WHITE STURGEON
Acipenser transmontanus (Richardson)

Status: High Concern. Annual recruitment of white sturgeon in California appears to have decreased since the early 1980s but several strong year classes are evident. Continued close management is required to sustain white sturgeon populations into the future.

Description: White sturgeon adults have wide, rounded snouts, with four barbels in a row on the underside, closer to the tip of the snout than to the mouth (Moyle 2002). They feed with a toothless, highly protrusible mouth and process food with a palatal organ in the pharynx. Their bodies have 5 widely separated rows of bony plates (scutes). Scute counts per row are: 11-14 (dorsal row), 38-48 (two lateral rows) and 9-12 (bottom rows). Four to eight scutes are also found between the pelvic and anal fin. Although they lack the large scutes behind the dorsal and anal fins found in green sturgeon (*A. medirostris)*, small remnant scutes (fulcra) may be present. The dorsal fin has one spine followed by 44-48 rays. The anal fin has 28-31 rays. The first gill arch has 34-36 gill rakers. Body coloration is gray-brown on the dorsal surface above the lateral scutes, while the ventral surface is white and fins are gray. Their viscera are black. Dispersing juveniles tend to be darker than dispersing free embryos (Kynard and Parker 2005). Juveniles less than one year old have 42 dorsal fin rays, 35 lateral scutes, and 23 gill rakers on the first arch.

Taxonomic Relationships: Recent genetic analysis supports the close relationship between white sturgeon and Amur sturgeon (*A. schrenckii;* found only in Asia), which had a common ancestor approximately 45.8 million years ago (Peng et al. 2007, Krieger et al. 2008). In California, some genetic differentiation was thought to exist among white sturgeon populations from different river systems (Bartley et al. 1985) but a detailed genetic analysis using microsatellites failed to reveal any such population structure (Schreier et al. 2011). Recent DNA analysis using microsatellites has determined that genetic differentiation ($F_{ST} = 0.19$) is high enough among white sturgeon from the Columbia, Fraser and Sacramento River basins to be able to distinguish them (Rodzen et al. 2004), despite mixing in the ocean and high levels of genetic diversity (Schreier 2011). Schreier (2011) found that sturgeon captured in non-natal estuaries could be assigned by genetic techniques to their natal river, although the high level of genetic diversity found in the three major anadromous sturgeon populations indicates that some mixing of stocks takes place. Nevertheless, there is now sufficient evidence to treat the Sacramento-San Joaquin white sturgeon stock as a Distinct Population Segment (DPS).

Life History: White sturgeon primarily live in estuaries of large rivers but migrate to spawn in fresh water and often make long ocean movements between river systems. They commonly aggregate in deep, soft-bottomed areas of estuaries, where they move about in response to changes in salinity (Kohlhorst et al. 1991). In the lower Columbia River, white sturgeon make seasonal and diel movements (Parsley et al. 2008), moving upstream in the fall and downstream in the spring. They are most active at night, when they move into shallower waters to feed. Some individuals express site fidelity by returning to previously occupied sites (Parsley et al. 2008).

In the ocean, some individuals may migrate large distances. White sturgeon tagged in the San Francisco Estuary have been recaptured in the Columbia River estuary (L. Miller 1972a,b, Kohlhorst et al. 1991). One of these fish was then subsequently recaptured 1,000 km upstream in the Columbia River. Tagged individuals have routinely been detected 1,000 km from the tagging site (Chadwick 1959, Welch et al. 2006). Recently, one white sturgeon tagged in May, 2002, in the Klamath River, was tracked to the Fraser River, British Columbia, a distance far greater than 1000 km (Welch et al. 2006). Because this individual spent nearly equal amounts of time in both the Fraser and Klamath rivers, it was difficult to determine which was the natal river. However, genetic studies suggest that extensive movements are associated with feeding rather than spawning (Schrierer 2011).

In estuaries, white sturgeon move into intertidal areas during high tides to feed. Most prey are taken on or near the bottom. Young white sturgeon (~ 20 cm FL) prefer amphipods (*Corophium* spp.) and opossum shrimp (*Neomysis mercedis*) (Radtke 1966, Muir et al. 1988, McCabe et al. 1993). Diet becomes more varied as they grow but continues to be dominated by benthic invertebrates such as shrimp, crabs, and clams. Today, most benthic invertebrate prey species in the San Francisco Estuary are nonnative, demonstrating the opportunistic feeding nature of white sturgeon (Moyle 2002). One heavily used prey is the overbite clam, *Corbula amurensis*, which became very abundant after its invasion into Suisun Bay in the 1980s. However, foraging on the overbite clam may inhibit growth, because some clams pass through the gastrointestinal tract without being digested, possibly decreasing nutritional intake (Kogut 2008). Fish, especially herring, anchovy, striped bass, starry flounder, and smelt, are consumed by larger sturgeon. In the San Francisco Estuary, white sturgeon feed on Pacific herring eggs (McKechnie and Fenner 1971), much as their Columbia River counterparts do on eulachon eggs (McCabe et al. 1993). In California, stomach contents of large individuals have also included onions, wheat, Pacific lamprey, crayfish, frogs, salmon, trout, striped bass, carp, pikeminnow, suckers and, in one instance, a cat (Carlander 1969).

In the San Francisco Estuary, young sturgeon reach 18-30 cm by the end of their first year (Kohlhorst et al. 1991). Maximum growth is achieved by juvenile white sturgeon grown in captivity on artificial diets, consuming 1.5 to 2% of their body weight each day at 18°C (Hung et al. 1989). As white sturgeon age, growth rates slow so that they reach 102 cm TL by their seventh or eight year. They may ultimately reach 6 m FL. The largest white sturgeon on record weighed 630 kg and was likely more than 100 years old; fish of this size were probably the largest freshwater fish in North America (Moyle 2002). The largest white sturgeon caught in Oregon measured 3.2 m FL and was 82 years old (Carlander 1969). In California, the largest white sturgeon on record was from Shasta Reservoir in 1963; it was 2.9 m TL, 225 kg, and at least 67 years old (T. Healy, CDFW, pers. comm. 2001). Today, in California, white sturgeon larger than 2 m and older than 27 years are uncommon.

