Potential Distribution of Zebra Mussels (*Dreissena polymorpha*) and Quagga Mussels (*Dreissena bugensis*) in California
Phase 1 Report

A Report for the
California Department of Fish and Game

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Contents

Scope of Phase 1 Report

A previous study (Cohen and Weinstein 1998) assessed 160 water bodies in California in terms of their suitability for supporting populations of zebra mussels (*Dreissena polymorpha*) based on water quality. A subsequent study (Cohen and Weinstein 2001) found that calcium concentration is the most critical water quality parameter controlling the potential distribution of zebra mussels in North America, and presented evidence suggesting that zebra mussels' calcium tolerance had been misinterpreted and often overestimated. In January 2007, the quagga mussel (*Dreissena bugensis*) was discovered in the lower Colorado River system and the Colorado River Aqueduct, near and within California waters.

This Phase 1 report assess the potential distribution of zebra and quagga mussels in California using the water quality data assembled for the 1998 study, based on an initial review of our current understanding of the environmental requirements of these mussels. To address the uncertainty in our understanding of the mussels' calcium tolerance, the assessment is repeated using five values for the calcium threshold (the minimum calcium concentration needed to establish a population).

Background

Zebra and quagga mussels are native to European waters in the Black and Caspian Sea basins. Juveniles and adults of both species attach to hard surfaces using a net of tough fibers called byssal threads, and also have the ability (significantly greater in quagga mussels) to build up populations over time on soft substrates (Mills *et al.* 1996; Berkman *et al.* 1998). Both species spawn in the spring to fall period and produce large numbers of planktonic larvae (veligers) that typically spend one to several weeks drifting in the water column before settling and attaching to the bottom (Sprung 1993; Ackerman *et al.* 1994; Cohen and Weinstein 2001). Developmental times and planktonic periods are longer at lower temperatures, and in some cases veligers may remain in the plankton over the winter (Nichols 1996; McMahon 1996). Juveniles and adults can detach, crawl short distances, and then reattach with new byssal threads, and juveniles can detach and drift in the plankton, sometimes "kiting" on byssal threads or crawling on the underside of the air-water surface (Oldham 1930; Martel 1993; Carlton 1993; Ackerman *et al.* 1994). Juveniles or adults that attach to aquatic plants can also travel significant distances when parts of the plants break off and float away. Natural dispersal upstream or overland between water bodies may possibly occur on birds (*e.g.* as veligers or small mussels in mud stuck to legs or feathers) or attached to other organisms (*e.g.* crayfish, turtles) (Carlton 1993; Mackie and Schloesser 1996; Johnson and Carlton 1996). Details of the mussels' life history are reviewed in several papers (*e.g.* Mackie *et al.* 1989; Claudi and Mackie 1994; Mackie and Schloesser 1996; McMahon 1996; Mills *et al.* 1996; Cohen and Weinstein 2001)

Zebra mussels began spreading out of their native range in the Caspian Sea basin to other watersheds in Europe as canal systems linked rivers in the 17th and 18th centuries. Quagga mussels are native to the lower Bug River, which drains into the northern Black Sea. They spread to the nearby Dneiper and Dneister rivers starting in the 1940s (Mills *et al.* 1996) and to the Danube, Don and Volga Rivers since the 1980s (Popa and Popa 2006; Zhulidov *et al.* 2006). Zebra mussels were first discovered in the North America in the Great Lakes in 1988, and the first quagga mussel was collected there in 1989 (Griffiths *et al.* 1991; Mills *et al.* 1996). The zebra mussel spread quickly and broadly in Eastern North America, from southern Canada to Louisiana and from New York to Oklahoma. The quagga mussel's spread was less extensive. It is found in Lake Erie, Lake Ontario and the St. Lawrence River, and in a few other lakes in the Great lakes Basin (including Lakes Cayuga and Seneca), was reported recently in Duluth Harbor at the western end of Lake Superior, and has been reported at a site in the Mississippi River, though it's not clear if it is established there (Mills *et al.* 1996). Wherever the two mussels co-occur, the quagga has tended to dominate, and it is the quagga that has now become established across the continental divide.

Methods

The scientific literature was reviewed for analyses of laboratory and field data on zebra and quagga mussel's environmental requirements in terms of temperature, calcium, pH, dissolved oxygen and salinity, and studies were reviewed that used limiting values of these factors to estimate zebra or quagga mussels' potential distribution. Limits were determined for use in this study, and applied to water quality data assembled in 1998 on 160 water bodies in California, augmented in a few cases by additional data, to assess the suitability of these waters to support reproducing populations of zebra mussels or quagga mussels. The scientific uncertainty in the calcium threshold (the lower limiting value for calcium) is large relative to the range of calcium values in California waters, so overall suitability was assessed using five values for the calcium threshold that span the range of uncertainty.

In general the approach to determining and applying limits was conservative in the sense of tending toward classifying some sites that are unsuitable as suitable (false positives) rather than classifying some sites that are vulnerable to colonization as safe (false negatives). At sites where data were not available for one or more parameters, this analysis in essence treated those parameters as if they were suitable values—another conservative measure. The results, indicating waters where zebra or quagga mussels may become established, are compiled in tables and maps, and are discussed relative to the two mussel species; in terms of the effect of varying the calcium threshold; and by region. The results for different values of calcium threshold were used to determine four levels of management priority (high, medium and low priority for management action, and not vulnerable to colonization).

Results: Literature Review and Limiting Values

The results from the literature review of zebra and quagga mussels' environmental requirements are summarized below, and the limiting values used in this study are explained. Three general points are worth noting.

- While reproductive, embryonic or larval life stages may be more vulnerable to certain environmental stresses that are adults, most of the laboratory studies on zebra or quagga mussels' environmental tolerances have been conducted on adults, typically using survival or sometimes growth as endpoints.
- For zebra or quagga mussels to become established, the water quality parameters must be suitable for all of their life stages and processes, including juvenile and adult survival and growth, gonad development, gametogenesis, spawning, fertilization, embryonic and larval development, and settlement. However, in some cases sizeable, non-reproducing "sink" populations may develop downstream of established, reproducing populations. For these sink populations, water quality parameters need only be suitable for late larval stages, settlement, and juvenile to adult survival and growth.
- Deep lakes and reservoirs often stratify in the summer, maintaining significant temperature differences between the warmer, upper water level (epilimnion) and the cooler, lower water level (hypolimnion). Since most of the water quality data assembled for this study is based on near-surface samples, a deep water body ranked by this study as unsuitable on the basis of high water temperatures may nonetheless be able to support a large mussel population at lower depths. High water temperature is only likely to serve as a limiting factor in waters that are both warm and shallow.

Temperature

Zebra mussels: Zebra mussels have become abundant in waters with average winter temperatures as low as 6°C (Stanczykowska and Lewandowski 1993), though freezing kills them (McMahon 1996). Summer water temperatures above 6-12°C are needed to support adult growth (Morton 1969; Stanczykowska 1977; Baker *et al.* 1993). Most studies have reported that temperatures above 12°C are needed for spawning, though limited spawning has been reported down to 10°C (Borcherding 1991; Neumann *et al.* 1993; Sprung 1993; Nichols 1996; McMahon 1996). Various studies have used mean summer temperatures in the range of 9-15°C as the lower limiting values for potential distribution (Sorba and Williamson 1997; Doll 1997).

Water temperatures of 26-33°C have been reported as zebra mussels' upper limit for short-term survival based on various laboratory experiments or field data (Stanczykowska 1977; Strayer 1991; Baker *et al*. 1993; Armistead 1996; Mills *et al.* 1996; Cohen 2005). Other studies have reported indefinite survival at 30°C, but 100% mortality with 1 wk exposure to 31°C, 100 hr exposure to 32°C, or 24 hr exposure to 35°C (Spidle *et al.* 1995; McMahon 1996; Elderkin and Klerks 2005). Various studies have used mean summer temperatures in the range of 30-32°C and maximum temperatures of 31°C as the upper limiting values for potential distribution (Sorba and Williamson 1997; Doll 1997; Cohen & Weinstein 1998).

Quagga mussels: I found no information on minimum temperatures needed for quagga mussel survival or growth. Quagga mussels at a depth of 23 m in Lake Erie spawned at a temperature of 9°C in the summer of 1994 and at 9-11°C in the summer of 1995, based on histologic examination (Claxton and Mackie 1998). Quagga mussels collected from the lake in the summer of 1996 at a depth of 55 m where the temperature was 4.8°C at the time of collection also showed evidence of spawning: 80% of the females had at least some mature eggs and 20% had spent gonads (Roe and MacIsaac 1997). Quagga mussels are also reported to spawn at depth in Lake Michigan when water temperatures there reach 6°C. Observations of quagga mussels being more abundant than zebra mussels at greater depths (Mills *et al.* 1993, 1996; Roe and MacIsaac 1997; Ricciardi and Whoriskey 2004) also suggest that quagga mussels are a more cold tolerant form, although other factors may be at work (*i.e.* different substrates, oxygen concentrations or food availability at depths).

Most of the information on quagga mussels' upper temperature limits comes from studies that compared quagga and zebra mussels, which generally suggest that quagga mussels are less tolerant of high temperatures. A study exposing mussels to various combinations of temperature and turbidity concluded that zebra mussels survived high temperatures better than quagga mussels (Thorp *et al.* 1998), but that result is clouded by the use of mussels collected at different latitudes. Quagga mussels acclimated to 20°C and subjected to temperatures rising at the rate of 0.3°C/min gaped open and did not respond to prodding at 36.4°C while zebra mussels only did so at 37.0°C (Domm *et al.* 1993). When moved directly from 20°C to 32°C water, quagga mussels lasted an average of 75 minutes before gaping and not responding, while zebra mussels lasted 275 minutes (Domm *et al.* 1993). Quagga mussels acclimated to 5°, 15° and 20°C and transferred to 30°C water suffered high mortality rates within 11-14 days, while all zebra mussels subjected to the same conditions survived these exposures (Spidle *et al.* 1995). Most quagga mussels died and all zebra mussels survived in two attempts to acclimate them to 25°C (Spidle *et al.* 1995). These data have led some researchers to conclude that the upper temperature is lower for quagga than for zebra mussels (*e.g.* Mills *et al.* 1996), perhaps as low as 25°C for quagga mussels compared to over 30°C for zebra mussels (Spidle *et al.* 1995).

