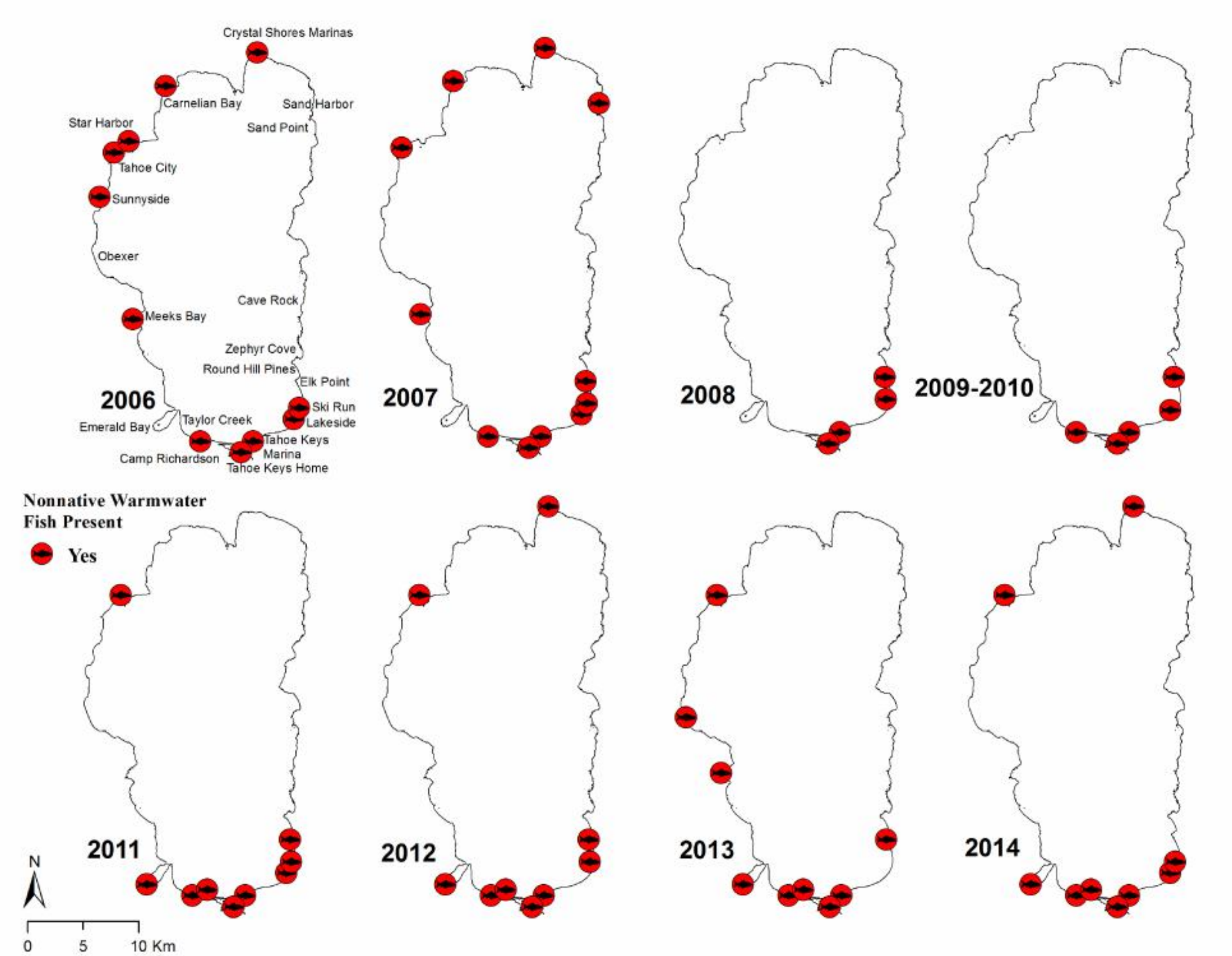

Figure 7. Warm water fish distribution (presences) in Lake Tahoe, 2006–2014. Surveys were conducted by snorkel or electroshocking. See Table 2 for list of warm water fish found in Lake Tahoe.

Warm water fish establishment has altered food web function and decreased the biodiversity of the native fish assemblages in other ecosystems (MacRae & Jackson 2001). Comparing historical and contemporary diet data for native and nonnative warm water fish in Lake Tahoe, Kamerath et al (2008) found both direct and indirect impacts of nonnative warm water fishes on the native fishes through predation and competition, when their habitats overlap. Chandra et al. (2009) recommended control and removal of largemouth bass and other nonnative warm water fish to minimize predation pressure on, and competition with, native fishes. In addition, based on the shift in largemouth diet to piscivory at two to four years (8.0 to 12.0 cm), Chandra et al. (2009) also recommended largemouth bass and other warm water fish removal, optimally every two years, to minimize predation pressure and competition with native fishes.

Control of warm water fish

There are a number of chemical and non-chemical methods available to control warm water fish species, and their efficacies are highly species and system dependent. Here, we provide a cursory background to some of these methods and report in detail on the findings from a Lake Tahoe-specific non-chemical warm water fish pilot removal program that took place from 2011-2014.

Table 2. Native and nonnative fishes found in the nearshore of Lake Tahoe.

Species (Common Name)	Latin Name
Native fishes	
Tahoe sucker	*Catostomus tahoensis*
Lahontan redside shiner	*Richardsonius egregius*
Lahontan speckled dace	*Rhinichthys oseulus robustus*
Tui chub	*Gila bicolor (obesus or 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*
Smallmouth bass	*Micropterus dolomieu*
Golden Shiners	*Notemigonus crysoleucas*

Examples of non-chemical, mechanical methods to control unwanted warm water fishes include angling, water level manipulation or dewatering, fyke nets, gill nets, minnow traps, seines, electro-fishing, and electric fields (Loppnow et al. 2013). Mechanical removal of non-native fishes in other lake systems has shown promising results by reducing reproductive success, thereby limiting recruitment, and helping restore native fish communities (Weidel et al. 2007). Unlike chemical methods, most mechanical methods are selective and can be used to target only nonnative species.

Chemical methods to control warm water fish include sodium cyanide, cresol, copper sulphate, toxaphene, Antamycin A, and the most commonly used fish toxicant, rotenone. Sodium cyanide is unacceptable in water supply reservoirs due to its toxicity to mammals, cresol is likely to cause tainting and toxaphene is undesirably persistent. Copper sulphate, at concentrations likely to kill fish, is very toxic to vegetation. Rotenone and Antimycin A were approved for use as piscicides in fisheries management, but fish contaminated by them are not acceptable for human consumption, primarily because no suitable methods are available for residue analysis. Rotenone acts by inhibiting oxygen uptake through the gills, resulting in suffocation. Antimycin

A has the advantage over rotenone in that fish do not avoid it. Rotenone and Antimycin A are non-selective, meaning it will kill all fish within the target tolerance level as well as other aquatic organisms. No piscicide is limited in its effects to those on fish, and many chemicals are lethal, at concentrations used on fish, to planktonic and benthic invertebrates, reptiles and amphibians, and occasionally toxic (but not necessarily lethal) to birds or mammals.

