Anodonta californiensis (Lea, 1852) / *Anodonta nuttalliana* (Lea, 1838)
California Floater / Winged Floater
Bivalvia: Unionidae

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SUMMARY

The California floater (*Anodonta californiensis*) and the winged floater (*Anodonta nuttalliana*) have been documented from the following states and provinces in western North America: [U.S.A.] Arizona, California, Idaho, Nevada, Oregon, Utah, Washington, and Wyoming; [Canada] British Columbia; and [Mexico] Chihuahua and Sonora. Although the current authority on names of mollusks (Turgeon *et al.* 1998) considers *A. californiensis* and *A. nuttalliana* to be separate species, more recent genetic research has suggested that they belong to a single clade (Chong *et al.* 2008) that may be comprised of six genetically distinct groups that cluster by hydrologic basin (Mock *et al.* 2010). This research has also revealed that the traditional method of distinguishing these two 'species' based on shell morphological characteristics is questionable. Therefore, in this status review, we are treating *A. californiensis* and *A. nuttalliana* as a single clade (*A. californiensis / A. nuttalliana*). However, in cases where we summarize statements made by other authors about only *A. californiensis* or only *A. nuttalliana*, we retain those author's treatment of the species by referring to only *A. californiensis* or only *A. nuttalliana*.*A. californiensis / A. nuttalliana* typically inhabit lakes, reservoirs, and slow- moving streams with mud or sand substrates, although they have also been found in rivers and creeks with gravel substrates. Much more information is needed to understand which fishes serve as hosts for these species, but the native hardhead, pit sculpin, Sacramento pikeminnow, and tule perch, and the non-native green sunfish have all been documented as hosts for *A. californiensis / A. nuttalliana* in northern California (Spring Rivers 2007, Table 1). *A. californiensis / A. nuttalliana*, like other freshwater mussels, can play significant roles in the aquatic ecosystem – for example, by filtering vast quantities of water or by increasing the abundance of other invertebrates in the benthos. Some populations within this clade may be more sensitive to environmental changes than others; those populations have the potential to be excellent biological indicators.

Threats to *A. californiensis* / *A. nuttalliana*, as well as other freshwater mussels, include: impoundments and loss of host fish; channel modification from channelization, dredging and mining; restoration activities; contamination; sedimentation; nutrient enrichment; water withdrawal and diversion; thermal pollution; livestock grazing in riparian areas; and the introduction of non-native fish and invertebrate species. Many of the above threats, especially thermal pollution and reduced stream flow resulting from water withdrawal in arid areas, are being exacerbated by climate change. *A. californiensis* / *A. nuttalliana* are specifically threatened by low genetic diversity as a result of recent population reductions (Mock *et al.* 2010). *A. californiensis* / *A. nuttalliana* has been extirpated from large parts of its historic range in southern California, Arizona, and Utah, and is vulnerable to extinction in these areas. In order

to conserve these animals, more research is needed to understand and name individual species that currently comprise this clade. In addition, more research is needed to understand the distribution, status and life history of this clade.

CONSERVATION STATUS

Xerces Red List Status: Vulnerable; populations in AZ, southern CA, and UT are Critically Imperiled
NatureServe Global Status:
  A. californiensis: (2006) G3Q
  A. nuttalliana: (2009) G4Q
NatureServe National Status:
  A. californiensis: United States-N3, Canada (2006)-N3
  A. nuttalliana: United States (2003)-N3N4, Canada (2009)-N4
NatureServe State Status:
  A. californiensis: Arizona (S1), California (S2), Idaho (SNR), Nevada (S1), Oregon (S2), Utah (S1), Washington (S1), Wyoming (SNR)
  A. nuttalliana: California (SNR), Nevada (SNR), Oregon (S1), Washington (SNR)
NatureServe Provincial Status – Canada: S4 (BC)
IUCN Red List: N/A
USA – Endangered Species Act: N/A
Canada – Canadian Species At Risk Act: N/A
American Fisheries Society Status (Williams *et al.* 1993): Undetermined

PROFILE

DESCRIPTION

The taxonomic designations of western *Anodonta* that have historically been made on the basis of shell morphology are incongruent with recent genetic research (see Chong *et al.* 2008, Mock *et al.* 2010); more research is needed to understand whether shell morphological characteristics (such as length to height ratios) can distinguish *Anodonta* species in the western U.S. It may also be possible to utilize soft tissue morphology to distinguish between western *Anodonta* species, but more research is needed to confirm whether or not that is possible. Below is a summary of some of the shell morphological descriptions that have historically been used to describe *A. californiensis* and *A. nuttalliana*. These descriptions should be interpreted with caution, since it is not known whether western *Anodonta* can be distinguished using shell morphological characteristics.

All *Anodonta*, including *A. californiensis* / *A. nuttalliana*, lack teeth (Henderson 1929, Burch 1973). *A. californiensis / A. nuttalliana* shells are thin, fragile (Henderson 1929, Burch 1973), up to five inches (Nedeau *et al*. 2009), elliptical, ovate (Ingram 1948), or trapezoid-ovate in shape (Clarke 1981), and may have a dorsal wing that varies in prominence (Clarke 1981, Nedeau *et al*. 2009). The height of the posterior half of the shell is greater than the anterior half (Burch 1973). The length / height ratio is usually less than 1.5 (Nedeau *et al.* 2009). The periostracum can be yellowish green, yellowish brown or brown, and the nacre tends to be white or bluish (Clarke 1981). The beak is small (Lea 1838, 1852; reported in Ingram 1948), and scarcely elevated above the hinge line (Nedeau *et al*. 2009). *A. californiensis* / *A. nuttalliana* have been historically distinguished as separate species primarily by the presence of a dorsal wing – morphs with a prominent dorsal wing were considered *A. nuttalliana*, and morphs without a prominent wing were considered *A. californiensis* (see Figures 1 and 2).

Figure 1. Photographs of putative *Anodonta californiensis* shells © Ethan Jay Nedeau, reproduced from the field guide *Freshwater Mussels of the Pacific Northwest* (Nedeau *et al*. 2009).

Figure 2. Photographs of putative *Anodonta nuttalliana* © Ethan Jay Nedeau, reproduced from the field guide *Freshwater Mussels of the Pacific Northwest* (Nedeau *et al*. 2009).

TAXONOMIC STATUS

The type locality for *A. californiensis* is: “Rio Colorado, California” actually a former distributary of the river, approximately New River, Imperial County, California (Frest & Johannes 1995, Bequart and Miller 1973). The type locality for *A. nuttalliana* is: “Wahlamat River near its junction with the Columbia” (Simpson 1914).

Phylum: Mollusca
Class: Bivalvia
Family: Unionidae
Genus: *Anodonta*
Species: *Anodonta californiensis* and *Anodonta nuttalliana*

Anodonta californiensis I. Lea, 1852 and *Anodonta nuttalliana* I. Lea, 1838 are both recognized as species in the current authority on the names of mollusks in the U.S. and Canada (Turgeon *et al*. 1998), although recent genetic research suggests that these two species actually belong to a single clade (Chong *et al*. 2008). Further genetic work has shown that this clade exhibits basin specific substructuring and may contain at least six distinct groups (Mock *et al*. 2010). However, before new species or genus level designations are made, the taxonomy for the entire Unionidae family needs to be resolved and, in addition to considering genetic factors, one should take ecology and life history factors into account (Crandall *et al.* 2000).