Table 1. Effects of high temperatures on Dreissenid populations in the Dneiper River, Ukraine (from Mills *et al.* 1996, citing Antonov and Skorbatov 1990)

	Zebra mussels	Quagga mussels
Onset of mortality	27-27.3°C	28.1°C
50% mortality	28.2-28.4°C	29.3°C
First fully open shells	28.6°C	29.7°C

However, there are some confounding data. In the Dneiper River, quagga mussels tolerate about one degree higher temperatures than do zebra mussels (Table 1). In 2007, quagga mussels large enough to have settled before the summer of 2006 were found in Lake Mead, in shallow waters where summer temperatures routinely reach 30°C (James LaBounty, Southern Nevada Water Authority, and Tom Burke, U.S. Bureau of Reclamation, pers. comm.). And in 12 trials of exposures to temperatures that rose from 3 acclimation temperatures (5°, 15° and 20°C) at 4 rates (1°C per 5, 15, 30 and 60 min), the temperature which caused 50% mortality (LT_{50}) for quagga mussels was estimated in a logit model to be significantly lower than the LT_{50} for zebra mussels in all but one trial, while the LT_{100} (the temperature producing 100% mortality) was significantly lower *only* in one trial (Spidle *et al.* 1995). These latter results suggest that while zebra mussel *populations* may have a greater overall tolerance to high temperatures than quagga mussel populations, the tolerance of the most high-temperature tolerant *individuals* within populations may not differ between the species. If so, then a quagga mussel population introduced to waters that experience periodic high temperatures could suffer initially high mortalities of the less high-temperature tolerant individuals, producing a population that is as tolerant of high temperatures as are zebra mussels.

Limiting values: The available temperature data for most of the 160 water bodies are for the mean and maximum summer water temperature over 15 years, with most of the measurements made at or near the surface. Lower limits for mean and maximum summer temperatures of 10° and 12°C for zebra mussels and 5° and 6°C for quagga mussels were selected to represent minimum temperatures needed for spawning. An upper limit of 31°C in flowing waters for both zebra and quagga mussels was selected to represent the long-term (acclimated) lethal temperature. Because many lakes and reservoirs stratify during the warmer months, with cooler temperatures in deeper waters where mussels could survive even when surface waters exceed lethal temperatures, the upper temperature limit was not applied to the maximum surface water temperatures for lakes and reservoirs. Instead, these data were omitted from the data table. Although some of the laboratory data suggests a lower lethal temperature for quagga mussels than for zebra mussels, the discovery of quagga mussels in the warm, shallow waters of Lake Mead and the possibility that the most tolerant quagga mussels are as tolerant of high temperatures as the most tolerant zebra mussels argues against using a lower limit for quagga mussels.

Calcium

Zebra mussels: The minimum calcium concentration for zebra mussels reported by different researchers varies widely—from just over 28 mg/L from a study of long-established populations in European lakes, to concentrations of 12-15 mg/L or lower from studies of North American distributions (reviewed in Cohen and Weinstein 2001). For example, in a review of 70 European lakes, zebra mussels were mainly reported in lakes with calcium levels above 20-40 mg/L and were absent from lakes with less than 20 mg/L (Strayer 1991); and a study of 76 European lakes found zebra mussels on in lakes with at least 28.3 mg/L of calcium (Ramcharan *et al.* 1992). In contrast, in North America zebra mussels have been reported at various sites with calcium concentrations of 12-19 mg/L (*e.g.* Mellina and Rasmussen 1993; Cusson and Lafontaine 1997; Jones and Ricciardi 2005) and in a few cases at calcium concentrations as low as 4-6 mg/L (Cohen and Weinstein 2001). Based on these data, researchers have generally used or recommended the use of minimum concentrations of 12-15 mg/L of calcium, or sometimes lower concentrations, to assess zebra mussels' potential distribution (*e.g*. Neary and Leach 1991; Baker *et al.* 1993; Claudi and Mackie 1994; McMahon 1996). However, the records at the lower calcium levels probably represent either misidentifications, limited or inaccurate calcium data, or non-reproducing sink populations recruited from populations established upstream in higher calcium waters (Cohen and Weinstein 2001).

Quagga mussels: I found only two studies that addressed quagga mussels' calcium limit. In the St. Lawrence River near Montreal, zebra mussels were found at sites where calcium concentrations were measured at 8 mg/L or more, while quagga mussels were only found at sites where calcium measured 12.4 mg/L (Jones and Ricciardi 2005). These sites occur at and just below the confluence of the Ottawa River (with low calcium concentrations and few or no zebra mussels present) and the mainstem of the St. Lawrence River draining out of the Great Lakes (with high calcium concentrations and high zebra mussel density). The zebra and quagga mussels at the sites near Montreal are almost certainly recruited from upstream sites and not the result of local reproduction, and the calcium concentrations at these sites must vary with changes in the relative flows from the two tributaries, so correlations between calcium levels and the presence or absence of mussels at these sites cannot be used to determine the calcium levels needed for establishment. In a contrasting study, in the Don River system in Russia quagga mussels dominated at sites with higher calcium concentrations (apparently over 100 mg/L), while zebra mussels dominated at sites with lower calcium concentrations (45-78 mg/L) (Zhulidov *et al.* 2004).

Limiting values: Because of the uncertainty in zebra and quagga mussel's calcium requirements, and the apparent importance of this factor in controlling the mussels' distribution, potential distributions were analyzed for five different calcium thresholds for both species—28, 25, 20, 15 and 12 mg/L—with the lower thresholds indicating a capacity to invade a larger number of water bodies. Water bodies that were determined to be vulnerable to colonization based on the higher thresholds were ranked as a higher priority.

pH

Zebra mussels: A study of 76 European lakes found that zebra mussels were absent from those with pH below 7.3 (Ramcharan *et al.* 1992), and in laboratory experiments veligers developed properly only at a pH between 7.4 and 9.4 (Sprung 1993). Researchers have generally used or recommended the use of pH limits between 6.5-7.5 and 9.0-9.5 to assess zebra mussels' potential distribution (summarized in Cohen 2005).

Quagga mussels: I found no information in the literature on quagga mussels' pH limits in the literature, and no distributional data suggesting any difference from zebra mussels.

Limiting values: Based on the above information, limiting pH values of 7.3 and 9.4 were selected for both zebra and quagga mussels.

Dissolved Oxygen

Zebra mussels: Zebra mussel larvae can survive short periods at 18°C with oxygen at 20% of saturation (about 2 ppm) (Baker *et al*. 1993). Adults are reported to need 25% saturation (between about 3 and 2 ppm at 10°-25°C) (Karatayev *et al.* 1998). Oxygen concentrations levels as low as 3.2 ppm have been found in parts of the Illinois River where zebra mussels are abundant (Kraft 1994). Studies have used limits of 4-6 ppm to assess zebra mussels' potential distribution (Doll 1997; Sorba and Williamson 1997; Cohen and Weinstein 1998).

Quagga mussels: I found no information in the literature on quagga mussels' oxygen limit in the literature, and no distributional data suggesting any difference from zebra mussels. McMahon (1996), however, speculated that quagga mussels may be more tolerant of hypoxic conditions than zebra mussels, based on their more effective colonization of hypolimnetic waters.

Limiting values: Based on the above information, a limiting value of 4 ppm of oxygen was selected for both zebra and quagga mussels.

Salinity and/or Desiccation

Zebra mussels: The salinity limits reported for zebra mussels vary widely, and may depend both on the rate at which salinity changes as well as on water chemistry (with higher tolerance to salinity that changes only gradually, or if the ratio of divalent to monovalent ions is high); it is possible that chloride content rather than salinity is actually the critical factor (Strayer and Smith 1993). Temperature also affects salinity tolerance (with higher tolerance in colder water), and tolerance may vary among populations (Baker *et al.* 1993). Zebra mussels occur up to a mean salinity of 0.6 ppt in Netherlands estuaries, up to nearly 1 ppt in the eastern Gulf of Riga, and up to nearly 2 ppt in the extreme eastern Gulf of Finland and in estuaries bordering the Black Sea. They occur in stunted populations in the Vistula estuary at up to 4.8 ppt, and in the Kiel Canal at 3.8 and 6.2 ppt. Zebra mussels are abundant in the northern Caspian Sea at salinities of 6-9 ppt, but not at 13 ppt, and have been found in the Dnieper-Bug estuary at up to 7.6 ppt. They were abundant throughout the Aral Sea at salinities of 10 ppt; as water diversions raised the salinity of the sea, populations began to decline at around 12 ppt and had nearly disappeared at 14 ppt (Strayer and Smith 1993; Mills *et al.* 1996). In North America zebra mussels have been collected in the Hudson River estuary at sites with maximum salinities up to 6 ppt (Baker *et al.* 1993). Laboratory studies conducted at different temperatures and using different acclimation procedures have reported a variety of lethal limits ranging from 1.6 ppt to 10-12 ppt (Mills *et al.* 1996; Cohen 2005). Studies have used or recommended limiting values ranging from 2 to 10 ppt to assess zebra mussels' potential distribution (Strayer and Smith 1993; Baker *et al.* 1993; Doll 1997; Cohen and Weinstein 1998).

Quagga mussels: Quagga mussels in the Dnieper-Bug estuary occur at a maximum salinity of 4.0 ppt compared to 7.6 ppt for zebra mussels; in laboratory trials, these quagga and zebra mussels had high survival from 40 d exposure to 5 ppt and 8 ppt, respectively, at 7-15°C, and 4 and 6 ppt, respectively, at 18-21°C (Mills *et al.* 1996). While adult quagga and zebra mussels from the Great Lakes showed no differences in responses to salinity in the laboratory, with no survival or either species from 18 d exposure to 5 ppt (Spidle *et al.* 1995), the embryos and larvae of quagga mussels were less tolerant of salinity than those of zebra mussels (Wright *et al.* 1996).

Limiting values: Based on the above information, maximum salinities of 6 ppt and 4 ppt were selected for zebra and quagga mussels respectively. For waters with rapidly fluctuating salinities (estuaries), these numbers are probably a few ppt too high. Information was also sought on whether inland, terminal lakes dried out during droughts, as salinities in these lakes rises as water volumes shrink; lakes reported to dry out completely during droughts were also considered unsuitable habitats for quagga or zebra mussels, regardless of their reported salinity levels.

