www.doi.org/10.51492/cfwj.108.5

California Fish and Wildlife 108(1):93-107; 2022

FULL RESEARCH ARTICLE

Status and distribution of Arroyo Chub within its native range

JOHN W. O'BRIEN[1] AND RUSSELL M. BARABE[2*]

[1] California Department of Fish and Wildlife, South Coast Region, 4665 Lampson Ave, Ste C, Los Alamitos, CA, USA

[2] California Department of Fish and Wildlife, South Coast Region, 3883 Ruffin Rd, San Diego, CA, USA

**Corresponding Author: Russell.Barabe@wildlife.ca.gov*

The Arroyo Chub (*Gila orcutti*) is a small cyprinid native to coastal drainages of Los Angeles, Orange, Riverside, and San Diego counties. We surveyed the seven drainages historically known to support the species in 2012-2014 and again in 2019 to determine current range and distribution. We compared our results to the most recent species account we could locate (1993). We detected Arroyo Chub in 18 of the 40 streams (45%) and within six of the seven native watersheds in our 2012-2014 surveys, while our 2019 surveys located fish in all of the seven native watersheds. This native species has retreated to the headwaters in most watersheds and the number of populations have declined since the most recent species account. Non-native species, habitat loss, urbanization, water development, flood control, and drought are thought to be the primary causes of this decline.

Key words: Arroyo Chub, *Gila orcutti*, status update

The Arroyo Chub (*Gila orcutti*) is a small cyprinid (Fig. 1) native to coastal drainages of Los Angeles, Orange, Riverside, and San Diego counties in California. This species has a relatively deep body and caudal peduncle, large eyes (for a cyprinid), a short rounded snout, and a subterminal mouth (Moyle 2002). Average adult lengths are 70–100 mm, and fish are silver or gray to olive green dorsally, white ventrally, and connected with a dull gray lateral band (Moyle 2002). Considered true omnivores, Arroyo Chub eat algae, insects, and small crustaceans (Moyle et al. 2015). Spawning generally occurs in June and July, but the eggs of females ripen in small batches (Tres 1992), allowing spawning to occur anywhere from February through August.

Typically, Arroyo Chub are found in slow-moving sections of cool to warm (10–26°C) streams dominated by sand and silt substrates (Wells and Diana 1975; Saiki et al. 2007; O'Brien et al. 2011), but Feeney and Swift (2008) found fish in pools with gravel, cobble, and boulder substrates, illustrating the diversity of habitat used by this species. These fish are adapted to survive the fluctuating conditions present in southern California streams, including warm, hypoxic conditions in summer (Castleberry and Cech 1986), and high flows and turbidity levels in winter.

Figure 1. Arroyo Chub captured in San Juan Creek, Orange County, California.

The decline of California's native fishes has been well documented (Moyle 1976; Moyle et al. 1989; Moyle et al. 1995; Moyle et al. 2011; Moyle et al. 2015), and Arroyo Chub are no exception. Reasons for the decline are numerous and include habitat loss, urbanization, water development, flood control, and the introduction of invasive species. These factors have led to a reduction in the preferred habitat of Arroyo Chub within the coastal plain of southern California. Unfortunately, it is impossible to accurately quantify the magnitude of this decline, because comprehensive, range-wide studies of Arroyo Chub prior to these anthropogenic impacts are absent. Swift et al. (1993) published the only range-wide assessment, while other reports have only described the species distribution within specific drainages (Haglund and Baskin 1995; Warburton et al. 2000; O'Brien et al. 2011; Packard 2012).

METHODS

We designed the present range-wide assessment of Arroyo Chub to determine: (1) which of the native streams still support Arroyo Chub populations and quantify the area occupied within each, and (2) identify potential locations where restoration and translocation could occur.

We conducted surveys throughout the seven watersheds to which Arroyo Chub are native. From north to south these are: Malibu Creek, Los Angeles River, San Gabriel River, Santa Ana River, San Juan Creek, Santa Margarita River, and the San Luis Rey River. Historic locations of the species were obtained from Swift et al. (1993), unpublished field reports, consultation with local fisheries experts, and records within the California Natural Diversity Database. We selected most survey locations based on historic records or sites within the historic native range that contained suitable habitat. However, the Walnut Creek sample location met neither of these conditions and was sampled based on information from a local resident.

