California Fish and Game 102(2):45-49; 2016

Range expansion of the Shimofuri goby (*Tridentiger bifasciatus*) in southern California, with emphasis on the Santa Clara River

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Key words: Shimofuri goby, tidewater goby, California State Water Project, invasive species

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Shimofuri gobies (*Tridentiger bifasciatus*) are native to Asian estuaries from Hokkaido, Japan to Hong Kong, China and were introduced to the San Francisco Bay most likely via ballast water exchange from cargo ships shortly prior to 1985 (Moyle 2002). Shimofuri gobies were first discovered in the Suisun Marsh, part of the upper San Francisco Estuary. Gobies then spread to the Sacramento-San Joaquin Delta (Delta) (Matern 2001). Shimofuri gobies have spread from the Delta more than 500 km through aqueducts of the California State Water Project (CSWP), over the Transverse Ranges, and into coastal drainages of southern California (Matern and Fleming 1995). Shimofuri gobies have invaded reservoirs associated with the East and West Branches of the CSWP in Southern California (Figure 1). These include Pyramid Lake (Swift et al. 1993), Castaic Lake (D. Black, California Department of Fish and Wildlife (CDFW), personal communication), Silverwood Lake, Lake Matthews, and Skinner Reservoir (Q. Granfors, CDFW, personal communication). Shimofuri gobies are likely also present in Lake Perris and Diamond Valley Lake because of connection to the CSWP, but have not been detected as of June 2016 (Q. Granfors, CDFW, personal communication). Gobies were collected in Lower Otay Reservoir in San Diego in June, 2016 (D. Black, CDFW, personal communication). Shimofuri gobies were first discovered in the Santa Clara River watershed in 1990 at Pyramid Lake and were later found downstream of Pyramid Dam in middle Piru Creek in 1992 (Swift et al. 1993). Swift (1993) described these fish as chameleon gobies (*Tridentiger trigonocephalus*), but later identified them as Shimofuri gobies (C. Swift, Natural History Museum of Los Angeles, personal communication). Piru Creek is connected to the CSWP via the California Department of Water Resources (DWR) Pyramid Lake. Pyramid Lake functions in conjunction with Castaic Lake (which also contains Shimofuri gobies, date of first observation unknown), also located in the Santa Clara River watershed, but the outflow of Castaic Lake, Castaic Creek, typically has zero flow except in exceptional rainfall years or during water rights releases.

Lake Piru, formed by Santa Felicia Dam, is located on Piru Creek approximately 29 km downstream of Pyramid Lake (Figure 2). United Water Conservation District, the operator of Santa Felicia Dam, has performed occasional snorkel surveys of 500 m of the creek just below the dam, typically focused on population monitoring for Southern California steelhead/coastal rainbow trout (*Oncorhynchus mykiss*). Fishes observed during surveys conducted

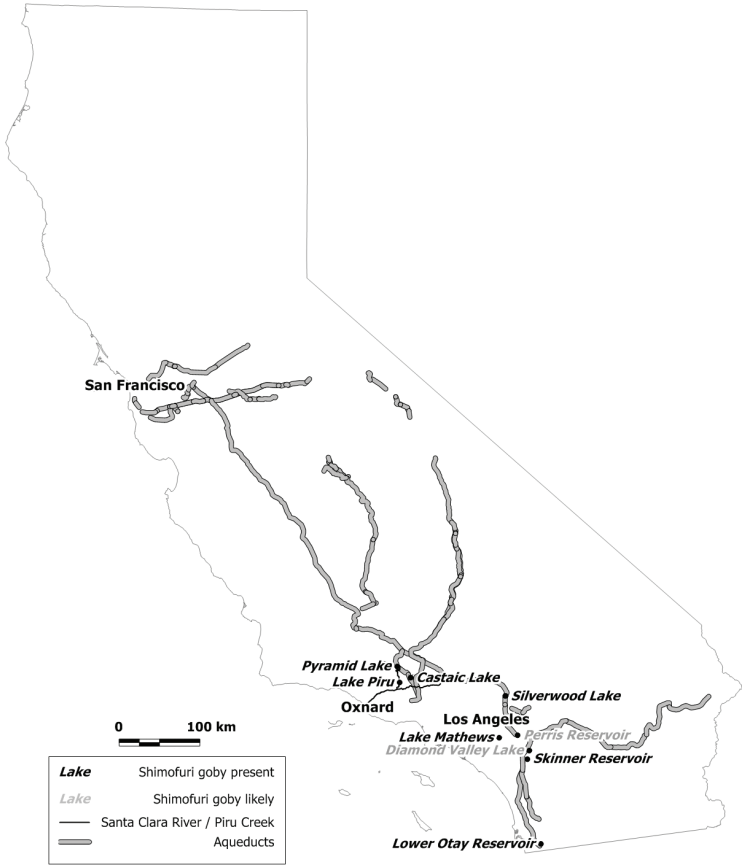

FIGURE 1.—Map of major canal and aqueduct systems in California, including the California State Water Project, highlighting lakes where Shimofuri gobies have been observed or are likely present in southern California.