A genetic analysis of *Anodonta* from Mexico needs to be completed to determine whether recent *Anodonta* specimens collected by Terry Myers from the Rio Casas Grandes drainage in Chihuahua and the Rio Yaqui drainage in Sonora and Chihuahua, Mexico closely resemble specimens from the *A. californiensis* / *A. nuttalliana* clade, or whether they represent a different taxonomic group. Mussels from both drainages in Mexico have previously been identified as *A. dejecta* based on shell characteristics; a method that is less than definitive for differentiating species of western *Anodonta*. Unfortunately, the use of genetic procedures to evaluate the relatedness of *A. californiensis* / *A. nuttalliana* to *A. dejecta* is problematic because, in the absence of an accepted type locality for the *A. dejecta*, there are no unequivocal *A. dejecta* populations with which to compare *A. californiensis / A. nuttalliana* specimens or the unidentified Mexican specimens. (T. Myers, personal communication).

LIFE HISTORY

A. californiensis / A. nuttalliana occur in lakes, slow rivers (Taylor 1981), and some reservoirs (Nedeau *et al.* 2009) with mud or sand substrates (Clarke 1981) and are typically found at low elevations (Frest and Johannes 1995). The distribution of freshwater mussels within a water body is probably dependent on the size and geology of the water body and patterns of host fish distribution during the mussel's reproductive period (Watters 1992). *A. californiensis* / *A. nuttalliana* are relatively sedentary filter feeders that consume plankton and other particulate matter that is suspended in the water column. As they feed, they filter large quantities of particulate matter and excrete those particles as 'pseudofaeces', which can be an important, nutrient rich food source for benthic macroinvertebrates (reviewed in Vaughn *et al.* 2008). In general, *Anodonta* species grow quickly, reach sexual maturity in four to five years, and probably have a maximum life span of about 15 years (Heard 1975, Dudgeon & Morton 1983).

Reproduction and Host Fish Associations

Like other freshwater mussels, *A. californiensis* / *A. nuttalliana* rely on host fishes to reproduce and disperse. Because freshwater mussels are not able to move far on their own, their association with fish allows them to colonize new areas, or repopulate areas from which mussels have been extirpated. Fertilization occurs when female mussels inhale sperm through their incurrent siphon during the appropriate reproductive period. Eggs incubate and hatch into larvae, or glochidia, which are released into the water, either individually or in packets (called conglutinates). Glochidia will attach to fish and encyst in host fish tissues from 2-36 hours after they attach. Once metamorphosed, juvenile mussels drop from their host fishes to the substrate. (McMahon and Bogan 2001).

More research is needed to identify the host fish relationships for *Anodonta californiensis* / *A. nuttalliana*. In the eastern U.S., *Anodonta* species rely on multiple hosts (Trdan and Hoeh 1982, Watters 1994). A report by Spring Rivers Ecological Consulting (2007) documented four native fish and one nonnative fish in the lower Pit River drainage of northeastern California that serve as hosts of *Anodonta californiensis* / *A. nuttalliana* (Table 1). Our criteria for considering a fish to be a glochidial host in Table 1 were twofold: 1) a glochidia infestation was observed in a natural setting (not artificially induced), and 2) metamorphosis of glochidia to juveniles was observed. Other fish species that are potential glochidial hosts for *A. californiensis* / *A. nuttalliana* are listed below in Table 2; more research is needed to determine if these fish species are viable hosts for *A. californiensis* / *A. nuttalliana*.

Heard (1975) reports hermaphrodism in *A. californiensis*. *Anodonta* have relatively large, triangular shaped glochidia with hooks on each valve (Barnhart *et al.* 2008, Hoggarth 1999, Spring Rivers 2007). Heard (1975) states that *A. californiensis* and *A. wahlametensis* (now considered a synonym of *A. nuttalliana*, Burch 1975) reproduce in October, whereas a more recent study reports that *A. californiensis* / *A. nuttalliana* are gravid during all months except from late July to mid-October (Spring Rivers 2007). An unpublished study for the Washington Department of Fish and Wildlife reports that fish are infected by *A. californiensis* glochidia from May through June (Lang 1998).

Table 1. Documented fish hosts for *A. californiensis / A. nuttalliana* are listed below. In order to determine that a fish is a host for *A. californiensis / A. nuttalliana*, glochidial infestation of the fish must have been observed in the wild and metamorphosis of the glochidia must have been observed.

Mussel species	**Fish species**	**Is fish species native to western U.S?**	**Glochidia infestation observed (natural or artificial)**	**Glochidia metamorphosis observed**	**Reference**
Anodonta californiensis / A. nuttalliana	Green sunfish *Lepomis cyanellus*	Non-native	Natural	Yes	Spring Rivers 2007
Anodonta californiensis / A. nuttalliana	Hardhead *Mylopharodon conocephalus*	Native	Natural	Yes	Spring Rivers 2007
Anodonta californiensis / A. nuttalliana	Pit sculpin *Cottus pitensis*	Native	Natural	Yes	Spring Rivers 2007
Anodonta californiensis / A. nuttalliana	Sacramento pikeminnow *Ptychocheilus grandis*	Native	Natural	Yes	Spring Rivers 2007
Anodonta californiensis / A. nuttalliana	tule perch *Hysterocarpus traski*	Native	Natural	Yes	Spring Rivers 2007

Table 2. Potential fish hosts for *A. californiensis / A. nuttalliana*. The fish species listed below may be suitable hosts for *A. californiensis / A. nuttalliana*, but either glochidia infestation has only been observed under artificial conditions, or glochidial metamorphosis has not been observed. Further studies should be conducted to determine whether or not the fish in this table serve as hosts for *A. californiensis / A. nuttalliana* under natural conditions.

Mussel species	Fish species	Is fish species native to western U.S?	Glochidia infestation observed (natural or artificial)	Glochidia metamorphosis observed	Reference
Anodonta californiensis	Mosquitofish, *Gambusia affinis*	Non-native	Artificial	Yes	D'Eliscu 1972
Anodonta sp.	speckled dace, *Rhynicthys osculus*	Native	Natural	No	Brim Box *et al.* 2002-2003
Anodonta californiensis	Utah chub*, *Gila atraria*	Native	-	-	Workman *et al*. 1979, Hovingh 2004
Anodonta californiensis	chiselmouth, *Acrocheilus alutaceus*	Native	Natural	No	Lang 1998
Anodonta californiensis	northern squawfish, *Ptychocheilus oregonensis*	Native	Natural	No	Lang 1998
Anodonta sp.	threespine stickleback, *Gasterosteus aculeatus*	Native	Natural	No	A. Smith, pers. comm., 2010

*P. Hovingh (2004) states that the Utah chub is the only fish in Redden Spring, western Utah, where *A. californiensis* are found, so it is likely a host of *A. californiensis*.

DISTRIBUTION

A. californiensis / A. nuttalliana are broadly distributed across western North America; one or both species have been documented from the following U.S. and Mexican states and Canadian provinces: [U.S.A.] Arizona, California, Idaho, Nevada, Oregon, Utah, Washington, and Wyoming; [Canada] British Columbia; and [Mexico] Chihuahua and Sonora. The maps in Figures 3 and 4 illustrate watersheds (8 digit HUCs) that contain records of mussels that were identified as *A. californiensis*, *A. nuttalliana*, and specimens that were only identified to the clade *A. californiensis / A. nuttalliana*. Observations and collections of *Anodonta* in the western U.S. that were not identified beyond genus were not included in the maps below, since they could have belonged to one of the other two *Anodonta* clades in western North America. Watersheds containing records of *A. californiensis / A. nuttalliana* that were observed or collected prior to 1985 appear in red and records of *A. californiensis / A. nuttalliana* observed or collected after 1985 appear in light blue in the maps below. Watersheds that contain records with no date associated are displayed with diagonal hash-marks. One may conclude that *A. californiensis / A. nuttalliana* has been extirpated from watersheds with only historical records (red), but that assumption may be incorrect if surveys have not been conducted in that watershed since 1985. To address this issue, we created a map of 'search effort' (Figure 4). Black dots represent locations where an individual searched for or collected any species of freshwater mussel. Of the thousands of mussel records and 'search effort' records that we received, we generally only had the capacity to map records that had geographic coordinates associated with them, which was a fraction of the total number of records. We manuscripted some 'search effort' points in southern

California and Arizona from geographic descriptions, since we considered those watersheds to be of high conservation priority. The representation of search effort in Figure 4 likely represents an underestimate of the true search effort that has occurred since 1985.