Male white sturgeon mature when10-12 years old (75-105 cm FL); females mature later at about 12-16 years old (95-135 cm FL) (Kohlhorst et al. 1991, Chapman et al. 1996). However, males mature at 3-4 years and females at 5 years while in captivity (Wang 1986). Photoperiod and temperature regulate maturation in adult white sturgeon (Doroshov and Moberg 1997). Prior to spawning, adults may move into the lower reaches of rivers during the winter months and later migrate upstream into spawning areas in response to increases in flow (Schaffter 1997a,b). Spawning initiates in response to high flows from late February to early June (McCabe and Tracy

1994). Only a small percentage of adults will spawn in any given year. In the Columbia River, males spawn every 1-2 years while females spawn every 3-5 years (McCabe and Tracy 1994).

Spawning in the Sacramento River occurs primarily between Knights Landing (233 rkm) and Colusa (372 rkm) (Schaffter 1997a,b). A few adults spawn in the Feather and San Joaquin rivers (Kohlhorst 1976, Kohlhorst et al. 1991), although recent activity in the Feather River is unconfirmed (A. Schierer, pers. comm. 2010). Genetic evidence suggests that there is little fidelity to spawning areas within the Sacramento River system (Schierer 2011). The fecundity of females from the Sacramento River averages 5,648 eggs/kilogram body weight, so an individual female (1.5 m TL) may contain 200,000 eggs (Chapman et al. 1996). White sturgeon typically spawn in deep water over gravel substrates or in rocky pools with swift currents. Eggs have been collected from the stream bed at depths of 10 m (Wang 1986). In the Columbia River, white sturgeon spawn over cobble and boulder at depths of 3-23 m and velocities of 0.6-2.4 m/sec (McCabe and Tracy 1994). Adults migrate back to the estuary after spawning.

Eggs (3.5-4.0 mm; in Billard and Lecointre 2001) become adhesive upon fertilization, allowing them to stick to stream substrates. Time to hatch is dependent on temperature but larvae generally hatch in 4-12 days (Wang 1986). Larvae are 11 mm at hatch and swim vertically while drifting towards the estuary. They switch to swimming horizontally and feed from the bottom once the yolk sac is absorbed, in about 7-10 days. Sacramento River white sturgeon larvae were found to be photonegative upon hatching, moving downstream short distances by swimming near the bottom, seeking cover (Kynard and Parker 2005). Larvae aggregated, swam, and foraged near the bottom and demonstrated an increasing trend to swim above the bottom. Strong dispersal occurred as early juveniles swam actively downstream. Consequently, Sacramento River white sturgeon are described as having a “two-step downstream dispersal” completed by larvae and early juveniles during both day and night, but peaking at night. Juvenile sturgeon use the less saline portions of estuaries, suggesting that the ability to osmoregulate increases with age and size (McEnroe and Cech 1987). Osmoregulation efficacy may also be size-dependent, even between individuals of the same age (Amiri et al. 2009). Consequently, size at time of estuary entry may be a limiting factor for juvenile survival. In the lower Fraser River, most juvenile white sturgeon use sloughs from June to August (Bennett et al. 2005); occupied sloughs were more than 5 m deep, turbid, and had multidirectional currents, soft sediments, and readily available prey (mysid shrimp, dipteran larvae, fish).

In the San Francisco Estuary, the white sturgeon population is dominated by a few strong year classes, reflecting variability of annual spawning success. Strong year classes result from years of high spring flows in the rivers (Kohlhorst et al. 1991, Schaffter and Kohlhorst 1999, Fish 2010). High spring flows may quickly move larval sturgeon downstream into suitable rearing areas (Stevens and Miller 1970) or induce more sturgeon adults to spawn (Kohlhorst et al. 1991). In the lower Columbia River, year class strength is correlated to the size and availability of prey at the onset of exogenous feeding (Muir et al. 2000). Amphipods (Corophiidae), copepods, and dipteran larvae and pupae are important prey to larval and young-of-year sturgeon. Predation on larvae, especially by prickly sculpin, may be another factor limiting recruitment in some areas (Gadomski and Parsley 2005, Gadomski and Parsley 2005b).

Habitat Requirements: White sturgeon adults respond to increases in flow to initiate spawning from late February to early June. Spawning takes place at temperatures ranging from 8 to 19°C, peaking at temperatures around 14°C (McCabe and Tracy 1994). Successful incubation requires stream substrates with minimum amounts of sand and silt because excessive siltation can smother embryos. Recruitment failure in the Nechako River, Canada, was attributed to siltation of main channel sediments after large scale (1,000,000 m^3) introduction of fine sediments by upstream stream avulsion (McAdam et al. 2005). The recruitment failure was attributed to egg suffocation and increased predation because larvae lacked interstitial spaces in the substrate in which to hide. Newly hatched embryos preferred substrates from 12 to 22 mm in laboratory tests (Bennett et al. 2007).

The first few months of life are considered to be critical for sustaining populations (Coutant 2004). Successful recruitment also appears to be associated with complex habitats, flooded riparian vegetation (floodplain habitat) and rocky substrates (Coutant 2004). Lack of cover in edge habitats downstream of spawning areas, along with low flows from the time of spawning until juvenile outmigration, decreases recruitment. Productive spawning areas in the Sacramento River are associated with areas where levees are set back, allowing access to floodplains and backwater habitats (e.g., Wilkins and Butte sloughs) during high spring flows.

Distribution: White sturgeon can be found in salt water from the Gulf of Alaska south to Ensenada, Mexico. However, spawning only occurs in a few large rivers from the Sacramento-San Joaquin system northward. Self-sustaining spawning populations are currently only known in the Fraser (British Columbia), Columbia (Washington), and Sacramento (California) rivers. Landlocked populations also occur above major dams in the Columbia River (McCabe and Tracy 1994). White sturgeon from California are caught in small numbers in the Columbia River and other estuaries (Schierer 2011). At least one white sturgeon tagged in the Klamath River spent extensive time in the Fraser River (Welch et al. 2006).

