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Research Article

An update on the freshwater exotic fauna in the Mediterranean region of Baja California, Mexico

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Abstract

Exotic species introductions are a major threat to biodiversity. The first step to their control involves identifying their presence, distribution, and impacts on native species and their habitats, especially in highly diverse regions. We update and document new records of exotic freshwater fauna from the Baja California Mediterranean region. We found 157 locality records of 17 exotic aquatic species; 16 genera and 15 families were recorded. Five species are new records for the region: Malaysian trumpet snail (*Melanoides tuberculata*), black bullhead catfish (*Ameiurus melas*), common carp (*Cyprinus carpio*), spiny softshell turtle (*Apalone spinifera*), and red-eared slider (*Trachemys scripta*). The catfish, carp, and softshell turtle have been previously reported from Baja California, but only from the Colorado River and adjacent Mexicali Valley, while the snail and slider represent new state records. Of the 157 locality records, 71 were found in published literature and 86 represent new records from field observations, collected specimens and citizen science observations. Based on discussions with local ranchers and landowners, some exotic species were introduced for food or aesthetic purposes, emphasizing the need for environmental programs to stop these actions.

Key words: biological invasions, exotic amphibians, exotic fish, invasive species, northwestern Baja California

Introduction

Exotic species are those species that have been transported by human activities beyond their original geographic range and into an area where they are not naturally found, as described by Blackburn et al. (2014). This movement enables the species to overcome inherent biogeographic barriers that would otherwise hinder its natural dispersion. The terms exotic, introduced, nonindigenous, or non-native are commonly used interchangeably (Blackburn et al. 2014). The introduction of exotic species is the second-greatest cause of species extirpation worldwide (Clavero and García-Berthou 2005; Blackburn et al. 2019) and is a global priority of the United Nations sustainable development goals for the 2030 Agenda. Exotic species are known to diminish and displace native wildlife populations

through direct predation, competition, disease transmission, and facilitation of invasion (Doherty et al. 2016). In addition, exotic species have strong impacts on the economy and human health (Cuthbert et al. 2021; Soto et al. 2022).

In Mexico, introducing exotic species has led to the extinction of 60% of native aquatic species (Mendoza and Koleff 2014). According to the National Advisory Committee on Invasive Species (NACIS 2010) to mitigate the negative effects of exotic species, the first step is to have a thorough understanding of their regional distribution to promote prevention, control, and eradication strategies.

The Mediterranean region of Mexico, located in northwestern Baja California, is one of 25 global biodiversity hotspots (Myers et al. 2000). This bioregion, extending into southern California and also known as the California Floristic Province (CFP), is an area with a great number of endemic plants and animal taxa in North America. For instance, in the Baja California region of the CFP, there are approximately 1800 native vascular plant species, with nearly half of them being rare, threatened, or regionally endemic species (Vanderplank et al. 2018). However, this region faces significant habitat loss and numerous conservation threats (Mittermeier et al. 2004; González-Abraham et al. 2015; Vanderplank et al. 2018). Furthermore, the number of exotic freshwater species, and their populations, have been growing in this hotspot (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014). This colonization is impacting the native freshwater species of Baja California, especially the endemic ones (Mendoza and Koleff 2014), such as population declines of the red-legged frog (*Rana draytonii*) and the Baja California pond turtle (*Actinemys pallida*) (Peralta-García et al. 2016; Valdez-Villavecencio et al. *in press*). In light of the foregoing, this contribution is a full review to provide an updated list of exotic freshwater species throughout the Mediterranean region of Baja California, Mexico, with the aim to document their overall distribution and dispersion in aquatic environments in this hotspot, which is crucial in regional conservation planning efforts.

Materials and methods

We gathered available information on exotic aquatic species from our own field observations from 2001 to 2008 and 2013–2021. We also conducted a literature search in databases such as BioOne, ISI Web of Science, JSTOR, Redalyc, Science Direct, SciELO Citation Index, and Scopus, in search of records and quantitative data supporting the presence of exotic freshwater fauna in the Mediterranean region of Baja California, Mexico. Finally, records were obtained from online database iNaturalist (= Naturalista; www.naturalista.mx) and Enciclovida (CONABIO 2023). These search tools allow filtering the search by taxonomic group, type of distribution (exotic, invasive exotic), state (Baja California), and environment (freshwater). All

these records were thoroughly reviewed and curated. Records with dubious identification or location were excluded and subjected to verification or removal, with the purpose of having in the database only those records that demonstrated greater certainty, plausibility, and accuracy in the presence locations (Clare et al. 2019; Cruickshank et al. 2019). Regarding citizen science records, we only utilize and subject to curation the observations categorized as "Research Grade", which are entries that include all the necessary metadata and have been identified down to the species level (Kittelberger et al. 2021).