Caution should be exercised in interpreting the maps below. Nearly all of the identifications were made using shell morphological characteristics – a method that recent research has called in to question. It is also problematic to conclude that a species is absent from an area that may have been searched only once. In addition, the 8-digit HUC watershed scale of the maps in Figures 3 and 4 is too coarse to show declines that have occurred in individual streams or rivers.

The maps below were created from thousands of records from the published literature, museum collections, unpublished reports, and state, tribal, nonprofit, retired and amateur biologists. Please contact mussels@xerces.org for more information about the records used to create these maps.

Figure 3. Map of watersheds containing historical (pre-1985, red) records of *A. californiensis / A. nuttalliana* and more recent (post-1985, blue) records of *A. californiensis / A. nuttalliana*.

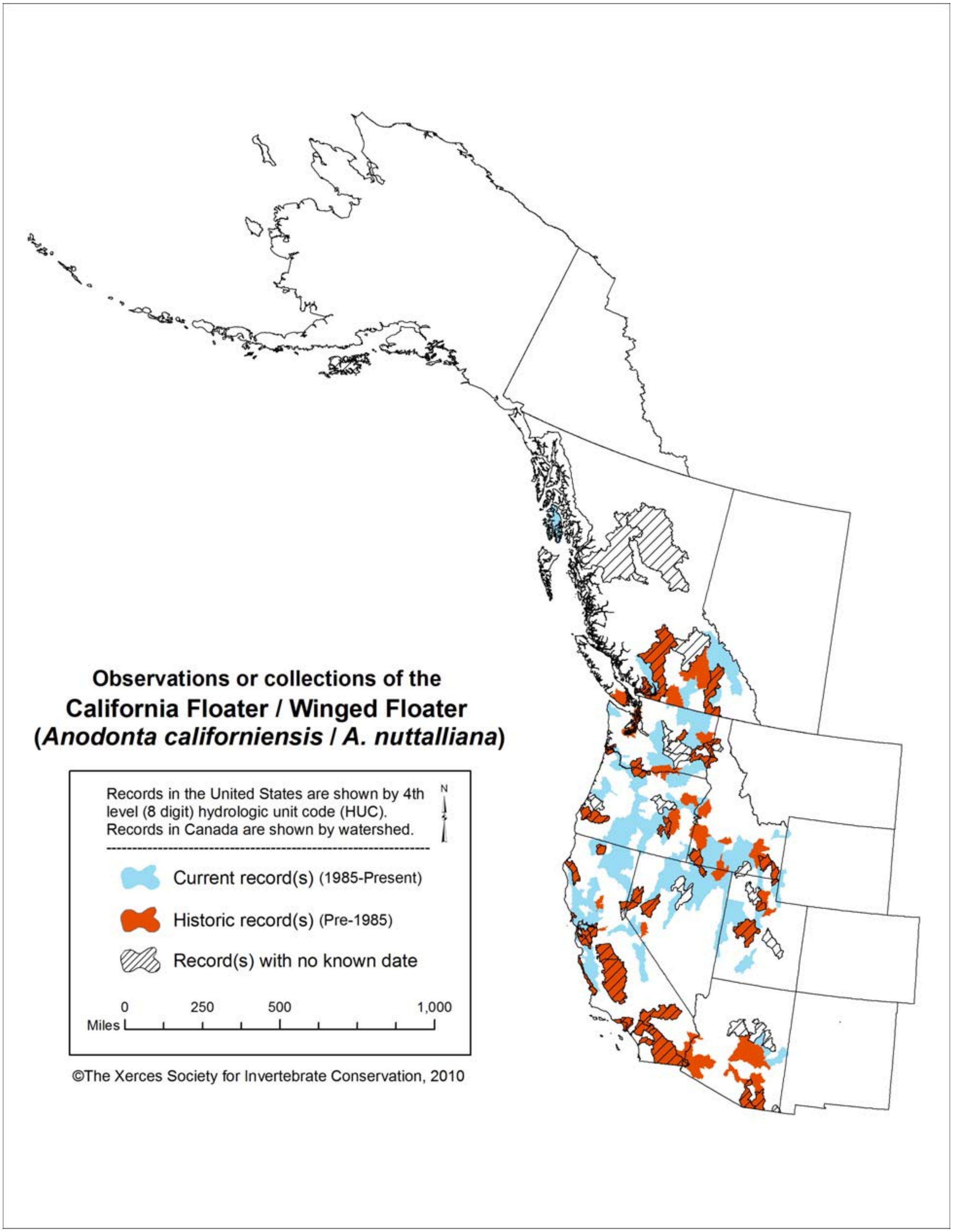
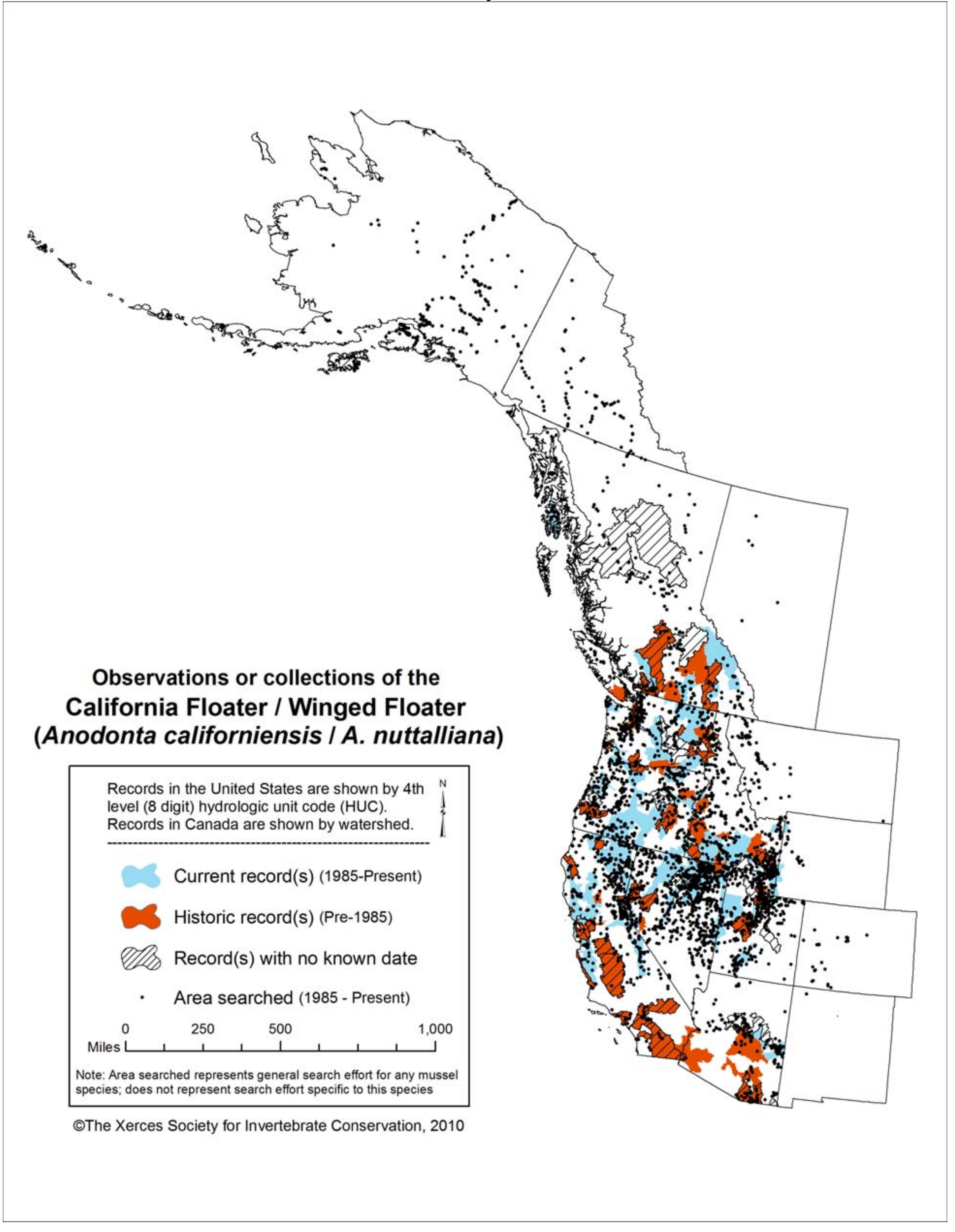


