Chapter 4
Threats and Conservation Status of Freshwater Crayfish (Decapoda: Cambaridae) in Mexico

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4.1 Introduction

Approximately 10% of the world's species inhabit freshwater ecosystems, although they occupy less than 1% of the earth's surface (Strayer and Dudgeon 2010). Freshwater resources sustain a rapidly growing human population, and their overexploitation is leading to a freshwater biodiversity crisis (Vörösmarty et al. 2010). As a consequence, growing evidence shows that freshwater taxa are at greater risk of extinction than other groups, such as terrestrial vertebrates (Darwall et al. 2011; Ricciardi and Rasmussen 1999). Given this, increasing the knowledge of the distribution and conservation status of freshwater species is fundamental for their conservation (Darwall et al. 2011).

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Previous studies have found that threats to crayfish worldwide are set to increase both in magnitude and extent (Richman et al. 2015). Therefore, there is an urgent need to understand the extinction risk and threats faced by freshwater crayfish. In this study, we assess the extinction risk of native Mexican crayfish species described up to 2022.

Freshwater crayfish comprise about 670 species worldwide and occur in all continents except for Antarctica and continental Africa (Crandall and De Grave 2017). They inhabit four main habitat types: streams, ponds/lakes/large rivers, caves, and burrows (Crandall and Buhay 2008). Species inhabiting a specific habitat type show distinctive morphological adaptations. For example, cave dwellers (stygobitic) commonly show a lack of pigmentation and eye loss, and elongated limbs and sensory structures, whereas stream-dwellers are intolerant to low oxygen levels in the water. In general, crayfish are preferably nocturnal, mainly omnivorous, and play a key role in freshwater trophic webs (Reynolds et al. 2013; Alvarez and Villalobos 2016). Most species are gonochoric and sexually dimorphic, but hermaphroditism, intersexuality, and parthenogenesis have been described for several species (Yazicioglu et al. 2016). They have direct development with yolky-rich eggs and eclosion of juveniles. Females display brood care. They are used by human communities as a food source or as a bait to fish other animal species in several regions and have been model organisms for a variety of studies.

Freshwater crayfish are grouped in two superfamilies: Astacoidea and Parastacoidea. Astacoidea shows an holarctic distribution and Parastacoidea a semi-pantropical distribution, including Australasia, South America and Madagascar (Crandall and De Grave 2017). Astacoidea is composed by three families, Astacidae with 4 genera and 20 species, Cambaridae with 14 genera and 449 species, and Cambaroididae with 1 genus and 6 species. Parastacoidea is composed of one family, Parastacidae, which includes 15 genera and 198 species (Miranda et al. 2018). Native species of crayfish in North America belong to Astacidae (6 spp.) and Cambaridae, which is endemic to the region. In Mexico, all native crayfish species belong to the family Cambaridae, and 97% (59 of 61 spp.) are endemic to the country with a major hotspot of diversity in the center and south of Mexico.

The Cambaridae inhabits all types of freshwater bodies along the eastern slopes of Mexico and the Trans-Mexican Volcanic Belt (TMVB). Two genera naturally occur in Mexico: *Cambarellus* with 12 species and *Procambarus* with 47, whereas *Faxonius virilis* has been introduced to some localities in the state of Chihuahua, probably from populations located further in North America. Three species of *Cambarellus* are described from the Northern Plateau, whereas the rest inhabit lentic water bodies along the TMVB. Conversely, most of the species of *Procambarus* inhabit several river basins along the gulf coast (Fig. 4.1), from the Río Bravo in the north to the Usumacinta basin in the south. Only two species in the genus inhabit localities from the Pacific slope, *Procambarus digueti* (Bouvier, 1897) (Fig. 4.1a), from the tributaries of the Chapala Lake in the Lerma basin, and *Procambarus bouvieri* (Ortmann, 1909) (Fig. 4.1c) from the highlands of the Balsas basin.