Tahoe Warm Water Fish Removal Pilot Project, 2011-2013

Starting in the spring of 2011, a three-year pilot control project for warm water fish was implemented in Lake Tahoe, with most effort focused on the Tahoe Keys. The main objective of this project was to determine the feasibility and effectiveness of using mechanical removal methods (mainly electro-fishing) for the management of warm water fishes. By reducing the reproductive populations of warm water fishes, the research could examine how this removal might facilitate native fish restoration in Lake Tahoe.

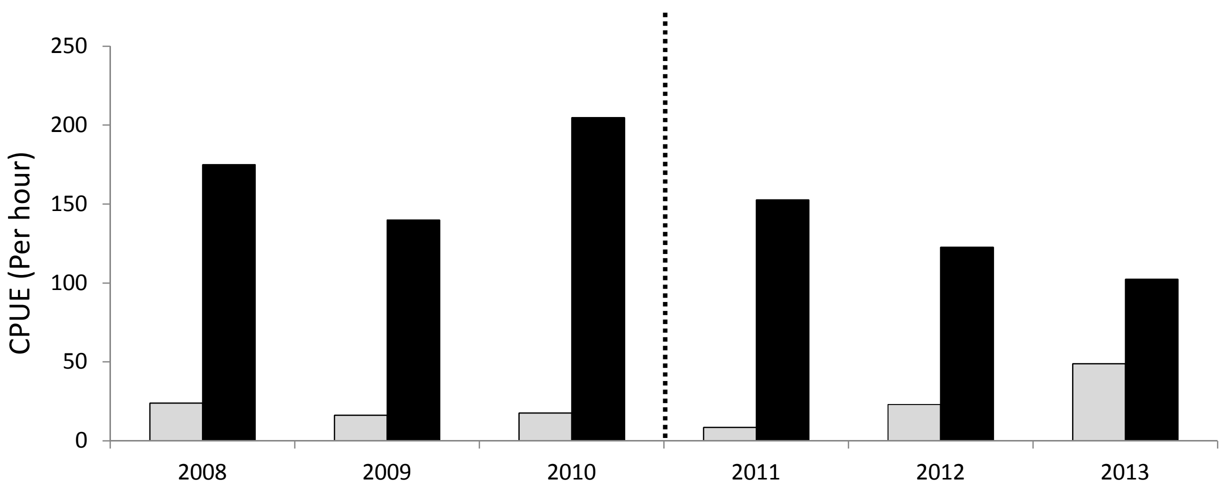

Figure 8. Catch per unit effort (CPUE) of native (solid bars) and non-native (line bars) fish in the Tahoe Keys, Lake Tahoe, 2008 – 2013. The warm water fish removal effort commenced in 2011 (represented by dashed line) and continued through 2013.

During this project, the overall abundance of warm water fish decreased and native fish increased (Figure 8). Despite this general trend, there were various outcomes for the different warm water fish taxa. A total of 51,142 nonnative warm water fish were removed by electrofishing between spring 2011 and fall 2013, with 99% of these fish collected in the Tahoe Keys. The distribution of nonnative warm water fish was uniform across all portions of the Tahoe Keys indicating no "hotspots" of warm water fish aggregation, and therefore, removal effort should be targeted uniformly across the region. Largemouth bass and bluegill made up the majority of the nonnative catch. In particular, large spawning largemouth bass adults (≥400mm) showed significant and consistent reduction in numbers over the project period, with no collections in 2013. This suggests that mechanical removal may be effective at reducing the reproductive population of spawning adult largemouth bass. For bluegill, demographic comparisons between pre and post removal years suggests that the removal effort shifted the size structure toward larger individuals and may have increased recruitment, particularly for individuals between 145 and 185mm. This is likely the result of a low bluegill catch rate, which allowed individuals to grow throughout the season.

Due to a lack of funding, control efforts ceased during the 2014 spring/summer period. A 2014 fall survey of the Tahoe Keys showed that after one year without any control effort, the relative abundance of largemouth bass may have recovered. This suggests that ongoing removal efforts may be necessary maintain low numbers of largemouth bass. Results from the 2014 fall survey also showed significant increases in catch of age-0 bluegill (<55mm) after one season of no control effort. This implies that mechanical removal may not be effective at reducing bluegill numbers in the Tahoe Keys.

Conclusions based on warm water fish control research

Based on the results of the electroshocking removal experiment (i.e. short term decreases in largemouth bass in the Tahoe Keys and potential impacts to bluegill sunfish population structure), we recommend continued mechanical removal for this species until alternate approaches (e.g. pesticides) can be utilized in the basin. Mechanical removal should be coupled with the development of a population harvest model to determine the effectiveness of removal for each taxa. In addition, it is important to establish a monitoring program for invasive fishes including cold water taxa such as small mouth bass recently discovered in the lake; these may live outside of marinas in rocky habitats.

Amphibians

American Bullfrog

The American bullfrog (*Rana catesbeiana*) is native to eastern North America but has become widespread across the U.S. It is the largest true frog in North America, reaching sexual maturity between three to five years following metamorphosis and living for upwards of 13 years. Like other bullfrogs, *R. catesbeiana* is cannibalistic, frequently consuming newly metamorphosized bullfrogs and larval tadpoles (Stuart 1993). Bullfrogs prefer wet vegetated areas to lay eggs, hide from predators and wait for prey. In the Tahoe Basin, American bullfrog has been observed since 2004 in the south shore region, with breeding populations occurring in Sawmill Pond, Seneca Pond, Taylor Creek, and Lake Baron (Figure 9). Information related to population growth, spread or breeding rates is currently unknown.

The American bullfrog is considered invasive largely due to its rapid population growth and voracious and unspecialized feeding habits (Lowe et al. 2000; Kraus 2009; CABI 2011; Jancowski and Orchard 2013). Bullfrogs develop nonlethal infections from chytridiomycosis, caused by the chytrid fungus (*Batrachochytrium dendrobatidis*) (Daszak et al. 2004). Chytrid fungus appears capable of infecting most amphibian species and has been linked to significant population declines (Fisher et al. 2009). Recent research suggests bullfrogs are also known to transmit the disease to other anuran species (Greenspan et al. 2012).

Control of American bullfrog

To control adult bullfrogs, a variety of methods may be employed, including shooting, spears/gigs, bow and arrow, clubs, nets, traps, angling, and by hand (Global Invasive Species

Database 2008). Recently, methods have been developed to collect and control frogs using a modified electro-fishing shocker. Collecting egg masses using a bilge pump can be an effective adjunct control (Govindarajulu 2004). Targeting egg searches to areas where male bullfrogs are heard calling during the night may improve the probability of detecting egg masses (Govindarajulu 2004). Incomplete removal of eggs or larvae, however, can inadvertently increase the growth and survival of the remaining individuals and cause an increase in the population (Govindarajulu 2004). Direct removal of bullfrog is often very difficult and typically unsuccessful due to their high fecundity rate, high dispersal capability, opportunistic diet, and the complex habitats in which they are often associated. Habitat manipulation, in association with direct removal efforts, could prove more successful. Maret et al. (2006) used a method of draining and drying ponds to eliminate bullfrogs. Because bullfrogs overwinter as larvae and are dependent on permanent water for growth, this method has shown success. Direct removal of adults in combination with periodic drying (approximately every two years) could allow native amphibians the opportunity to reestablish (Doubletree et al. 2003). Although this dual pronged approach may be successful, it is unclear how periodic draining would impact native species that also rely on a permanent water source.