In California, white sturgeon spawn primarily in the Sacramento River (to Keswick Dam) but may also spawn in the San Joaquin River (Jackson and Van Eenennaam 2013) and in the Feather River (to Oroville Dam facilities), when water quality and flow conditions are favorable (Schaffter 1997a,b). The lower Pit River was likely an important spawning area, prior to construction of Shasta Dam in the 1940s (T. Healey, CDFW, pers. comm. 2001). Sturgeon became trapped behind Shasta Dam, establishing a landlocked population that became self-sustaining and supported a small fishery (Moyle 2002). However, subsequent dam construction on the Pit River blocked access to spawning areas and prevented ongoing reproduction of this population (T. Healey, CDFW, pers. comm. 2001). Long-lived individuals and fish from stocking attempts in the 1980s are still occasionally caught in Shasta Reservoir. Historically, small runs also occurred in the Russian, Klamath and Trinity rivers. White sturgeon have also been documented in the Eel River (M. Gilroy, CDFW, pers. comm. 2011). It is doubtful that any of these latter four rivers currently support populations of white sturgeon.

Aquaculture facilities now cultivate white sturgeon in California and juvenile sturgeon can be sold to aquarists. Presumably, aquarium releases have resulted in occasional white sturgeon being found in reservoirs in southern California (C. Swift, pers. comm. 1999) and the San Francisco region (e.g., a 21 kg individual caught in Lafayette Reservoir, Contra Costa County).

Trends in Abundance: The California Department of Fish and Wildlife has been monitoring trends in white sturgeon abundance for decades and information on trends for nearly 80 years is available. From that body of work, it is clear that large variations in recruitment, frequently including 5 or more consecutive years of low or no recruitment, have been routine since the 1930s and the proximate cause for this variation is low flows during winter and/or spring. Managing the population through predictable ebbs in abundance is the key to conservation of white sturgeon and protection of its fishery.

The CDFW's index of annual white sturgeon recruitment from age-0 and age-1 fish suggests that peak recruitment has decreased trend-wise since the early 1980s, recruitment in most years is a small fraction of peak recruitment, and the most recent notably-high recruitment was in 2006 (Figure 1). This trend is completely plausible and expected from the relationship between hydrology and recruitment, but the slope of the trend may be biased toward decline due to release of fingerlings by hatcheries from 1980-1988.

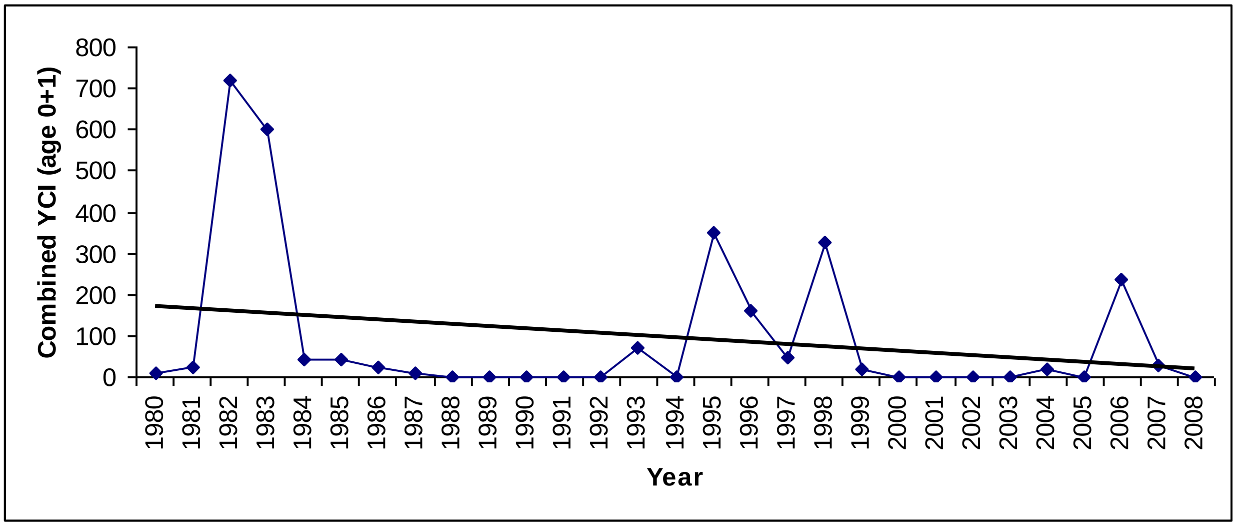

Figure 1. White sturgeon year class indices (age-0 and age-1 combined), San Francisco Bay, 1980-2012.

Trends since 1980 in the abundance of subadult and adult white sturgeon are as expected from variations in river hydrology and indices of recruitment, though abundance estimates are generally imprecise and sometimes lack confidence intervals. Interpretation of catch-per-unit-effort (CPUE) data from the fishery is confounded somewhat due to changes in regulations regarding size limits, daily bag limits, and annual bag limits. Length frequency distributions are a particularly important component when interpreting trends in abundance.

Estimated annual abundance of white sturgeon >= 102 cm Total Length (TL) has ranged from approximately 2,500-300,000 since 1980 (DuBois et al. 2011); the best estimates ranged from approximately 75,000-150,000 fish. The most recent and rigorous estimates are for fish 117-168 cm TL from the period 2007-2011, and those ranged from approximately 30,000-56,000 fish (DuBois and Gingras 2011). Extreme CPUE values should be discounted because they likely indicate unusual distributions of fish rather than rapid changes in the population's abundance. Using standardized fish capture and tagging techniques as part of a CDFW mark-recapture study, annual CPUE of white sturgeon 117-168 cm TL has varied from approximately

1-13 fish/100 net-fathom hours since 1980 and was less than 2 fish/100 net-fathom hours during the period 2005-2012 (DuBois and Gringas 2013).

Nearly all historical fishery-dependent data comes from Commercial Passenger Fishing Vessel (CPFV, a.k.a. party boat) logbooks. Annual white sturgeon CPUE in that fishery has varied between approximately 2-4 fish/100 hours of fishing effort since 1980 (DuBois and Gringas 2013). However, length data are not collected by the CPFV fleet and, since 1980, the size limit (TL) on white sturgeon changed from >=102 cm to 107-183 cm, 112-183 cm, 117-183 cm, and 117-168 cm in subsequent years, so it is only possible to describe coarse changes in white sturgeon demographics using CPFV data.