Figure 4. Map of watersheds containing historical (pre-1985, red) records of *A. californiensis / A. nuttalliana* and more recent (post-1985, blue) records of *A. californiensis / A. nuttalliana*. Black dots indicate locations that have been surveyed for freshwater mussels since 1985.



THREATS

Like other freshwater mussels in North America, threats to *A. californiensis* / *A. nuttalliana* include: impoundments and loss of host fish, channel modification from channelization, dredging and mining, restoration activities, contamination, sedimentation, nutrient enrichment, water withdrawal and diversion, thermal pollution, livestock grazing in riparian areas, and the introduction of non-native fish and invertebrate species. Many of these impacts, especially a reduction in stream flow and thermal pollution in arid areas, are being exacerbated by climate change. *A. californiensis* / *A. nuttalliana* are specifically threatened by low genetic diversity as a result of recent population reductions; Mock *et al.* (2010) found evidence of a recent demographic bottleneck in most populations of this clade that were sampled; populations were sampled from seven states across the range of these species. After conducting an extensive survey of thousands of sites in the Intermountain west, Hovingh (2004) concluded that *A. californiensis* now occupies streams and springs in higher reaches of drainage basins with high water quality, as well as in regions with low human population densities.

<u>Impoundments and loss of host fish</u>

Numerous freshwater mussel species in eastern North America have gone extinct as a direct result of dams (Vaughn and Taylor 1999, Watters 1996, Williams *et al.* 1992), which can change a water body's fish fauna, substrate composition, benthic community, water chemistry, dissolved oxygen levels and temperature (Bogan 1993). The elimination of a host fish species is likely the most harmful effect that dams have on freshwater mussels; Williams *et al.* (1992) report instances of 30-60 percent of a region's mussel fauna being extirpated as a result of dam construction. In addition, the flow regime of a river is frequently altered by dams; researchers in northern California suggest that the unnatural pulses in stream discharge from dams (pulsed flows) have the ability to interfere with the reproductive success of freshwater mussels by reducing contact between glochidia and host fish and preventing settlement of juveniles after excystment, if pulsed flows occur during key periods of the mussel species' reproductive cycle (Spring Rivers 2007). Terry Myers (unpublished, 2005) suggests that the decline of *A. californiensis* in the Colorado River basin may be attributed in part to an increase in peak flows that scour drainage bottoms, "flush out" mussels from suitable habitat, and destroy mussel habitat. In a recent study that examined the genetic diversity of multiple populations of *A. californiensis / A. nuttalliana* across its range, Mock *et al.* (2010) found that most populations had higher genetic diversity downstream than upstream; the study implies that dams may be interfering with *A. californiensis / A. nuttalliana* reproduction through reduced host fish (or habitat) availability upstream. In stream culverts also likely pose a significant obstacle to the dispersal of *A. californiensis / A. nuttalliana*, since they frequently inhibit fish passage (Vaughan 2002).

The most fragile part of a mussel's life cycle is its obligatory association with a host fish; in some cases, damming has extirpated a mussel species' obligate host fish and that, in conjunction with increased siltation and pollution, has led to a rapid decline in many species of freshwater mussels (Bogan 1993). Since the beginning of the 20^{th} century, 5% of native North American fish fauna have gone extinct, and an additional 364 fish species are considered endangered, threatened, or of special concern (Williams *et al.* 1989). Terry Myers (unpublished, 2005) suggests that the apparent demise of *A. californiensis* in the Colorado River basin may be partly attributed to the loss or decline of native fish communities or native fish abundance. In western

North America, little is known about which species of fish serve as hosts for *A. californiensis / A. nuttalliana*; this lack of host fish information will certainly impede conservation of this group of animals.

Channel modification

Dredging and channelization

River channels are regularly dredged and modified for navigation, flood control, and drainage, which has led to the local extirpation of freshwater mussel populations in the southeastern U.S. (Bogan 1993). Sedentary mussels are directly displaced by dredging operations, and frequently killed in dredge spoils (Neves *et al.* 1997). Dredging and channelization increases erosion and sedimentation and destabilizes the substrate, which decreases habitat suitability for freshwater mussels (Neves *et al.* 1997). Dredging and channelization leads to headcutting, which also causes erosion and sedimentation (Hartfield 1993).

Mining

Instream mining of gravel and suction dredge mining for gold and other metals are common practices in the western U.S. Instream gravel mining removes substrate and leads to siltation downstream (Bogan 1993), which can directly and indirectly harm freshwater mussels. In a study investigating the impact of suction dredge mining on freshwater mussels in the Similkameen River in Washington state, Krueger *et al.* (2007) found that freshwater mussels died when covered with tailings from a suction dredge, rather than excavate themselves, although species in the genus *Anodonta* were not included in this study. Similarly, Vannotte & Minshall (1982) reported that large western pearlshells (*Margaritifera falcata*) were unable to uncover themselves and perished when they were covered with sediment.

Restoration Activities

Activities such as culvert removal, dam removal, and stream reconfiguration to restore aquatic habitat for salmonids have become very common, especially in the Pacific Northwest. Frequently, these activities are undertaken without considering the distribution or conservation needs of freshwater mussels occurring in those streams. These operations can involve temporary stream dewatering, movement of personnel and equipment in streams, and flushing of sediments – all of which could have a negative impact on the survival of mussel populations.