Conclusions based on American bullfrog control research

At this time, it is not clear whether American bullfrogs are expanding their populations within the Tahoe Basin or what unwanted effects this species may be having on native species, recreational use or ongoing restoration efforts in the basin. In addition, it is not known which mechanical or chemical methods may be the most suitable for effective control, particularly at sites that are undergoing restoration, such as Taylor Creek. As both mechanical and chemical control options have yielded some success in other systems, we recommend continued assessment of the population dynamics, life histories and impacts to other species, in order to better characterize the magnitude of the threat and to understand when control activities would best be applied. Further, experimentation of *in situ* control actions would significantly inform decision-making for this species moving forward.

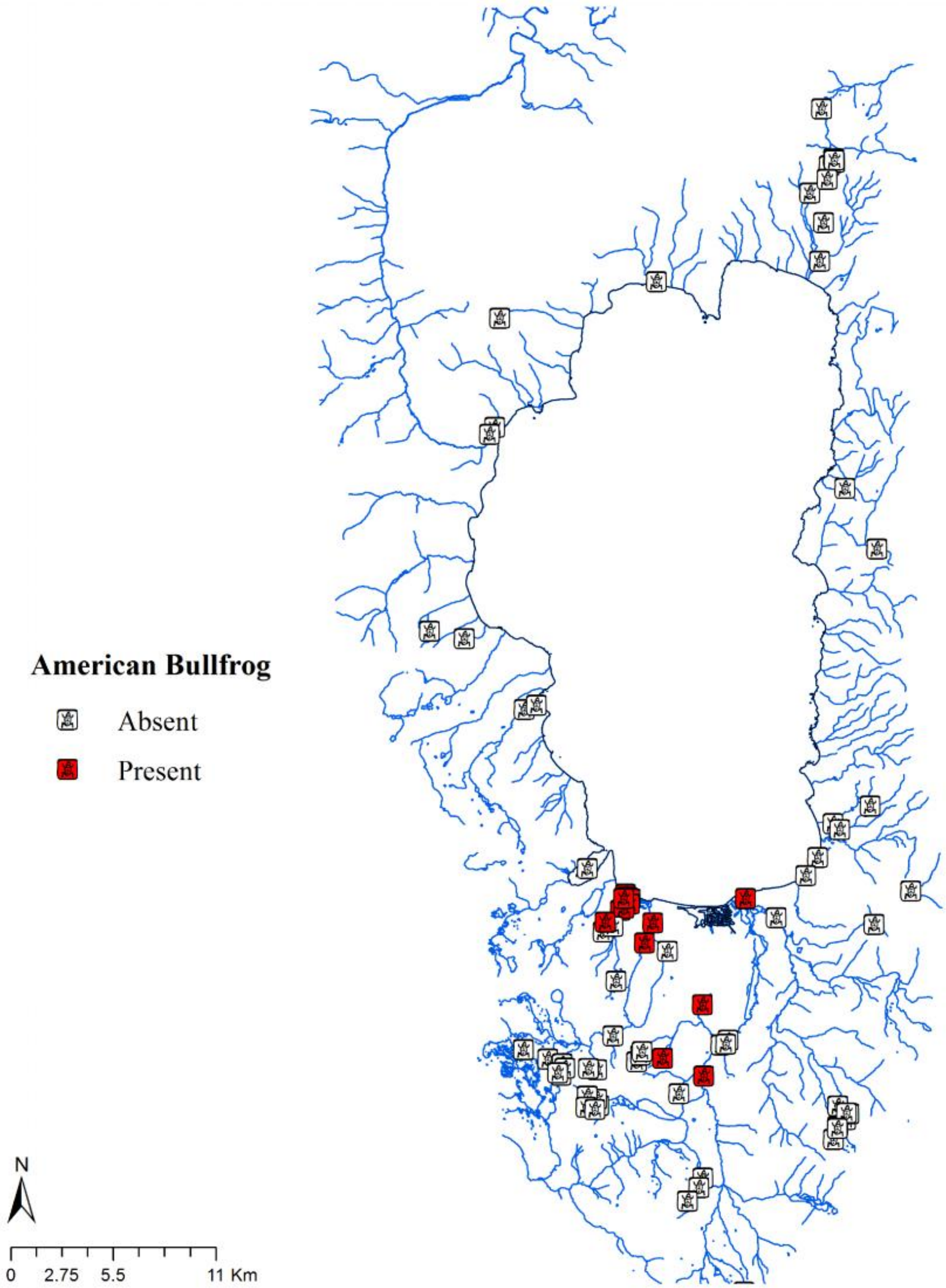

Figure 9. American bullfrog (*Rana catesbeiana*) distribution in the Tahoe Basin, 2004 – 2008, 2011 – 2014. Data from Taylor-Tallac Ecosystem Restoration Plan, S. Muskopf, USFS LTBMU, Sept 30, 2009 and American Bullfrog 2013 Summary, 13-CO-11051900-039 TRPA AIS. Presence indicates at least one life stage of Bullfrog found.

Prioritization of species, locations for control and recommended actions

Introduction

A strategic approach to management of an invasive species can be defined as a spatial and temporal distribution of effort that yields the greatest benefit from the available resources (Grice 2010). Four strategic goals for countering biological invasions can be identified: prevention, eradication, containment and control. Prevention is only applicable prior to the transport and introduction stages (Lockwood et al. 2013). Generally, eradication is possible either during the establishment stage, or during the earliest part of the spread stage, (Lockwood et al. 2013). When eradication of an invasive species becomes impractical, containment or adaptation may be the most appropriate strategy. Containment and control strategies seldom have an end point, and often the size of the infestation is positively correlated with the time required to control the infestation (Rejmánek & Pitcairn 2002).

The current AIS implementation plan for Lake Tahoe focuses on the selection of AIS taxa for management targets, specific site selection for management actions, and recommendations for control strategies. These recommendations contribute to the four strategic goals presented above, which also directly overlap with the three goals of the Lake Tahoe AIS Management Plan. The prioritization of this implementation plan is based on several well-established principles in invasion ecology and management and is motivated by the following concept:

The reduction of AIS from the highest ranked sites will reduce overall expansion in the lake.

Thus, at this time, containment and control are the objectives for selected AIS in Lake Tahoe. While instances of localized eradication for aquatic invasive plants may be possible, the goal of implementation is reduction of biomass of AIS at existing locations and the suppression of spread of AIS to new locations. Further, this implementation plan is intended to guide management actions over a 3-5 year period. Whether species eradication is possible over the longer term can potentially be better informed after a systematic management and control program is implemented in Lake Tahoe.

To prioritize and recommend site- and species- specific AIS control actions, this section includes five components: (1) Categorization of AIS into management groupings, (2) An ecologically-based prioritization of site selection the top management grouping (which includes invasive aquatic plants and warm water fish, (3) Recommended management actions for all species of concern, (4) Recommendations for monitoring, and (5) Identification of knowledge gaps.

Aquatic invasive species management groupings

Based upon the information provided in the preceding section, which describes control actions taken either in Lake Tahoe or in other systems, three management groupings have been determined for the AIS considered for control actions in Lake Tahoe. The three management groupings have been determined based on the feasibility of control actions as determined in previous sections, relative to the biology of the AIS under consideration, and subject to the regulations currently in place in Lake Tahoe. These management groupings are based on the best available knowledge and management options for all of the considered species may change depending on changes to regulations in the Tahoe region, the development of novel technologies or other means by which to control AIS in Lake Tahoe, or new knowledge or information gained through research, monitoring or other AIS management actions at Tahoe or elsewhere.