The sampling occurred annually at some sites from 2012 through 2021, with a wide-

spread effort from 2012–2014. Before sampling a selected location, we performed visual surveys and sometimes covered several miles of stream to locate water, suitable habitat, and fish. After the widespread effort from 2012–2014, we focused our efforts thereafter on locations where positive detections occurred. We sampled each site with a 1.2 × 1.8 m seine with a mesh size of 3 mm or dip nets with a mesh size of 3 mm. Most sites were in small streams rarely more than 5 m wide or deeper than 1 m. Since Arroyo Chub are most commonly found in shallow, slow-moving streams with pools that contain aquatic vegetation, such areas were preferentially sampled. Every effort was made to sample a minimum of 100 m at each sampling location, but intermittent streams often prevented this. We used dip nets in areas that could not be effectively seined such as undercut banks or complex structure such as boulders and woody debris.

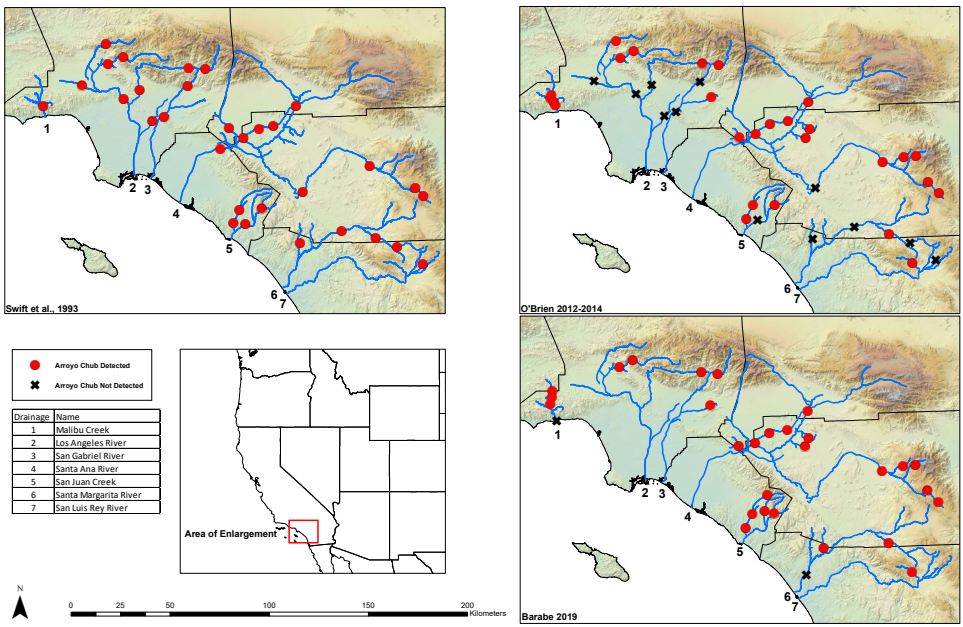

Figure 2. Arroyo Chub presence/absence within each of the seven native watersheds by survey year.

RESULTS

Between April 2012 and June 2014, we surveyed a total of 95 sites within 40 streams across the seven watersheds of which Arroyo Chub are native (Table 1). Fish were detected in 18 of the 40 streams (45%) and within six of the seven native watersheds. Of the 18 streams where Arroyo Chub were still present, nine streams (50%) also contained non-native aquatic fauna. We conducted range-wide surveys again in 2019 and report the survey results chronologically from north to south below.

Malibu Creek— Historic survey data (Swift et al. 1993) reported Arroyo Chub at one location in Malibu Creek (mainstem). Our surveys conducted in 2012–2014 found fish at four locations within the watershed (Upper and Lower Malibu Creek, Liberty Canyon, and Lower Las Virgenes Creek). The Liberty Canyon fish were only in the lower section near the confluence with Malibu Creek. Our 2019 surveys found fish at three locations (Upper

and Lower Las Virgenes Creek, and Liberty Canyon) (Fig. 2). No documentation of the species occurring in Las Virgenes Creek and Liberty Canyon could be found and the Las Virgenes population began immediately above a 2 m barrier to upstream migration. It is likely this barrier has prevented invasive species from colonizing the upper section and any project attempting to remove this barrier should carefully consider potential impacts to Arroyo Chub. All locations we sampled in the mainstem contained non-native gamefish (Table 2) including Largemouth Bass (*Micropterus salmoides*), Common Carp (*Cyprinus carpio*), and Black Bullhead (*Ameiurus melas*).