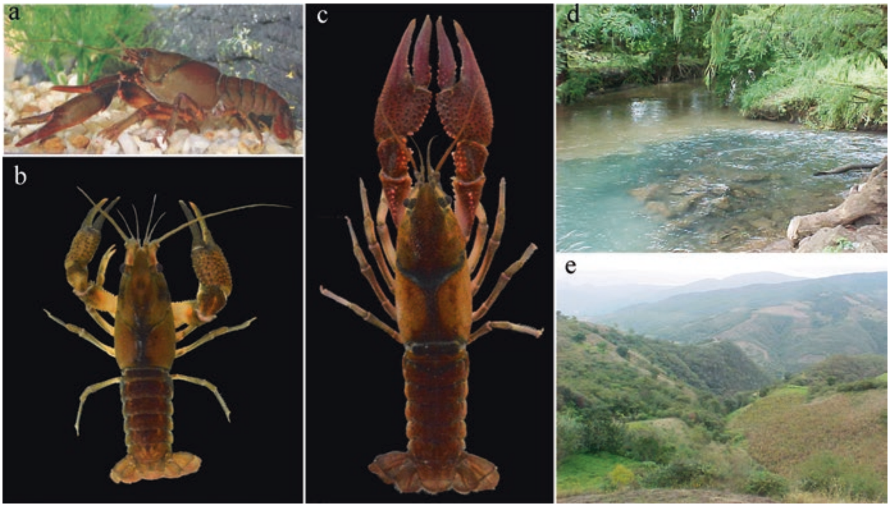

Fig. 4.1 Some examples of Mexican Crayfish species and their habitats. (**a**) *Procambarus digueti*; (**b**) *P. hoffmanni*; (**c**) *P. bouvieri*; (**d**) the Camécuaro river (at the right of the picture), habitat of *P. digueti*, joining to the Duero river, which shows contrasting habitat conditions in terms of pollution and physical modifications; (**e**) common conditions surrounding the habitat of several species dwellers of headwater streams (a small stream running down between hills), showing some modifications such as agriculture and livestock

4.2 Current Threats and Conservation Challenges

4.2.1 Introduced Species

Three crayfish species have been introduced into Mexico. Although naturally occurring in the Río Bravo basin, *P. clarkii* was translocated to distinct locations and from there it has spread to regions in the states of Baja California, Chiapas, Coahuila, Chihuahua, Durango, Nuevo León, Sonora, and Tamaulipas (Campos and Rodríguez-Almaraz 1992; Hernández et al. 2008).

Two more exotic crayfish represent a threat for native species. Populations of *Faxonius virilis* (native to the east part of the USA and southern Canada but now found widely in both countries) have now become established in northern Mexico in at least two localities (Campos-González and Contreras-Balderas 1985; Alvarez and Villalobos 2015). Although presently not showing a widespread distribution, the invasive potential of this species has been shown by its spread in non-native basins in other countries and justifies the need to avoid its translocation to other localities.

Furthermore, the Australian redclaw crayfish, *Cherax quadricarinatus*, brought to Mexico for aquacultural purposes, has escaped and established populations in Jalisco, Morelos, Nayarit, Nuevo León, San Luis Potosí, Sinaloa and Tamaulipas, and has been recently reported in the Sierra Gorda Biosphere Reserve, Querétaro (Rodríguez-Almaraz et al. 2018; Álvarez et al. 2014). Mendoza-Alfaro et al. (2011) reviewed the status of *C. quadricarinatus* in Mexico. Studies describing the possible impact on local environments and on native crayfish are urged in these zones, especially in the Pánuco watershed, a region harboring a striking diversity of Mexico's crayfish. This is especially true for *P. roberti*, endemic to the Media Luna Valley, in San Luis Potosí where *C. quadricarinatus* has invaded. Sampling of *P. roberti* showed a marked decline in populations from 2004 when compared to those in 2019. Individuals were very rare in the Lagoon, whereas in the outlet channels, a low abundance of individuals was observed. In contrast, *C. quadricarinatus* now has a thriving population in the Lagoon, which could be explained by a possible displacement of *P. roberti* by the exotic species. From the Media Luna Valley, there are high probabilities for dispersal of *C. quadricarinatus* to the rest of the Pánuco basin, inhabited by a high number of endemic crayfish species. Farming of the redclaw crayfish is part of an active aquaculture plan by the Mexican government at a national scale, so founding and spread of new populations from additional points in additional basins is expected in the near future if this program keeps operative. New feral populations have been established even in natural reserves, where native species inhabit, such as *Procambarus xihui*, endemic to the Sierra Gorda Biosphere Reserve.