Results: Quagga Mussel vs. Zebra Mussel

While the analysis used the same limits for both species for most parameters, it used lower temperature limits and upper salinity limits that were lower for quagga mussels than for zebra mussels. Despite these differences, the determinations of potential distribution worked out to be the same for both species. While the higher temperature thresholds used for zebra mussels did result in a few more sites being classified as unsuitable in terms of temperature, all of these were also unsuitable in terms of calcium, so the overall number of suitable and unsuitable sites did not change.

Results: Effect of Varying Calcium Threshold

Changing the calcium threshold had a marked effect on the number of suitable and unsuitable sites. At the highest calcium threshold (28 mg/L), 43 sites were found to be suitable for calcium (27% of the total 160 sites), while at the lowest threshold (12 mg/L), 94 sites were suitable for calcium (59% of the total). Overall suitability, taking all the parameters into account, went from 33 suitable sites (21% of the total) at the highest calcium threshold to 84 suitable sites (53% of the total) at the lowest calcium threshold.

Results: By Region

The sites are numbered and organized by regions that are defined by hydrologic contiguity or interconnection, and that include the water delivery systems that draw from them.

The North Coast region, which includes 20 sites (numbers 1-18, 21 and 28), consists of watersheds that drain to the coast north of San Francisco Bay. The temperature, pH, dissolved oxygen and salinity at these sites are suitable for both zebra and quagga mussels. Calcium concentrations range from levels that are clearly too low (*e.g.* 4-9 mg/L on the Trinity River) to levels that are clearly adequate (*e.g.* 31 mg/L). Thus, calcium concentrations alone determine the vulnerability of sites in this region. At the highest calcium threshold analyzed (28 mg/L) only one site, the Eel River at Scotia, is vulnerable to colonization (5% of the region's sites), while at the lowest threshold (12 mg/L) 15 sites are vulnerable (75% of the region's sites).

The next seven regions are all part of a "super-region" that consists of the entire watershed of the San Francisco Bay and Delta and covers roughly 40% of California. The West Sacramento Valley region, with 8 sites (numbers 19-20 and 22-27), includes watersheds that drain to the Sacramento River from the west. The average temperature, pH, dissolved oxygen and salinity at these sites are suitable for both mussel species. Maximum temperature is high at Thomes Creek, but fine at the other sites. Calcium concentrations at these sites range from 16 to 31 mg/L, that is, from within the uncertain range to clearly suitable. At the highest calcium threshold only one site, Black Butte Reservoir, is vulnerable to colonization (12.5% of the region's sites), with 6 being found unsuitable because of low calcium. At the lowest calcium threshold only Thomes Creek is environmentally unsuitable (87.5% of the region's sites are vulnerable).

The Upper Sacramento River region consists of the watershed above Shasta Dam plus the Whiskeytown Reservoir site, with a total of 10 sites (numbers 29-38). Dissolved oxygen and salinity at all of these sites are suitable for both mussel species. One site, McCloud Reservoir, has average and maximum temperatures that are too low for zebra but not quagga mussels; and Siskiyou Lake has a pH of 7.1, too low for both species. Calcium levels range from 5 to 19 mg/L, from too low up into the range of uncertainty. At the highest calcium threshold, no sites are suitable for either species; at the lowest calcium threshold, two sites are suitable for either species.

The Sierra Nevada region includes 44 sites (numbers 39-82). Dissolved oxygen and salinity at all of these sites are suitable for both species; average temperature is too low for zebra mussels at 1 site; maximum temperature is too low for zebra mussels at 2 sites and too high for either mussel at 1 site; and pH is too low for either mussel at 16 sites. Calcium levels range from 2 to 25 mg/L, from too low up into the range of uncertainty. All of the sites with unsuitable pH or temperature have calcium concentrations of 10 mg/L or less, and thus all of these are unsuitable in terms of calcium even using the lowest calcium threshold of 12 mg/L. Overall, at the highest calcium threshold there are no sites vulnerable to colonization by either mussel , and only 6 vulnerable sites (14% of the region's sites) at the lowest calcium threshold.

The Sacramento River mainstem region consists of 5 sites on the river or on appurtenant canals (numbers 83-87). Temperature, pH, oxygen and salinity are suitable for both mussels at all sites. Calcium ranges from 9-11 mg/L, and is unsuitable for either mussel at all sites at all calcium thresholds.

The San Joaquin River mainstem region includes 3 sites on the river (numbers 88-90). At the most upstream site, just below Friant Dam, both pH and calcium are unsuitable for either species at all calcium thresholds. At the 2 downstream sites all parameters are suitable for both species at all calcium thresholds. Calcium concentrations rise from 3 mg/L at the upstream site to 31-59 mg/L at the downstream sites and pH rises from 7.1 to 7.8, suggesting a major influx of calcium somewhere along this reach. This is consistent with sites on the Fresno and Chowchilla Rivers and Mariposa Creek (sites 69-71), which flow into the San Joaquin along this reach, having anomalously high calcium levels and somewhat high pH levels for Sierra Nevada sites.

The Delta region includes 6 sites (numbers 91-96). Temperature, pH and oxygen are suitable for both mussels at all sites. Salinity is estimated to normally be below 1 ppt at all of these sites, and thus suitable for either species. Calcium concentrations range from 6-33 mg/L, and thus from clearly too low to clearly high enough. At the highest calcium threshold, 2 sites (33% of the region's sites) are vulnerable to either mussel and at the lowest threshold 3 sites (50% of the region's sites) are vulnerable, the remainder being unsuitable because of low calcium. Notably, Clifton Court Forebay was found to be unsuitable for mussels at the higher calcium thresholds but suitable at the lower thresholds. In terms of calcium, the Delta is a mix of three types of source water: low calcium water brought in by the Sacramento, Cosumnes and Mokelumne rivers, high calcium water brought in by the San Joaquin River, and high calcium ocean-derived water brought in by tidal mixing and gravitational circulation from Suisun Bay. Thus the vulnerability of different parts of the Delta to zebra and quagga mussel colonization depends in large part on the volumes and patterns of mixing of these three water types. As one proceeds further down the Delta and into the upper part of Suisun Bay, more ocean-derived water is mixed with Delta outflow, which has the effect of both increasing the salinity and thus decreasing the suitability of the water to support zebra or quagga mussels, and increasing the calcium concentration and thus increasing the suitability of the water for mussels. Which effect wins out over this reach, and precisely where the salinity gets too high to support dreissenid mussels is unclear. The same considerations and uncertainties apply to Delta management scenarios that involve greater variation in Delta salinity.

The San Francisco Bay Local Watershed region includes 16 sites (numbers 97-112). Temperature, pH, oxygen and salinity are suitable for both mussels at all of these sites. Calcium concentrations range from 13 to 36 mg/L, thus ranging from within the uncertain range to clearly suitable. Seven sites are vulnerable to colonization by either mussel at the highest calcium threshold (44% of the region's sites), while all 16 sites are vulnerable at the lowest threshold .

The Central Coast region consists of watersheds that drain to the coast between San Francisco Bay and Ventura, and includes 10 sites (numbers 113-122). All sites are vulnerable to colonization by either mussel at all calcium thresholds except for the San Benito River (with a calcium concentration of 27 mg/L) at the highest calcium threshold.

The California Aqueduct/Delta-Mendota Canal includes 11 sites (numbers 123-133) in those water delivery systems. Temperature, pH, oxygen and salinity are suitable for both mussels at all of these sites. Calcium concentrations range from 18 to 32 mg/L. Three sites are vulnerable to colonization by either mussel at the highest calcium threshold (27% of the region's sites), while all are vulnerable at the two lowest calcium thresholds.

The South Coast region consists of watersheds that drain to the coast south of Ventura, and includes 7 sites (numbers 134-140). Average temperature, oxygen and salinity are suitable for both mussels at all of these sites. Three sites have maximum temperatures that are too high. One site (the Los Angeles River at Long Beach) also has high pH; possibly this indicates an admixture of ocean water (salinity data are not available for this site). One site (San Diego River) is low in calcium relative to the highest calcium threshold but not relative to the lowest. Overall, 3 sites are vulnerable to colonization by either mussel at the highest calcium threshold (43% of the region's sites), and 4 sites at the lowest threshold (57% of the region's sites).

The Northeastern California Region consists of the northeastern corner of the state, which is characterized by interior, terminal drainages (*i.e.* not draining to the sea). It includes 5 lake sites (numbers 141-145). There is only limited water quality data for these sites, but all appear to be unsuitable for either mussel species. Three dry out periodically in drought years; 3 have calcium levels that are too low at any of the thresholds (calcium data are not available for the other 2 lakes). One has a reported salinity that is too high for either mussel, though salinities in the others presumably vary with lake level and may also be too high at times.

The East Side of the Sierra/Mojave region consists of desert and interior drainages. It includes 7 sites (numbers 146-152). Average temperature and dissolved oxygen are suitable for both mussels at all of these sites. One site, Mono Lake, is unsuitable because of high salinity, high pH and low calcium. The Mojave River site is unsuitable due to high maximum temperature. Calcium concentrations range from 4 mg/L (Mono Lake) to 34 mg/L (Mojave River), thus ranging from clearly too low to clearly high enough; they are too low at 6 sites at the highest calcium threshold and too low at 3 sites at the lowest threshold. Overall there are no suitable sites for either mussel at the highest calcium threshold and 3 suitable sites (43% of the region's sites) at the lowest calcium threshold.

The Colorado River Basin includes 8 sites (numbers 153-160). Average temperature, pH, dissolved oxygen and calcium concentrations (which are above 75 mg/L at all sites) are suitable for either mussels at all sites at all calcium thresholds. Maximum temperatures are too high for both mussels at 2 river sites (the Alamo and New rivers), and salinity is too high at one site (the Salton Sea). While maximum water temperatures near the surface are too high in 2 still water bodies (Lake Havasu and the Salton Sea), deeper waters may have suitable temperatures. Overall, 5 sites are vulnerable to colonization by either mussel (63% of the region's sites).

Priorities for Management Actions

The assessments based on different calcium thresholds were used to group sites into four priority classes for management actions such as site-based education and outreach efforts, boat inspection and cleaning programs, detection monitoring programs, the development of site-specific rapid-response plans, and facility modifications. Sites that were found to be vulnerable to colonization using a calcium threshold of 25 mg/L were classified as high priority sites, and accounted for 25% of the analyzed sites. Sites that didn't qualify as high priority but are vulnerable to colonization at a calcium threshold of 15 mg/L were classified as medium priority (22% of sites). Sites that didn't qualify as medium priority but are vulnerable at a threshold of 12 mg/L were classified as low priority (6% of sites). The remaining sites were classified as not vulnerable, and are not recommended for management actions. As described above, the vulnerability of different regions varied widely, ranging from 100% of Central Coast sites classified as high priority, to 100% of Northeastern California sites classified as not vulnerable (Table 2).