Annual length frequency distributions from CDFW's mark-recapture study and a pilot study using longlines clearly show the recruitment, growth, and subsequent decrease in abundance of strong year classes (Schaffter and Kohlhorst 1999, DuBois et al. 2011, DuBois and Gringas. 2013), as do length frequency distributions from CDFW Sturgeon Fishing Report Card data (CDFW Sturgeon Fishing Report Card reports, DuBois et al. 2011). Report cards have been in use since 2007. Because anglers commonly volunteer data on the lengths of fish too small to keep, the cards are helping bridge the long-standing gap in information on fish aged 2-8.

Trends of year-class indices (YCI), based on the number of age-0 and age-1 juveniles, suggest recruitment has decreased significantly, with low recruitment for 12 of the 29 years (1980-2008) on record (Figure 1). Although the present white sturgeon population appears to have been reduced over the last 30 years, some recent population trends are encouraging and stakeholder concerns about the white sturgeon population and fishery in California have resulted in highly restrictive angling regulations, new monitoring and research efforts, strong anti-poaching measures, and fish passage and habitat restoration efforts.

Nature and Degree of Threats: All sturgeon species worldwide are in serious decline and some are on the verge of extinction. Principal threats to sturgeon worldwide are similar to those in California (Table 1) and include: harvest (especially poaching), dam-related flow alteration and reduction, habitat degradation, and pollution (Billard and Lecointre 2001).

Major dams. Dams block access to important upstream spawning habitats and alter flows, which results in reduced habitat quantity and quality for early life stages (Coutant 2004). The major 'rim dams' in California largely lack fish passage facilities, so sturgeon are confined to downstream areas. In the Sacramento River, years of high spring outflow have been associated with strong year classes. The large dams on nearly all Central Valley rivers reduce the frequency, volume, and duration of these flows, reducing the frequency of successful sturgeon year classes (Moyle 2002). Dam operations can attenuate winter and spring flows required for the initiation of spawning and outmigration. Changes in the hydrograph can disconnect main channel habitats from floodplains, which may be especially important rearing habitats. Changes in sediment budgets and flow regime can decrease the quality and quantity of spawning and incubation habitats. For example, dam-attenuated winter flows can limit the amount of cover available in interstitial spaces in rocky substrates because the substrates are scoured less frequently. Changes to hydrographs can influence juvenile movements and predation rates. Lower turbidity levels and simplified channels as result of dam construction/impoundment may result in increased main channel predation of juveniles (Gadomski and Parsley 2005b). Lack of suitable habitats below dams may limit recruitment or lead to recruitment failure (Kynard and

Parker 2005).

Agriculture. Levees and land reclamation along rivers and estuaries have substantially eliminated large areas of floodplain habitats and their connectivity to main river channels, reducing access to important juvenile rearing areas. These historically abundant habitats once offered protection for sturgeon and many other native fishes from high flows, provided foraging habitats, and served as holding areas during migration. Diversion of water for agriculture can also reduce flows to the extent that sturgeon populations can no longer be supported in some areas (Moyle 2002). White sturgeon are particularly sensitive to agricultural pollutants. They readily bioaccumulate toxins from fertilizers and pesticides, which can cause deformities, decrease growth, and reduce reproductive potential. In the Columbia River, the incidence of physical deformities, such as misshapen fins, abnormal (short or forked) barbels and malformed or missing eyes increased with age, suggesting that they were a result of continued exposure to sediments contaminated with organic pollutants (Burner and Rien 2002). Exposure to organochlorine pesticides caused an overall decrease in the condition factor of juveniles, as well as decreasing the concentrations of sex hormones (testosterone and estradiol) in white sturgeon blood plasma (Gundersen et al. 2008). Electrophilic pesticides that can bond to DNA and other cellular macromolecules are common in the Sacramento River (Donham et al. 2006). Concentrations of mercury in white sturgeon livers also increased with age, suggesting that white sturgeon are prone to the bioaccumulation of heavy metals (Webb et al. 2006). Liver mercury content is negatively correlated with relative weight and gonadosomatic index. Consequently, exposure to mercury likely negatively affects white sturgeon reproductive potential and the potential for long-term mercury exposure in the Sacramento River basin is high.

Selenium entering the San Francisco Estuary from agricultural drainage (Presser and Luoma 2006) can decrease juvenile survival. Juveniles fed diets with high concentrations (> 41.7 ug Se/g) of selenium decreased swimming activity and grew less than other groups (Tashjian et al. 2006). Selenium accumulates in the kidney, muscle, liver, gill, and plasma tissues of these fish, contributing to decreased survival, particularly when exposed to brackish water (> 15 ppt) (Tashjian et al. 2007). Contaminated fish also had less energy reserves (whole body protein, lipids), perhaps limiting foraging activity and escape from predation. Although current regulatory thresholds for selenium toxicity (10-20 ug Se/g) may protect white sturgeon from adverse impacts, the concentration of selenium by the alien overbite clam, a major prey of sturgeon, may be resulting in increased levels in sturgeon as well.

Fertilizers entering the estuary cause algal blooms which may harm sturgeon both through release of toxins (*Microcystis*) and through depleting oxygen and increasing CO_2 in backwaters. Hypercapnia (elevated levels of CO_2) can cause mortality or morbidity in juvenile white sturgeon because energy normally used for growth, disease resistance and lipid storage is redirected toward maintaining homeostasis (Cech and Crocker 2002, Crocker and Cech 2002).

	Rating	Explanation
Major dams	High	All rivers occupied in CA are dammed, blocking access to spawning habitats and altering flows and habitat suitability
Agriculture	High	Water demands result in decreased flows in rivers during critical life history periods; pollution from agricultural return waters may acutely affect sturgeon
Grazing	Low	Effects mostly upstream of reaches occupied by sturgeon
Rural residential	Low	Rural residences occur along white sturgeon streams (e.g., Klamath River) but the effects from rural development are likely minor
Urbanization	High	Urban water demand, runoff and pollution inputs can create toxic environments; habitat alteration and simplification are severe in urban areas; multiple large urban areas within existing range
Instream mining	Low	Effects unknown but present in some coastal streams
Mining	Medium	Most toxic runoff is above dams, although Iron Mountain mine poses a major threat if controls of tailings and effluent fail
Transportation	Low	Roads, railroads, shipping lines and associated bridges and channelization modify rivers occupied by white sturgeon
Logging	Low	Impacts from sedimentation, etc. may affect rivers other than Sacramento River (e.g., Klamath River) but not likely to affect reproduction
Estuary alteration	High	California estuaries are severely altered; San Francisco Estuary and Delta habitats substantially altered and degraded from past
Recreation	Low	Boating and other activities can disturb sturgeon spawning and foraging; white sturgeon fatalities from vessel strikes are not uncommon
Fire	Low	Erosion from burned areas can increase fine sediment delivery to streams, but most impacts occur above major dams
Harvest	Medium	Legal and illegal harvest cause adult mortality, although legal harvest is now typically less than 10% of harvestable fish; illegal harvest for caviar and meat is a much greater threat
Hatcheries	Low	Aquaculture facilities exist for white sturgeon, but fish have not been released into the wild since approximately 1988
Alien species	Low	Alien species present throughout range; impacts largely unknown

