

Resilience under threat: Possible impacts of climate change and human activities on the native shrimp *Macrobrachium tenellum*

Resiliencia amenazada: Posibles Impactos del cambio climático y actividades humanas en el langostino nativo *Macrobrachium tenellum*

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ABSTRACT

The objective of this study was to analyze the anthropogenic effects on native shrimp populations through documentary evidence. To this end, documents found in databases addressing anthropogenic factors affecting these species were analyzed. Additionally, surveys were conducted among local residents to gather information on the use of the species and the anthropogenic effects identified by the communities. Furthermore, the nutritional quality of *Macrobrachium tenellum* muscle was analyzed using chemical computation to determine its protein quality based on essential amino acids. The research identified six main factors threatening *M. tenellum* populations: habitat modification and fragmentation, water pollution from agricultural, industrial, and urban activities, destructive fishing practices, introduction of invasive species, climate change impacts, and intestinal microbiome alteration. Nutritional analysis showed that *M. tenellum* has high-quality protein, with adequate amounts of essential amino acids. There is a clear need to implement a holistic conservation approach that integrates environmental protection measures, sustainable management, and socioeconomic considerations to ensure the preservation of the species and the well-being of dependent communities.

KEY WORDS: Pollution, Nutrition, Overfishing, Social impact, Habitat modification.

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RESUMEN

El presente trabajo tuvo como objetivo analizar los efectos antropogénicos en las poblaciones de langostinos nativos a través de evidencia documental. Para ello, se llevó a cabo el análisis de documentos detectados en bases de datos que abordaran los factores antropogénicos sobre estas especies. Además, se llevó a cabo la realización de encuestas a habitantes locales para recopilar información sobre el aprovechamiento de la especie y los efectos antropogénicos identificados por las comunidades. Adicionalmente, se llevó a cabo el análisis de la calidad nutricional del músculo de *Macrobrachium tenellum* mediante cómputo químico para determinar su calidad proteica basada en aminoácidos esenciales. La investigación identificó seis factores principales que amenazan las poblaciones de *M. tenellum*: modificación y fragmentación del hábitat, contaminación del agua por actividades agrícolas, industriales y urbanas, prácticas de pesca destructivas, introducción de especies invasoras, impactos del cambio climático y alteraciones en el microbioma intestinal. El análisis nutricional demostró que la proteína de *M. tenellum* es de alta calidad, con cantidades adecuadas de aminoácidos esenciales. Se evidencia la necesidad de implementar un enfoque de conservación holístico que integre medidas de protección ambiental, manejo sostenible y consideraciones socioeconómicas para garantizar la preservación de la especie y el bienestar de las comunidades dependientes.

PALABRAS CLAVE: Contaminación, Nutrición, Sobrepesca, Impacto social, Modificación del hábitat.

Introduction

Due to human actions, climate change has been accelerating, becoming one of the most complex challenges in socio-political and socio-economic aspects, aspects—related to air, water, soil, or emissions, as well as in environmental quality—and ecological facets, understood as those that directly affect the relationships between organisms and their ecosystems. Latin America and the Caribbean are regions that stand out as being most vulnerable to climate change, while also having the most biodiverse areas in the world (Uribe, 2015). Carabias *et al.* (2005) point out that climate change intensifies the vulnerability of ecosystems and of the human populations that depend on them, particularly affecting freshwater habitats, which depend on ecological processes in remote areas and suffer both direct and indirect impacts from human activities and environmental alterations (Carabias *et al.*, 2005; Molina *et al.*, 2017). Fisheries, as dynamic socio-ecological systems, are undergoing rapid changes related to markets, exploitation, and forms of

governance, making them particularly vulnerable to the impacts of climate change (Daw *et al.*, 2009). Flores *et al.* (2010) recognize that fish catches are indicators of global climate change, as rising temperatures significantly influence physical and biological processes at regional and global scales, affecting the life cycles of species at the population level. This is reflected in the dispersion, recruitment, and efficiency of individuals at various stages of their life cycle. However, climate change has not been the only factor identified as a potential modifier of ecosystems and, therefore, of the organisms associated with them. Some factors have been clearly studied as deleterious modifiers of these natural systems, and in many cases have contributed to the decline or extinction of species. Heavy metal and pesticide pollution, watercourse alteration, overfishing, and the introduction of exotic species are just some of the threats facing these ecosystems (Escobar, 2002; Mokaya *et al.*, 2004) and not only affect biodiversity but also jeopardize ecosystem services vital to human well-being (Mendiguchía, 2005), which in turn has repercussions on food security and the economy of local communities that depend on them.