Table 2. Priority classification of California sites for actions to prevent or minimize the impacts of zebra mussel or quagga mussel establishment

	Number (Percentage) of sites in region with Priority...			
Region	High	Medium	Low	Not Vulnerable
North Coast	3 (15%)	8 (40%)	4 (20%)	5 (25%)
West Sacramento Valley	1 (13%)	6 (75%)	0 (0%)	1 (13%)
Upper Sacramento River	0 (0%)	1 (10%)	1 (10%)	8 (80%)
Sierra Nevada	1 (2%)	3 (7%)	2 (5%)	38 (86%)
Sacramento R. (mainstem)	0 (0%)	0 (0%)	0 (0%)	5 (100%)
San Joaquin R. (mainstem)	2 (67%)	0 (0%)	0 (0%)	1 (33%)
Delta	2 (33%)	1 (17%)	0 (0%)	3 (50%)
SF Bay Local Watersheds	9 (56%)	5 (31%)	2 (13%)	0 (0%)
Central Coast	10 (100%)	0 (0%)	0 (0%)	0 (0%)
SWP & CVP Aqueducts	4 (36%)	7 (64%)	0 (0%)	0 (0%)
South Coast	3 (43%)	1 (14%)	0 (0%)	3 (43%)
Northeastern California	0 (0%)	0 (0%)	0 (0%)	5 (100%)
East of Sierra/Mojave	0 (0%)	3 (43%)	0 (0%)	4 (57%)
Colorado River Basin	5 (63%)	0 (0%)	0 (0%)	3 (38%)
All regions	40 (25%)	35 (22%)	9 (6%)	76 (48%)

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Appendices

1. Maps

    - Map 1. Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 28 mg/L)
    - Map 2. Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 25 mg/L)
    - Map 3. Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 20 mg/L)
    - Map 4. Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 15 mg/L)
    - Map 5. Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 12 mg/L)
    - Map 6. Zebra Mussel and Quagga Mussel Management Priority

2. Data Table

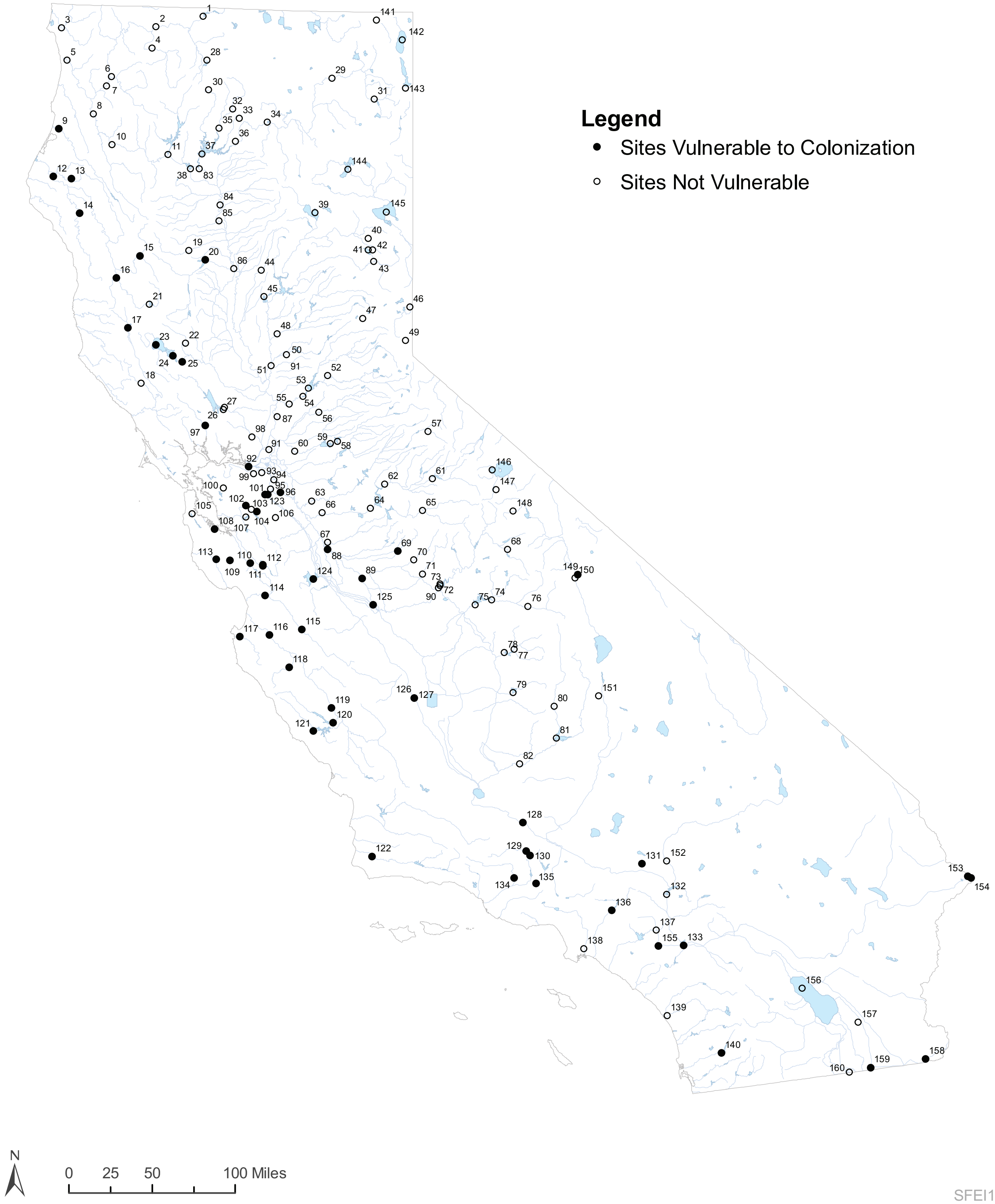
3. Priority Table

Map 1
Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 28 mg/L)

SFEI182

Map 2
Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 25 mg/L)

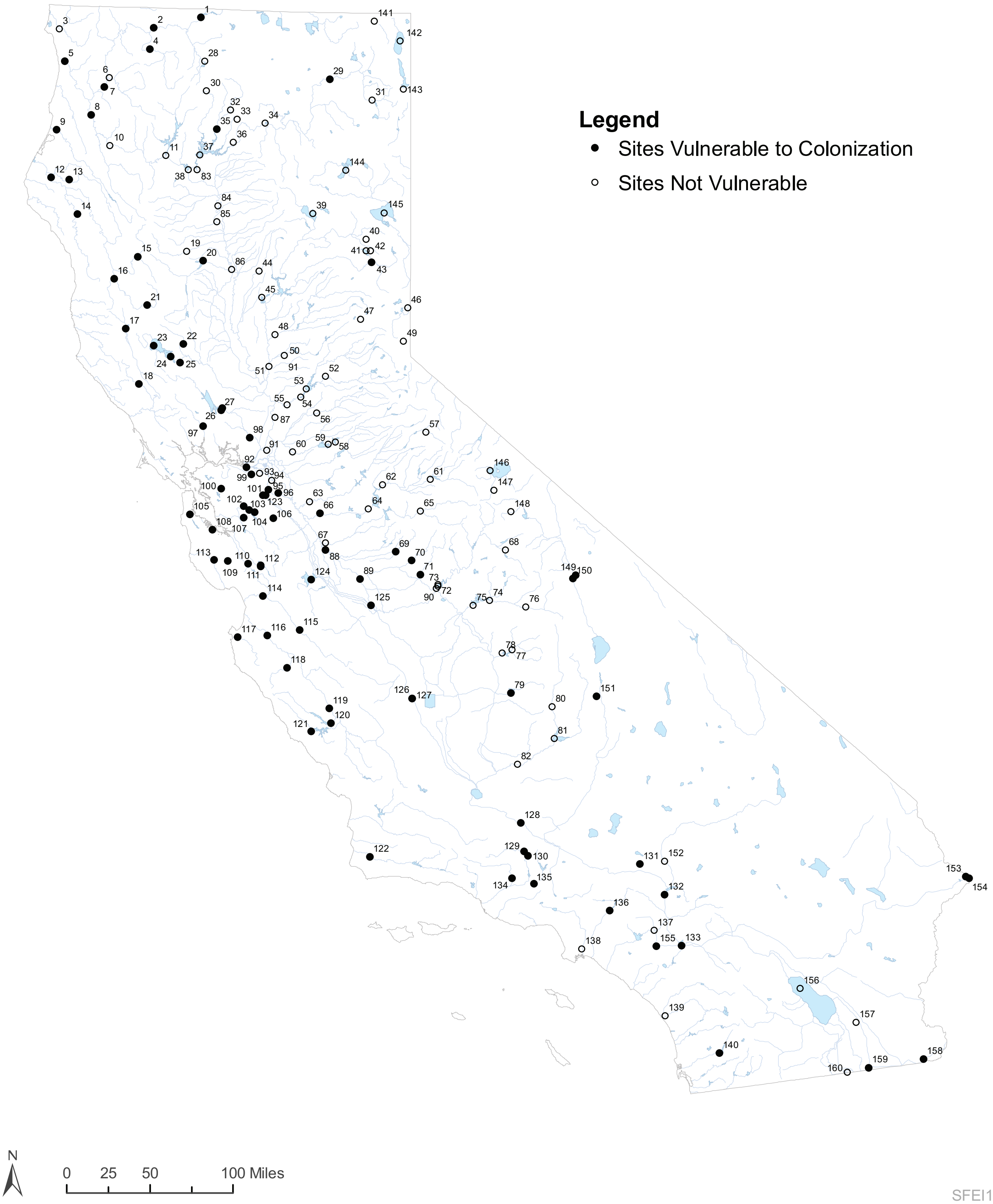
Map 3
Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 20 mg/L)



SFEI184

Map 4
Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 15 mg/L)

Map 5
Zebra Mussel and Quagga Mussel Potential Distribution (based on calcium threshold of 12 mg/L)