The management groupings are as follows: (A) Species which have feasible control options available at this time. Potential control actions are for species or species groups for which information exists from studies at Tahoe or the scientific literature, and where removal of one species may lead to the reduction of additional AIS (e.g., fish-plant interaction). (B) Species for which potential actions exist, but there is ample uncertainty at the current time to implement right away. This includes species groups for which there may be some evidence of potential control or biomass reduction strategies, but whether these strategies have long-term feasibility, or ability to be successfully applied in the Tahoe environment is unknown. (C) No feasible control options are available at this time. This designation is based upon experimentation or practice observed either in Lake Tahoe or outside of Lake Tahoe. In the cases considered here, reasons for the infeasibility of potential control options can be attributed to biological or ecological characteristics of species which may prohibit effective control, a lack of technologies or tools, or cost-prohibitiveness of available or existing control options. As more information becomes available, or the development of novel control strategies or technologies arise, designations of species may likely change. The species groupings are as follows:

A) Feasible control actions:

- Eurasian watermilfoil
- Curlyleaf pondweed
- Warm water fish

B) Potential control actions:

- Signal crayfish
- American bullfrog

C) No feasible control options at this time:

- Mysid shrimp
- Asian clam

Site prioritization for invasive aquatic plants and warm water fish removal

Here, we employ a prioritization scheme for the invasive aquatic plants and warm water fish in Lake Tahoe. This prioritization is based on several well-established principles in invasion ecology and management and is motivated by the following concept:

The reduction of AIS from the highest ranked sites will reduce overall expansion in the lake.

Methods of the ecologically based site prioritization model

The metrics used in the prioritization model described below concern the following: (1) fish-plant interactions, (2) size of infestation, (3) human interaction with infestations, and (4) location of infestation. Other factors of major significance concerning the control of AIS such as suitability of the receiving habitat, proximity to sensitive native species, or potential impact of control actions on the surrounding environment are vital components of site selection, but are not included in this model due to lack of available data.

This prioritization is built upon these four concepts, in part, because they are well supported in the empirical and theoretical literature and also through experimentation and data collection carried out in Lake Tahoe. Vital knowledge gaps related to aquatic invasive species and their harmful effects will be identified in the following section, and should be integrated into this prioritization scheme as they are addressed through future research and management efforts. As such, the current prioritization scheme is quantified based on the following:

(1) Locales with fish-plant interactions: The presence of aquatic macrophytes enhances the ability for warm water fish to establish and to increase in population size (Dibble et al. 1996; Hoyer & Canfield 1996). In Lake Tahoe, aquatic plants provide important habitat for warm water fish reproduction and survival (Kamerath et al. 2008; Tucker et al. 2010). We assume that the removal of invasive aquatic plants in Lake Tahoe will not only decrease the unwanted effects from these species, but will also remove habitat for warm water fish.

We have identified 28 sites in Lake Tahoe that have had either current or historically established populations of Eurasian watermilfoil, curlyleaf pondweed, warm water fish or some combination of the three. Each site that is known to have established populations of these species as of 2012 (aquatic plants) - 2014 (warm water fish) is given a score of "1" for each of these three taxonomic categories. The scoring of these sites are based upon results from the warm water fish removal and surveillance efforts carried out by University of Nevada Reno (UNR) or other aquatic plant surveys conducted by various surveillance teams as coordinated by the Tahoe Resource Conservation District. These categories are additive; a score of "3" indicates that Eurasian watermilfoil, curlyleaf pondweed and warm water fish are all present. A score of "2" indicates that only two of these species groups are present.

(2) Plant infestation size: There is a demonstrated positive relationship between the size of the population and the number of viable offspring or propagules it creates (Lockwood et al. 2013). The more offspring or viable propagules, the greater the likelihood of establishment, spread and range expansion for a species within a particular ecosystem (Lockwood et al. 2005). Therefore, we assume that targeting large populations may reduce the overall abundance of the species within a system. In 2012-14, field surveys were conducted to estimate the areal invasive plant coverage in the nearshore of Lake Tahoe. We converted estimated areal coverages into site-specific proportions relative to the overall coverage in Lake Tahoe. Thus, each site that is positive for invasive plant presence, will receive a score between 0 - 1. This value is intended to represent a location's potential relative contribution of propagules (aka propagule pressure) for the rest of the lake. A high score indicates that a site contributes more to the likelihood of spread within the lake.

(3) Human use and visitation: Species invasions are associated with human disturbance. Aquatic ecologists have often modeled human movement patterns as a means to capture the frequency, type and transport mechanism of non-native species introduction events (Carlton 1993; Leung et al. 2006; Herborg et al. 2007). As an example, established populations as well as viable plant fragments of AIS are found in greater abundance in estuaries with high rates of recreational boating compared to areas with less recreational boating (Mosisch & Arthington 1998; West et al. 2009; Clarke Murray et al. 2011). Here, recreational boater visitation is used to quantify the amount of site-specific use intensity, in relative terms. We assume that areas with more recreational boat pressure represent areas of invasive species propagation.

Through an interview-based survey of approximately 800 Lake Tahoe recreational boaters, the number of in-lake recreational boat trips to nearshore sites in Lake Tahoe has been quantified (Wittmann et al. 2015). Using this metric of recreational boater visitation as an indication of human pressure, each site is given a score between 0-1, representing the number of boater visits to that site, relative to the overall in-lake recreational boat visits to all sites in Lake Tahoe. A score closer to one indicates that a site is visited by all boaters in the lake. A score of zero indicates no visitation by recreational boaters.

(4) Isolated, or satellite populations: Remotely located populations (e.g., satellite populations) of invasive species may increase the range expansion of that species within a system (Shigesada & Kawasaki 1997; Tobin & Blackburn 2008). It has been demonstrated that satellite populations increase the rate of expansion of an invasion (Lockwood et al. 2013) and targeting such populations for reduction or removal can act to reduce spread rates.

Each nearshore site that contains AIS is scored by determining the straight line distance between the set of all nearshore sites that presently or historically contain invasive aquatic plants or warm water fish, and standardizing these distances over the whole set of distances. Thus, a site with a higher score relative to other sites indicates that its nearest neighbor is relatively farther away compared to other sites.

Site Prioritization Model

Overall site prioritization was then determined through a combination of the categorical (species presence/absence) and continuous (e.g., size of infestation, human pressure, satellite populations) variables described above. The sites were then ranked according to the overall score received through the aggregation of these variables. The following describes the model.

For each site, *i*:

$$\mathrm{rank}(S_i) = (CL_i + MF_i + WF_i) * PP_i * BV_i * ED_i$$

Where,

S_i = Site specific prioritization score
CL_i = Curlyleaf pondweed presence (0,1)
MF_i = Eurasian watermilfoil presence (0,1)
WF_i = Warm water fish presence (0,1)
PP_i = Proportion of plant areal coverage in the lake (0-1)
BV_i = Proportion of boater visitation (0-1)
ED_i = Shortest distance from nearest AIS establishment site (0-1)

It is important to note that all components of the continuous elements of the model are scale invariant (meaning there are no units associated with them) and that they are equally weighted. Thus, we assume that each of the three variables, PP, BV, and ED are equally as important as each other. In addition, each of the categorical variables (e.g., MF, CL, WF) also receive equal score assignments, which indicates that the presence of all three species receives the highest priority. Further, due to the seasonal variability in AIS biomass, survey techniques and detection capabilities, there are some uncertainties associated with the presence and size of several infestations around the lake.