Los Angeles River— Swift et al. (1993) reported Arroyo Chub at seven locations within the watershed (Rio Hondo, Arroyo Seco, two in the mainstem, two in Big Tujunga Wash, and Pacoima Creek). Our 2012–2014 surveys found fish at two locations (Big Tujunga Wash and Pacoima Creek), and our 2019 surveys found fish at one location (Big Tujunga Wash) (Fig. 2). Pareti and Morales (2019) reported Arroyo Chub in Haines Creek, a tributary of Big Tujunga Creek. Non-native gamefish were found in Pacoima Creek (2019) and Big Tujunga Wash (Table 2).

San Gabriel River— Historic accounts of Arroyo Chub (Swift et al. 1993) reported fish at four locations within the San Gabriel Watershed (two in the mainstem, East Fork San Gabriel River, and West Fork San Gabriel River). Surveys conducted in 2005 observed large numbers of Arroyo Chub in Cogswell Reservoir and Upper West Fork (J. O'Brien, California Department of Fish and Wildlife, unpublished data). Our surveys conducted in 2012–2014 found fish at four sites (West Fork San Gabriel River, Bear Creek (tributary to the West Fork), East Fork San Gabriel River, and Walnut Creek). Walnut Creek is not reported as a historic location for this species. Additional surveys in 2017 confirmed continued Arroyo Chub presence in Upper West Fork, and our 2019 surveys found fish at five locations (East and West Forks of the San Gabriel River, Bear Creek (tributary to West Fork), Cattle Canyon (tributary to East Fork), and Walnut Creek) (Fig. 2). Non-native fishes were noted (Table 2) at two sites, including the first documented occurrence of the Oriental Weather Loach (*Misgurnus anguillicaudatus*) in Walnut Creek. In October 2020, the Bobcat Fire burned 46,861 ha (115,796 acres) of the Angeles National Forest (Inciweb 2020), including 93% of the West Fork Watershed (USFS 2020). Follow up surveys in 2021 have indicated significant debris flows occurred resulting in major habitat modifications. This likely impacted Arroyo Chub in the short-term, but no surveys have been conducted as of the writing of this manuscript.

Santa Ana River— Swift et al. (1993) reported Arroyo Chub at ten locations within the Santa Ana Watershed (five in the mainstem, Aliso Creek, Temescal Wash, two in San Jacinto Creek, and Indian Creek). Our 2012–2014 surveys found fish in two locations (Aliso Creek and the mainstem Santa Ana River). We found dry reaches in several streams including the formally occupied site within Temescal Wash, and non-native fishes were encountered at most sites. Data provided by Riverside Corona Resource Conservation District (RCRCD) from 2015–2021 reported Arroyo Chub at nine locations within the watershed (two in the mainstem, Sycamore Canyon Creek, Goldenstar Creek, Indian Creek, South Fork San Jacinto River, North Fork San Jacinto River, Aliso Creek, and Hemet Lake (B. Mills, Riverside Corona Resource Conservation District, personal communication)(Fig. 2). Annual invasive species removal efforts (Table 2) in the mainstem typically result in Arroyo Chub as bycatch, but RCRCD has noted a sharp decline in the number of this species captured in the last few years. We sampled the Aliso Creek population in 2020 and had difficulty locating Arroyo Chub within the stream, but easily captured Fathead Minnows (*Pimephales promelas*).

Table 1. Sites surveyed to assess presence/absence of Arroyo Chub in southern California from 2012–2014.