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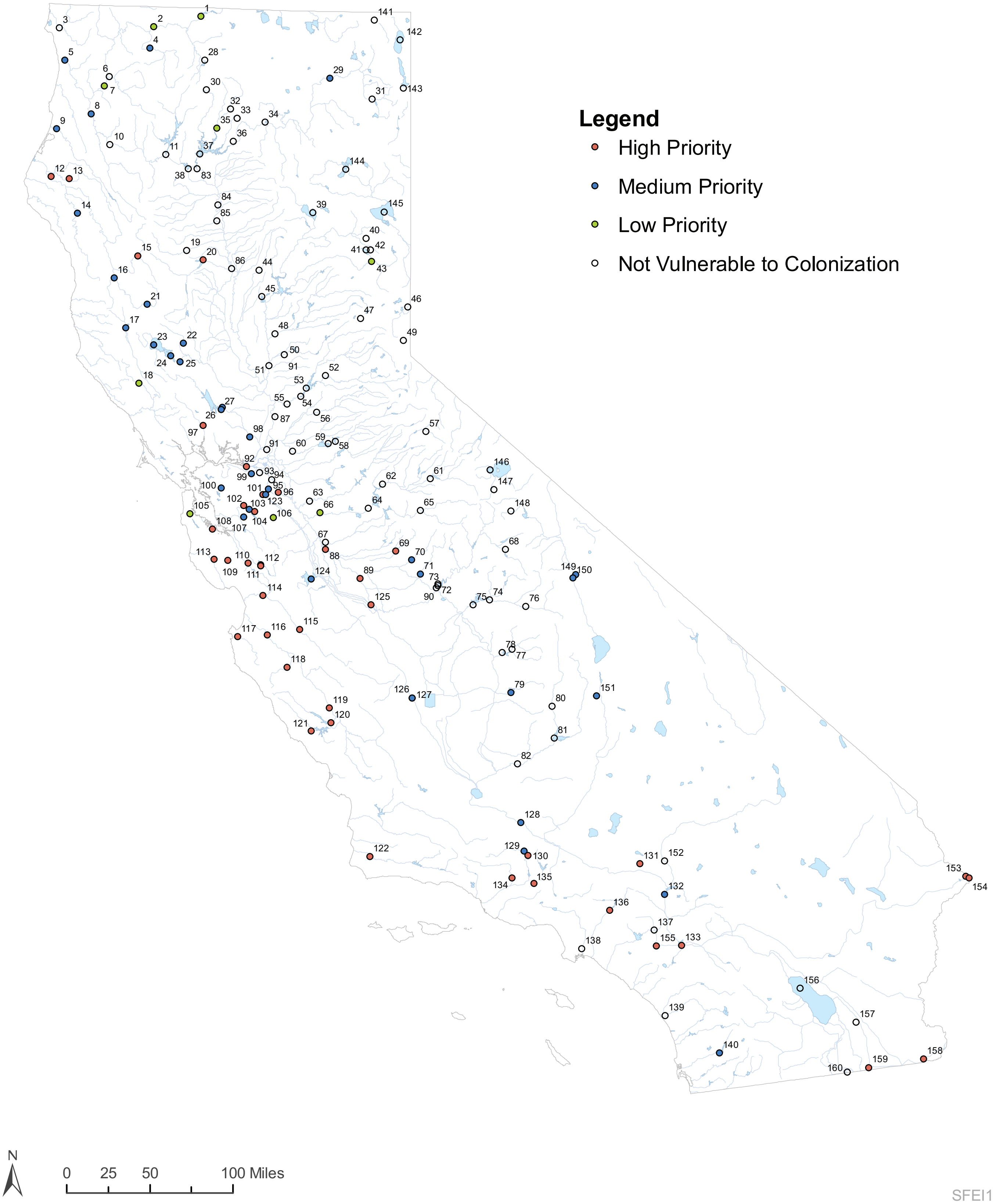
Map 6
Zebra Mussel and Quagga Mussel Management Priority



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DATA TABLE

Site #	Region	Site Name	Latitude	Longitude	Water Quality Data							Sites with Suitable Water Quality, assuming a Calcium Threshold of…					Priority
					pH	Avg Temp (°C)	Max Temp (°C)	Salinity (ppt)	DO (ppm)	Ca (ppm)	Dessi-cation (no=1)	12	15	20	25	28	
1	North Coast	Klamath River below Iron Gate Dam	41.93	-122.44	8.2	18.4	24.0	0	9.6	12	1	1	0	0	0	0	3
2	North Coast	Klamath River at Hamburg	41.83	-122.98	8.2	19.4	26.5	0	9.7	13	1	1	0	0	0	0	3
3	North Coast	Smith River near Crescent City	41.79	-124.08	8.2	17.4	22.5	0	9.6	7	1	0	0	0	0	0	4
4	North Coast	Scott River near Fort Jones	41.64	-123.02	8.1	19.8	25.5	0	10.2	19	1	1	1	0	0	0	2
5	North Coast	Klamath River near Klamath	41.51	-124.00	8.4	19.0	23.5	0	9.4	15	1	1	1	0	0	0	2
6	North Coast	Salmon River at Somesbar	41.38	-123.48	7.6	15.4	23.5	0	10.2	9	1	0	0	0	0	0	4
7	North Coast	Klamath River at Orleans	41.30	-123.53	7.9	17.0	27.0	0	10.2	13	1	1	0	0	0	0	3
8	North Coast	Trinity River at Hoopa	41.05	-123.67	7.8	16.9	26.5	0	10.2	16	1	1	1	0	0	0	2
9	North Coast	Mad River near Arcata	40.91	-124.06	7.9	18.0	23.5	0	10.5	22	1	1	1	1	0	0	2
10	North Coast	Trinity River near Burnt Ranch	40.79	-123.44	7.6	15.5	20.0	0	10.2	9	1	0	0	0	0	0	4
11	North Coast	Trinity River at Lewiston	40.72	-122.80	7.6	10.9	13.0	0	11.1	4	1	0	0	0	0	0	4
12	North Coast	Eel River at Scotia	40.49	-124.10	8.3	20.4	24.0	0	9.7	31	1	1	1	1	1	1	1
13	North Coast	Van Duzen River near Bridgeville	40.48	-123.89	7.9	17.2	22.0	0	10.1	25	1	1	1	1	1	0	1
14	North Coast	Eel River South Fork Near Miranda	40.18	-123.78	8.1	19.1	26.0	0	10.8	21	1	1	1	1	0	0	2
15	North Coast	Eel River at Black Butte River	39.83	-123.08	7.9	17.6	27.0	0	10.3	27	1	1	1	1	1	0	1
16	North Coast	Eel River near Dos Rios	39.63	-123.34	8.1	19.6	29.0	0	9.5	23	1	1	1	1	0	0	2
17	North Coast	Russian River near Ukiah	39.20	-123.19	7.4	13.6	22.0	0	10.2	20	1	1	1	1	0	0	2
18	North Coast	Lake Sonoma- Dry Creek Arm	38.72	-123.02	7.5	16.3	–	0	8.5	14	1	1	0	0	0	0	3
19	West Sacramento Valley	Thomes Creek at Paskenta	39.89	-122.53	8.2	20.3	32.1	0	9.5	31	1	0	0	0	0	0	4
20	West Sacramento Valley	Black Butte Reservoir	39.81	-122.34	8.0	21.1	–	0	6.5	31	1	1	1	1	1	1	1
21	North Coast	Pillsbury Lake near Potter Valley	39.41	-122.96	7.8	16.8	–	0	8.8	18	1	1	1	0	0	0	2
22	West Sacramento Valley	Indian Valley Reservoir	39.08	-122.54	7.8	15.6	–	0	6.4	17	1	1	1	0	0	0	2
23	West Sacramento Valley	Clear Lake - upper arm	39.06	-122.87	7.9	21.0	–	0	7.4	20	1	1	1	1	0	0	2
24	West Sacramento Valley	Clear Lake - lower arm	38.97	-122.68	7.7	21.2	–	0	7.8	21	1	1	1	1	0	0	2
25	West Sacramento Valley	Cache Creek near Lower Lake	38.92	-122.57	7.8	20.8	27.0	0	8.3	22	1	1	1	1	0	0	2
26	West Sacramento Valley	Putah Creek below Monticello Dam	38.53	-122.09	7.8	12.5	12.9	0	9.4	16	1	1	1	0	0	0	2
27	West Sacramento Valley	Lake Berryessa at dam	38.51	-122.10	7.3	15.1	–	0	8.9	17	1	1	1	0	0	0	2
28	North Coast	Shasta River below Dwinnell Reservoir	41.55	-122.38	8.1	17.8	24.5	0	8.0	11	1	0	0	0	0	0	4
29	Upper Sacramento River	Pit River near Canby	41.41	-120.93	8.1	18.9	25.5	0	8.6	19	1	1	1	0	0	0	2
30	Upper Sacramento River	Siskiyou Lake - upper end near Shasta City	41.29	-122.35	7.1	12.3	–	0	9.3	3	1	0	0	0	0	0	4
31	Upper Sacramento River	Pit River - South Fork near Likely	41.23	-120.44	8.1	15.4	25.0	0	9.0	10	1	0	0	0	0	0	4
32	Upper Sacramento River	McCloud Reservoir at dam	41.13	-122.07	7.6	10.0	–	0	10.1	8	1	0	0	0	0	0	4
33	Upper Sacramento River	Iron Canyon Reservoir	41.05	-121.99	7.8	14.1	–	0	10.4	8	1	0	0	0	0	0	4
34	Upper Sacramento River	Lake Britton at Ferry Crossing	41.02	-121.67	7.8	14.5	–	0	7.5	10	1	0	0	0	0	0	4
35	Upper Sacramento River	McCloud River above Shasta Lake	40.96	-122.22	7.8	14.1	20.0	0	10.3	13	1	1	0	0	0	0	3
36	Upper Sacramento River	Pit River near Montgomery Creek	40.85	-122.03	7.9	16.5	19.5	0	9.9	10	1	0	0	0	0	0	4
37	Upper Sacramento River	Shasta Lake near Shasta Dam	40.73	-122.41	7.5	16.0	–	0	7.3	9	1	0	0	0	0	0	4
38	Upper Sacramento River	Whiskeytown Reservoir at dam	40.60	-122.54	7.3	15.0	–	0	8.0	5	1	0	0	0	0	0	4
39	Sierra Nevada	Lake Almanor - east arm	40.24	-121.11	7.8	10.0	–	0	9.4	8	1	0	0	0	0	0	4
40	Sierra Nevada	Antelope Lake	40.02	-120.50	7.6	15.5	–	0	8.6	9	1	0	0	0	0	0	4
41	Sierra Nevada	Frenchman Lake	39.92	-120.45	7.8	13.3	–	0	9.0	12	1	0	0	0	0	0	4
42	Sierra Nevada	Lake Davis	39.92	-120.50	7.7	17.3	–	0	6.7	8	1	0	0	0	0	0	4
43	Sierra Nevada	Feather River Middle Fork near Portola	39.82	-120.44	7.5	14.3	19.5	0	8.4	12	1	1	0	0	0	0	3
44	Sierra Nevada	Butte Creek near Chico	39.73	-121.71	7.8	17.3	22.0	0	10.3	10	1	0	0	0	0	0	4
45	Sierra Nevada	Thermalito Afterbay	39.50	-121.67	7.2	17.7	–	0	9.4	8	1	0	0	0	0	0	4
46	Sierra Nevada	Truckee River at Farad	39.42	-120.03	7.6	11.2	18.5	0	8.3	8	1	0	0	0	0	0	4
47	Sierra Nevada	South Yuba River near Cisco	39.32	-120.56	7.1	11.8	13.4	0	10.1	3	1	0	0	0	0	0	4