River shrimp of the genus *Macrobrachium* live in all tropical and subtropical regions of the world and adapt to a variety of environments, such as rivers, streams, estuaries, swamps, and coastal lagoons (Vega-Villasante *et al.*, 2014; Vega-Villasante *et al.*, 2017). Cruz-Sánchez *et al.* (2019) highlight their economic importance due to their high protein value, taste, and visual appeal. García-Guerrero *et al.* (2013) point out that there are few studies on this genus and its use. Previous studies have pointed to the limited scientific production on the *Macrobrachium* genus, especially in relation to its sustainable use and economic potential (Chong-Carrillo *et al.*, 2015; Chong-Carrillo *et al.*, 2021). These studies identify structural weaknesses in regional research and highlight the importance of strengthening applied knowledge on these species. Despite their importance, native shrimp populations face multiple threats associated with urban expansion, intensive land use, water pollution, and overexploitation. CONASPECA (2021) has reported stagnation and even a decline in the production of shrimp species in recent years. Specifically, *M. tenellum* (Smith, 1871) is a freshwater aquaculture species native to the Pacific slope, distributed from northwestern Mexico to Peru. It inhabits mainly rivers and streams that flow directly into the sea, forming part of estuarine systems and freshwater-brackish transition zones. Its capture represents an important supplementary income for artisanal fishermen. Not only is it an important component of aquatic biodiversity, but it is also part of the food identity of many riverside communities in regions such as Jalisco, Nayarit, and Oaxaca.

In the specific case of *M. tenellum*, the alteration of aquatic systems due to anthropogenic activities such as agriculture, mining, and industry puts not only the species at risk but also the people who consume it (Cruz-Sánchez *et al.*, 2019). Understanding these factors and their effects is crucial for developing conservation and sustainable management strategies that ensure the persistence of these species and the ecosystem services they provide. As Altieri *et al.* (2013) point out, there is a close relationship between social and ecological resilience, particularly in groups or communities that depend directly on environmental resources for their survival. The present study aims to determine how human activities may affect river shrimp populations, with particular attention to *M. tenellum*, by searching for specialized information in databases and through the perceptions that the inhabitants of the area themselves have about this shrimp. The nutritional quality of *M. tenellum* was also analyzed through chemical analysis in order to compare with other

common protein sources in populations with limited resources, to determine the possible effect of the decline or loss of this resource on the nutrition of riverside communities.

Material and Methods

Bibliometric study

A search was conducted for published articles on climate change and anthropogenic effects on *Macrobrachium*. It should be noted that the bibliometric analysis was carried out at the genus level, considering all species reported in the database consulted. Based on these general results, a comparative and reflective analysis was performed, focusing particularly on *M. tenellum*, given its presence in literature and its relevance in the regional context of the study. The search was carried out in the SCOPUS database. The information was collected using the keywords: “anthropogenic,” “*Macrobrachium*,” “climate change,” and “global warming,” limiting the search to titles, abstracts, and keywords. The results were filtered to retain only articles that referred to the established topic. The analysis took into account the timeline of article production from 2000 to 2024, the authors, affiliations, countries, subject areas, and document type. The database was transferred to Excel for management and graph generation.