Watershed	Stream/Site	Arroyo Chub Found	# Sites surveyed	Latitude	Longitude	Historical Information	Abundance	Invasive Species Present
Malibu Creek	Cold Creek	N	1	34.07911	-118.69906	None	None	N
	Lower Malibu Creek	Y	2	34.04997	-118.69037	CNDDB	Common	Y
	Upper Malibu Creek	Y	1	34.16443	-117.89645	CNDDB	Common	Y
	Liberty Canyon Creek	Y	1	34.10989	-118.71529	None	Common	N
	Medea Canyon Creek	N	2	34.11693	-118.75555	None	None	Y
	Triunfo Canyon Creek	N	2	34.12674	-118.79599	None	None	Y
	Lower Las Virgenes Creek	Y	1	34.09694	-118.72017	Survey report	Common	Y
	Upper Las Virgenes Creek	N	1	34.144	-118.70131	None	None	Y
Los Angeles River	Lower Big Tujunga Creek	Y	3	34.30241	-118.25996	CNDDB	Rare	Y
	Upper Big Tujunga Creek	N	1	34.28667	-118.22869	Survey report	None	N
	Haines Creek	N	1	34.26673	-118.34906	CNDDB	None	Y
	Los Angeles River	N	2	34.17773	-118.4962	CNDDB	None	Y
	Bull Creek	N	1	34.17964	-118.49784	None	None	Y
	Little Tujunga Creek	N	1	34.28227	-118.3705	CNDDB	None	N
	Pacoima Creek	Y	2	34.34469	-118.36119	Survey report	Rare	N
San Gabriel River	North Fork San Gabriel River	N	3	34.24928	-117.86193	CNDDB	None	N
	West Fork San Gabriel River	Y	3	34.24928	-117.87653	CNDDB	Common	Y
	East Fork San Gabriel River	Y	3	34.23335	-117.79562	CNDDB	Rare	Y
	Cattle Canyon Creek	N	1	34.22797	-117.76517	CNDDB	None	N
	Bear Creek	Y	1	34.24513	-117.88713	CNDDB	Rare	N

Watershed	Stream/Site	Arroyo Chub Found	# Sites surveyed	Latitude	Longitude	Historical Information	Abundance	Invasive Species Present
	Big Mermaids Canyon Creek	N	1	34.2447	-117.90062	CNDDB	None	N
	Walnut Creek	Y	2	34.09139	-117.82872	Survey report	Rare	Y
	San Gabriel River	N	1	34.16443	-117.89645	CNDDB	None	Y
Santa Ana River	Upper Santa Ana River	Y	1	34.03765	-117.3567	CNDDB	Common	Y
	Upper Santa Ana River	N	1	34.99435	-117.3905	CNDDB	None	Y
	Middle Santa Ana River	N	1	34.97113	-117.42235	CNDDB	None	Y
	Middle Santa Ana River	N	1	34.92499	-117.59613	CNDDB	None	Y
	Sunnyslope Creek	N	1	34.97142	-117.43099	CNDDB	None	Y
	Aliso Canyon Creek	Y	3	33.89435	-117.69127	Survey report	Rare	N
	Arroyo Tequisquite Creek	N	1	34.96761	-117.43175	CNDDB	None	Y
	San Jacinto River	N	1	33.73975	-116.83772	CNDDB	None	N
	Temescal Creek	N	3	33.89933	-117.59142	CNDDB	None	Y
San Juan Creek	Lower San Juan Creek	N	1	33.47724	-117.6784	CNDDB	None	Y
	OSO Creek	N	1	33.52059	-117.67479	CNDDB	None	Y
	Upper San Juan Creek	Y	3	33.58618	-117.52002	CNDDB	Rare	Y
	Middle San Juan Creek	N	3	33.50559	-117.6443	CNDDB	None	Y
	Bell Creek	Y	2	33.63047	-117.55424	CNDDB	Rare	N
	Hot Springs Creek	Y	2	33.5986	-117.51233	CNDDB	Rare	N
	Upper Trabuco Creek	N	3	33.67421	-117.53709	CNDDB	None	N
	Middle Trabuco Creek	Y	1	33.58087	-117.6388	CNDDB	Rare	Y
	Lower Trabuco Ck	N	1	33.58384	-117.63751	CNDDB	None	Y