					Water Quality Data							Sites with Suitable Water Quality, assuming a Calcium Threshold of…					
Site #	Region	Site Name	Latitude	Longitude	pH	Avg Temp (°C)	Max Temp (°C)	Salinity (ppt)	DO (ppm)	Ca (ppm)	Dessication (no=1)	12	15	20	25	28	Priority
48	Sierra Nevada	Yuba River near Marysville	39.18	-121.52	7.5	16.3	18.1	0	10.0	7	1	0	0	0	0	0	4
49	Sierra Nevada	Lake Tahoe	39.13	-120.08	7.7	-	-	0	-	8	1	0	0	0	0	0	4
50	Sierra Nevada	Bear River near Wheatland	39.00	-121.41	7.8	18.1	20.6	0	9.0	10	1	0	0	0	0	0	4
51	Sierra Nevada	Feather River near Nicolaus	38.90	-121.58	7.5	18.4	20.5	0	9.9	8	1	0	0	0	0	0	4
52	Sierra Nevada	American River - South Fork near Lotus	38.82	-120.95	7.2	15.0	18.5	0	10.0	2	1	0	0	0	0	0	4
53	Sierra Nevada	Folsom Lake near Folsom	38.71	-121.16	7.0	16.2	-	0	7.2	4	1	0	0	0	0	0	4
54	Sierra Nevada	American River at Nimbus Dam	38.64	-121.22	7.1	17.5	19.0	0	8.2	4	1	0	0	0	0	0	4
55	Sierra Nevada	American River near Carmichael	38.57	-121.37	7.0	18.4	19.5	0	8.6	5	1	0	0	0	0	0	4
56	Sierra Nevada	Cosumnes River at Michigan Bar	38.50	-121.04	7.5	21.0	28.7	0	8.6	6	1	0	0	0	0	0	4
57	Sierra Nevada	Stanislaus River - Middle Fork at Dardanelle	38.34	-119.83	7.3	7.9	11.0	0	10.1	3	1	0	0	0	0	0	4
58	Sierra Nevada	Pardee Reservoir	38.25	-120.83	7.6	-	-	0	-	3	1	0	0	0	0	0	4
59	Sierra Nevada	Camanche Reservoir	38.23	-120.91	7.1	17.6	-	0	8.0	3	1	0	0	0	0	0	4
60	Sierra Nevada	Mokelumne River at Woodbridge	38.16	-121.30	7.3	18.8	22.5	0	9.1	4	1	0	0	0	0	0	4
61	Sierra Nevada	Hetch Hetchy Reservoir	37.93	-119.78	7.8	-	-	0	-	9	1	0	0	0	0	0	4
62	Sierra Nevada	Don Pedro Reservoir at influent	37.88	-120.31	6.5	23.7	-	0	8.1	3	1	0	0	0	0	0	4
63	Sierra Nevada	Stanislaus River at Ripon	37.73	-121.11	7.5	17.3	24.8	0	9.2	8	1	0	0	0	0	0	4
64	Sierra Nevada	Tuolumne River at La Grange Bridge	37.67	-120.46	7.1	12.6	16.0	0	10.4	3	1	0	0	0	0	0	4
65	Sierra Nevada	Merced River - South Fork near El Portal	37.65	-119.89	7.3	10.0	10.0	0	10.9	3	1	0	0	0	0	0	4
66	Sierra Nevada	Tuolumne River at Modesto	37.63	-120.99	7.8	21.8	30.0	0	9.7	13	1	1	0	0	0	0	3
67	Sierra Nevada	Merced River near Stevinson	37.37	-120.93	7.5	21.2	32.5	0	8.6	10	1	0	0	0	0	0	4
68	Sierra Nevada	San Joaquin R - S Fork at Mono Hot Springs	37.31	-118.96	7.3	12.2	17.0	0	8.5	1	1	0	0	0	0	0	4
69	Sierra Nevada	Mariposa Creek below Mariposa Dam	37.30	-120.16	8.0	17.6	23.0	0	12.2	25	1	1	1	1	1	0	1
70	Sierra Nevada	Chowchilla River below Buchanan Dam	37.22	-119.99	7.6	17.7	27.0	0	10.9	15	1	1	1	0	0	0	2
71	Sierra Nevada	Fresno River near Daulton	37.10	-119.89	7.5	15.4	22.0	0	9.7	18	1	1	1	0	0	0	2
72	Sierra Nevada	Millerton Lake near Friant Dam	37.01	-119.70	7.1	17.0	-	0	9.1	3	1	0	0	0	0	0	4
73	Sierra Nevada	Friant-Kern Canal at Friant	37.00	-119.70	6.7	15.9	22.0	0	9.9	2	1	0	0	0	0	0	4
74	Sierra Nevada	Kings River near Trimmer	36.87	-119.14	7.3	16.7	23.5	0	9.7	2	1	0	0	0	0	0	4
75	Sierra Nevada	Pine Flat Reservoir above dam	36.83	-119.32	7.2	13.0	-	0	6.5	3	1	0	0	0	0	0	4
76	Sierra Nevada	Kings River - South Fork at Cedar Grove	36.81	-118.75	7.2	10.6	19.0	0	10.1	2	1	0	0	0	0	0	4
77	Sierra Nevada	Kaweah River at Three Rivers	36.44	-118.90	7.6	17.5	25.0	0	10.0	10	1	0	0	0	0	0	4
78	Sierra Nevada	Kaweah River below Terminus Dam	36.41	-119.01	7.4	16.3	24.0	0	9.8	9	1	0	0	0	0	0	4
79	Sierra Nevada	Tule River below Success Dam	36.06	-118.92	7.6	18.6	28.0	0	9.6	18	1	1	1	0	0	0	2
80	Sierra Nevada	Kern River above Fairview	35.94	-118.48	7.3	11.5	15.0	0	10.3	4	1	0	0	0	0	0	4
81	Sierra Nevada	Lake Isabella at Engineer Point	35.66	-118.46	7.5	16.9	-	0	6.4	7	1	0	0	0	0	0	4
82	Sierra Nevada	Kern River near Bakersfield	35.44	-118.86	7.5	18.2	23.0	0	9.1	10	1	0	0	0	0	0	4
83	Sacramento R. (mainstem)	Sacramento River at Keswick	40.60	-122.44	7.5	11.2	15.0	0	10.4	9	1	0	0	0	0	0	4
84	Sacramento R. (mainstem)	Sacramento River near Red Bluff	40.29	-122.19	7.5	12.4	15.5	0	10.7	9	1	0	0	0	0	0	4
85	Sacramento R. (mainstem)	Tehama-Colusa Canal near Red Bluff	40.15	-122.20	7.6	14.5	18.5	0	10.5	10	1	0	0	0	0	0	4
86	Sacramento R. (mainstem)	Glenn-Colusa Canal near Hamilton City	39.74	-122.02	8.0	20.0	20.0	0	9.8	9	1	0	0	0	0	0	4
87	Sacramento R. (mainstem)	Sacramento River at Freeport	38.46	-121.50	7.7	19.5	25.0	0	8.8	11	1	0	0	0	0	0	4
88	San Joaquin R. (mainstem)	San Joaquin River near Stevinson	37.31	-120.93	7.8	22.6	29.0	-	8.1	59	1	1	1	1	1	1	1
89	San Joaquin R. (mainstem)	San Joaquin River at Highway 152 Bridge	37.06	-120.55	7.8	22.0	22.0	-	8.7	31	1	1	1	1	1	1	1
90	San Joaquin R. (mainstem)	San Joaquin River Below Friant Dam	36.98	-119.72	7.1	12.8	22.0	0	11.6	3	1	0	0	0	0	0	4
91	Delta	Sacramento River at Delta	38.17	-121.59	7.9	16.1	19.5	-	10.0	6	1	0	0	0	0	0	4
92	Delta	San Joaquin River at Antioch Ship Channel	38.02	-121.81	7.8	20.8	25.0	-	8.5	33	1	1	1	1	1	1	1
93	Delta	Rock Slough at Plant	37.97	-121.66	7.7	21.8	-	-	-	12	1	0	0	0	0	0	4
94	Delta	Old River Intake	37.91	-121.53	7.4	22.0	25.3	-	9.0	9	1	0	0	0	0	0	4
95	Delta	Clifton Court Forebay	37.83	-121.56	7.9	20.5	-	-	8.8	15	1	1	1	0	0	0	2
96	Delta	Old River at Tracy Road Bridge	37.80	-121.45	7.8	21.2	27.0	-	7.6	32	1	1	1	1	1	1	1