4.2.2 Freshwater Extraction and Increased Rate of Desiccation

Freshwater extraction is a common practice in the habitats of a number of crayfish species. Many of them inhabit mountain springs, surviving surrounded by human activities such as dwelling construction, livestock raising, and agriculture, which routinely use water either directly from springs and stream headwaters, or indirectly from extraction by wells. Water extraction directly from water bodies has been observed in sampling efforts and has probably caused the complete dry-up of some localities. The spread of such activities seems to be on the rise, aided by human population growth in these locations, or the rise in economic activities highly dependent on water availability.

Cambarid populations inhabiting headwater stream ecosystems are especially sensitive to rainy conditions, as short and severe periods of drought may represent a high risk of extinction (Boulton 2003). The last decade along the Sierra Madre Oriental has been dryer than preceding decades (Seager et al. 2009). The most severe drought recorded from this region was during 2010–2015, with the year 2012 being the most intense (Mendoza-Villa et al. 2018). Climatic predictions at a regional scale indicate that naturally occurring sub-decadal droughts will be made more frequent and widespread by anthropogenic climate change (Seager et al. 2009). Impacts driven by climate change are expected to be substantial on headwater stream ecosystems, which makes diagnosing and planning for conservation an urgent task (Durance and Ormerod 2007). From this perspective, the conservation of the rivers' headwaters, as well as the maintenance of seasonal water regimes, is of utmost importance to preserve endemic species, especially those that have very narrow distributions. This is especially true for several species of the genus *Procambarus* that inhabit springs and mountain streams under high pressure from human activities, like agriculture and livestock raising (see Fig. 4.1e).

4.2.3 Pollution

Freshwater ecosystems in central Mexico are among the most disturbed habitats, severely altered by industrial, urban, crop, and livestock waste waters. In mountainous regions, unregulated mining and crop activities are important pollutants of small streams. Agriculture pollutes water with pesticides, greatly affecting crayfish populations to the extent of local extinction in the points receiving such discharges. Pollution is more relevant in aquatic ecosystems along the TMVB, habitat of most of the species of *Cambarellus*. But pollution is occurring in the habitats of several of *Procambarus* too. For example, *Procambarus digueti*, an inhabitant of the TMVB, at the Tangancicuaro Valley, part of the Duero basin before its junction to the Chapala lake. Only two localities have been recorded for the species in the last 20 years of samplings, corresponding to two oligotrophic and isolated springs, which are now channelized or polluted by urban and crop activities shrotly after its origin (pers. obs.; García et al. 2004) (see Fig. 4.1e).

Other highly endemic species illustrate the imperiled state of many Mexican crayfish. After extensive sampling along the Pánuco basin, *Procambarus strenthi* has only been found at the type locality, Santa Anita spring, close to Ciudad Valles, San Luis Potosí, and along the outlet stream extending approximately 100 m. Beyond that point, sugarcane monocultures begin, and no crayfish have been recorded further on. Water conditions change rapidly from oligotrophic in the spring to highly turbid in the downstream river, suggesting strong pollution associated with the surrounding cultures. Similar conditions have been observed for the only population found to date of *P. villalobosi* in a small basin from the Pánuco watershed. Similarly, the species has only been recorded from its type locality, composed by a small stream running along a small cave by ca. 50 m and emptying to a small shallow reservoir (around 12 m^2). Beyond that point, a small channel less than 1 m wide is formed and within 50 m is dammed into a small pool with no outlet. The locality is surrounded by agricultural fields, and a small town is located a bit higher in the mountain. Water is not clear when running underground, which makes us suppose some level of water pollution is already present. After the small cave, the habitat is strongly modified, and water becomes dirtier. Crayfish have been recorded only from the cave, possibly because conditions at the surface are non-suitable. As a troglophile, but non-stygobitic species, the habitat inside the cave is probably the only one available to date for the species.