before 2013 were partially armored threespine stickleback (*Gasterosteus aculeatus*), arroyo chub (*Gila orcuttii*), Santa Ana sucker (*Catostomus santaanae*), Southern California steelhead/coastal rainbow trout, prickly sculpin (*Cottus asper*), fathead minnow (*Pimephales promelas*), green sunfish (*Lepomis cyanellus*), and largemouth bass (*Micropterus salmoides*). During snorkel surveys in April, May, and August 2013, Shimofuri gobies were observed only during the August 2013 survey, but were abundant throughout the reach. On 20 August 2013, 17-voucher specimens were collected by seine directly below the Santa Felicia Dam outlet works. These specimens ranged in size from 36 mm standard length (SL) to 68 mm SL, and were submitted to the Natural History Museum of Los Angeles County ichthyology collection (LACM 58175-1) on 4 September 2013. A scuba dive survey on 7 July 2015, in Lake Piru showed Shimofuri gobies at high abundance near the intake for the penstock of the dam as well as other areas of the lake, but gobies were not observed in Piru Creek during a snorkel survey on 4 August 2015. Gobies were present in low numbers during seining

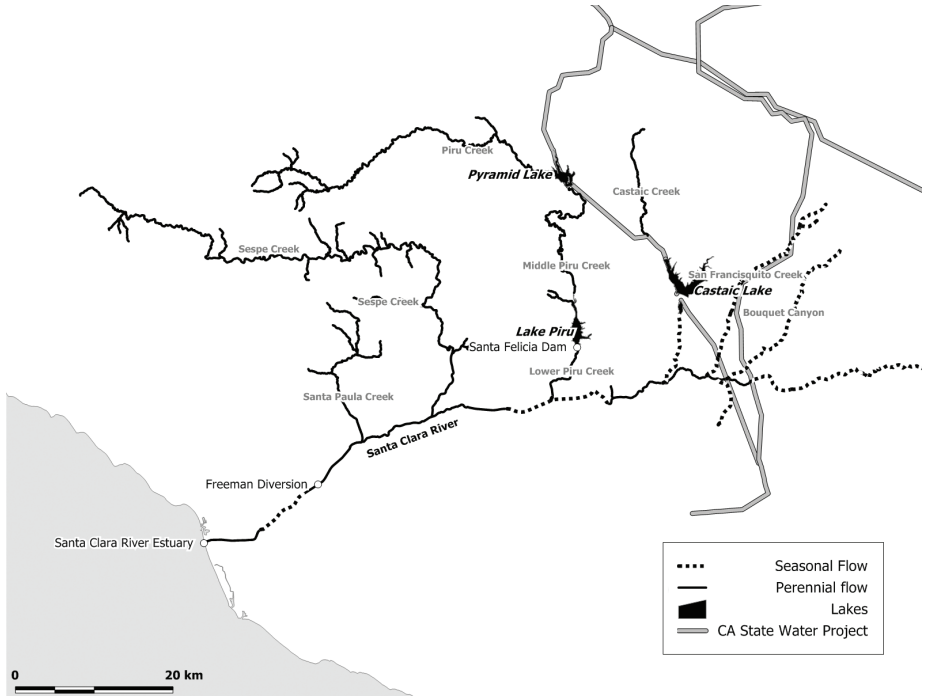

FIGURE 2.—Map of the Santa Clara River drainage and major tributaries, highlighting the California State Water Project aqueduct and lakes with Shimofuri gobies, the seasonally intermittent connection of the Santa Clara River and Piru Creek, and the Santa Clara River estuary.

surveys on 20 April 2016, below the Santa Felicia Dam outlet works. Gobies observed during snorkel and seine surveys in Piru Creek ranged from 40 mm total length (TL) to 80 mm TL.

Because regular monitoring did not occur on lower Piru Creek prior to 2013, it is not possible to definitively identify the timing of the invasion. However, based on the closely spaced surveys in 2013, and absence of the fish during the April and May 2013 surveys, it is possible that the invasion into lower Piru Creek occurred during a maintenance operation at Santa Felicia Dam on 30 July 2013. Typical water releases from Santa Felicia Dam route water through a series of pipes and valves that constrict the flow and release the water in a high velocity, turbulent spray into lower Piru Creek. While high flow releases (e.g., 5.66 m^3/s) may suction fish out of the lake or scour them out of the penstock due to pipe velocities that exceed 3.1 m/s, all typical flow release conditions likely kill or injure fish passing through the valves due to excessive velocity and turbulence at the pipe exit orifice. Unlike typical releases, during the maintenance draining operation the penstock pipe slowly dewaters with substantially slower and less turbulent flows, and allows fish to pass through alive and undamaged.