The selected studies were organized and analyzed according to the established themes: i) Climate change: Projections on the geographical distribution of species and physiological responses to temperature increases and extreme events were evaluated. ii) Habitat modification: The effects of physical barriers, such as dams and river diversions, on population connectivity and reproductive cycles were analyzed; iii) Overfishing and illegal practices: The impacts of overfishing, destructive fishing gear, and lack of regulation on population sustainability were documented; iv) Pollution: Studies on the bioaccumulation of heavy metals, microplastics, and other pollutants and their physiological and ecological effects were reviewed; v) Sociocultural and economic importance: Information was collected on the role of *Macrobrachium* in the local economy and in the cultural traditions of coastal and riverine communities. vi) Nutritional quality: Data on the biochemical composition (proteins, lipids, and minerals) of the species (detailed below) and the possible effects of pollution on its quality were analyzed. vii) Resilience: Arguments for and against the species' ability to adapt and persist in the face of environmental impacts were identified and categorized, highlighting genetic, ecological, and management factors that could influence its adaptive capacity.

Determination of nutritional quality: chemical computation

Chemical score (CS) is a method for evaluating the nutritional value of a protein based on the amount of essential amino acids it contains, comparing them with human requirements (FAO/WHO, 2013). The digestibility-corrected chemical score (PDCAAS) takes into account not only the amino acid profile of the protein, but also its digestibility, i.e., how well the body can digest and absorb it (FAO/WHO, 2013). The amino acid profile of the caudal muscle (tail) of *M. tenellum* was obtained from the study carried out by Espinosa-Chaurand *et al.* (2013). The CS and PDCAAS

were determined following the method implemented by Montoya-Martínez *et al.* (2016) and Basto-Rosales *et al.* (2020).

The chemical score (CS) was calculated as follows:

$$CS = \frac{((\text{mg of essential amino acids in the evaluated protein}))}{((\text{mg of the same amino acids in the reference protein}))} \quad (1)$$

For the corrected chemical score, the reported digestibility for shrimp muscle with a digestibility of 83.46 % (Orlien *et al.*, 2021) was used. The PDCAAS was evaluated as follows: milligrams of essential amino acid in 1 g of the test protein/milligrams of the same amino acid in 1 g of the reference protein, based on its digestibility.

The values of CS and PDCAAS equal to or greater than 1 demonstrate that the food meets the protein requirements necessary to satisfy human nutritional needs. On the other hand, values lower than 1 indicate which amino acids are limiting.

The PDCAAS of *M. tenellum* muscle was compared with that of tilapia (*Oreochromis niloticus*), carp (*Cyprinus carpio*), and tuna (*Thunnus thynnus*) (Basto-Rosales *et al.*, 2020) to determine the nutritional similarities or differences between them.

In addition, a social perception component was included through surveys aimed at the general population. The surveys were distributed through Google Forms, with closed, multiple-choice, and dichotomous questions. Their purpose was to assess knowledge about the species, perceptions of anthropogenic factors affecting its populations, and attitudes toward its conservation. They were conducted between May 2024 and February 2025.

Results and Discussion

Bibliometric analysis

The results presented in this section are derived from a systematic review covering both general studies of the genus *Macrobrachium* and those specific to *M. tenellum*. This dual inclusion is due to the limited availability of scientific information focused exclusively on this species, thus allowing a broader and more contextualized view of the environmental and socioeconomic impacts analyzed. A total of 64 publications were analyzed covering the period between 2000 and 2024. The years 2022 and 2024 stood out as the most productive in terms of scientific output, with eight publications each. From 2020 onwards, there was a notable increase in scientific output related to the impact of climate change and anthropogenic factors on the *Macrobrachium* genus (Figure 1).