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of populations of white sturgeon in California. Factors were rated on a five-level ordinal scale where a factor rated “critical” could push a species to extinction in 3 generations or 10 years, whichever is less; a factor rated “high” could push the species to extinction in 10 generations or 50 years whichever is less; a factor rated “medium” is unlikely to drive a species to extinction by itself but contributes to increased extinction risk; a factor rated “low” may reduce populations but extinction is unlikely as a result. A factor rated “n/a” has no known negative impact. Certainty of these judgments is moderate. See methods section for descriptions of the factors and explanation of the rating protocol.

Urbanization. The impacts from urbanization on white sturgeon are similar to those from agriculture, although perhaps not quite as widespread. Pollutants from sewage treatment plants, storm drains, and surface runoff have the potential to negatively affect sturgeon, as does often severe habitat simplification associated with urban development along river and stream corridors.

Mining. Iron Mountain Mine, an abandoned heavy metal mine above Keswick Reservoir (below Shasta Dam) on the Sacramento River, is an EPA Superfund site. While extensive measures have been taken to reduce the potential for toxic spills from the site, the impacts of a spill would be severe enough that even a low probability of failure rates concern. If the earthen retaining dam designed to impound mine effluents fails, an acidic slurry of toxic heavy metals could spill into the river, potentially resulting in massive fish kills; white sturgeon would likely be especially vulnerable to both acute (short-term) and subacute (long-term) exposure to these toxins, given their benthic foraging behavior and long life spans.

Logging. In the Sacramento River watershed, sturgeon are isolated from the effects of logging in headwaters by major dams, which minimizes their exposure to sedimentation and increased temperatures. However, white sturgeon may be negatively affected by logging in the Klamath and other river basins within their range. Introduced fine sediments (silt, sand, fine gravel) can fill substrate interstitial spaces and cause recruitment failure (McAdam et al. 2005). Laboratory experiments using Kootenai River white sturgeon found that fine sediment (5 mm) covering embryos resulted in 0-50% survival, delayed hatching and decreased larval length (Kock et al. 2006). Exposure of juvenile (3-78 days old) white sturgeon to didecyldimethylammonium chloride (DDAC), a highly soluble pesticide commonly used to protect lumber in Canada, resulted in mortality and sublethal effects (Teh et al. 2003). Didecyldimethylammonium chloride exposure resulted in 50% mortality of 78 day-old juveniles, the most resistant age group, within 18 and 36 hours of exposure. Sublethal effects to all age groups included decreased growth (weight and length) and decreased swimming activity. Juveniles that expressed sublethal effects had not recovered 21 days after exposure, perhaps increasing susceptibility to predation and disease and decreasing the probability of reaching sexual maturity. Although of particular concern in the Fraser River, Canada, DDAC may also impact sturgeon that migrate between rivers in California and Canada.

Estuary alteration. White sturgeon in California spend much of their life cycle in the heavily altered San Francisco Estuary or other smaller estuaries. The Delta's levees and rip-rapped channels restrict foraging habitat for sturgeon. At times, much of the freshwater inflow to the Delta is diverted into the pumps of the south Delta, altering or reducing river flow and entraining small sturgeon. Suisun Bay, Suisun Marsh and San Pablo Bay are primary rearing areas and are also subject to altered flows, contamination from many toxic compounds, invasions of alien species, and reduced water quality from urban runoff and effluent. Given the altered condition of the estuary and the fact that it is continuing to rapidly change, it is remarkable that white sturgeon have persisted in even moderately large populations (see Lund et al. 2007, 2008, Moyle 2008).

Harvest. White sturgeon populations were substantially reduced by commercial fishing in the San Francisco Estuary in the 19th century; consequently, commercial harvest has been prohibited since the mid-1900s (Moyle 2002). The sport fishery has become increasingly restrictive over time but, unlike in Oregon and Washington, California has not adopted a harvest quota.

White sturgeon fishing is currently closed in the north coast district (Humboldt, Del Norte, Trinity, Siskiyou counties), reaches of the Sacramento River in the Sierra and Valley districts (Shasta, Tehama, Glenn counties), in parts of San Francisco Bay, and at low-head dams (weirs) controlling flow into bypasses of the Sacramento River. The Sacramento River closure was implemented in 2009, closures at weirs were implemented in 2013, and other closures have been in effect for decades. Sport fishing regulations, established in 2007, allow individual anglers to harvest one fish per day and up to a total of three fish per year, whereas previous regulations did not limit the annual harvest. Also, in 2007, the size limit was changed from 46-72" TL to 46-66" TL. The size limits implemented are considered protective, yet were a compromise that still allows for potential harvest of female fish that have not yet spawned for the first time. In addition, Sturgeon Fishing Report Cards are required for all sturgeon anglers and are to be returned to the California Department of Fish and Wildlife upon completion; all harvested white sturgeon must be tagged. The Sturgeon Fishing Report Card and associated tags are the mechanisms whereby the daily and annual bag limits are enforced (see Management Recommendations section).

In anticipation of higher numbers of white sturgeon released in association with more restrictive angling regulations, several additional measures were taken in 2013 to improve the survival rates of fish that anglers are required to, or voluntarily, release. These protective regulations include: (a) only one single-point, single shank, barbless hook may be used on a line when taking white sturgeon, (b) snares may not be used to assist with landing a white sturgeon, (c) description of length limits in terms of fork length rather than total length, and (d) white sturgeon greater than 173 cm (68 in.) fork length may not be removed from the water and must be released immediately.