Contaminants

Contaminants can destroy populations of freshwater mussels directly (by exerting toxic effects) and indirectly (by harming host fishes and/or food sources). (Havlik and Marking 1987). Many contaminants occur regularly in aquatic environments; for example, a study in the Columbia River documented that *Anodonta* sp. have a concentration of DDT (dichlorodiphenyltrichloroethane) from 14.9 ppb in spring to 2 ppb in fall and a concentration of PCBs (polychlorinated biphenyls) of 35-160 µg/kg wet weight (Claeys *et al.* 1975). Pollution from papermills, chemical factories, steel mills, and tanneries has been implicated in the extirpation of freshwater mussel populations in the eastern U.S. in the first half of the 20th Century (Bogan 1993). A review by Havlik and Marking (1987) reported that the following aquatic contaminants are lethal to freshwater mussels at various concentrations: cadmium, copper sulfate, ammonia, potassium, chromium, arsenic trioxide, copper, and zinc. Cadmium was the most toxic at only 2 ppm (parts per million) and copper sulfate was found to be toxic at levels of 2-18.7 ppm. Long term exposure to copper sulfate was lethal to mussels at concentrations as low as 25 ppb (parts per billion). Ammonia, which is a common pollutant from agricultural fertilizers and municipal sewage, was found to be toxic to mussels at only 5 ppm. (Havlik and Marking 1987). In an Illinois river, no mussels were found in an area with ammonia concentrations that exceeded 6 ppm, and mussels began to appear downstream where ammonia concentrations were progressively lower (Starrett 1971).

Freshwater mussels can be valuable indicators of pollutants, since they are sedentary, occupy a low position on the food chain, frequently bioaccumulate heavy metals, pesticides, and other contaminants, and are generally long-lived. Toxins in the shell are indicative of past exposure, whereas toxins in the soft tissues indicate more recent exposure. Because freshwater mussels frequently bioaccumulate contaminants, substances can be detected in their tissues that are too low in concentration to be detected in the surrounding water body. To this end, McCleneghan *et al.* (1981) reported using *A. californiensis* to monitor toxic substances at numerous sites in California (Havlik and Marking 1987).

Sedimentation and nutrient enrichment

Because freshwater mussels are filter feeders, they generally can not handle high levels of siltation that come from agricultural runoff, silvicultural operations and headcutting (Bogan 1993). The EPA considers fifty percent of U.S. rivers and streams that were assessed to be impaired, primarily due to sedimentation, nutrient enrichment, contamination with pathogens and habitat alterations (U.S. EPA 2010). Terry Myers (unpublished, 2005) suggests that the apparent loss of *A. californiensis* from the Colorado River basin may be attributed in part to increased occurrence of rapid sediment deposition resulting in the smothering of mussels.

Water withdrawal and diversion

Numerous streams in North America have been modified by water flow diversion and groundwater use (Dudley and Larson 1976). A review of the effects of artificially reduced stream flow on invertebrates and instream habitat revealed that these activities lead to increased sedimentation, decreased velocity, wetted width and depth, and can alter water temperature and chemistry (Dewson *et al.* 2007). These impacts generally reduce habitat diversity and alter invertebrate community composition (Dewson *et al.* 2007). Terry Myers (unpublished, 2005) suggests that the apparent disappearance of *A. californiensis* from much of the Colorado River basin may be attributed in part to the loss of backwater habitats along mainstream channels and the loss of perennial flows and connectivity of perennial surface waters. Climate change is projected to exacerbate the impact of low stream flow on mussels. For example, streamflows have decreased at a rate of approximately 2% per decade for the past century in the Rocky Mountain region of the western U.S. as a result of climate change (Rood *et al.* 2005).

Thermal pollution

Increased water temperatures as a result of decreased streamflow, loss of riparian vegetation, and global climate change are likely to stress, and perhaps eradicate, freshwater mussels. In a study in Fall River Lake in northern California, Spring Rivers (2007) found that high water temperatures (27.3°C or 81.1°F) and low water levels (<1 meter) may have caused the abortion of egg masses and premature onset of a non-gravid period that they observed in *A. californiensis*

/ *A. nuttalliana*. They note that thermal stress has caused abortion in other freshwater mussel species (Aldridge and McIvor 2003).

Livestock grazing in riparian areas

Livestock grazing in and near streams degrades the high water quality that freshwater mussels require for survival. Freshwater mussels generally require high levels of dissolved oxygen (Voshell 2002), yet the presence of livestock has been shown to increase eutrophication in water bodies (Mathews *et al.* 1994), which in turn can reduce levels of dissolved oxygen in water. Livestock tend to remain near streams because water, shade and forage abound (Strand & Merritt 1999), which exacerbates the impact of cattle on aquatic communities. Cattle grazing in riparian areas frequently leads to headcutting, which can increase sedimentation in the water body – a condition that freshwater mussels generally cannot handle (Bogan 1993). Grazing and trampling of riparian vegetation also increases water temperatures; high water temperatures may impede the ability of freshwater mussels to survive.

Introduction of non-native species

The nonnative Asian clam (*Corbicula fluminea*) is widespread in water bodies in western North America and may compete with native mussels (Clarke 1988), directly consume mussel glochidia and impact nutrient cycling (Leff *et al.* 1990, Strayer 1999, Vaughn and Spooner 2006). Sada and Vinyard (2002) speculate that the disappearance of *A. californiensis* from the Owens River basin may be due to the introduction of the Asian clam.

The zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena rostriformis bugensis*) aggressively compete with native mussels, although they are less widespread in western North America than the asian clam. West of the Continental Divide, zebra and/or quagga mussels currently occur in waterbodies in Nevada, Arizona, California, Colorado and Utah. Zebra and quagga mussels can attach directly to the shells of native freshwater mussels and impede their ability to feed (Mackie 1991, Schloesser *et al*. 1996, Strayer 1999, Strayer and Malcolm 2007). They have free-swimming larvae that do not require a host fish to reproduce, and thus have a high reproductive advantage over native freshwater mussels.

The Bureau of Reclamation is considering introducing the nonnative triploid Black Carp (*Mylopharyngodon piceus*) into Lake Mead to control the highly invasive quagga mussel (Egan 2009). The Black Carp is already on the list of injurious wildlife regulated under the Lacey Act. Black carp are known molluscavores that can reach 150 pounds, and even triploid black carp can form self-reproducing populations (Nico *et al.* 2005). Such an action, if carried out, would pose a real threat to the already vulnerable populations of *A. californiensis / A. nuttalliana* that remain in Nevada, southern California and Arizona.

Many other species of non-native fish have been introduced into western North America, primarily for sport fishing, which has led to the reduction or elimination of native fish species (Moyle *et al.* 1986, Rinne and Turner 1991, Andersen and Deacon 1996). In the Great Basin alone, fifty non-native fish species have been intentionally introduced (Sada & Vinyard 2002). These activities pose a threat to *A. californiensis / A. nuttalliana*, since these mussels likely co-evolved with native host fish and may not be able to readily adapt to using non-native fish as hosts. However, without knowing which fish species *A. californiensis / A. nuttalliana* can utilize as hosts, it is not possible to evaluate the risk that non-native fish pose. Based on an extensive survey of thousands of sites in the Intermountain west, Hovingh (2004) notes that *A. californiensis* now occupies streams and springs that are not actively managed for introduced sport fish.

CONSERVATION STATUS

A. californiensis / A. nuttalliana are highly vulnerable, and this clade has been extirpated from much of their historic range in Arizona, southern California, and Utah. This clade is probably also imperiled in Nevada, and populations sampled from multiple U.S. states in its historic range show evidence of inbreeding (Mock *et al*. 2010). Under the U.S. Endangered Species Act, distinct population segments of invertebrates cannot be listed as threatened or endangered. Thus, because *A. californiensis / A. nuttalliana* are a widespread clade and populations in Pacific Northwest states appear to be relatively stable, these animals are unlikely to receive protection under the U.S. Endangered Species Act until their taxonomy is resolved and new species names are given to genetically distinct populations.