Results of the site prioritization and species- and site-specific recommendations
See Table 3 and Figure 10 for results of the site prioritization. Site rankings are based on the site-specific prioritization score (S_i) that each site received. Note the large difference (sometimes an order of magnitude in size) between site-specific prioritization scores (Figure 10). Please see below for a discussion of these differences.

Relative to other nearshore locations in Lake Tahoe, the **Tahoe Keys** locations scored very high and ranked #1 and #2. This priority ranking was largely due to the magnitude of the plant and fish infestations as well as the high recreational use of these areas by Tahoe boaters. These sites also had very little sensitivity to changes in estimates of plant coverage or other model variables, and thus always remain in the top priority spots. We defer to the Tahoe Keys Integrated Weed Management Plan for microsite-specific recommendations for the treatment of aquatic plants. However, due to the notable abundance of invasive and nuisance native aquatic plants in this system, an integrated program for removal which not only includes the use of non-chemical removal efforts such as bottom barriers and diver assisted suction removal, but other actions such as the reduction of nutrient loads, plant fragment collection, and herbicide application is recommended to reduce unwanted plant biomass.

Based on preliminary results from the experimental mechanical fish removal project at this location, continued electroshocking for the removal of largemouth bass and other warm water fishes is recommended. However, further research to determine the effects of this removal on various age classes of warm water fish, and the effort required to successfully reduce warm water fish populations at this and other Tahoe sites is needed. Based on feedback from the external expert review panel, a suggested 90% reduction of warm water fish biomass in the Tahoe Keys may be feasible and the amount of effort currently being allocated is not adequate

(Hoff, pers. comm 2015). Also recommended is the development of a targeted warm water fish nest control program.

Site Name	EWM	CLP	WWF	Plant	BV	ED	S_i	Rank
TK Main Lagoon and Channel (West)	x	x	x	0.791	0.122	0.041	1.2E-02	1
TK Marina Lagoon and Channel (East)	x	x	x	0.151	0.122	0.025	1.4E-03	2
Meeks Bay	x		x	0.007	0.052	0.197	1.5E-04	3
Ski Run Marina/Channel	x	x	x	0.022	0.006	0.039	1.4E-05	4
Tahoe City Dam	x		x	0.008	0.017	0.021	5.6E-06	5
Lakeside Marina	x	x	x	0.006	0.043	0.004	3.0E-06	6
Regan Beach	x	x		0.001	0.009	0.065	1.7E-06	7
Taylor Creek	x	x	x	0.000	0.046	0.046	1.4E-06	8
Crystal Bay 2	x		x	0.000	0.008	0.441	6.4E-07	9
Crystal Bay 1	x		x	0.000	0.008	0.441	6.4E-07	9
Crystal Bay 3	x		x	0.000	0.008	0.441	6.4E-07	9
Lakeside Swim Area	x	x		0.002	0.043	0.004	5.8E-07	12
Tahoe Tavern	x			0.004	0.005	0.021	3.5E-07	13
Timber Cove Pier	x	x	x	0.000	0.001	0.039	1.3E-08	14
Elk Point Marina	x		x	0.003	0.001	0.003	1.2E-08	15
Nevada Beach	x			0.000	0.001	0.003	3.4E-11	16
Logan Shoals Marina	x			0.005	0.000	0.172	8.9E-16	17
Baldwin Beach	x		x	0.000	0.009	0.046	0.0E+00	18
Emerald Bay, Avalanche Beach			x	0.000	0.155	0.171	0.0E+00	18
Emerald Bay, Vikingsholm			x	0.000	0.155	0.171	0.0E+00	18
Emerald Bay, Parson's Rock			x	0.000	0.155	0.171	0.0E+00	18
Upper Truckee River	x	x	x	0.000	0.003	0.025	0.0E+00	18
Camp Richardson			x	0.000	0.046	0.083	0.0E+00	18
Homewood (Obexer's)				0.000	0.040	0.042	0.0E+00	18
Boatworks Marina			x	0.000	0.024	0.025	0.0E+00	18
Sunnyside Marina			x	0.000	0.036	0.074	0.0E+00	18
Zephyr Cove				0.000	0.041	0.046	0.0E+00	18
Fleur du Lac Marina				0.000	0.000	0.042	0.0E+00	18

Table 3. Lake Tahoe Site Prioritization Table. EWM = Eurasian watermilfoil presence (x = present, blank = absent), CLP = curlyleaf pondweed presence (x = present, blank = absent), WWF = warm water fish presence, (x = present, blank = absent), PP = proportion of areal plant coverage relative to lake wide value (0-1), Prop Low = lower estimate of areal plant coverage relative to lake wide value, Prop High = higher estimate of areal plant coverage relative to lake wide value, BV = proportion of recreational boater visitation, ED = Euclidean distance of site, relative to nearest infested site, S_i = Site specific prioritization score, Rank = Ranking based on best estimate of plant areal coverage.

Meeks Bay, the highest ranked location after the Keys, was scored high and prioritized largely due to its "remote" location and presence of all three species of concern, but also because of the large size of its estimated areal plant coverage. Due to the uncertainties associated with the invasive aquatic plant survey information, an updated but detailed site survey at this location is recommended. Without a better understanding of the extent of the Meeks Bay infestations, at this time, targeted removal efforts at this location will make planning difficult. Warm water fish removal utilizing electroshocking is also recommended within the marina in 2015.