We focus on the northwestern watersheds of Baja California, Mexico (Figure 1) that are part of the Mediterranean region that experiences winter and spring rains and dry summers. Predominant habitats in the region include coastal sage scrub, coastal succulent scrub, chaparral, riparian woodland, and salt marsh (Garcillán et al. 2012). A strong rainfall gradient is clearly evident when moving south along the Pacific coast of the northern peninsula of Baja California (Vanderplank et al. 2018). This annual precipitation can fluctuate between 100 and 700 mm (González-Abraham et al. 2010). Monthly average temperatures show minimal fluctuations along this gradient (Tijuana: 13 °C, in winter and 23 °C in summer, and El Rosario: 14 °C, in winter and 24 °C in summer) (Vanderplank et al. 2018). The elevation within this region ranges from sea level and includes two mountain ranges, the Sierra Juárez and the Sierra de San Pedro Mártir, with maximum heights of 1,200 m and 3,100 m, respectively (González-Abraham et al. 2010).

During the fieldwork between 2013 and 2018, we captured exotic fish and crayfish by using active capture methods. At most of the sites, we used six minnow traps; 45 cm long, 6.4 mm mesh netting and 2.5 cm openings at both ends (Ruiz-Campos et al. 2012). The traps were left in place for three days and were checked daily. We also captured species using dip nets or by hand. For the morphological identification of mollusks, crustaceans, fish, and amphibians, at least 3 individuals were fixed in situ in 96% ethanol and subsequently stored in a freezer at −10 °C. Specimen identification was conducted using specialized identification guides (see Supplementary material Appendix 1). Diacritical characters were included in Appendix 1, supplemented with information from the Information System on Invasive Species in Mexico (CONABIO 2017). Collected specimens were deposited in the vertebrate collections (Ichthyological and Herpetological) of the Facultad de Ciencias, Universidad Autónoma de Baja California (UABC; Ensenada). Photographic evidence was uploaded to iNaturalist platform. We also interviewed local ranchers and landowners to acquire information about the origins of introductions. For the final dataset, nearby localities (3 km) were aggregated as a single locality. This criterion was adopted with the aim