In general, harvest rates of fish 117-168 cm TL (e.g., the legally-harvestable size as of March, 2007, and a subset of all prior legal sizes) during 2000-2008 were lower than rates during the 1980s (DuBois et al. 2011) and the overall harvest rate trend is decreasing (M. Gingras, CDFW, pers. comm. 2013). Harvest rates have ranged from approximately 2-9%, but are likely biased low.

Illegal commercialization (poaching) of white sturgeon is common because of the high value of their caviar. As a consequence, the CDFW makes enforcement of sturgeon fishing regulations a high priority and, in 2007, a law was enacted that facilitated easier enforcement against those participating in illegal commercialization and drastically increased the severity of financial penalties associated with these activities.

White sturgeon contribute to a small Native American fishery in the Klamath River but only 186 juvenile and adult white sturgeon were caught by the Klamath River fishery from 1980 to 2002, about eight fish per year (Welch et al. 2006). Sacramento River white sturgeon may also be caught in fisheries in the Columbia River region but the potential effects on California populations are not known.

Hatcheries. In response to wide fluctuations in white sturgeon abundance and intermittent decreased catch rates over time in the sport fishery, outplanting of hatchery sturgeon stocks to augment natural populations has, although the subject of much debate, been proposed. White sturgeon have been raised in California aquaculture facilities for meat and caviar since 1980 and juvenile white sturgeon from those facilities were outplanted from 1980-1988; however, no hatchery stocks have been released into the wild since that time. The contribution of outplanted fish was not evaluated and records are sparse; nonetheless, it is estimated that a total of approximately 500,000 fry and fingerlings were released during the 1980s.

Hybridization of wild and hatchery stocks may have detrimental effects on the population structure of wild stocks, as studies of salmon populations have demonstrated (see Chinook salmon accounts in this report). Hatcheries may also facilitate the spread of disease such as iridovirus. Iridovirus infection of white sturgeon reduces the growth and survival of fry and fingerlings (Raverty et al. 2003).

Alien species. Alien fishes are abundant in the estuaries and rivers that white sturgeon inhabit. Alien fishes can reduce white sturgeon survival through predation on juveniles (Gadomski and Parsley 2005c), although this has not been demonstrated to be a problem in California. In the San Francisco Estuary, white sturgeon feed heavily on the overbite clam, which invaded in the 1980s. This clam (and other alien clams on which sturgeon feed) concentrate selenium and other heavy metals, which bioaccumulate in sturgeon and have the potential to negatively affect reproductive success.

Effects of Climate Change: Increases in water temperatures associated with climate change may decrease white sturgeon reproductive success. Successful spawning appears to be linked to cool water temperatures (< 18°C) and high spring flows. Females holding in 18-20°C water had inhibited ovulation and oocyte development (Webb et al. 1999, Linares-Casenave et al. 2002). Although based on laboratory results, these findings indicate that the pre-spawning temperature regime is important for normal ovarian development and should be considered in management of wild stocks. Bioenergetic modeling of white sturgeon in the Snake River also demonstrated that small increases in maximum water temperatures (19 to 24 °C) decreased growth and reproduction (spawning frequency, fecundity) because of decreases in caloric assimilation resultant from increases in energy costs (Bevelhimer 2002). Increased water temperatures may also hasten developmental times, perhaps resulting in a mismatch between the onsets of exogenous feeding and prey availability. Prey availability at onset of exogenous feeding was determined to be important in determining year class strength (Muir et al. 2000). Increased water temperatures may also make white sturgeon more susceptibility to disease. White sturgeon iridovirus is thought to be present in rivers throughout their range, and has been verified to occur in the anadromous waters of California’s Central Valley (M. Gingras, CDFW, pers. comm. 2013). The virus is a slow wasting disease that primarily affects growth in fry and fingerlings by infecting the top layers of the skin, including the gills, barbels and nares (Drennan et al. 2007). Stressful conditions associated with poor water quality can induce the virus. Consequently, increased temperatures predicted from climate change models, in combination with pollution, may make young sturgeon more susceptible to the virus.

Climate change models predict seasonal shifts in precipitation, as well as increased frequency of floods and drought. Higher or more flashy winter flows may flush juvenile white sturgeon into estuarine areas before they are capable of adjusting to saline environments. The ability to osmoregulate is likely size dependent (Amiri et al. 2009), so younger and smaller juvenile sturgeon may be at risk, especially if floodplain and edge-habitat refuges are lacking, as is the case in much of the lower Sacramento River system. Coupled with predicted increases in estuary salinity levels due to sea level rise, earlier entry of juveniles into estuarine habitats may limit juvenile survival. In contrast, lower summer flows, exacerbated by increasing water demands, may decrease spawning and outmigration success.

Status Determination Score = 2.3 - High Concern (see Methods section Table 2). Despite a relatively robust population that presently includes tens of thousands of sub-adults and adults, white sturgeon must be managed carefully due to already demonstrated population cycles that may be exacerbated in the future by climate change, increasing human water demand, further degradation of habitats, overharvest, or some combination thereof. Management of white sturgeon is complicated by the combination of exposure to pollutants, freshwater and estuarine habitat alteration (particularly in the San Francisco Estuary), harvest, and because its long life span can mask the detection of poor reproductive success. NatureServe ranks white sturgeon as Globally secure (G4) but Imperiled (S2) in California due to anthropogenic impacts on their habitats. The American Fisheries Society considers the species to be Endangered (Jelks et al. 2008). Several populations in California are also considered "conservation dependent" (Musick et al. 2000).

Metric	Score	Justification
Area occupied	1	The only self-sustaining population in California appears to be in the Sacramento River
Estimated adult abundance	3	Based upon 2000-2009 estimates of age-15 fish and other demographic data
Intervention dependence	3	The population and fishery need to be monitored and managed closely, flows regulated, and pollution inputs and poaching reduced
Tolerance	2	Juvenile white sturgeon are intolerant of poor water quality, including high temperatures
Genetic risk	4	High genetic diversity
Climate change	2	Very sensitive to temperature increases, degraded water quality and flow changes predicted by climate change models
Anthropogenic threats	1	The combination of illegal harvest, pollution, and habitat alteration continue to threaten white sturgeon in the wild (see Table 1)
Average	2.3	16/7
Certainty (1-4)	4	

Table 2. Metrics for determining the status of white sturgeon, where 1 is a major negative factor contributing to status, 5 is a factor with no or positive effects on status, and 2-4 are intermediate values. See methods section for further explanation.