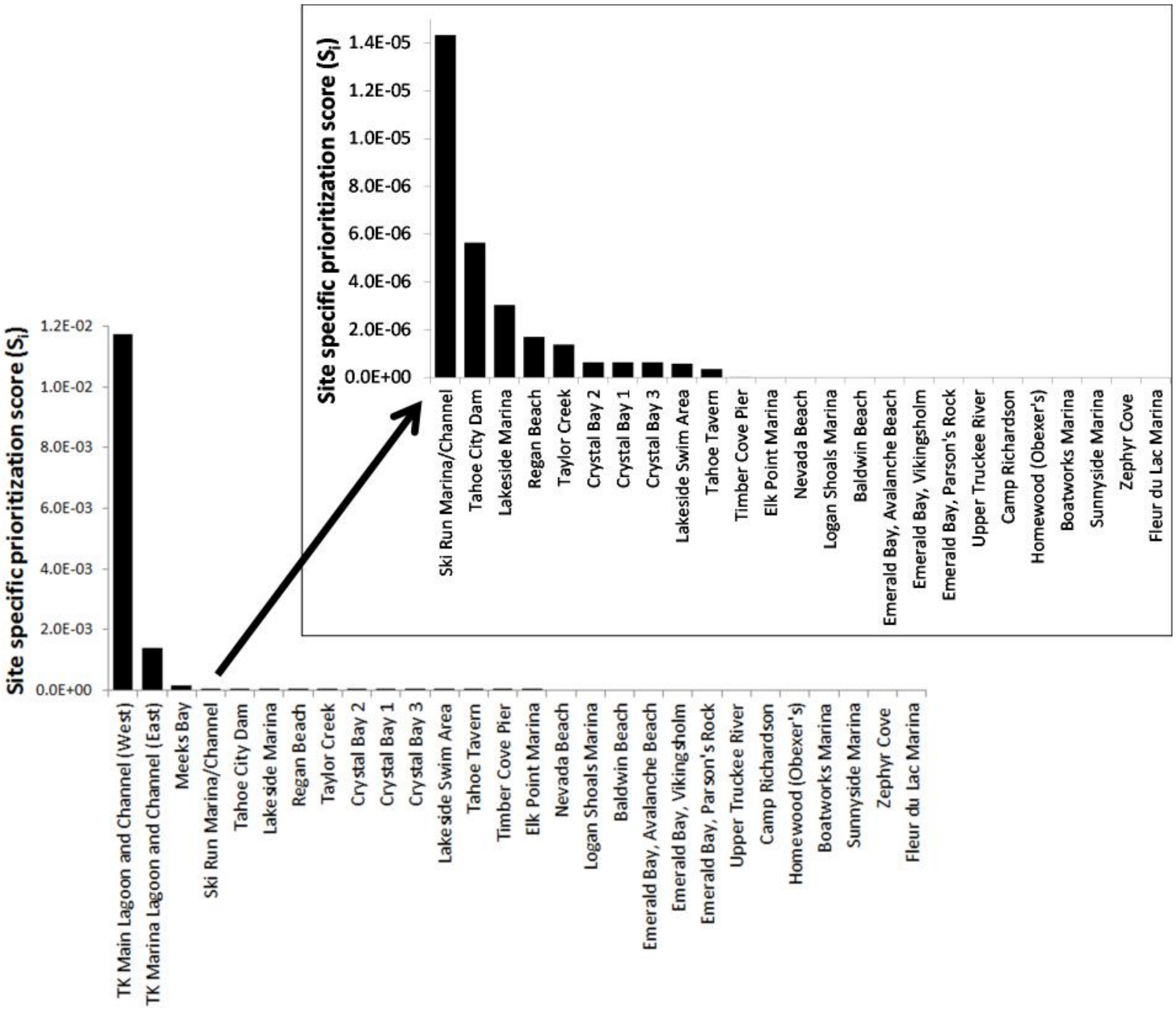

Figure 10. Site prioritization based on site-specific prioritization score, S_i. The prioritization score incorporates invasive aquatic plant and warm water fish presence/absence, areal coverage of aquatic plant infestation, recreational boater use and location of infestation. The Tahoe Keys (TK) Lagoons and Channels (West and East) score extremely high relative to other sites in Lake Tahoe.

The **Ski Run Marina and Channel** was the highest ranked location after the Tahoe Keys with reliable plant areal coverage and warm water fish information, thus making it suitable for immediate control action. Control activities as early as 2015 are recommended at this location based on the established and existing partnership between the Marina managers and the Tahoe Resource Conservation District, the high abundance of invasive aquatic plants both within and outside of the marina, and the high intensity recreational boater use. Because of the presence of both Eurasian watermilfoil and curlyleaf pondweed, an integrated program utilizing hand pulling, diver-assisted suction removal, and bottom barriers will certainly be necessary here. Due to the high density of curlyleaf pondweed at this location, control actions or experimentation targeted at turion inhibition (e.g., integrated bottom barrier and acetic acid application) as well as rhizome reduction is recommended. Warm water fish removal utilizing electroshocking is also recommended within the marina in 2015.

The **Tahoe City Dam** location scored as the fifth highest priority in this assessment. Due to this location's importance as a source of viable plant fragments for AIS establishment in the lower Truckee River below the dam, immediate action is recommended; particularly with respect to ongoing mechanical removal efforts led by the Tahoe Resource Conservation District (TRCD). The integrated use of hand-pulling and bottom barriers may be especially effective in 2015 due to low water conditions. Similar to these non-chemical methods, the use of herbicides at this time may be effective due to increased application efficacy attributable to the low water condition. However, at present herbicide usage is not permitted; therefore alternative methods will need to be used to control aquatic plants and warm water fish at these locations.

The following sites were ranked from 6 - 12: **Lakeside Marina (and swim area), Regan Beach, Taylor Creek and the Crystal Bay Marinas/Rock Cribs.** Characteristics of these locations indicate their importance for targeted invasive plant and also warm water fish removal; however, uncertainties which pose management obstacles occur at each location. For example, the **Lakeside Beach and Marina locations** as well as the **Crystal Bay Marinas** have been part of invasive plant control efforts over the past few years (2011-2013). However, post treatment monitoring and plans for continued removal efforts are currently unknown. We recommend integrated removal programs using bottom barriers (gas impermeable at Lakeside (due to presence of Eurasian watermilfoil and curlyleaf pondweed) and gas permeable at Crystal Bay (due to presence of Eurasian watermilfoil)) and diver-assisted suction removal, coupled with multi-year efficacy monitoring and surveillance. There is conflicting information concerning the size and location of aquatic plant infestations at both **Regan Beach** and **Taylor Creek**. Updated and detailed site surveys in both locations is warranted. In particular, Taylor Creek is currently undergoing a large scale restoration project and is home not only to invasive aquatic plants and warm water fish, but also bullfrogs which may be using Eurasian watermilfoil beds as habitat along this creek system (S. Muskopf pers. comm., 2015). More information is needed regarding the density and distribution of aquatic plants in this system.

Of the 28 sites considered, 11 sites did not have any aquatic invasive plant coverage in 2012-2014. However, of these 11, 6 had warm water fish, although in low abundance. Sites without aquatic invasive plant presence were ranked lowest as a result, and we recommend continued monitoring. It is important to note that all three locations in Emerald Bay (e.g., Parson's Rock, Avalanche Beach and Vikingsholm) have been scored zero for curlyleaf pondweed and Eurasian watermilfoil. Despite the historical abundance Eurasian watermilfoil and a one-time observation of curlyleaf pondweed at this location, we assume for the sake of this prioritization exercise that both of these species are currently absent in Emerald Bay. This assumption is based on reports of the multi-year Emerald Bay aquatic plant removal program collaboratively funded and implemented by the California State Lands Commission, California Department of

Parks and Recreation, Tahoe RCD and TRPA, and the most recent (2014) survey results. Continued monitoring (and associated rapid response actions) is encouraged at Emerald Bay.

Recommendations for species in other management groups

American bullfrog: At this time, it is not clear whether American bullfrogs are expanding their populations in the Tahoe Basin. Further which mechanical or chemical methods may be most suitable for effective control of American bullfrog in the Tahoe Basin is unknown, particularly in sites that are undergoing restoration work (i.e. Taylor Creek). Continued assessment of the population dynamics, life histories and impacts to other species (including humans) in the Tahoe Basin are recommended. These assessments will allow for the characterization of the biological properties of these populations, magnitude of the invasion, and the feasibility of mechanical or chemical control options given these properties. Understanding where and when breeding populations may occur in the Tahoe Basin can help develop specifics of mechanical removal efforts for this species. Further, experimentation of *in situ* control actions or the initiation of a pilot control project will significantly inform decision-making concerning targeted control efforts for this species moving forward.