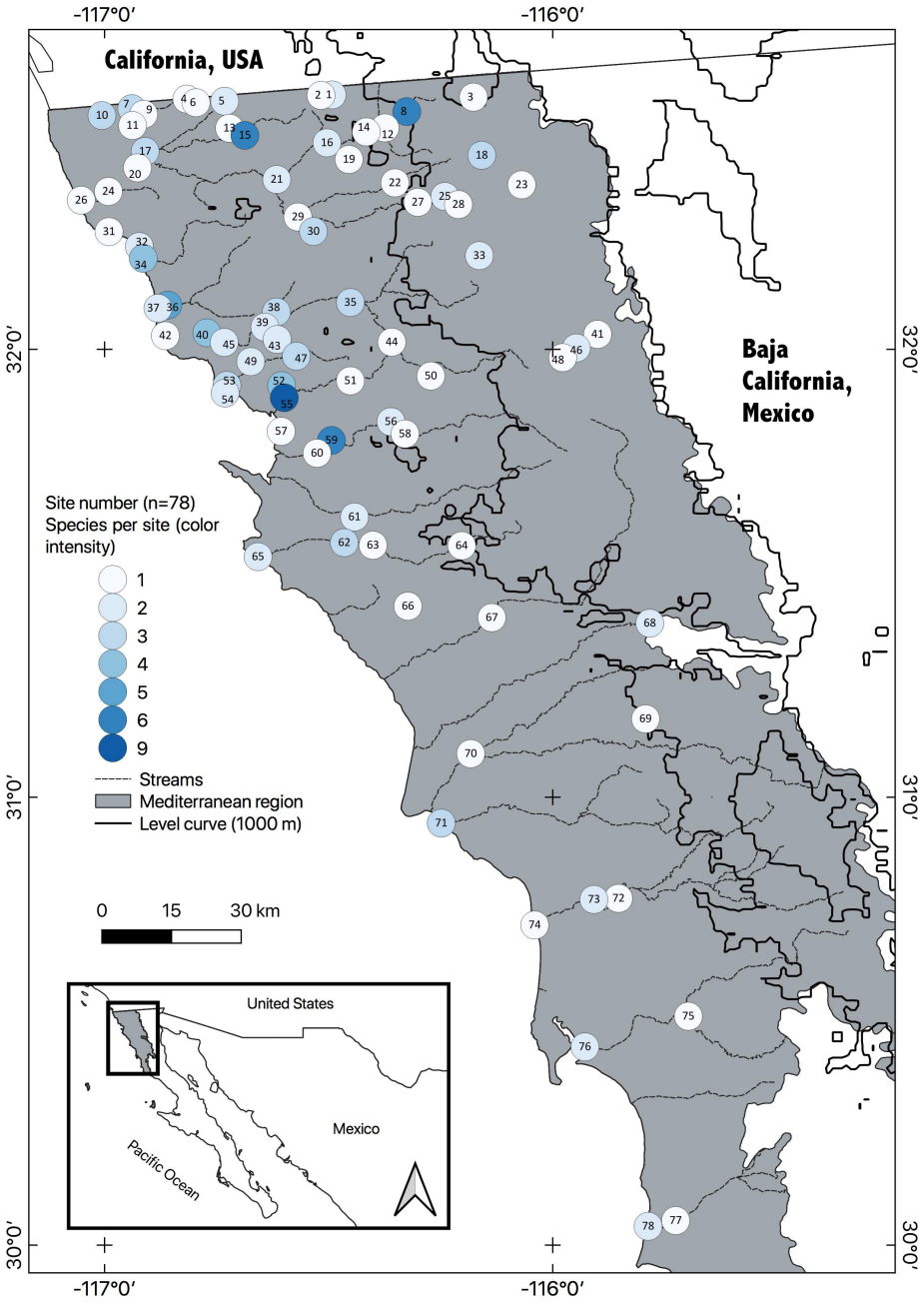

Figure 1. Distribution of freshwater exotic species in the Mediterranean region of Baja California, Mexico (gray area). Circles represent the localities with exotic species (n = 78); numbers correspond to localities in Supplementary material Table S1. Blue color intensity shows the number of exotic species per site (1–9).

of enhancing accuracy and reducing potential redundancies in our dataset, given that the close proximity of these localities often involves similar environmental conditions.

Results

Our list includes 157 records of 17 exotic species at 78 localities throughout the Mediterranean region of Baja California (Figure 1 and Table S1). Of the 17 exotic species, 12 have been previously reported in the region, while five are newly reported here: Malaysian trumpet snail (*Melanoides tuberculata*),

black bullhead (*Ameiurus melas*), common carp (*Cyprinus carpio*), spiny softshell (*Apalone spinifera*), and red-eared slider (*Trachemys scripta*). The bullhead, carp, and softshells have been previously reported from Baja California, but only in the Colorado River region located along the boundary of northeastern Baja California, while the snail and slider represent new state records. The most widespread exotic species were mosquito fish (*Gambusia affinis*), red swamp crayfish (*Procambarus clarkii*), and green sunfish (*Lepomis cyanellus*). Of the 78 localities with records of exotic freshwater species in the Mediterranean region, 38 localities have one exotic, 21 locations have two, 11 localities have three, three locations have four, one locality has five, three localities have six, and one locality has nine exotic species (Figure 1).

Below is a summary of the exotic species records. Site numbers correspond to Table S1. Information about species identification is included in Appendix 1, while information about catalog numbers for all records is included in Appendix 2.

Mollusks

We record five occurrences of three exotic mollusk species, two of which have been previously documented (Wakida-Kusunoki et al. 2015) and three are new records. These exotic mollusk species were observed at three distinct sites, with occurrences ranging from sea level to an elevation of 285 m (Table S1).