Watershed	Stream/Site	Arroyo Chub Found	# Sites surveyed	Latitude	Longitude	Historical Information	Abundance	Invasive Species Present
Santa Margarita River	Tijeras Creek	Y	1	33.59278	-117.63131	Survey report	Rare	N
	Santa Margarita River	N	4	33.43125	-117.19633	CNDDB	None	Y
	Temecula Creek	Y	3	33.43071	-116.85472	CNDDB	Rare	Y
	Rainbow Creek	N	2	33.41033	-117.20885	CNDDB	None	Y
	De Luz Creek	N	3	33.44308	-11732076	CNDDB	None	N
	Sandia Creek	N	2	33.42998	-117.24756	CNDDB	None	N
San Luis Rey River	Murrietta Creek	N	3	33.56082	-117.23654	None	None	Y
	Upper San Luis Rey River	N	1	33.30852	-116.69429	CNDDB	None	Y
	Agua Caliente Creek	N	1	33.28832	-116.65341	CNDDB	None	N
	Lower San Luis Rey River	N	8	33.2204	-117.35718	None	None	Y
	Middle San Luis Rey River	N	2	33.35456	-117.03879	None	None	Y

We were only able to capture the target species in one short section of intermittent stream. The Blue Ridge Fire burned the entirety of the Aliso Creek Watershed in October 2020 and will likely impact this isolated population.

San Juan Creek— Historic survey data (Swift et al. 1993) reported Arroyo Chub in four locations within the San Juan Watershed (two in the San Juan Creek mainstem, and two in Arroyo Trabuco). Arroyo Chub were absent from the lower mainstem site in our 2012–2014 surveys but were found in the upper mainstem site and in tributaries such as Hot Springs Creek, Bell Creek, and Tijeras Creek. One section of Upper Arroyo Trabuco and middle San Juan Creek mainstem was dry. Non-native minnows and Western Mosquitofish (*Gambusia affinis*) (Table 2) were common at most of the sampling locations, but were not observed in Tijeras Creek, Upper San Juan Creek, and Upper Arroyo Trabuco. We found an additional population of the target species in the headwaters of Arroyo Trabuco in 2016 (R. Barabe, California Department of Fish and Wildlife, unpublished data). Our 2019 surveys found fish in three locations (Lower Arroyo Trabuco, Tijeras Creek, and San Juan Creek) (Fig. 2). Although the populations in Bell Creek and Upper Arroyo Trabuco could not be located in 2018 and 2019, both were relocated in 2021. Dam removal in San Juan Creek (conducted by the US Forest Service) led to an expansion of the occupied habitat approximately 0.24 km upstream.

Santa Margarita River— Swift et al. (1993) found Arroyo Chub at four locations within the Santa Margarita Watershed (De Luz Creek, and three locations in Temecula Creek). Our 2012–2014 surveys only found fish in one location (the headwaters of Temecula Creek), which has a series of perennial pools with no invasive species. Most of our survey sites had sufficient flow and instream habitat for the target species but contained non-native predatory fishes (Table 2). Our follow up surveys in 2019 detected fish in the same single location in Temecula Creek (Fig. 2). Surveys conducted in summer of 2021 show this area drying quickly. An additional population of Arroyo Chub was known to persist in the mainstem Santa Margarita River on Marine Corps Base Camp Pendleton, but no fish have been seen since a high flow event in 2017 (D. Cie, USMC Camp Pendleton Base Biologist, personal communication). An additional population of the target species was discovered in Sandia Creek (Fig. 2) (June 2021). A few invasive Redeye Bass (*Micropterus coosae*) were seen in Sandia Creek.

San Luis Rey River—Swift et al. 1993 reported Arroyo Chub in one location (Agua Caliente Creek), a small, headwater tributary. Our 2012–2014 surveys were unable to locate fish within this watershed, although multiple locations were sampled (Table 1). In addition to the sites listed, several other sites were visually surveyed but not sampled due to a lack of water or suitable habitat. Large sections of the San Luis Rey River mainstem were dry, channelized, or contained non-native fish species (Table 2). We found Arroyo Chub in the West Fork San Luis Rey River in 2017 (Fig. 2). The fish were found in a short section of intermittent stream where a series of seven perennial pools persist. We have revisited this site annually to monitor this population and conduct invasive species removal.

DISCUSSION

When comparing the survey data from Swift et al. (1993) to the data collected in 2012–2014, and from 2016–2021, significant declines in the number of Arroyo Chub populations were noted in the Los Angeles, San Gabriel, and Santa Margarita rivers. In the Los Angeles River Watershed, four populations were apparently extirpated from 1993 to

Table 2. Invasive species observed within each watershed sampled for Arroyo Chub in 2012-2014 and 2019.