4.2.4 Vulnerable and Restricted Habitats

Six species have been recorded exclusively in subterranean habitats, five of them showing troglomorphic (cave) adaptations. Cave systems not only have high levels of endemism due to the low dispersal ability of many cave-dwelling species but are also sensitive to environmental changes by disturbances directly to the cave or from the surrounding land cover, which may drive climatic changes within the underground system (Boulton 2020). Most Mexican cave-adapted crayfish have been recorded from one locality only. A paradigmatic case is *Procambarus xilitlae*, endemic to the bottom of the Sótanos de las Huahuas, San Luis Potosí, more than 420 m underground. Specimens have only been sampled on three occasions. In 1979, the first collected specimens motivated its description (Hobbs and Grubbs 1982), later, in 1981, allowed a more detailed description of genitalia (Hobbs and Grubbs 1986), and recently, in 2020, a sampling effort recorded some new specimens (pers. obs.). The population was observed as very scarce, inhabiting only some small, shallow ponds (less than 2 m long and around 15 cm deep) and composed by a few individuals. That is the case of most other species of troglobites, considered 'short-range' endemics (Harvey 2002) for which disturbances coming from water extraction, climate change, tourism and deforestation of the surrounding lands, could mean a loss of water infiltration and the greatest threat to their extinction.

Some species in the genus *Procambarus* inhabit low-altitude, high-order rivers, or the habitats associated with them, such as *P. clarkii*, *P. hoffmanni* (Fig. 4.1), *P. toltecae,* or *P. acanthophorus*. However, around 20 crayfish species inhabit headwater stream ecosystems or the springs from which these rivers originate and, in most cases, consist of small portions of streams harboring corresponding small populations. Headwater streams might be especially vulnerable to disturbances in the surrounding catchment, which correlates with a higher risk of biodiversity loss (Lowe and Likens 2005). Locally, populations inhabiting headwater stream ecosystems are especially sensitive to human disturbances, as these can easily drive populations to local extinction due to the small size of their distribution and corresponding population sizes. In fact, Mexico is considered as a hotspot of climate change-vulnerable crayfish species (Hossain et al. 2018), most of them restricted to such vulnerable habitats.

4.2.5 Habitat Modification (Channelization, Damming, Desiccation)

Drastic habitat modifications are observed for *Procambarus* species inhabiting headwater streams with oligotrophic conditions. As an example, *Procambarus bouvieri* inhabits only its type locality, a spring ca. 16 m^2 and a small outlet stream, which is dammed after about 100 m. The spring is located in a small locally protected area but surrounded by the second-largest city of the state of Michoacán. Historically, no individuals have been located in or downstream from the dam in all the surveys carried out in the area. Similar cases have been recorded for a number of species in the genus. Almost all *Cambarellus* species inhabit greatly modified ecosystems, especially through damming and channelization. However, members of this genus are probably tolerant to such modifications as the ecological requirements of this group are often found in lentic conditions. This does not mean that all levels of such disturbances can be tolerated by these species, as exemplified by the only two species of crayfish extinct to date, *C. alvarezi* and probably *C. areolatus*. *Cambarellus alvarezi* was endemic to a single location, the spring of Ejido El Potosí, Galeana, in the state of Nuevo Leon, Mexico (Rodríguez-Almaraz and Campos 1994). This spring no longer exists, having undergone reduction due to water extraction, and since 1994 has been permanently dry. Furthermore, this species has been surveyed additional times, over a period of 4–5 years within the only known habitat, but no specimens have been found. The most recent visit to the site in 2009 confirmed there was no surface water at Ejido El Potosí. The other species, *C. areolatus,* was also known from its type locality, near Parras, Coahuila; however, this location has now been flooded and is artificially managed. Recent surveys have found no specimens, and further survey work is planned. Here, *C. areolatus* is considered as critically endangered, although its situation probably corresponds to the status of extinct.

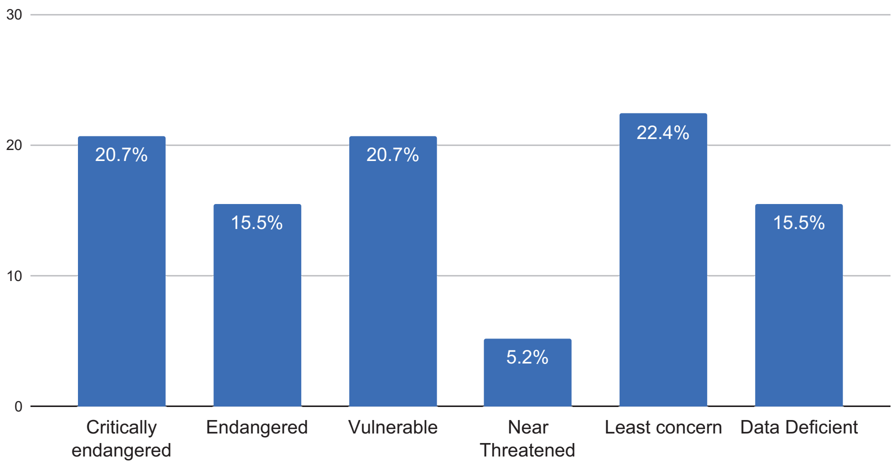

Fig. 4.2 Percent of native extant species of crayfish in Mexico assigned to a conservation status (CR, EN, VU), to other categories (NT, LC) or considered as data deficient