Corbicula fluminea (Muller, 1774). Within Baja California, this species was initially reported in 1970 from the Colorado River irrigation canals (Fox 1970). For the Mediterranean region, there is one previous record from El Carrizo reservoir east of Tijuana (site 15) (Wakida-Kusunoki et al. 2015). Here, we report two new ocurrence records for this species from Emilio L. Zamora reservoir (site 55) and Cañón San Carlos, Ensenada (site 59). This species is found from sea level to 285 m.

Dreissena bugensis Andrusov, 1897. There is one record of the species at El Carrizo reservoir (Wakida-Kusunoki et al. 2015). No additional new records of this species were found during the sampling of this study.

Melanoides tuberculata (Müller, 1774). First record for the state of Baja California. Here, we report a new occurrence record for this species at a small pond located in Cañón San Carlos, Ensenada (site 59) at an elevation of 112 meters in July 2018. Approximately fifty individuals were observed.

Malacostracans

The only member of this group reported in this region is the red swamp crayfish.

Procambarus clarkii (Girard, 1852) was recorded from 36 sites: 14 were previously reported in the literature (Sánchez-Saavedra et al. 1993;

Hernández et al. 2008; Peralta-García et al. 2016). Here, we report 22 new ocurrence records for this species (Table S1). This species is found from sea level to 1,270 m.

Fishes

There are 77 occurrences for exotic fishes in the region (49 previously published and 28 new records), representing nine species (Ruiz-Campos et al. 2012; Peralta-García et al. 2016). Exotic fish species are located at 50 sites, with records from sea level to 1,610 m elevation. Half of all fish occurrences refer to *Gambusia affinis* (38 records), and 30% to *Lepomis cyanellus* (23 records).

Ameiurus melas (Rafinesque, 1820). Within Baja California, this species has been previously reported from the lower Colorado River (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014). Here, we report the first occurrence record for the species in the Mediterranean region. We collected ten specimens at a pond at Arroyo La Misión (site 36) at an elevation of 5 meters in May 2013.

Cyprinus carpio Linnaeus, 1758. Within Baja California, this species has been reported from the Colorado River and the Mexicali Valley (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014). Here, we report the first occurrence record for the species in the Mediterranean region. Several individuals (~ 10) were seen at a small pond at Rancho El Chaco (site 30) at an elevation of 30 meters in April 2016, and at a reservoir at Rancho San Faustino, Sierra Juárez (site 33) at an elevation of 1,270 meters in 2013. Ranchers from El Chaco indicated that they introduced the species for fishing, and ranchers at San Faustino indicated that a nearby rancher stocked this species.

Dorosoma petenense (Günther, 1867). There is one previous record of the species at the Emilio L. Zamora reservoir, Ensenada (Site 55) (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014). Here, we report an additional record of occurrence for the species (Table S1). We collected a specimen from El Carrizo reservoir east of Tijuana (site 15) at an elevation of 285 meters in 2015.

Gambusia affinis (Baird & Girard, 1853). There are 25 sites with previous records for the species (Ruiz-Campos et al. 2012, 2014; Peralta-García et al. 2016). Here, we report 13 new occurrence records for this species (Table S1). The species is now found at 38 sites, with records from sea level to 1,596 m elevation.

Ictalurus punctatus (Rafinesque, 1818). There is one record of the species at the Emilio L. Zamora reservoir (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014). No additional new records of this species were found during the sampling of this study.

Lepomis cyanellus Rafinesque, 1819. There are 17 sites with previous records for this species (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014).

Here, we report five new ocurrence records for this species (sites 16, 23, 30, 36 and 53; Table S1). The species is now found at 22 sites, with records from sea level to 1,610 m elevation.

Lepomis macrochirus Rafinesque, 1819. There are two previous records of the species: one previous record at the Emilio L. Zamora reservoir and one from Laguna Hanson (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014). Here, we report a new ocurrence record for this species at site 18 (1,255 m elev; Table S1).

Micropterus salmoides (Lacepède, 1802). There are two sites with previous records: Emilio L. Zamora reservoir and the mouth of Arroyo San Simon (Ruiz-Campos et al. 2012; Ruiz-Campos et al. 2014). Here, we report three new occurrence records for this species (sites 8, 15, and 18, Table S1) with records from sea level to 1,255 m elevation.

Coptodon zillii (Gervais, 1848). There is one record of the species at Emilio L. Zamora reservoir (Ruiz-Campos et al. 2012). No additional new records of this species were found during the sampling of this study.