A. californiensis was petitioned to be listed as threatened or endangered under the U.S. Endangered Species Act (ESA) in 1989 by Thomas Hulen of the Pueblo Grande Museum in Phoenix, AZ (Hulen 1989). In 1990, the U.S. Fish and Wildlife Service (FWS) determined that the petition did not present substantial information to indicate that listing *A. californiensis* as endangered or threatened was warranted, as it focused on the species status in Arizona, and did not include any information on status in the majority of the range of *A. californiensis* (USDI Fish and Wildlife Service 1990, Federal Register 55(209):43389). In this same finding, the Service added *A. californiensis* to their list of candidates for federal listing as a Category 2 candidate species (Federal Register 55(209):43389). In 1993, *A. californiensis* was again petitioned for listing under the ESA by the Oregon Natural Resources Council as part of a petition to list 83 mollusc species as endangered. In 1994, the FWS made a positive 90-day finding, but made a not-warranted 12 month finding in response to the petition to list *A. californiensis* as endangered (USDI Fish and Wildlife Service 1994, Federal Register 59(131):35305-35307). In that same Federal Register notice, the FWS stated that they lacked evidence of specific threats throughout the ranges of all 83 petitioned taxa, especially any threat associated with a population decline. They also noted that the taxonomic distinctiveness or validity of many of the 83 species had not yet been determined. *A. californiensis* was dropped as a candidate species when the FWS eliminated all Category 2 candidate species in 1996 (USDI Fish and Wildlife Service 1996, 59 FR 58982, 61 FR 7595-7613). *A. californiensis* remains a Federal Species of Concern (U.S. EPA 2002), although that designation provides no formal protection. In 2006, NatureServe assigned *A. californiensis* a global status of G3Q, meaning that this species is vulnerable and its taxonomy is in question (NatureServe 2010). In 2009 NatureServe assigned *A. nuttalliana* a global status of G4Q, meaning that it is apparently secure and its taxonomy is in question (NatureServe 2010).

To the best of the authors' knowledge, the winged floater (*Anodonta nuttalliana*) has never been petitioned for listing under the U.S. Endangered Species Act.

The conservation status of *A. californiensis / A. nuttalliana* in each U.S. and Mexican state and Canadian province where one or both species is known to occur is detailed below.

United States

Arizona

Arizona ranks *A. californiensis* as S1 or Critically Imperiled within the state (NatureServe explorer 2010). Freshwater mussels that occur in Arizona are all considered to be *Anodonta californiensis* (Culver *et al.* 2007). Historically, *A. californiensis* occurred in most of the major drainages of Arizona, including the Colorado River Basin (Black, Colorado, Gila, Little Colorado, Salt, San Pedro, Santa Cruz and Verde Rivers) and the Rio Yaqui Basin (San Bernadino River) (Culver *et al.* 2007). Currently, *A. californiensis* is only known from a few miles of perennially flowing waters in the Upper Black River of the Colorado River system (Culver *et al.* 2007, Myers 2005 unpublished) and Chevelon Creek in the Little Colorado River system (J. Sorensen, pers. comm. 2009).

In an unpublished document, T. Myers (2005) documents numerous *Anodonta* records from Arizona in recent and archeological history. From these records and his experience in the field (although he did not conduct systematic surveys), T. Myers suggests that *Anodonta* have likely been extirpated from the following places in Arizona: the lower mainstem of the Colorado River, the lower Gila River watershed, the Arizona portion of the Santa Cruz River watershed, the Tonto Basin, Phoenix Basin and New River in the Salt River watershed, the Verde River watershed, the west fork of the Black River in the Black River watershed, and the San Pedro River system in the San Pedro watershed.

Bequart and Miller (1973) document the extirpation of *A. californiensis* from numerous locations with historical records in Arizona: the Colorado River, the Little Santa Cruz River outside of Tucson, San Bernardino Ranch (Cochise County), Oak Creek Canyon (Cococino County), and the Little Colorado River near Springerville (Apache County). They note the considerable alterations that the Colorado River has undergone and doubt that *A. californiensis* still exists in the Colorado River. *A. californiensis* was apparently common and abundant in the Little Santa Cruz River outside Tucson, AZ in the late 1800's; but had been extirpated by the early 1900s (Bequart and Miller 1973). Bequart and Miller (1973) note that *A. californiensis* was widespread in Arizona a century ago and now is near extinction and suggest that the change is likely due to loss of host fish.

Although Bequart and Miller (1973) suggested that *A. californiensis* were extirpated from the entire Little Colorado River system, *Anodonta* valves were collected from Chevelon Creek in the Little Colorado River watershed and photographed by T. Myers in June of 2007 (J. Sorensen, pers. comm., 2009). T. Myers (2005) notes that in the Black River watershed, *Anodonta* are extant in the North Fork and East Fork of the Black River and Boneyard Creek. T. Myers (2005) suggests that *Anodonta* are 'apparently extant' in the upper tributaries of the Upper Rio Yaqui Watershed (which spans the Arizona, Sonora and Chihuahua in the U.S. and Mexico), at least in Rio Papigochic, Chihuahua (based on reports of local individuals in Chihuahua).

T. Myers notes that the status of *Anodonta* in Cibecue Creek, Canyon Creek and other drainages on Ft. Apache Indian reservation in the Salt River watershed and in the mainstem of the Black River in the Black River watershed is unknown (T. Myers 2005).

Preliminary genetic studies indicate that *Anodonta* collected from Arizona and Chihuahua, Mexico are different than the *Anodonta* collected from Jalisco, Mexico (Culver *et al.* 2007).

California

A. californiensis is ranked as S2 or Imperiled in California, whereas *A. nuttalliana* has not been ranked in the state (NatureServe 2010).

<u>Southern California</u>

Jeanette Howard conducted surveys at 42 historic (pre-1995) *Anodonta* sites in northern and southern California, and did not find *Anodonta* at any of the southern California sites searched. She found *Anodonta* at only nine of historic sites searched, all of which are in northern California, and concludes that *A. californiensis* has been extirpated from southern California. (Howard 2010).

In a 1981 publication, D. Taylor stated that *A. californiensis* is "probably extinct in most of the Central Valley and southern California. […] Probably most natural populations in the state have been eradicated." A decade later, in a California Department of Fish and Game report, Coney compared specimens from the Los Angeles County Museum that were collected between 1912 and 1945 to his own collections made between 1984 and 1992, and concluded that *A. californiensis* had been extirpated from "all of southern California" (Coney 1993, C-7). He documented historical records of *A. californiensis* from the Los Angeles River, Arroyo Seco, East Park/Lincoln Park Lake, Silver Lake and Hollenbeck Park, and noted that in eight years of active searching, he has not turned up any *A. californiensis* (Coney 1993). Coney states that "<u>Anodonta californiensis</u> Lea, 1852, should be investigated for qualification of endangered species status" (Coney 1993, C-8).

Bequart and Miller (1973) note the considerable alterations that the Colorado River has undergone and doubt that *A. californiensis* still exists in the Colorado River.

<u>Northern California</u>

In 1981, D.W. Taylor published a distributional checklist of freshwater mollusks in California. He speculated that *A. californiensis*, *Gonidea angulata* and *Margaritifera falcata* had been extirpated from most of their original ranges in the state (Taylor 1981). Frest (1999) suggested that *A. californiensis* is apparently extinct in the upper Sacramento River.