4.3 Conservation Status

Our analysis on the major threats faced by crayfish fauna in Mexico reveals an alarming situation. One species is definitely extinct in nature (Fig. 4.2), one more is probably in a similar situation after in situ confirmation (*C. areolatus*), and one additional species faces a very likely scenario of extinction in the short term (*C. chihuahuae*). Of the 58 species of cambarids native to Mexico and extant to date, more than half are assigned to a conservation status (33 species, 56.9%) either as CR, EN, or VU.

One species of Cambaridae is extinct in Mexico, *Cambarellus alvarezi* (EX) (Table 4.1). Its habitat, the spring of Ejido El Potosi, has been completely dry for nearly 30 years and has been lost as well as several other freshwater endemic species from the site. The fate of this species resembles that of many other, whose habitats have somehow endured the incoming disturbances for some time, but if such trends are maintained at the regional and local scales, these habitats could become unsustainable in a relatively short time.

Twelve native species of Cambaridae are found to be critically endangered (CR) (Table 4.1), which corresponds to 20.7% of the extant native species in Mexico. Assignation to such conservation status for most of these species is justified by criterion B1 (Extent of Occurrence, EOO), as they have only been recorded from one locality and the EOO is less than 100 km^2. Sometimes, such reduced occurrence is explained by the specificity of their habitats, that is why several of them inhabit only one cave location, and they are assumed to be unable to sustain populations in surface habitats, as they are cave adapted. In addition, strong disturbances have been recorded in their only locality, which represents a high risk of extinction. This is the case of *P. adani*, and *P. xilitlae*. As previously mentioned, any disturbance directly in the caves or in the surrounding lands could affect the population and hence pose a high risk of extinction for these species. Their localities are already affected by human activities such as deforestation, direct modification of cave habitats, climate change, or an increased rate of desiccation at a regional scale, which threatens the conservation of their populations in the short term.

Two species of the genus *Cambarellus* are also in this category, *C. chihuahuae* and *C. areolatus*. *Cambarellus chihuahuae*, previously occurring in several spring habitats in the Guzman desert basin, Chihuahua, had been considered extinct by previous IUCN evaluations because the habitat of all populations known to that date had been documented to be dried up, as a consequence of the intense water extraction carried out in the region for crop irrigation (Alvarez et al. 2010). However, some years later, one additional population was discovered in Ojo Solo spring (Carson et al. 2015). The locality, however, is still under great danger and is possibly affected by the same disturbances causing the extinction of the rest of its neighbour springs. Efforts are being made to build a refuge under protection, but the species is evidently under great risk of extinction in the short term if no additional efforts are taken to ensure the prevalence of this last natural population. In the case of *C. areolatus*, the drastic habitat modification and the failure to recover

Table 4.1 Species of Cambaridae from Mexico, major threats affecting their conservation and updated status of conservation based on IUCN criteria