Site #	Region	Site Name	Latitude	Longitude	— — — Water Quality Data — — —							Sites with Suitable Water Quality, assuming a Calcium Threshold of…					Priority
					pH	Avg Temp (°C)	Max Temp (°C)	Salinity (ppt)	DO (ppm)	Ca (ppm)	Dessi-cation (no=1)	12	15	20	25	28	
97	SF Bay Local Watersheds	Napa River near Napa	38.37	-122.30	8.1	19.4	24.5	–	9.2	28	1	1	1	1	1	1	1
98	SF Bay Local Watersheds	North Bay Aqueduct at Barker Slough	38.28	-121.78	7.6	19.9	26.8	0	7.3	18	1	1	1	0	0	0	2
99	SF Bay Local Watersheds	Contra Loma Reservoir	37.96	-121.75	7.5	17.7	–	0	10.6	19	1	1	1	0	0	0	2
100	SF Bay Local Watersheds	San Pablo Reservoir	37.83	-122.08	8.5	–	–	0	–	18	1	1	1	0	0	0	2
101	SF Bay Local Watersheds	South Bay Pumping Plant	37.78	-121.62	7.9	19.7	24.1	0	8.3	–	1	1	1	1	1	1	1
102	SF Bay Local Watersheds	San Antonio Reservoir	37.68	-121.83	8.4	24.1	–	0	–	28	1	1	1	1	1	1	1
103	SF Bay Local Watersheds	South Bay Aqueduct at Mile 16.27	37.65	-121.77	8.1	20.5	23.3	0	9.6	17	1	1	1	0	0	0	2
104	SF Bay Local Watersheds	Lake Del Valle at Glory Hole	37.63	-121.71	8.5	17.8	–	0	7.8	32	1	1	1	1	1	1	1
105	SF Bay Local Watersheds	San Andreas Reservoir	37.60	-122.42	8.2	22.5	–	0	–	13	1	1	0	0	0	0	3
106	SF Bay Local Watersheds	Crystal Springs Reservoir	37.58	-121.50	8.2	18.5	–	0	–	13	1	1	0	0	0	0	3
107	SF Bay Local Watersheds	South Bay Aqueduct at Santa Clara Terminus	37.58	-121.83	7.9	20.8	26.3	0	9.1	18	1	1	1	0	0	0	2
108	SF Bay Local Watersheds	Upper San Leandro Reservoir	37.47	-122.17	8.5	–	–	0	–	26	1	1	1	1	1	0	1
109	SF Bay Local Watersheds	Lexington Reservoir at dam near Los Gatos	37.20	-121.99	7.9	16.3	–	0	7.0	36	1	1	1	1	1	1	1
110	SF Bay Local Watersheds	Calero Reservoir near New Almaden	37.18	-121.77	8.1	19.2	–	0	8.3	26	1	1	1	1	1	0	1
111	SF Bay Local Watersheds	Coyote Creek below Anderson Dam	37.17	-121.63	8.0	13.8	22.0	0	10.2	35	1	1	1	1	1	1	1
112	SF Bay Local Watersheds	Anderson Reservoir at dam	37.16	-121.63	7.7	19.8	–	0	9.3	33	1	1	1	1	1	1	1
113	Central Coast	San Lorenzo River near Boulder Creek	37.21	-122.14	8.3	14.1	17.0	0	9.6	76	1	1	1	1	1	1	1
114	Central Coast	Pajaro River at Chittenden	36.90	-121.60	8.1	18.6	23.0	0	7.9	81	1	1	1	1	1	1	1
115	Central Coast	San Benito River near Willow Creek School	36.61	-121.20	8.4	21.3	26.0	0	10.1	27	1	1	1	1	1	0	1
116	Central Coast	Salinas River near Chualar	36.56	-121.55	8.4	22.4	28.5	0	9.5	49	1	1	1	1	1	1	1
117	Central Coast	Carmel River near Carmel	36.54	-121.87	7.7	16.7	20.5	–	9.8	33	1	1	1	1	1	1	1
118	Central Coast	Arroyo Seco near Soledad	36.28	-121.33	8.2	20.1	22.0	0	10.0	62	1	1	1	1	1	1	1
119	Central Coast	Salinas River near Bradley	35.93	-120.87	8.1	21.3	23.5	0	9.4	48	1	1	1	1	1	1	1
120	Central Coast	San Antonio River below San Antonio Dam	35.80	-120.85	8.2	20.3	24.0	0	11.3	50	1	1	1	1	1	1	1
121	Central Coast	Nacimiento Reservoir - lower arm	35.73	-121.06	8.0	22.0	–	0	8.7	28	1	1	1	1	1	1	1
122	Central Coast	Santa Ynez River at Narrows near Lompoc	34.64	-120.43	8.0	20.1	30.5	–	9.6	110	1	1	1	1	1	1	1
123	SWP & CVP Aqueducts	Delta Mendota Canal at head	37.78	-121.59	7.6	20.6	25.0	0	8.9	20	1	1	1	1	0	0	2
124	SWP & CVP Aqueducts	San Luis Reservoir at trashracks	37.05	-121.08	8.3	19.6	25.2	0	9.8	24	1	1	1	1	0	0	2
125	SWP & CVP Aqueducts	Delta Mendota Canal 2.2 mi S of Firebaugh	36.83	-120.43	8.0	19.3	26.0	0	7.6	28	1	1	1	1	1	1	1
126	SWP & CVP Aqueducts	California Aqueduct near Check 21	36.02	-119.98	7.9	21.4	27.0	0	8.4	18	1	1	1	0	0	0	2
127	SWP & CVP Aqueducts	California Aqueduct near Kettleman	36.02	-119.98	7.7	22.3	26.8	0	8.5	23	1	1	1	1	0	0	2
128	SWP & CVP Aqueducts	California Aqueduct at Check 41	34.93	-118.83	7.9	20.8	26.3	0	8.5	22	1	1	1	1	0	0	2
129	SWP & CVP Aqueducts	Pyramid Lake at inlet	34.68	-118.80	8.4	20.8	–	0	8.9	24	1	1	1	1	0	0	2
130	SWP & CVP Aqueducts	Piru Creek release from Pyramid Dam	34.64	-118.76	7.8	14.6	22.0	0	10.1	32	1	1	1	1	1	1	1
131	SWP & CVP Aqueducts	Lake Castaic	34.55	-117.58	9.0	21.3	–	0	10.1	30	1	1	1	1	1	1	1
132	SWP & CVP Aqueducts	Silverwood Lake at San Bernardino	34.28	-117.33	8.4	19.1	–	0	9.0	18	1	1	1	0	0	0	2
133	SWP & CVP Aqueducts	Lake Perris at inlet	33.83	-117.17	8.5	23.2	–	0	8.7	26	1	1	1	1	1	0	1
134	South Coast	Sespe Creek near Fillmore	34.45	-118.93	8.6	20.9	26.0	0	9.1	86	1	1	1	1	1	1	1
135	South Coast	Santa Clara River at LA-Ventura Co. line	34.40	-118.70	8.2	22.5	28.0	0	8.1	122	1	1	1	1	1	1	1
136	South Coast	San Gabriel River at Azusa	34.15	-117.91	8.3	19.6	26.0	0	8.9	43	1	1	1	1	1	1	1
137	South Coast	Santa Ana River at MWD Crossing	33.97	-117.45	–	23.2	34.5	0	–	94	1	0	0	0	0	0	4
138	South Coast	Los Angeles River at Long Beach	33.82	-118.21	9.7	27.9	34.0	–	19.3	75	1	0	0	0	0	0	4
139	South Coast	San Luis Rey River at Oceanside	33.22	-117.36	8.0	25.7	35.0	–	8.7	147	1	0	0	0	0	0	4
140	South Coast	San Diego River at El Capitan Dam	32.88	-116.81	8.0	26.0	31.0	0	8.5	24	1	1	1	1	0	0	2
141	Northeastern California	Goose Lake	41.92	-120.42	9.1	18.8	–	–	9.1	11.5	1	0	0	0	0	0	4
142	Northeastern California	Upper Alkali Lake	41.75	-120.12	–	–	–	–	–	–	0	0	0	0	0	0	4
143	Northeastern California	Lower Alkali Lake	41.33	-120.08	–	–	–	3	–	7	0	0	0	0	0	0	4
144	Northeastern California	Eagle Lake	40.62	-120.74	9.1	15.7	–	0.4	8.8	9	1	0	0	0	0	0	4
145	Northeastern California	Honey Lake	40.25	-120.30	–	–	–	7	–	–	0	0	0	0	0	0	4

Site #	Region	Site Name	Latitude	Longitude	— — — Water Quality Data — — —							Sites with Suitable Water Quality, assuming a Calcium Threshold of…					Priority
					pH	Avg Temp (°C)	Max Temp (°C)	Salinity (ppt)	DO (ppm)	Ca (ppm)	Dessication (no=1)	12	15	20	25	28	
146	East of Sierra/Mojave	Mono Lake	38.00	-119.12	9.9	-	-	69	-	4	1	0	0	0	0	0	4
147	East of Sierra/Mojave	Los Angeles Aqueduct - Grant Lakes	37.83	-119.08	7.4	12.7	18.0	0	7.8	6	1	0	0	0	0	0	4
148	East of Sierra/Mojave	Mammoth Creek at Highway 395	37.64	-118.90	7.9	10.7	18.0	0	10.2	9	1	0	0	0	0	0	4
149	East of Sierra/Mojave	Los Angeles Aqueduct - Tinemaha	37.08	-118.20	8.3	19.5	25.4	0	7.6	21	1	1	1	1	0	0	2
150	East of Sierra/Mojave	Owens River below Tinemaha	37.05	-118.23	8.1	17.8	23.0	0.3	8.5	18	1	1	1	0	0	0	2
151	East of Sierra/Mojave	Los Angeles Aqueduct - Merritt Cut	36.02	-118.00	8.2	20.2	26.2	0	8.1	17	1	1	1	0	0	0	2
152	East of Sierra/Mojave	Mojave River near Victorville	34.57	-117.32	7.9	25.2	32.0	-	7.3	34	1	0	0	0	0	0	4
153	Colorado River Basin	Colorado River at Aqueduct intake	34.32	-114.16	8.0	22.3	-	0	7.6	79	1	1	1	1	1	1	1
154	Colorado River Basin	Lake Havasu at Parker Dam	34.30	-114.13	7.8	22.5	-	0	6.5	75	1	1	1	1	1	1	1
155	Colorado River Basin	Colorado River Aqueduct - Lake Mathews	33.83	-117.43	8.5	24.4	-	0	-	77	1	1	1	1	1	1	1
156	Colorado River Basin	Salton Sea - midpoint near County Line	33.42	-115.95	8.3	26.6	-	40	-	1416	1	0	0	0	0	0	4
157	Colorado River Basin	Alamo River near Calipatria	33.10	-115.39	8.0	26.5	32.5	-	7.4	177	1	0	0	0	0	0	4
158	Colorado River Basin	All American Canal	32.75	-114.71	7.9	28.0	30.4	-	8.0	67	1	1	1	1	1	1	1
159	Colorado River Basin	East Highline Canal	32.70	-115.28	8.3	25.2	30.0	0	7.6	76	1	1	1	1	1	1	1
160	Colorado River Basin	New River at international boundary	32.67	-115.50	7.7	27.4	31.8	-	-	250	1	0	0	0	0	0	4