Management Recommendations: White sturgeon in the Sacramento River and the San Francisco Estuary have been regarded as well managed since the 1950s because they have sustained a fairly large fishery (Moyle 2002), though not as well managed as white sturgeon in Oregon and Washington. Unfortunately, increasing pollution, water diversion, habitat degradation, impacts from climate change, and poaching may limit recovery or contribute to further decline. The following are management recommendations to afford greater protection for white sturgeon in California:

Harvest management. Harvest regulations for white sturgeon have become increasingly restrictive, with severe limits placed on sport harvest in 2006 and, again, in 2009. However, California lags behind Oregon and Washington in regards to adaptive management of sturgeon harvest and has no white sturgeon management policy or plan.

Productivity of white sturgeon in California is lower than in Oregon and Washington, yet the white sturgeon fishery is very culturally and economically important; therefore, it is imperative to apply adaptive management to the recreational fishery and tight controls over harvest, both legal and illegal. The decline and subsequent listing of the southern green sturgeon DPS in California as threatened under the federal ESA may be indicative that white sturgeon are on the same trajectory and signals a need for greater conservation measures, monitoring, law enforcement and related resources to prevent further declines.

As a top priority, the California Fish and Game Commission should implement an annual quota on harvest of white sturgeon and should assure the continued availability of pertinent white sturgeon demographic and fishery statistics, implementation of a study on the effects of poaching, and the development of a white sturgeon management plan.

As noted, regulations established in 2007 require that sturgeon anglers record all fishing activity on Sturgeon Fishing Report Cards to be returned to the CDFW upon completion and that anglers tag all white sturgeon harvested. Data from Sturgeon Fishing Report Cards provide a much better description of the fishery than was available previously and complement the CDFW's on-going mark-recapture study. Prior to use of Sturgeon Fishing Report Cards, annual harvest could only be coarsely estimated from imprecise abundance estimates and annual harvest rate estimates. Data gathered from 2007-2012 Sturgeon Fishing Report Cards indicate that annual harvest was 1424-2048 fish and anglers released 4171-5802 fish. Accuracy of Sturgeon Fishing Report Card data is the subject of on-going investigation, but the trends and year-over-year numbers are generally consistent and reasonable.

Information on fishing effort for white sturgeon is incomplete and suggests a mixed picture. The only trend data available are from the CPFV fishery, where fishing effort from CPFVs that landed white sturgeon has declined trend-wise from a peak of nearly 25,000 hours in 1986 to a record low of barely 3,000 hours in 2012. Estimated annual fishing effort during daylight (i.e., biased low), in the Sacramento River watershed to Carquinez Strait, ranged from approximately 110,000-320,000 hours during 2006-2009.

Information on the number of sturgeon anglers in California is incomplete, but the number of issued Sturgeon Fishing Report Cards shows that interest in the recreational fishery is substantial. An annual average of roughly 55,000 Sturgeon Fishing Report Cards were issued for free, when issued by hand, an annual average of roughly 112,000 were issued for free, when issued by an automated system, and approximately 55,000 were issued 6 months into the first year they were sold ($7.50 plus up to 8% in fees), utilizing an automated system. One incongruity in the recent management of white sturgeon is that there are far fewer legal-sized white sturgeon than are authorized for harvest through issuance of Sturgeon Fishing Report Cards. In general, Sturgeon Fishing Report Cards provide valuable data and insights into the fishery and should be continued to be issued and their data analyzed into the future.

Illegal commercialization of white sturgeon remains a significant concern, given the high value of individual fish and the relative ease with which the largest and most fecund females are targeted. More intensive efforts are needed to identify, arrest and convict poachers and the dealers who buy illegal caviar and legislative action should be taken to increase the numbers of CDFW Wildlife Officers and ensure a dedicated number are assigned to white sturgeon-related enforcement throughout their range in the state.

Reducing pollution (especially from agriculture). White sturgeon are very sensitive to many pollutants (heavy metals, selenium, organic pollutants, pesticides), even when the pollutants are at low concentrations, in part because sturgeon are long-lived and bioaccumulate toxins over long periods of time in their bodies as well as in their eggs (passing them on to sensitive larvae). Improved monitoring and treatment of non-point source pollution is necessary to minimize impacts on white sturgeon. Restoration of tidal wetlands and floodplain habitats would likely enhance detoxification of water draining from agricultural fields and sewage.

Heavy metals, especially selenium, are of particular concern because of their effects on reproduction. Thus, both point and non-point sources of polluted effluents into Central Valley rivers and the San Francisco Estuary need to be identified and prioritized for treatment, containment, or other mitigation measures. Fortunately, selenium from oil refineries has been reduced to very low levels, while selenium inputs from farms on the west side of the San Joaquin Valley into the San Joaquin River have also been declining. These reductions have decreased selenium concentrations in overbite clams, a major sturgeon prey item (S. Luoma, pers. comm. 2009). This example demonstrates that pollution mitigation measures can be effective but efforts needs to be more comprehensive and systematic, focused on reducing inputs into waterways and eliminating point sources via treatment.

Habitat improvement. Freshwater and estuarine habitat alteration, especially from dam and levee construction, as well as elimination of most of the Central Valley's historic floodplain habitats, has limited spawning and rearing success in the Sacramento River (and possibly the Klamath River as well). Thus, restoring habitats required for juvenile rearing and spawning adults needs to be a priority in the Sacramento River basin. Access to rearing habitats with abundant prey may help mitigate effects of increased water temperatures resulting from climate change because larvae can better withstand increased temperatures when they feed at optimum (~ 15% body weight/day) or near-optimum feeding rates (Amiri et al. 2009). Restoration of tidal sloughs in California could also provide important rearing habitat.