	Threats								IUCN status and criteria	
Species	1	2	3	4	5	6	7	8	9	10
1. *Cambarellus* (*Cambarellus*) *alvarezi* Villalobos, 1952	•	•				•			EX	–
2. *Cambarellus* (*Cambarellus*) *areolatus* Faxon, 1885	•	•		•		•			CR	B1
3. *Cambarellus* (*Cambarellus*) *chapalanus* Faxon, 1898		•	•	•	•		*	•	VU	–
4. *Cambarellus* (*Cambarellus*) *chihuahuae* Hobbs, 1980	•	•		•		•			CR	A2, B1, B2a,b,c,
5. *Cambarellus* (*Cambarellus*) *lermensis* Villalobos, 1943		•	•	•	•		*		LC	–
6. *Cambarellus* (*Cambarellus*) *moi* Pedraza-Lara, Ortíz-Herrera and Jones, 2021		•	•	•	•	•			VU	B1
7. *Cambarellus* (Cambarellus) *montezumae* de Saussure, 1857			•	•	•	•	*	•	VU	B1
8. *Cambarellus* (*Cambarellus*) *occidentalis* Faxon, 1898			•				*		LC	–
9. *Cambarellus* (*Cambarellus*) *patzcuarensis* Villalobos, 1943		•	•		•		*	•	VU	B1
10. *Cambarellus* (*Cambarellus*) *prolixus* Villalobos and Hobbs, 1981		•	•		•		*	•	CR	B1
11. *Cambarellus* (*Cambarellus*) *zacapuensis* Pedraza-Lara and Doadrio, 2015		•	•	•			*		LC	–
12. *Cambarellus* (*Cambarellus*) *zempoalensis* Villalobos, 1943							*		LC	–
13. *Faxonius virilis* (Hagen, 1870)	–	–	–	–	–	–	–	–	–	–
14. *Procambarus acanthophorus* Villalobos, 1948									LC	–
15. *Procambarus achilli* López, Mejía and Álvarez, 2003		•		•			*		VU	B1,D2
16. *Procambarus adani* Alvarez, Torres and Villalobos, 2021			?			•			CR	B1,D2
17. *Procambarus bouvieri* (Ortmann, 1909)		•		•		•	*		CR	B1
18. *Procambarus caballeroi* Villalobos, 1944			•						VU	B1,B2a, D2
19. *Procambarus catemacoensis* Rojas, Álvarez and Villalobos, 2000							*		EN	B1
20. *Procambarus cavernicola* Mejía-Ortiz, Hartnoll, and Viccon-Pale, 2003			?	•					EN	B1
21. *Procambarus chacalli* López-Mejía, Álvarez and Mejía-Ortiz, 2004	?	?	?	?	?	?	?		DD	–
22. *Procambarus citlaltepetl* Rojas, Álvarez and Villalobos, 1999		•		•		•			VU	B1
23. *Procambarus clarkii* (Girard, 1852)								•	LC	–
24. *Procambarus contrerasi* (Creaser, 1931)	?	?	?	?	?	?			DD	–
25. *Procambarus cuetzalanae* Hobbs, 1982	?	?	?	?	?	?			NT	–
26. *Procambarus cuevachicae* (Hobbs, 1941)		•		•		•			EN	B1
27. *Procambarus digueti* (Bouvier, 1897)			•	•	•	•	*	•	CR	B1
28. *Procambarus erichsoni* Villalobos, 1950	?	?	?	?	?	?			DD	–
29. *Procambarus gonopodocristatus* Villalobos, 1958	•	•	•	•		•	*		EN	B1

(continued)

Table 4.1 (continued)

	Threats								IUCN status and criteria	
Species	1	2	3	4	5	6	7	8	9	10
30. *Procambarus hidalgoensis* López-Mejía, Álvarez and Mejía-Ortiz, 2005	•		•			•			EN	B1
31. *Procambarus hoffmanni* (Villalobos, 1944)									LC	–
32. *Procambarus hortonhobbsi* Villalobos, 1950	?	?	?	?	?	•			DD	–
33. *Procambarus llamasi* Villalobos, 1954							*	•	LC	–
34. *Procambarus maya* Álvarez, López-Mejía and Villalobos, 2007						•			DD	–
35. *Procambarus mexicanus* (Erichson, 1846)									LC	–
36. *Procambarus mirandai* Villalobos, 1954	?					?			LC	–
37. *Procambarus oaxacae* Hobbs, 1973	?	?	?	•		•			EN	B1,B2a
38. *Procambarus olmecorum* Hobbs, 1987									DD	–
39. *Procambarus ortmannii* (Villalobos, 1949)	?	?	?	?	?	•			EN	B1
40. *Procambarus paradoxus* (Ortmann, 1906)	•		•			•			CR	B1
41. *Procambarus pilosimanus* (Ortmann, 1906)							*		LC	–
42. *Procambarus reddelli* Hobbs, 1973	?	?	?	•		•			VU	B1,B2a, D2
43. *Procambarus regiomontanus* (Villalobos, 1954)	•	•	•	•		•	•		CR	B1,B2a
44. *Procambarus riojai* (Villalobos, 1944)									LC	–
45. *Procambarus roberti* Villalobos and Hobbs, 1974	•	•	•	•		•	•		CR	B1
46. *Procambarus rodriguezi* Hobbs, 1943			?			•			VU	B1
47. *Procambarus ruthveni* (Pearse, 1911)		?	?	?	?	?			VU	B1
48. *Procambarus sbordonii* Hobbs, 1977	?	?	?		?	•			DD	–
49. *Procambarus strenthi* Hobbs, 1977		•	•			•			CR	B1
50. *Procambarus teziutlanensis* (Villalobos, 1947)					?				VU	B1
51. *Procambarus tlapacoyanensis* (Villalobos, 1947)					?				VU	B1
52. *Procambarus toltecae* Hobbs, 1943							*		LC	–
53. *Procambarus vazquezae* Villalobos, 1954							*		NT	B1
54. *Procambarus veracruzanus* Villalobos, 1954		?	?	?	?	?			DD	–
55. *Procambarus villalobosi* Hobbs, 1967	•	•	•	•	•	•			CR	B1,D
56. *Procambarus xihui* Pedraza-Lara, Gutiérrez-Yurita and De jesús-Bonilla, 2021	•	•	•			•	•		EN	B1
57. *Procambarus xilitlae* Hobbs and Grubbs, 1982	•		?			•			CR	B1,D
58. *Procambarus xochitlanae* Hobbs, 1975	?	?	?						VU	B1,D2
59. *Procambarus zapoapensis* Villalobos, 1954	?	?	?	?	?	?	?		NT	–
60. *Procambarus zihuateutlensis* Villalobos, 1950	?	?	?	?	?	?			DD	–