Amphibians (anurans)

There are 31 occurrences (6 published, 25 new) of two exotic amphibians in the region (Grismer 2002; Peralta-García et al. 2014). Exotic amphibians are found from sea level to 970 m elevation.

Lithobates catesbeianus (Shaw, 1802). There are two sites with prior records of this species, located within the Río Colorado drainage in northeastern Baja California and areas to the east of Tijuana in the northwest (Grismer 2002). Here, we report 18 new occurrence records for this species (Table S1). Ranchers at Rancho Ciénega Redonda (site 8) indicate that the American bullfrog was introduced 27 years ago from Mexicali. At the mouth of Arroyo El Rosario (site 78), adults have been observed since May 2002. The species is now located at a total of 20 sites, with records from sea level to 970 m elevation.

Xenopus laevis (Daudin, 1802). There are four sites with previous records for this species (Ruiz-Campos and Valdez-Villavicencio 2012; Peralta-García et al. 2014). Here, we report seven new occurrence records for this species (Table S1). The species is now present at a total of 11 sites, with records from sea level to 400 m elevation.

Reptiles (turtles)

There are no previous records of introductions of exotic turtles in the Mediterranean region. We report five records for two different species. Exotic turtle species are located at four localities within the region.

Apalone spinifera (LeSueur, 1827). Here, we report two new occurrence records for the species in the Mediterranean región (Table S1). At Rancho

Ciénega Redonda (site 8), local ranchers showed photographs and provided detailed descriptions of the species. They informed us that at one time there were four individuals, but now, only one remains (July 2015). The owners reportedly introduced this species from the Mexicali Valley irrigation canals where the species has been previously reported (Grismer 2002). At Cañada Los Alisos (site 3; 912 m elev.), we saw up to four softshell turtles at this little reservoir in 2021 and 2022 (photos taken 15 April 2022).

Trachemys scripta (Thunberg, 1792). Here, we report six new occurrence records for the state of Baja California (Table S1). We observed six individuals basking (3 adults and 3 juveniles) at Rancho Ciénega Redonda (site 8) and three individuals at a dam at Rancho El Compadre (site 25). Other localities include Parque de la Amistad and Parque Morelos in Tijuana (sites 7 and 11), Ejido Francisco Zarco in Guadalupe Valley (site 39), and Emilio López Zamora reservoir, Ensenada (site 55). At Rancho Ciénega Redonda and Rancho El Compadre, the turtles were intentionally released by the owners. At Rancho El Compadre, ranchers indicate the species has been there since 2008 and believe they have never reproduced. This species is found from sea level to 1,115 m.

Discussion

Exotic aquatic species are widespread across the freshwater systems of northwestern Baja California. This update increases the number of 70 previous records to 157 records. While the rate and timing of colonization is not well known, the oldest record is from 1945 corresponding to a sunfish (*Lepomis cyanellus*) (Follett 1960; Ruiz-Campos et al. 2012). The occurrence and spread of exotic species could be related to different causes, but is predominately by anthropogenic means (Hernández et al. 2008; Mendoza and Koleff 2014). For example, in the Sierra Juárez, several ranchers reportedly introduced fish, crayfish, and turtles for fishing or aesthetic purposes (sites 18, 23, 25, 33). Ranchers also report the introduction of American bullfrogs at Rancho Ciénega Redonda (site 8) from Mexicali in the 1990s for aesthetic reasons. Similarly, fish, crayfish, and American bullfrogs were introduced in the late 1970s at Emilio López Zamora reservoir, Arroyo San Carlos, and Arroyo San Antonio de las Minas for aesthetic or recreation reasons. All but one record of bullfrog is located in the northern part of the study region. The one exception is the southernmost surveyed location at El Rosario (site 78), where the means of introduction are unknown, but the first sightings are from early 2002. According to ranchers and local residents introducing and translocating exotic species is a common practice in Baja California, which highlights the need for environmental education about the negative effects on biota and their ecosystems.