More recently, Jeanette Howard conducted a systematic survey of 42 historic (pre-1995) *Anodonta* sites in California and found *Anodonta* at only nine of those sites searched, all of which are in northern California (Howard 2010). In 2008, J. Howard surveyed 115 sites in northern California, in the following National Forests: Plumas, Tahoe, El Dorado and Lake Tahoe Basin Management Unit. No live *Anodonta* were found during that survey, although *Anodonta* shells were found in Donner Lake. Howard notes that the Feather, Yuba, American, Truckee and Consumnes Rivers, and Lake Tahoe are impacted by some or all of the same factors that are implicated in the decline of freshwater mussels in eastern North America: damming, channel modification, agriculture and forestry (Western Mollusk Sciences 2008).

In a recent study of *A. californiensis / A. nuttalliana* across its range, Mock *et al*. (2010) found evidence of a recent genetic bottleneck in 8 out of 24 populations sampled, including three populations in northern California: the Pit River, Walker River and Willow Creek.

In a joint thesis project on the freshwater mussels of the Mid-Klamath and Lower Salmon Rivers, Emily Davis (2008) and Aaron David (2008) surveyed 55 sites and found *Anodonta* at only a single site – below the Irongate dam on the Mid-Klamath River. They did not identify *Anodonta* beyond genus. Historical mussel records are sorely lacking for this area; Davis and David found only nine historical freshwater mussel records (representing all three genera) from the Mid-Klamath, although interviews with Karuk tribal members living on the mid-Klamath revealed that freshwater mussels were a significant portion of their tribe's traditional diet and a valuable cultural resource until the mid 20th century (Davis 2008, David 2008). In the Xerces Freshwater Mussel Database (2010, created as part of this status review), which includes approximately 4,800 historical and more recent western freshwater mussel records, nine historical (pre-1985) records of *Anodonta* exist from the Klamath River.

In a survey of 26 sites of suitable habitat for *A. californiensis* in the Middle Fork American River drainage, no live specimens or shells of this species were found (Placer County Water Agency 2009).

Anodonta sp. are still known from approximately 20 rivers and lakes in northern California (Howard 2010, Xerces Freshwater Mussel Database 2010).

Idaho

The Idaho Conservation Data Center assigned *A. californiensis* a state rank of S2, or imperiled in the state of Idaho, and notes that its distribution has been reduced and its populations are declining (Idaho Conservation Data Center 2010). Historic and current records of *A. californiensis / A. nuttalliana* are primarily from the Snake River and its tributaries in the south and west of Idaho, although there are also historic records from the Spokane River in northern Idaho (Figure 4). Frest (1999) and Frest and Johannes (2000) state that *A. californiensis* is locally common in the Snake River and its major tributaries (Frest 1999, Frest and Johannes 2000). Although, in a recent survey for mollusks in reservoirs, tributaries and the main stem of the Snake River of Hells Canyon, researchers found only dead *A. californiensis* and shells of *A. californiensis* (Richards *et al*. 2005). In a survey of more than 500 sites in the Columbia Basin by Frest and Neitzel in 1993, only 3 of those sites had live or recently dead specimens of *A. californiensis* (Frest 1999).

Although numerous sites in Idaho have been surveyed for freshwater mussels, to the best of the authors' knowledge, there has not yet been a systematic effort to revisit historic sites to determine whether and to what extent *A. californiensis / A. nuttalliana* are still extant. Without that information, and with little information on historic abundance of these animals in Idaho, it is difficult to determine the status of *A. californiensis / A. nuttalliana* in Idaho. Sites identified as historic should be targeted for resurveys to determine whether, and to what extent, *A. californiensis / A. nuttalliana* may have been extirpated from water bodies in Idaho.

Nevada

The Nevada Natural Heritage Program assigns *A. californiensis* a state ranking of S1 or critically imperiled (NV NHP 2009, NatureServe 2010); *A. nuttalliana* has not been ranked in Nevada (NatureServe 2010). Frest (1999) suggested that *A. californiensis* is now probably extinct in parts of the Humboldt drainage in Nevada. Hovingh (2004) surveyed 67 river sites and 448 additional sites in the Lahontan Basin, primarily in Nevada, and found *A. californiensis* to be widely distributed in the Humboldt River drainage of northern Nevada. However, Hovingh reported that a 1912 study found that *A. californiensis* was abundant in the Humboldt River near Carlin, that it still occurred there in 1939, but was not found in that location in more recent surveys (reported in Hovingh 2004). Hovingh (2004) also stated that this species is "still widely distributed, but very scarce" in the intermountain region of the western U.S. Mock *et al.* (2010) found evidence of a genetic bottleneck in one population of *A. californiensis / A. nuttalliana* from the Walker River in the Lahontan Basin in western Nevada, suggesting that this population has undergone a significant decline.

Historic (pre-1985) records of *A. californiensis* exist primarily from the Humboldt River and its tributaries, and historic records of *A. nuttalliana* are primarily from Walker Lake and Pyramid Lake. More recent (post-1985) records of *A. californiensis* in Nevada are from the Humboldt River and its tributaries, the upper and lower Bruneau River and the South Fork of the Owyhee River (both tributaries of the Snake River), Walker River and the Carson River.

New Mexico

In New Mexico, *A. californiensis* has been found in Native American middens in numerous locations in the Gila River and the Mimbres River drainages, although live specimens have never been documented in this state. It is possible that the shells were transported from another location to the middens, and that *A. californiensis* never occurred in New Mexico. However, if the species did exist in New Mexico historically, it has almost certainly been extirpated from the state. (T. Myers, unpublished report 2005, pers. comm. with B. Lang 11 February 2009 and J. Sorenson 11 February 2009).

Oregon

Oregon ranks *A. californiensis* as S2 or Imperiled and *A. nuttalliana* as S1 or Critically Imperiled (Natureserve 2010).

Mock *et al*. (2010) found evidence of a recent genetic bottleneck in 8 of 24 populations of *A. californiensis / A. nuttalliana* sampled across its range, including one in the Upper Umatilla River of Oregon. In surveys of the Umatilla River and its tributaries, Brim Box *et al.* (2002-2003) found that only 7-8% of all sites surveyed had live *Anodonta* sp., and they concluded that freshwater mussels have been extirpated from much of the Umatilla River.

In a survey of more than 500 sites in the Columbia Basin by Frest and Neitzel in 1993, only three of those sites had live or recently dead specimens of *A. californiensis* (Frest 1999). Frest and Johannes (1995) did not find any *A. californiensis* specimens in surveys of the Willamette and lower Columbia Rivers from 1988-1990, and they suggest that this species has been heavily impacted by damming. However, *A. californiensis / A. nuttalliana* have been found recently in these areas, such as the Columbia River slough of Oregon (Figure 3, Xerces Freshwater Mussel Database 2010).

Hovingh (2004) conducted a comprehensive survey of numerous river and spring sites in the Great Basin, including sites in southeastern Oregon. He found *A. californiensis* in the Malheur and Warner Basins in Oregon, but noted that it is difficult to determine the conservation status of this species because it is both widely distributed and very scarce.

Although *A. californiensis / A. nuttalliana* has been recorded recently from numerous water bodies across Oregon, its conservation status in the state is unclear. In order to better understand the conservation status of *A. californiensis / A. nuttalliana* in Oregon, water bodies with only historical records (pre-1985) for *A. californiensis / A. nuttalliana* in Oregon should be revisited to determine if these animals are extant (see the Xerces Freshwater Mussel Database 2010 for specific historic site locality information).

Utah

A. californiensis is ranked as S1 or Critically Imperiled in Utah and *A. nuttalliana* is not ranked in Utah (NatureServe 2010). The State of Utah lists *A. californiensis* as a species of concern (Utah Department of Natural Resources 2007).