To test whether the draining of the penstock was a likely pathway for goby introduction to lower Piru Creek, on 9 May, 2016, all the water draining from the penstock during a maintenance event (approximately 450 m^3) was passed through a seine or dipnet to capture any fish released through the valves. Both Shimofuri gobies (155 individuals)

and prickly sculpin (38 individuals) were captured during the draining event. All but one fish exited the drain near the end of the event, when the penstock was nearly empty and the velocity and volume of flow was minimal. Fish in the penstock appeared to maintain their position until dewatering was imminent, resulting in the transfer of live fish from Lake Piru into Piru Creek. Gobies collected from the penstock drain ranged from 25 mm TL to 90 mm TL.

The invasion of lower Piru Creek provides a direct, if intermittent, pathway for gobies to disperse to the Santa Clara River estuary. Typical flow releases from Santa Felicia Dam (0.20 m^3/s) to lower Piru Creek typically percolate subsurface at or near the confluence with the Santa Clara River 9.6 km downstream. The Santa Clara River at the confluence of Piru Creek is typically dry, and falls in the middle of an 11 km "dry gap" of the Santa Clara River, which is generally only wetted during significant storm events (Figure 2). Flow from Piru Creek to the Santa Clara River is contiguous when elevated flows are released from Santa Felicia Dam for groundwater recharge and diversion, steelhead migration, or when the dam is above storage capacity and spills. Between 2012 and 2015, only one high flow release occurred in Piru Creek, from 1 March to 7 March 2014. The high flow event consisted of a 5.66 m^3/s release for two days followed by a five day gradual ramp-down to baseflow of 0.20 m^3/s. This was the only flow event during this period where Shimofuri gobies had the opportunity to disperse from Piru Creek into the Santa Clara River. During this period, Castaic Lake (Figure 2) did not release water into Castaic Creek and was unlikely to be a source contributing gobies into the Santa Clara River.

United Water Conservation District typically operated a steelhead and Pacific lamprey (*Entosphenus tridentatus*) downstream migrant trap at the Freeman Diversion daily from January to June, 1994 to 2014, when streamflow was present. The diversion is located on the Santa Clara River approximately 43.5 km downstream from the base of Santa Felicia Dam (Figure 2). Shimofuri gobies were not detected at the Freeman Diversion prior to 2014. Due to extended drought and low flows in the Santa Clara River in 2014, the downstream migrant trap was only operated from 4 March to 30 April 2014, when a large storm increased river flow. On 5 March 2014, five Shimofuri gobies were collected in the downstream migrant trap. At a minimum, these fish traveled 43 km downstream in five days, assuming dispersal started at the beginning of the release on 1 March, a dispersal rate of approximately 8.6 km/day. Additional Shimofuri gobies were collected on 6 March (one individual), 8 (two individuals), and 11 (one individual), 2014, but were not observed for the remainder of the monitoring season.

This is the first known dispersal of this species within a natural river system in southern California. These observations indicate that a functional dispersal pathway exists to the Santa Clara River estuary 59 km below Santa Felicia Dam and 16 km below the Freeman Diversion (Figure 2), home to the federally threatened tidewater goby (*Eucyclogobius newberryi*). However, no Shimofuri gobies were collected during a survey of the estuary on 19 August, 2014 (Cardno-ENTRIX 2014) or observed in subsequent surveys between 2014 and 2016 (E. Bell and K. Jarrett, Stillwater Sciences, personal communication).

The invasion of alien gobies, including the Shimofuri goby, may negatively affect the native tidewater goby. Tidewater gobies are present in the Santa Clara River estuary, but the population appears to be in decline. Shimofuri gobies, which have established populations in the San Francisco Bay region (Moyle 2002), compete with and prey upon smaller tidewater gobies (R. Swenson, Environmental Science Associates (ESA), personal communication).

Initial experiments indicated that Shimofuri gobies aggressively intimidate, outcompete, and prey upon tidewater gobies in the laboratory (R. Swenson, ESA, personal communication). Tidewater goby and Shimofuri goby diets overlap, including benthic macroinvertebrates like oligochaetes, polychaetes, ostracods, copepods, and isopods (Swenson and McCray 1996), and may result in direct competition for food resources. To date, the possible effects of interactions in the wild between exotic goby species and tidewater gobies are largely conjectural (U.S. Fish and Wildlife Service 2005), and effects may be less than those observed in the laboratory because Shimofuri gobies prefer hard substrates, whereas tidewater gobies prefer sandy substrates. Further monitoring in the Santa Clara estuary may provide insight into real world interactions between these goby species and potential consequences for tidewater gobies in the future.

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Received 17 June 2016
Accepted 21 July 2016
Associate Editor was Peter Kalvass