Signal crayfish: The negative effects of signal crayfish are significant, both in Lake Tahoe and elsewhere. Continued monitoring of crayfish populations is important for understanding long term dynamics of the nearshore systems, and particularly to understand potential population changes from harvest areas in the lake. The harvest of crayfish has significantly reduced population numbers in other systems over short time periods (1-3 years), and potentially over longer intervals (e.g., 10 years) (Vander Zanden pers. comm., 2015). Continued exploration of the use of commercial or non-commercial harvest as a means to reduce population densities and associated impacts of crayfish where they may be impacting native species, water clarity or other aspects of the Lake's functioning is recommended.

Asian clam: While both bottom barriers and suction dredging may be useful to reduce Asian clam populations in the short term, the species' observed rapid recolonization rates likely pre-empts any potential for effective widespread removal and control of Asian clam in Lake Tahoe with these methodologies. This is supported by evidence from technical reports and peer-reviewed studies of Asian clam control experiments in both Lake Tahoe and Lake George, and from suggestions put forth in the USGS Non-indigenous Aquatic Species database (e.g., Foster et al. 2015). Further, treatment of Asian clams with molluscicides is likely not feasible in Lake Tahoe due to difficulties associated with exposure time in open water conditions. However, the potential for molluscicide treatment applied in combination with bottom barriers may provide a means to improve effectiveness of application and contact time as well as containment of molluscicide.

In scenarios where there may be an exceptional need to manage clams, such as where infestations may negatively affect water clarity, recreation, the survival of native taxa or other important attributes of the lake, further investigation into various removal strategies over small scales to mitigate some of the potential damages that Asian clam may cause is recommended.

Mysid shrimp: Based on life history characteristics, high population growth rates, and distribution throughout the lake, harvest of mysid shrimp in Lake Tahoe does not appear feasible at this time. Further monitoring of impacts to native or sport fish species relative to mysid population densities is recommended to better understand how actions related to the restoration or promotion of other species in Lake Tahoe may be negatively impacted by *Mysis* shrimp.

Recommended efficacy monitoring

The progress and consequences of containment and control programs must be effectively monitored in order to provide both information and feedback to managers. Monitoring data is necessary to the process so that management actions can be modified, adjusted or concluded, if/when new information arises. Monitoring should document changes in the distribution or abundance of an invasive species, or changes in components of the system, such as variables like water clarity, productivity, or native species abundance (Grice 2010). Well-designed monitoring programs should not only contribute to the knowledge of the impacts of particular invasive species, but also to the value of the containment and control actions used to help manage them. Further, efficacy monitoring can serve to significantly reduce control costs as it improves the ability to rapidly respond to small, incipient populations that may arise after treatment. This is in contrast to observing a recolonization after it has achieved significant areal coverage or biomass.

Efficacy monitoring for aquatic plant, warm water fish, and all AIS control activities should be conducted on a project-specific basis. Any site-specific targeted removal action (either mechanical removal or chemical treatment) should have an accompanying efficacy monitoring plan that is based on both the timing of the control action and phenology of the AIS. Specific efficacy monitoring actions for invasive aquatic plants and warm water fish include:

- Quantification of areal coverage, and when possible, density of Eurasian watermilfoil, curlyleaf pondweed and/or warm water fish in treatment area and in adjacent non-treatment area prior to treatment action.
- Quantification of areal coverage, and when possible, density of native aquatic plants and native fish in the treatment area, and in adjacent non-treatment area prior to treatment action.
- Repeated quantification of the two items listed above ***immediately after treatment action, 6 months after treatment, and 1 year after treatment (or some other determined time intervals)***. The surveillance carried out one year after treatment (or some other determined time interval) can inform the level of effort and materials needed for upcoming treatments.
- Quantification of the ***effort*** per spatial unit spent to implement site-specific removal. For example, the number of hours spent by divers, boat operators, data enterers, data assessors to implement and evaluate the information associated with a removal activity.
- Localized populations should not be considered eradicated unless a five year period has passed without an observation of an incipient population (e.g., see Anderson 2005). Continued surveillance is recommended at all locations due to potential reintroductions

from outside of Lake Tahoe (e.g., recreational boater or waterfowl dispersal) and within Lake Tahoe (e.g., other established populations).

Knowledge Gaps

Through the development of this AIS Control Implementation Plan, a number of important informational needs required in order to improve planning and implementation for any AIS control actions to be carried out in Lake Tahoe have been identified by the authors, the AISCC and the external expert review panel. Addressing these items can facilitate AIS control implementation in Tahoe, as well as a strategic AIS management plan moving forward. Not listed in any order of priority, these gaps include:

1. Need for established metrics or goals to evaluate success of AIS management: The ability to set eradication versus control objectives will improve implementation of AIS management at Tahoe. At this time, there is no defined, desired outcome for control in the Basin. The ability to determine whether eradication or containment is a site or species-specific objective is a key step to setting goals for any AIS management plan. Further, as potential control options or technologies are introduced, it will be helpful to know which could be used for eradication or which could be used for control. Over the next 3-5 years, evaluating the success of invasive aquatic plant removal by determining the change in areal coverage (e.g., plants) or fish density at each site location and effort expended can inform future control efforts.

2. Aquatic plant distribution: Estimates of areal coverage of aquatic invasive plants in Lake Tahoe range widely; our highest-confidence estimate for whole-lake coverage was 125 acres, with a minimum range of 25 and a maximum of 146 acres. The Tahoe Keys alone has been estimated to be about 130 acres of aquatic plants: mainly *M. spicatum*, *C. demersum* and to a lesser extent, *P. crispus*, with some seasonal nuisance filamentous algae as well. Planning, resource acquisition and implementation for site-specific control actions depends heavily on the accurate measurement of species infestations. Site-specific inconsistencies in the aquatic plant survey information could potentially be resolved with a standardized surveillance program with consistent methodologies and surveillance parameters. Namely:

- **Taylor Creek and the Upper Truckee River:** The identification and distribution of aquatic invasive plants Taylor Creek is highly uncertain. A detailed survey of the creek between Fallen Leaf Lake and Lake Tahoe is warranted to understand the magnitude of the infestation, particularly because this region is an upstream source for AIS for Lake Tahoe. The same is true for populations in the Upper Truckee River.
- **Baldwin Beach, Tahoe Tavern and Sunnyside Marina** all have conflicting reports of aquatic plant presence.
- **Meeks Bay** has not been surveyed for aquatic plant coverage since 2009. A high priority site; a detailed species specific survey is warranted at Meeks Bay.
- **Fleur du Lac and Logan Shoals Marinas**: These marina locations have historical establishments of Eurasian watermilfoil and have either been resurveyed as part of individual efforts (e.g., Logan Shoals surveyed by L. Anderson in 2010), have not been recently resurveyed (Fleur du Lac), or have conflicting reports.

3. Curlyleaf pondweed control actions. Citing examples from both the published literature and Tahoe specific research actions, the non-chemical removal of Eurasian watermilfoil in moderate abundances may be feasible in certain locations. However, the feasibility of non-chemical mechanical treatments for curlyleaf pond weed are uncertain at this time due to uncertainties related to the timing of its growth and reproduction, longevity of turion survival, propagation via rhizomes relative to turions, and other Tahoe specific dynamics. How mechanical or chemical treatments relate to the phenology and recolonization of curlyleaf pondweed in Lake Tahoe at this time is currently not well understood. Recent publications indicate that combined treatment using acetic acid (e.g., vinegar) or hot water and EPDM bottom barriers inhibit turion growth (Barr & Ditomaso 2014, Barr &Ditomaso In Press). Integrating these potential turion inhibition treatments with other pilot removal products may provide important information for long-term implementation planning in Tahoe.