Suitability
1 = Suitable
2 = Not Suitable

Priority
1 = High Priority
2 = Medium Priority
3 = Low Priority
4 = Not Vulnerable

	12	15	20	25	28
Number of sites with suitable water quality:	84	75	54	40	33

Number and Percent of High Priority sites:	40	25%
Number and Percent of Medium Priority sites:	35	22%
Number and Percentof Low Priority sites:	9	6%
Number and Percent of sites that are not vulnerable to colonization:	76	48%

PRIORITY TABLE

#	Region	Site Name	#	Region	Site Name
PRIORITY 1					
12	North Coast	Eel River at Scotia	115	Central Coast	San Benito River near Willow Creek School
13	North Coast	Van Duzen River near Bridgeville	116	Central Coast	Salinas River near Chualar
15	North Coast	Eel River at Black Butte River	117	Central Coast	Carmel River near Carmel
20	West Sacramento Valley	Black Butte Reservoir	118	Central Coast	Arroyo Seco near Soledad
69	Sierra Nevada	Mariposa Creek below Mariposa Dam	119	Central Coast	Salinas River near Bradley
88	San Joaquin R. (mainstem)	San Joaquin River near Stevinson	120	Central Coast	San Antonio River below San Antonio Dam
89	San Joaquin R. (mainstem)	San Joaquin River at Highway 152 Bridge	121	Central Coast	Nacimiento Reservoir - lower arm
92	Delta	San Joaquin River at Antioch Ship Channel	122	Central Coast	Santa Ynez River at Narrows near Lompoc
96	Delta	Old River at Tracy Road Bridge	125	SWP & CVP Aqueducts	Delta Mendota Canal 2.2 mi S of Firebaugh
97	SF Bay Local Watersheds	Napa River near Napa	130	SWP & CVP Aqueducts	Piru Creek release from Pyramid Dam
101	SF Bay Local Watersheds	South Bay Pumping Plant	131	SWP & CVP Aqueducts	Lake Castaic
102	SF Bay Local Watersheds	San Antonio Reservoir	133	SWP & CVP Aqueducts	Lake Perris at inlet
104	SF Bay Local Watersheds	Lake Del Valle at Glory Hole	134	South Coast	Sespe Creek near Fillmore
108	SF Bay Local Watersheds	Upper San Leandro Reservoir	135	South Coast	Santa Clara River at LA-Ventura Co. line
109	SF Bay Local Watersheds	Lexington Reservoir at dam near Los Gatos	136	South Coast	San Gabriel River at Azusa
110	SF Bay Local Watersheds	Calero Reservoir near New Almaden	153	Colorado River Basin	Colorado River at Aqueduct intake
111	SF Bay Local Watersheds	Coyote Creek below Anderson Dam	154	Colorado River Basin	Lake Havasu at Parker Dam
112	SF Bay Local Watersheds	Anderson Reservoir at dam	155	Colorado River Basin	Colorado River Aqueduct - Lake Mathews
113	Central Coast	San Lorenzo River near Boulder Creek	158	Colorado River Basin	All American Canal
114	Central Coast	Pajaro River at Chittenden	159	Colorado River Basin	East Highline Canal
PRIORITY 2					
4	North Coast	Scott River near Fort Jones	95	Delta	Clifton Court Forebay
5	North Coast	Klamath River near Klamath	98	SF Bay Local Watersheds	North Bay Aqueduct at Barker Slough
8	North Coast	Trinity River at Hoopa	99	SF Bay Local Watersheds	Contra Loma Reservoir
9	North Coast	Mad River near Arcata	100	SF Bay Local Watersheds	San Pablo Reservoir
14	North Coast	Eel River South Fork Near Miranda	103	SF Bay Local Watersheds	South Bay Aqueduct at Mile 16.27
16	North Coast	Eel River near Dos Rios	107	SF Bay Local Watersheds	South Bay Aqueduct at Santa Clara Terminus
17	North Coast	Russian River near Ukiah	123	SWP & CVP Aqueducts	Delta Mendota Canal at head
21	North Coast	Pillsbury Lake near Potter Valley	124	SWP & CVP Aqueducts	San Luis Reservoir at trashracks
22	West Sacramento Valley	Indian Valley Reservoir	126	SWP & CVP Aqueducts	California Aqueduct near Check 21
23	West Sacramento Valley	Clear Lake - upper arm	127	SWP & CVP Aqueducts	California Aqueduct near Kettleman
24	West Sacramento Valley	Clear Lake - lower arm	128	SWP & CVP Aqueducts	California Aqueduct at Check 41
25	West Sacramento Valley	Cache Creek near Lower Lake	129	SWP & CVP Aqueducts	Pyramid Lake at inlet
26	West Sacramento Valley	Putah Creek below Monticello Dam	132	SWP & CVP Aqueducts	Silverwood Lake at San Bernardino
27	West Sacramento Valley	Lake Berryessa at dam	140	South Coast	San Diego River at El Capitan Dam
29	Upper Sacramento River	Pit River near Canby	149	East of Sierra/Mojave	Los Angeles Aqueduct - Tinemaha
70	Sierra Nevada	Chowchilla River below Buchanan Dam	150	East of Sierra/Mojave	Owens River below Tinemaha
71	Sierra Nevada	Fresno River near Daulton	151	East of Sierra/Mojave	Los Angeles Aqueduct - Merritt Cut
79	Sierra Nevada	Tule River below Success Dam			
PRIORITY 3					
1	North Coast	Klamath River below Iron Gate Dam	43	Sierra Nevada	Feather River Middle Fork near Portola
2	North Coast	Klamath River at Hamburg	66	Sierra Nevada	Tuolumne River at Modesto
7	North Coast	Klamath River at Orleans	105	SF Bay Local Watersheds	San Andreas Reservoir
18	North Coast	Lake Sonoma- Dry Creek Arm	106	SF Bay Local Watersheds	Crystal Springs Reservoir
35	Upper Sacramento River	McCloud River above Shasta Lake			
PRIORITY 4					
3	North Coast	Smith River near Crescent City	64	Sierra Nevada	Tuolumne River at La Grange Bridge
6	North Coast	Salmon River at Somesbar	65	Sierra Nevada	Merced River - South Fork near El Portal
10	North Coast	Trinity River near Burnt Ranch	67	Sierra Nevada	Merced River near Stevinson
11	North Coast	Trinity River at Lewiston	68	Sierra Nevada	San Joaquin R - S Fork at Mono Hot Springs
19	West Sacramento Valley	Thomes Creek at Paskenta	72	Sierra Nevada	Millerton Lake near Friant Dam
28	North Coast	Shasta River below Dwinnell Reservoir	73	Sierra Nevada	Friant-Kern Canal at Friant
30	Upper Sacramento River	Siskiyou Lake - upper end near Shasta City	74	Sierra Nevada	Kings River near Trimmer
31	Upper Sacramento River	Pit River - South Fork near Likely	75	Sierra Nevada	Pine Flat Reservoir above dam
32	Upper Sacramento River	McCloud Reservoir at dam	76	Sierra Nevada	Kings River - South Fork at Cedar Grove
33	Upper Sacramento River	Iron Canyon Reservoir	77	Sierra Nevada	Kaweah River at Three Rivers
34	Upper Sacramento River	Lake Britton at Ferry Crossing	78	Sierra Nevada	Kaweah River below Terminus Dam
36	Upper Sacramento River	Pit River near Montgomery Creek	80	Sierra Nevada	Kern River above Fairview
37	Upper Sacramento River	Shasta Lake near Shasta Dam	81	Sierra Nevada	Lake Isabella at Engineer Point
38	Upper Sacramento River	Whiskeytown Reservoir at dam	82	Sierra Nevada	Kern River near Bakersfield
39	Sierra Nevada	Lake Almanor - east arm	83	Sacramento R. (mainstem)	Sacramento River at Keswick
40	Sierra Nevada	Antelope Lake	84	Sacramento R. (mainstem)	Sacramento River near Red Bluff
41	Sierra Nevada	Frenchman Lake	85	Sacramento R. (mainstem)	Tehama-Colusa Canal near Red Bluff
42	Sierra Nevada	Lake Davis	86	Sacramento R. (mainstem)	Glenn-Colusa Canal near Hamilton City
44	Sierra Nevada	Butte Creek near Chico	87	Sacramento R. (mainstem)	Sacramento River at Freeport
45	Sierra Nevada	Thermalito Afterbay	90	San Joaquin R. (mainstem)	San Joaquin River Below Friant Dam
46	Sierra Nevada	Truckee River at Farad	91	Delta	Sacramento River at Delta
47	Sierra Nevada	South Yuba River near Cisco	93	Delta	Rock Slough at Plant
48	Sierra Nevada	Yuba River near Marysville	94	Delta	Old River Intake
49	Sierra Nevada	Lake Tahoe	137	South Coast	Santa Ana River at MWD Crossing
50	Sierra Nevada	Bear River near Wheatland	138	South Coast	Los Angeles River at Long Beach
51	Sierra Nevada	Feather River near Nicolaus	139	South Coast	San Luis Rey River at Oceanside
52	Sierra Nevada	American River - South Fork near Lotus	141	Northeastern California	Goose Lake
53	Sierra Nevada	Folsom Lake near Folsom	142	Northeastern California	Upper Alkali Lake
54	Sierra Nevada	American River at Nimbus Dam	143	Northeastern California	Lower Alkali Lake
55	Sierra Nevada	American River near Carmichael	144	Northeastern California	Eagle Lake
56	Sierra Nevada	Cosumnes River at Michigan Bar	145	Northeastern California	Honey Lake
57	Sierra Nevada	Stanislaus River - Middle Fork at Dardanelle	146	East of Sierra/Mojave	Mono Lake
58	Sierra Nevada	Pardee Reservoir	147	East of Sierra/Mojave	Los Angeles Aqueduct - Grant Lakes
59	Sierra Nevada	Camanche Reservoir	148	East of Sierra/Mojave	Mammoth Creek at Highway 395
60	Sierra Nevada	Mokelumne River at Woodbridge	152	East of Sierra/Mojave	Mojave River near Victorville
61	Sierra Nevada	Hetch Hetchy Reservoir	156	Colorado River Basin	Salton Sea - midpoint near County Line
62	Sierra Nevada	Don Pedro Reservoir at influent	157	Colorado River Basin	Alamo River near Calipatria
63	Sierra Nevada	Stanislaus River at Ripon	160	Colorado River Basin	New River at international boundary