Unfortunately, there are few studies in the region that address the specific effects exotics have on the native fauna. The effects of exotic

species on native species on the Baja California peninsula have been assessed in the lower Colorado River basin (Rorabaugh et al. 2002; Varela-Romero et al. 2003) and in the oases of Baja California Sur (Alaníz-García et al. 2004; Luja and Rodríguez-Estrella 2010; Andreu-Soler and Ruiz-Campos 2013), but not in northwestern Baja California. Despite this, it is widely known that exotics have negative consequences. For example, native amphibian tadpoles are susceptible to predation by American bullfrog and experiments confirm that mosquito fish influence the overall health and rate of growth of native species (Lawler et al. 1998). *Lithobates catesbeianus* is known to eat a wide variety of prey, such as frogs, turtles, snakes, small birds, and rodents, and competitively exclude native species (Ortíz-Serrato et al. 2014). In California, American bullfrog has been implicated in a demographic shift in population age-class of the western pond turtle (*Actinemys pallida*), with fewer small individuals being recruited into populations (Nicholson et al. 2020). At Cañada Miracielo in Arroyo San Antonio (site 47), we have documented the decline of this native freshwater turtle with the arrival of the *L. catesbeianus* (Valdez-Villavecencio et al. *in press*). Similarly, the California red-legged frog (*Rana draytonii*) can no longer be found in the northern part of its historic range in Baja California, probably due to exotic species (Moyle 1973; Peralta-García et al. 2016). However, there is no direct evidence that exotic species are the main reason for the decline of native turtle or frog populations, they have likely played a role directly, or indirectly, as they have in other parts of the California Floristic Province (Fisher and Shaffer 1996; Nicholson et al. 2020). *Procambarus clarkii*, *C. carpio*, *L. catesbeianus*, *X. laevis*, *M. tuberculate*, and *C. fluminea* are high priority exotic species for Mexico, due to their severe effect on the ecosystem (NACIS 2010; Mendoza and Koleff 2014). Research is needed to document the specific effects that exotics have on native species and their habitats in the Mediterranean region and so that measures of control/eradication will be more effectively implemented.

In northwestern Baja California, native species are adapted to a winter storm cycle with dry summers. Because the natural stream systems are ephemeral and flow episodically, exotic species are not well adapted to episodic heavy rains followed by long duration droughts, which make them susceptible to natural extirpations, and provide an opportunity for management and implementation of eradication programs. In southern California, the natural disruption of water flow has been shown to reduce the co-occurrence of exotic species with native amphibians, giving species like the arroyo toad (*Anaxyrus californicus*) the chance to breed (Miller et al. 2012). One management method to reduce or remove *L. catesbeianus* includes the drying out of occupied ponds combined with eradication programs (Peralta-García et al. 2016). In northwestern Baja California, this

is likely more difficult in stream systems than isolated ponds, but if timed with the seasonal water flow or periods of drought, some reductions might be achieved. Man-made ponds are present which may be temporarily drained to remove fishes and the American bullfrog since their tadpoles may take up to one year to complete the metamorphosis. According to Grismer (2002) northern Baja California could be one of the last refuges for the southern population of *R. draytonii* due to the destruction of its habitat, the introduction of bullfrogs in Southern California, and its initial commercial exploitation during the late 19th and early 20th centuries. From our updated list, we recommend managing exotic species and applying restoration actions to conserve the wetlands of this Mediterranean region.

Lastly, we propose a series of actions aimed at managing aquatic exotic species in the Mediterranean region of Baja California. These actions encompass the implementation of regular monitoring programs to identify and control the presence and expansion of these species. Furthermore, we advocate for the establishment of stringent regulations that restrict the introduction of exotic species into water bodies and facilitate subsequent control efforts. It is also crucial to promote education and awareness among the local community about the risks and effects associated with aquatic exotic species. To address competition and the establishment of these species, we suggest enhancing the restoration and conservation of native aquatic habitats. Finally, we emphasize the importance of collaborating with local communities, scientists, and authorities to develop comprehensive management strategies that effectively tackle the challenge posed by aquatic exotic species in the region.

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Authors' contribution

APG and JHVV designed the research. APG, JHVV, and RALR wrote the manuscript. APG and ANT acquired funding. All authors collected data. All authors revised drafts and approved the final manuscript.

Permits

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Supplementary material

The following supplementary material is available for this article:

Table S1. Freshwater exotic species from the Mediterranean region of Baja California, México.

Appendix 1. Identification and literature used.

Appendix 2. Record information and catalog numbers.

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