4. Warm water fish harvest and removal: Ongoing efforts to remove warm water fish are largely based on mechanical removal. Based on recommendations from the external expert review panel, increases in electroshocking effort in the Tahoe Keys are highly recommended. Further, establishing stock-recruitment models based on the harvest of warm water fish from the Tahoe Keys or at other locations in Lake Tahoe should be developed to guide future mechanical removal methods with a focus on developing alternative, efficient methods for removing these taxa.

5. Consistent surveillance for aquatic plant and warm water fish populations: The evaluation of AIS expansion in Lake Tahoe, as well as the efficacy of control actions carried out in Lake Tahoe is dependent on information that consistently describes the size and location of AIS populations, as well as the discovery of new species occurrences (e.g., the first observation of smallmouth bass in Tahoe in 2011). Inconsistencies in timing, strategy and methodology of aquatic plant surveillance has led to uncertainties concerning aquatic plant distribution in the Lake (see knowledge gap #1 above), which affects the ability to accurately identify the resources required for site specific management actions. Consistency in terms of surveillance efforts and collection protocols will tend toward more effective program evaluation and success. We recommend the development of:

- Species-specific data collection protocols that enable future users of the information to utilize spatial visualization tools (e.g., GIS) or employ other types of analyses that contribute to ecosystem functioning and systematic program evaluation.
- Consistent timing of surveillance efforts. Seasonal differences when surveys are conducted may account for some of the variability in field observations.
- Use of hydroacoustic/GPS/mapping systems will help provide baseline and post-control conditions while generating quantitative metrics that can be compared across all infested areas, including the Tahoe Keys sites.
- Whole-lake surveillance rather than selectively returning to sites with known infestations.

- Centralization of a data or information database; designate an entity to keep information so that it can be quality assured and easily accessible to Tahoe Basin managers and researchers.

5. Control methodologies for Asian clam, Signal crayfish, American bullfrog: Further exploration into novel technologies or integrated methods for the control of Asian clam is warranted. While the use of bottom barriers and suction dredging can reduce the abundance of Asian clam in the short term, this species' reproductive capabilities limits the use of these methods over large scales. However, in smaller scale settings where Asian clam may be having an unwanted impact, these or other methodologies may be effective at reducing these impacts. Similar to Asian clam, there may be promise in the continued or focused use of harvest to reduce the abundance of this species and impacts to other native taxa in the Lake. For Asian clam, Signal crayfish and American bullfrog, there remains much uncertainty concerning the magnitude and dynamics of the unwanted impacts they may be having on Tahoe's ecosystem. For all species, action is recommended to quantify the unwanted impacts that each may have, as well as to identify potential novel control techniques for each.

6. Comprehensive surveillance program for species not yet established in the Tahoe Basin: At present, there is no comprehensive surveillance program to monitor or detect novel species introductions or establishments within the Lake Tahoe Basin. The ability to carry out a rapid response, and thus minimize damages caused by AIS, for an incipient population of a nonindigenous species is highly dependent on early detection. The utilization of regularly scheduled field surveillance efforts, coupled with new technologies such as environmental DNA (eDNA) tools, stakeholder involvement such as citizen science efforts, or rapid data collection through the development of smartphone apps, may increase the efficiency and coverage of a consistent surveillance program.

6. Use of Aquatic Pesticides: The use of aquatic pesticides for Eurasian watermilfoil, curlyleaf pondweed, warm water fish species (particularly egg and juvenile stages) and other AIS of concern in the Lake Tahoe Basin have shown to be effective in laboratory and field settings elsewhere. At this time, the discharge of pesticides into Lake Tahoe is prohibited. However, further exploration of the safe and effective use of pesticide as an integrated AIS management tool in Lake Tahoe is recommended.

7. Need to improve site-specific prioritization model: At present, each of the scoring categories is equally weighted. This suggests that each of the elements which determines the ranking of specific sites, such as site size, location or recreational boater visitation is equally important. It is highly likely that these elements do not necessarily each play an equal role in the determination of invasion patterns or dynamics in Lake Tahoe, however it is unknown what the relative contribution of these and other elements may be to the rate of range expansion of AIS. The ranking of locations provided here is sensitive to this aspect of the model. In addition, other factors that determine the establishment of a species, such as the abiotic as well as biotic characteristics of the nearshore habitats in Lake Tahoe, are not currently included because of a lack of information. Further, the sensitivity of the site-specific model to the explanatory variables or potential weights assigned to each explanatory variable has not been quantified. Understanding the relative importance of each variable through model validation may provide a more effective implementation plan.

8. Understanding of how Tahoe AIS are impacting nearshore indicators or other components related to management or regulatory thresholds: As the decision to invest in the prevention or control of an invasive species is determined by how much damage it may cause, the understanding of how a species may impact an ecological system is a key component of informed decision-making. Information that adequately quantifies the impacts of AIS in the nearshore region of Lake Tahoe is unknown. Better understanding of the impacts caused by these species can aid in decision-making for available management options and pursuits.

9. The role of nearshore algal growth and AIS establishment: Recent observations of increased or altered algal growth in the nearshore zone may influence not only water clarity but also the establishment of AIS. Further, feedbacks between AIS and algal communities may be creating synergistic effects that promote the establishment and growth of both AIS and algal communities. Experimental evidence or data that may be able to inform scientists and managers about these relationships is unknown.

Next steps

The following are recommended next steps to implement the site and species specific recommendations provided in this implementation plan over the next 3-5 year period:

1. Act now: Use species and site specific recommendations provided herein as a guide to prioritize non-chemical treatments of aquatic plants in the highly prioritized sites. As the ability to treat the largest infestations of nuisance aquatic plants in the Tahoe Keys will be highly resource intensive, we recommend prioritizing specific sites as resources allow.

2. Determine metrics for successful outcomes: We recommend the use of the following metrics: plant areal coverage, fish density (specific to size class) and effort allocated to evaluate the outcomes of each implementation and control action.

3. Develop a lakewide monitoring and surveillance plan: We recommend regular surveillance for invasive aquatic plants and warm water fish every year, for invasive invertebrates every other year, and the integration of the use of novel technologies such as eDNA for species that are not yet present in the Basin.

4. Integration of AIS control with the nearshore plan: The control of AIS in Lake Tahoe should be in accordance with the recommendations put forward in the 2013 Lake Tahoe Nearshore Evaluation and Monitoring Framework (Heyvaert et al. 2013).

5. Development of a research plan for addressing data gaps as identified in this implementation plan and elsewhere. Identified knowledge or data gaps can negatively impact the successful implementation of the control or removal of biological species within an aquatic system. Targeted experimentation or assessment to address these management-oriented research questions can reduce overall costs and increase efficacy for an AIS control program.

6. Aligning available funding sources with the priority locations and species proposed in this implementation plan. Determining optimal allocation of resources, as they become available, will improve budgetary and activity planning for implementation of AIS control actions in Lake Tahoe. Further, seeking cooperation between local partners and implementers can improve sustainable AIS removal programming.

7. Support the exploration or development of new strategies or technologies for the control of AIS in Lake Tahoe. This includes investigation of the safe use of chemical or other non-traditional methods for control or efficacy monitoring of AIS in Lake Tahoe.

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