In 1999, Oliver and Bosworth wrote that *A. nuttalliana* had not been reported in Utah since 1940 and suggested that the species was rapidly declining in Utah, and possibly extirpated. *A. californiensis* has been observed recently in only six locations in the Bonneville Basin of Utah, including: Bear River, Redden Spring, Pruess Lake, Piute Reservoir, Otter Creek Reservoir, and Burriston Ponds (Mock *et al.* 2004). Hovingh (2004) reported that *A. californiensis* was widely distributed in the Bonneville Basin in Utah, yet the map that he included in his monograph shows only five extant locations and at least 15 historic localities. Mock *et al*. (2004) surveyed nine historic *Anodonta* localities in the Bonneville Basin, and did not find any live *Anodonta*. At some sites, they found only shells, suggesting that small populations may still exist there. *A. californiensis / A. nuttalliana* has likely been extirpated from at least six sites in Utah, including Utah Lake, which may have included the largest population in the state (Utah DNR 2007). In a study of *A. californiensis / A. nuttalliana* across its entire range, Mock *et al*. (2010) found evidence of a recent genetic bottleneck in eight out of twenty-four populations sampled, including one population in Redden Springs, Utah. Two populations in Utah – Bear River and Redden Springs – had such low genetic diversity that they may not be viable (Mock *et al.* 2004, Utah DNR 2007).

Washington

Washington ranks *A. californiensis* as S1 or Critically Imperiled, whereas *A. nuttalliana* has not been ranked by the state (NatureServe 2010). *A. californiensis* is a Washington state candidate species (WDFW 2009a).

In a survey of more than five hundred sites in the Columbia Basin by Frest and Neitzel in 1993, only three of those sites had live or recently dead specimens of *A. californiensis* (Frest 1999).

A. californiensis has been extirpated from three locations in the Little Spokane River. B. Lang observed a 'good population' of *A. californiensis* at Chattaroy Bridge in 1968, he observed them again in 1972, and found the population gone in 1992 and 2000. The same researcher observed a good population of *A. californiensis* at Spokane House on the Little Spokane River in 1973, and reports that they disappeared by 2000. At Pine River Park on the Little Spokane River, B. Lang again notes that *A. californiensis* was observed from 1967-1984, but a decline was noted in 1982 and "none [were] observed in several checks after 1984." (WDFW 2009b). The same researcher reported in 1998 a high ratio of intact dead *A. californiensis* to live *A. californiensis* in Curlew Lake, WA, and suggested that the lake is heavily impacted by eutrophication (Lang 1998).

A population of *A. californiensis* in the Lower Granite Reservoir was likely extirpated by a drawdown that occurred in 1991; mortality was documented during this drawdown (Frest & Johannes 1992).

Tom Burke noted a large population of *A. californiensis* at the mud flats below the mouth of the Colville River. However, since 1993/1994, he has noticed that there is abundant smartweed, and *A. kennerlyi* appears to have replaced *A. californiensis* (T. Burke, personal communication, 2/18/2009).

At one portion of the McNary Reservoir on the Columbia River near Richland, WA, in an aggregation area of 1560 m^2, 107 dead *Anodonta* sp. were observed, while only 16 live *Anodonta* sp. were observed. Because *Anodonta* were not identified beyond genus in this study, it is unknown whether these individuals belonged to the *A. californiensis / A. nuttalliana* clade or the *A. oregonensis / A. kennerlyi* clade. (Helmstetler and Cowles 2008).

In a recent study of *A. californiensis / A. nuttalliana* across its range, Mock *et al*. (2010) found evidence of a recent genetic bottleneck in eight out of twenty four populations sampled, including three populations in Washington: the Snake River, the Walla Walla River at its confluence with the Columbia River, and Wenas Creek.

Wyoming

Neither *A. californiensis* nor *A. nuttalliana* have been assigned a conservation status rank in Wyoming (NatureServe 2010).

Current and historical records exist of both *A. californiensis* and *A. nuttalliana* from the southwestern corner of the state – specifically the Woodruff Narrows Reservoir in Uinta county and the Bear River in Lincoln and Uinta counties (Xerces Freshwater Mussel Database 2010, pers. comm. with G. Edwards, April 2009). The status of *A. californiensis / A. nuttalliana* in Wyoming is unknown.

Canada

British Columbia

A. nuttalliana has been assigned a rank of S4 or Apparently Secure in British Columbia, whereas *A. californiensis* has not been ranked in the province (NatureServe 2010). The report *National General Status Assessment of Freshwater Mussels in Canada* (Metcalfe-Smith and Cudmore-Vokey 2004) states that *A. californiensis* is "clearly declining in abundance and distribution throughout its range" and *A. nuttalliana* is "probably eradicated over much of its original range." Both are ranked in the report as '3=sensitive' (on a scale where 0=extinct, 1=at risk, 2=may be at risk, 3=sensitive, and 4=secure).

Little information on population sizes or distribution is available for *A. californiensis / A. nuttalliana* in B.C., although scattered historical and more recent records exist primarily from lakes in the province (Xerces Freshwater Mussel Database 2010, Lee and Ackerman 1998).

Mexico

Chihuahua

It is currently unknown to what extent the range of *A. californiensis / A. nuttalliana* extends into Mexico. Preliminary genetic research indicates that *Anodonta* collected from Arizona and Chihuahua, Mexico are different than *Anodonta* collected further south in Jalisco, Mexico (Culver *et al.* 2007).

The conservation status of *A. californiensis / A. nuttalliana* in Chihuahua, Mexico is also unknown. *Anodonta* records from Mexico are not illustrated on the maps in Figures 3 and 4, and few records were collected by the authors of this review.

T. Myers (unpublished, 2005) noted that the apparent loss of perennial flows in some systems in the Guzman Basin of New Mexico and Chihuahua indicates that *A. californiensis* has likely been extirpated from that Basin. Fragments of *A. californiensis* valves were collected by J. Landye in 1971 from the Casas Grandes River near Zaragoza and Rio Sirupa, Chihuahua (specimens in the National Museum of Natural History). Specimens were collected in 1852 near Palotada, Chihuahua and labeled *A. dejecta* (Myers unpublished, 2005). It is unknown whether *A. dejecta* exists currently, is now extinct, or is the same as *A. californiensis / A. nuttalliana*. Historically, *A. dejecta* (and other western freshwater mussels) have been identified based on shell morphological characteristics; a method that is less than definitive for differentiating species of *Anodonta* in western North America. The type locality for *A. dejecta* no longer exists, so there are no unequivocal *A. dejecta* populations with which to compare specimens.

CONSERVATION NEEDS

Populations and genetically distinct units of *A. californiensis / A. nuttalliana* (see Mock *et al.* 2010) should be protected where they occur. A high priority should be placed on populations in the most vulnerable areas, such as Arizona, Utah, California and Nevada. Threats to water quality and quantity, explained above, should be addressed to minimize impacts to all native freshwater mussels, including *A. californiensis / A. nuttalliana.*

RESEARCH NEEDS

Additional research to understand the host fish associations and other life history and habitat requirements of *A. californiensis / A. nuttalliana* should be undertaken. That information should be evaluated with the recent molecular research of Chong *et al.* (2008) and Mock *et al.* (2010) to identify and name new species in the *A. californiensis / A. nuttalliana* clade. Historic sites across the entire range of *A. californiensis / A. nuttalliana* should be revisited to determine if these animals are still extant at those sites (similar to Howard 2010). Extant populations of *A. californiensis / A. nuttalliana* should be censused to provide abundance data and enable biologists to monitor population statuses over time.

RESOURCES

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Personal Communication
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ADDITIONAL RESOURCES

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