Improving stream flows. The Sacramento River is a highly regulated river and white sturgeon depend on rare high water years - when dams spill or flood releases are high - for reproduction that leads to large year classes in the population. However, too little is known about specific flow requirements for spawning, instream rearing, downstream migration, growth rates, and mortality rates of young fish to evaluate the cost to benefit of alternative management of river flows. More research on white sturgeon life history and environmental tolerances (especially flow requirements at all life stages) may show that winter flow releases from dams would initiate additional spawning and alter substrate for improved survival of eggs and larvae, additional spring flows may improve downstream migration and survival of juveniles, and sustained high flows in the spring could also provide access to important floodplain habitats (e.g., Yolo bypass) for rearing and enhanced growth.

Potential use of hatcheries. White sturgeon aquaculture has been proven to be successful; therefore, there may be an inclination to use hatchery stocks to enhance the sturgeon fishery in California. However, dependence on hatcheries for either supplementing the sport fishery or meeting conservation and recovery objectives brings inherent risk and should not be prioritized over conservation and management measures intended to reverse declines of wild stocks. A long-term management and monitoring plan needs to be developed that includes management goals and genetic analyses to identify differences between wild and domesticated stocks. A principal goal should be to prevent domestication of wild stocks and to maintain maximum genetic and life history diversity. However, if populations become even more severely reduced, a conservation hatchery may be required. Proper use of wild broodstocks may serve to augment declining populations and allow time for conservation and restoration actions designed to improve spawning and rearing success, as well as adult and juvenile survivorship, to be implemented. In cases where hatchery- reared sturgeon have been used in conservation (e.g., Kootenai River, Idaho), a time lag of up to 3 years was necessary for hatchery-reared white sturgeon to adapt to natural conditions (Ireland et al. 2002). During that time, fish experienced decreased growth and populations exhibited 60-90% annual survival. If high survival rates to augment a population are important, hatchery-reared fish should be released after reaching 134 mm TL (~ 5 months old), because laboratory results suggest that fish of this size and larger are less vulnerable to predation (Gadomski and Parsley 2005c). All hatchery fish should be marked with coded wire tags so success of different management strategies can be evaluated.

Research. White sturgeon are well-studied but research is still needed to determine priorities for habitat restoration and best flow regimes to support successful reproduction and survivorship. There is also a continuing need for long-term monitoring of populations in order to develop population trends. Monitoring of tagged fish could help determine movement patterns, habitat utilization across life history stages, and potential interactions of Sacramento River white sturgeon with other populations. In particular, the role of the Klamath River in supporting the California white sturgeon population needs further study.

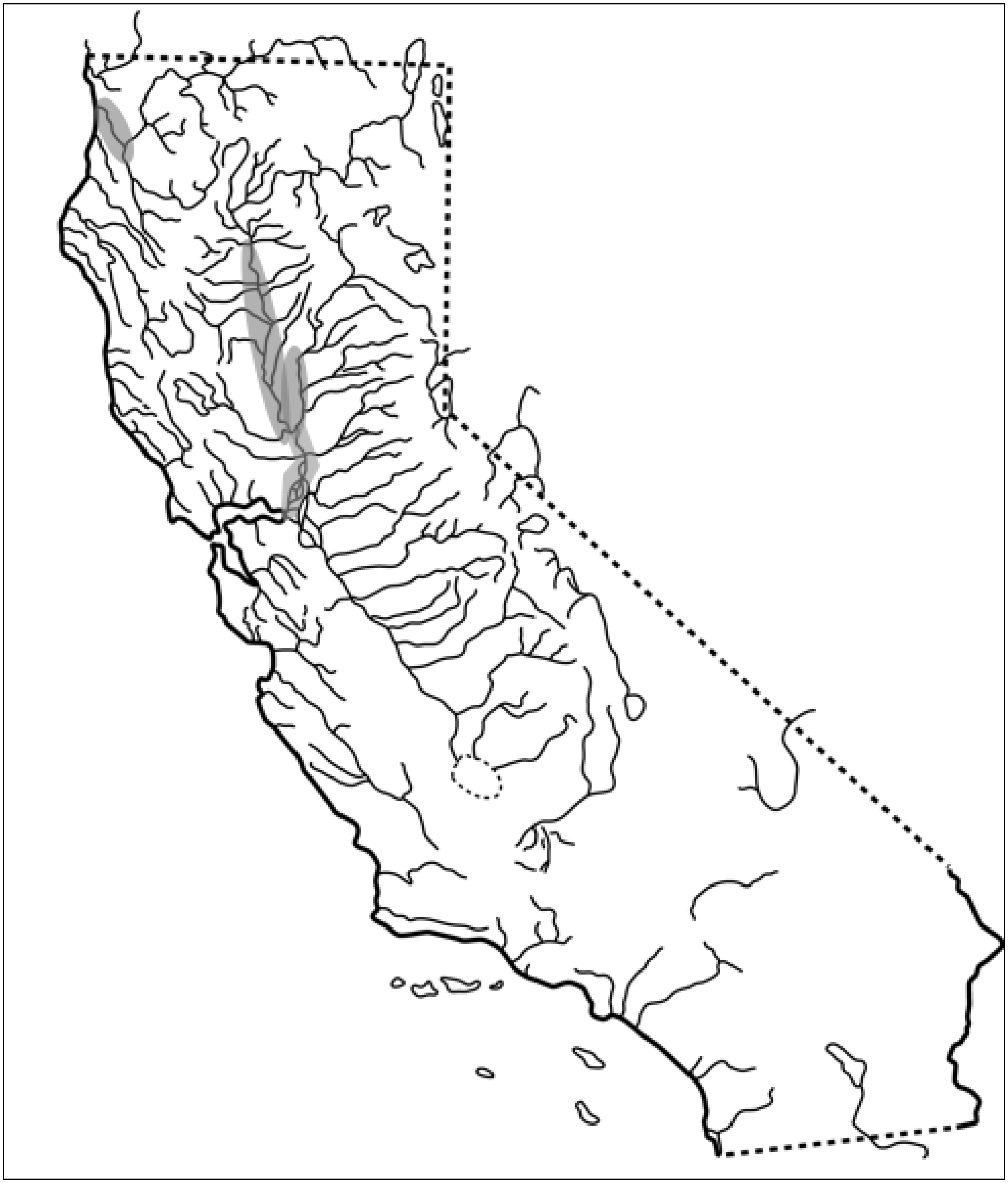

Figure 2. Distribution of white sturgeon, *Acipenser transmontanus* (Richardson), in California. Only freshwater distribution in the Sacramento and Klamath River basins is shown.