• means that the disturbance has been observed and is estimated to affect the conservation status of the species; ? indicates no data are available; *EX* extinct in the wild, *CR* critically endangered, *EN* endangered, *VU* vulnerable, *DD* data deficient (there is no data to evaluate the conservation status), (1) Increased rate of desiccation at regional scale (including possible impact of climate change), (2) freshwater extraction, (3) pollution, (4) habitat modification (dam, Channelization, dry up), (5) eutrophication, (6) fragmentation or isolation of populations, (7) impact by introduced species (* = introduced fish species co-occur and probably affect their populations, here, • = an introduced species of crayfish co-occur and represents a clear threat), (8) unregulated exploitation or culture of the species, (9) IUCN updated status, (10) IUCN fulfilled criteria individuals in previous sampling attempts made us suppose it is possibly extinct; however, this has to be confirmed by further sampling efforts. *C. prolixus* inhabits only very specific conditions at the Chapala Lagoon, in the Lerma basin, where the species is subject to severe changes in water regime, pollution and fishing.

The rest of epigean species assigned to a CR status also occur in one or a very reduced number of locations and their habitats face an increasing number of strong disturbances. That is the case of *P. bouvieri*, *P. digueti*, *P. paradoxus*, *P. regiomontanus*, *P. roberti*, *P. strenthi,* and *P. villalobosi*. For all of these, an increasing rate of habitat degradation, fragmentation, pollution, or local extinction has been observed in previous surveys. In addition, some species are under fishery pressure, such as *P. digueti*, which is intensively fished for human consumption without any regulation. If actual trends do not change, all these species are under great danger of extinction.

Nine species are assigned a status of endangered (EN): *P. catemacoensis*, *P. cavernicola*, *P. cuevachicae*, *P. gonopodocristatus*, *P. hidalgoensis*, *P. oaxacae*, *P. ortmanni, P. rodriguezi*, and *P. xihui*. This represents 13.8% of the native extant species in the country. These species have in common that they inhabit sensitive and reduced habitats; only one or a small number of populations have been recorded or these are fragmented or affected by different kinds of disturbances. Still, the habitat of these species is available, making their estimated distribution possibly larger than recorded, or its populations can probably reach each other eventually. These are, however, species with great risk of extinction in the middle term if no measures are taken to change the actual trends in local and regional disturbances affecting their habitats. Localities include headwater ecosystems or highly fragmented locations due to intensive agricultural practices which have isolated populations or for which there are records of locally extinct populations. That is the case of *P. gonopodocristatus*, recently recorded in a small well which fed a large citric culture zone in Veracruz, and *P. xihui*, for which three out of five recorded populations have become extinct in a period of nearly 20 years (Pedraza-Lara et al. 2021). Four cave-dwelling species are also considered as endangered: *P. cavernicola* from Oaxaca, *P. cuevachicae* from San Luis Potosí, *cP. oaxacae* also from Oaxaca and *P. rodriguezi* from Veracruz. Although some records exist from epigean populations for *P. cuevachicae*, they need posterior taxonomic confirmation because cave populations show some degree of morphological or genetic differentiation. Consequently, the only record confidently assigned to the species comes from the cave it was described from, and underground water is being extracted directly from the habitat. In the case of *P. cavernicola*, *P. oaxacae* and *P. rodriguezi*, they are only known from their cave type locality and they are among the six described species in Mexico showing morphological modifications to cave life, which similar to the rest of cave-adapted crayfish from Mexico, makes them especially vulnerable to disturbances, as it seems unlikely that they could sustain surface populations in the case of local disturbances are sustained inside or surrounding their cave habitats.