Site	Non-native species found
Malibu Creek	Largemouth Bass *Micropterus salmoides* Black Bullhead *Ameiurus melas* Common Carp *Cyprinus carpio* Crayfish *Procambarus clarkia*
Los Angeles River	Largemouth Bass *Micropterus salmoides* Black Bullhead *Ameiurus melas* Green Sunfish *Lepomis cyanellus* Red Shiner *Cyprinella lutrensis* Western Mosquitofish *Gambusia affinis* Crayfish *Procambarus clarkia*
San Gabriel River	Largemouth Bass *Micropterus salmoides* Weather Loach *Misgurnus anguillicaudatus* Common Carp *Cyprinus carpio*
Santa Ana River	Largemouth Bass *Micropterus salmoides* Channel Catfish *Ictalurus punctatus* Black Bullhead *Ameiurus melas* Green Sunfish *Lepomis cyanellus* Black Crappie *Pomoxis nigromaculatus* Fathead Minnow *Pimephales promelas* Red Shiner *Cyprinella lutrensis* Golden Shiner *Notemigonus crysoleucas* Western Mosquitofish *Gambusia affinis* Crayfish *Procambarus clarkia* Bluegill *Lepomis macrochirus*
San Juan Creek	Golden Shiner *Notemigonus crysoleucas* Red Shiner *Cyprinella lutrensis*
Santa Margarita River	Largemouth Bass *Micropterus salmoides* Black Bullhead *Ameiurus melas* Green Sunfish *Lepomis cyanellus* Redeye Bass *Micropterus coosae* Western Mosquitofish *Gambusia affinis* Crayfish *Procambarus clarkia*
San Luis Rey River	Largemouth Bass *Micropterus salmoides* Common Carp *Cyprinus carpio* Black Bullhead *Ameiurus melas* Green Sunfish *Lepomis cyanellus* Western Mosquitofish *Gambusia affinis*

2012, and an additional one was lost from 2012 to 2021. Two populations were lost in the San Gabriel River Watershed from 1993 to 2012, and the Santa Margarita River Watershed lost four populations from 1993 to 2012. A range contraction occurred in the Malibu Creek Watershed, where fish were not found in the mainstem, and no fish were seen in Agua Caliente Creek (San Luis Rey River Watershed).

Moyle et al. (2015) reported Arroyo Chub as vulnerable to extinction in its native range within the next 100 years but considers the species more stable when non-native populations are included. In his overview of the species, Swift et al. (1993) listed fish as common in only four streams within its native range: Santa Margarita River (including De Luz Creek), Arroyo Trabuco, San Juan Creek, and Malibu Creek. Within these four streams, the 2012–2014 surveys found Arroyo Chub abundant only in Malibu Creek (note that sampling did not occur in lower Santa Margarita River where they were reported to be still extant), and small, but stable populations, in Las Virgenes Creek (Malibu Watershed), Bell Creek (San Juan Watershed), Walnut Creek (San Gabriel Watershed) and in the upper Santa Ana River. A robust and dispersed population was found in the West Fork San Gabriel River Big Tujunga Creek (Los Angeles Watershed) between Hansen and Big Tujunga dams. Surveys conducted in 2019 found fish abundant in San Juan Creek, Arroyo Trabuco, Tijeras Creek (San Juan Watershed), West Fork San Gabriel River (San Gabriel Watershed), Big Tujunga Creek (Los Angeles Watershed), and Las Virgenes Creek (Malibu Watershed).

Considering the preferred habitat of Arroyo Chub is slow-moving or backwater sections of streams with muddy or sandy bottoms (Moyle 2002), it is likely the species occupied much of the low elevation channels of all seven native streams, meaning an even larger range-wide contraction occurred after European settlers began colonizing this area. The current distribution (Fig. 3) shows how this species has been relegated to upstream, headwater sections of streams. Most of the streams where the species still occur are on U.S. Forest Service land, which are generally mid to high gradient mountain stream systems.