Twelve species are assigned the category of vulnerable (VU), representing 20.7% of the native extant species of cambarids. These species maintain a population assessed as relatively stable but occupy sensitive habitats or are surrounded by intermediate disturbances such as flood plains or suburban sewage discharge. In addition, it is believed that availability of its habitat can result in larger areas of occurrence than currently known, but they are already noticeably disturbed. That is the case of several epigean species occurring in headwaters or at intermediate altitudes. In addition, three species have been reported from relatively healthy cave ecosystems, such as *P. rodriguezi*, *P. teziutlanensis,* and *P. xochitlanae*, although they do not show morphological modifications to cave life or, as in the case of *P. reddelli*, are recorded in multiple cave localities, along a relatively large area.

Three species are assigned the category of near threatened (NT), by the proximity of the species to the criteria for the category vulnerable, especially regarding the estimates of population size or because there are no current threats, but there are plausible events that may cause the species to decline. Still, such events are unlikely to make the species extinct or critically endangered in the short term. This is the case of *P. cuetzalanae*, *P. zapoapensis* and *P. vazquezae*., which are only known from their type locality and a few sites nearby. Their populations in such sites, although subject to intermediate disturbances nowadays, could face habitat deterioration in the mean time, if trends are maintained. Assessed as least concern (LC) are species whose populations are stable in the long term and either threats are not detected in their habitats or they are apparently capable of tolerating such changing conditions. Thirteen species are classified in this category, which corresponds to 22.4% of the native, extant cambarids. That is the case of some species in *Cambarellus*, which are frequently observed in dammed conditions. Also included here are species of *Procambarus* which inhabit low-altitude water courses and could probably maintain stable populations in such habitats.

Finally, nine species could not be assessed because there is a lack of information and regarded as data deficient (DD). Most of them have only been collected one or a few times in the past from localities of difficult access. They probably occupy a small geographical area. Also, some of the regions from where they are reported are known to maintain the mentioned threats on aquatic habitats to some degree. Consequently, although the lack of information prevented their assessments, our expectations of the conservation status are not optimistic for most of them and it is possible that the numbers of species under any category will rise with the advancement in future surveys.

Together with the advance in surveys of crayfish populations, this fauna has been increasingly recognized as in need of 'conservation attention' (Taylor et al. 2007; Furse 2014). Approximately one-third of crayfish species worldwide are considered as threatened with extinction (Richman et al. 2015). Previous works have estimated that 48% of North American species and 25% of Australian species are threatened (Taylor et al. 2007; Furse 2014; Furse and Coughran 2011). In the near future, extinction rates for crayfish may increase by more than an order of magnitude exceeding those of freshwater fishes and amphibians (Ricciardi and Rasmussen 1999). This work shows that the situation of freshwater crayfish in Mexico is even more imperative, where more than half of the species are in danger of being lost if no measures are taken in order to revert current trends in habitats at local and regional scales. Future work should consider efforts to preserve this fauna through transdisciplinary studies to increase awareness on their ecological and cultural value and take steps to combine scientific knowledge with convenient public measures that will ensure that human needs will be resolved without the need to lose most of this unique component of the diversity. Furthermore, it is also important to promote the development of other lines of research to determine with certainty the population status of several species that have not been sampled in recent years. Recently, a significant number of crayfishes from different locations in Mexico have been deposited in the National Crustaceans Collection, at the Biology Institute, UNAM, particularly interesting are those from western and southeastern Chiapas, which probably represent several species complexes related to *P. mirandai* and *P. pilosimanus*, which are also being threatened by the development of the human communities. In such cases, we risk losing many species without ever knowing they existed.

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