There are a number of factors implicated in the observed decline of Arroyo Chub, including urbanization (habitat loss, habitat fragmentation, non-native species introductions, channelization, water extraction/addition, and agriculture) climate change and drought. For example, five of the seven native streams have large segments that are not suitable for Arroyo Chub due to channelization, which reduces or eliminates access to floodplain habitat with side channels and back-water pool habitat while increasing flow velocity.

Each of the seven native watersheds have extensive urbanization. Urban and commercial development near streams can lead to an increase in non-native species introductions (Copp et al. 2005) and the loss of freshwater fishes (Marchetti et al. 2006). Additionally, Brown et al. (2005) found alien species dominant at urban sites in southern California. Non-native aquatic species were present within each of the seven native watersheds, usually in areas no longer occupied by Arroyo Chub. In Malibu Creek, lower Arroyo Trabuco, Santa Margarita and San Luis Rey rivers, relatively good habitat was present in certain sections, but Arroyo Chub were not detected. This is likely due to abundant populations of non-native fishes such as Largemouth and Redeye Bass, Green Sunfish (*Lepomis cyanellus*), Black Bullhead, Western Mosquitofish, and minnow species. Schrank et al. (2001) found extirpation of the endangered Topeka Shiner (*Notropis topeka*) in Kansas was linked to the abundance of introduced Largemouth Bass, and Western Mosquitofish have been implicated in eliminating small fish species in many locations through predation and competitive interactions (Myers 1965; Meffe and Snelson 1989; Moyle 2002). Each of these non-native species were

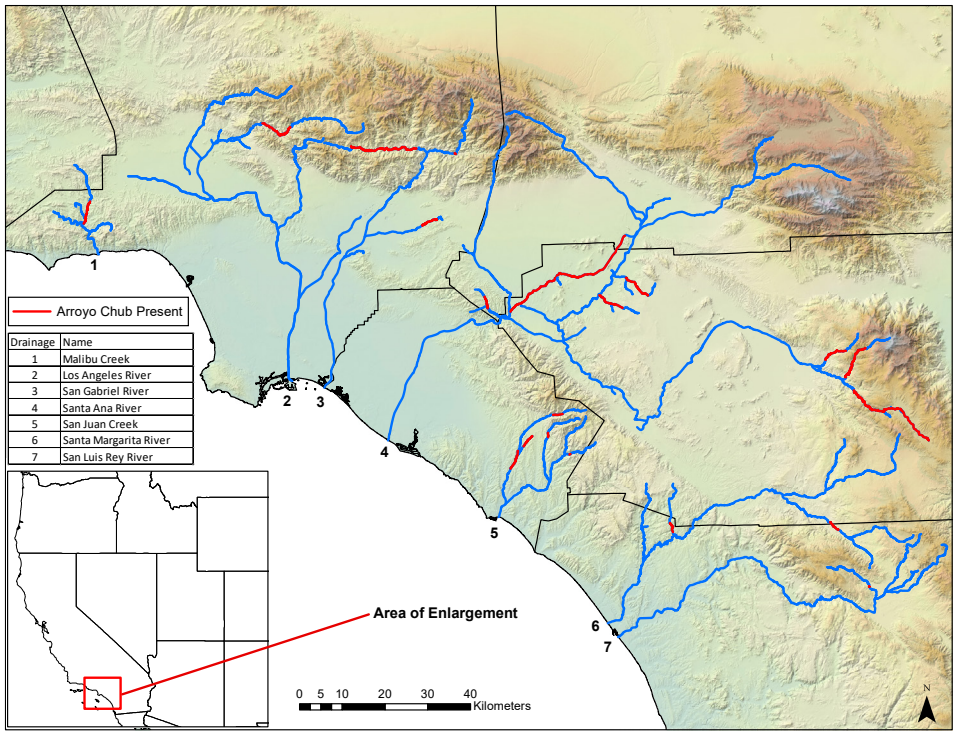

Figure 3. The approximate upstream and downstream extent of each Arroyo Chub population (in red).

observed across the survey range and were often far more abundant and widespread than Arroyo Chub. Additionally, the Red Swamp Crayfish, (*Procambarus clarkia*), is known to predate on fish eggs and larvae (Mueller et al. 2006) and was ubiquitous throughout the low elevation flood plains of all seven native watersheds. Crayfish were especially abundant in Malibu, San Juan, and Walnut creek watersheds.

From 2012 through 2016, California experienced one of the most severe droughts in over a century (Griffin and Anchukaitis 2014; Swain et al., 2014). Persistent drought conditions reduced streamflow and some historically occupied sites such as Agua Caliente (San Luis Rey Watershed) and substantial sections of De Luz Creek (Santa Margarita Watershed), San Juan, and Pacoima (Los Angeles Watershed) creeks were dry when sampling occurred. The 2013–2014 water year had some of the lowest precipitation totals observed for southern California (Griffin and Anchukaitis 2014). In many cases, follow-up sampling the ensuing year was also not productive as stream flows were even lower due to the ongoing drought. Surveys conducted in 2019 failed to locate Arroyo Chub in Pacoima Creek, and extirpation of this population is believed to have occurred as a result of this drought.

Arroyo Chub exhibit a high temperature tolerance and are physiologically adapted to hypoxic conditions and wide temperature fluctuations present in southern California streams (Moyle 2002). Both authors have observed fish in standing pools where water temperature exceeded 30° C. These traits, coupled with the ability to persist in small streams with widely fluctuating flows, have led Moyle et al. (2013) and others (Castleberry and Cech 1986), to the conclusion that Arroyo Chub are less vulnerable to climate change when compared to species with narrower environmental tolerances.

Most of the stable Arroyo Chub populations are small and isolated in headwaters (Fig. 3), leaving them vulnerable to extirpation through the combined effects of stochastic events and the loss of genetic diversity (Benjamin et al. 2016). Stream fragmentation has been reported to increase the risk of extinction by reducing connectivity, habitat area, and complexity (Rieman and McIntyre 1993, 1995, 1996; Reeves et al. 1995; Schlosser and Angermeier 1995; Dunham et al. 1997).

Recent genetic analysis of the remaining Arroyo Chub populations reported a high level of population differentiation both within and between drainages, likely stemming from barriers to gene flow such as dams, and current watershed boundaries (Benjamin et al. 2016). Furthermore, Benjamin et al. (2016) found eight distinct populations from the six native watersheds sampled (no fish were captured in the San Luis Rey River). Fish from Pacoima Creek and Big Tujunga Wash (both in the Los Angeles Watershed) and the West Fork San Gabriel River and Walnut Creek (both in the San Gabriel Watershed) were reported as distinct populations, illustrating how quickly the effects of barriers to downstream migration can lead to changes in population structure. Urbanization has also been linked to reductions in genetic variation and impacts to gene flow have been reported (Bessert and Orti 2008).

Arroyo Chub were once considered a nuisance species in Crystal Lake (Vestal 1942) and populations may continue to persist in other lentic waters such as Big Bear Lake. Future research is recommended to determine if these populations persist. Additionally, there are populations outside of their native range in the Santa Clara, Ventura, and Santa Maria river basins, where habitat modifications are less severe. Future research is also recommended to determine the genetic origins of these non-native populations as they could be useful in maintaining the genetic diversity of the native populations and serve as a backup in case of loss due to a stochastic event.

Climate change, urbanization, development, and invasive species impacts could lead us to a grim outlook for Arroyo Chub, but the current population in Tijeras Creek provides a bright spot. This population is present and thriving in water currently proposed for 303(d) listing as impaired for benthic macroinvertebrates and phosphorous. The key here is likely the absence of non-native competitors and predators. Leveraging Arroyo Chub tolerance to poor water quality could prove to be an advantage in conservation of the species. In those streams where we did not detect the target species, yet a historical account of the species exists, over half (54%) contained non-native aquatic fauna. Conducting invasive species removals in small natural bottom creeks throughout the native range could provide additional habitat, and coupled with translocation, could help us prevent this species from becoming threatened or endangered.

ACKNOWLEDGMENTS

This manuscript would not be possible without significant contributions from H. Hansen, M. Stephens, K. Sankary, and I. Ralston. Additional information regarding Arroyo Chub in the Santa Ana River Watershed was generously provided by the Riverside Corona Resource Conservation District.

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Submitted 20 July 2021
Accepted 8 October 2021
Associate Editor was J. Kelly