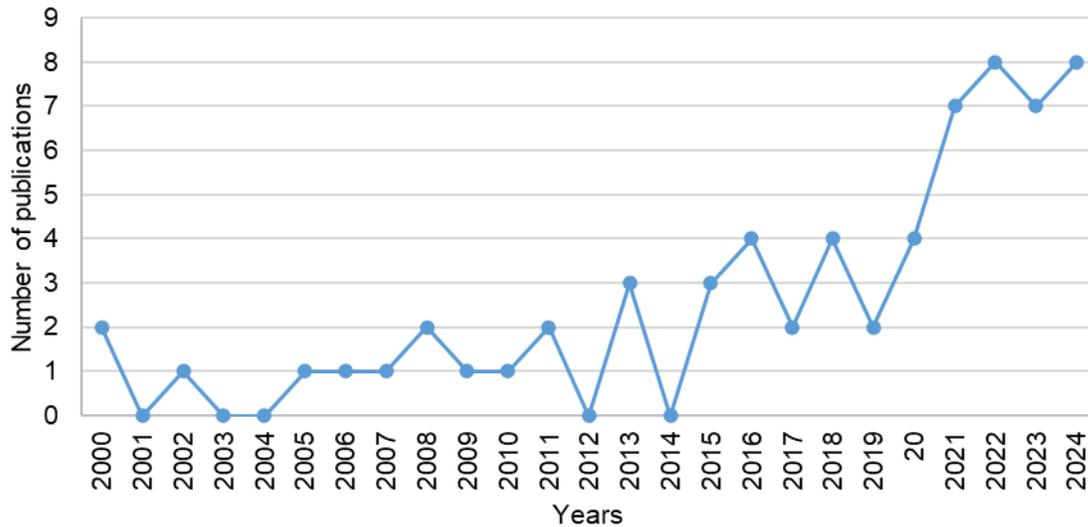


Figure 1. Timeline of scientific publications related to the effect of climate change and anthropogenic factors on the genus *Macrobrachium*.

A total of 18 authors contributed to scientific publications related to the impact of climate change and anthropogenic factors on the genus *Macrobrachium*. Of these, most presented two publications, while a smaller number of authors (Abanikanda, O.T.F., Abolaji, O.V., and Albuquerque, F.E.A.) registered only one publication each. The distribution suggests active but concentrated participation by certain authors in this field of study (Figure 2).

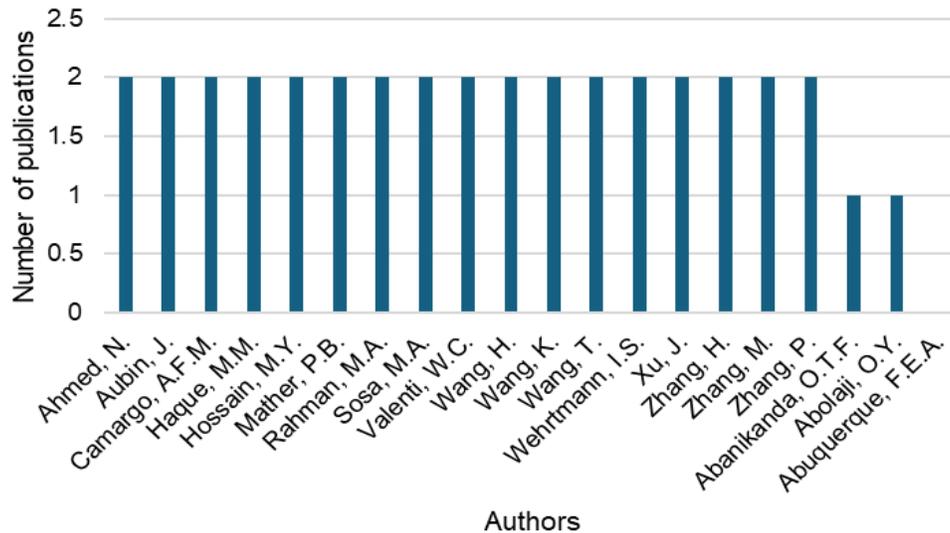


Figure 2. Authors of scientific publications related to the effect of climate change and anthropogenic factors on the genus *Macrobrachium*.

More than 20 institutions worldwide were identified that contribute to research on the *Macrobrachium* genus in relation to the effects of climate change and anthropogenic factors. The participating institutions are distributed across several continents, reflecting the global interest in this line of research. At the institutional level, the University of São Paulo, the Paulista Júlio de Mesquita State University, and the Bangladesh University of Agriculture lead scientific production with five, four, and two publications, respectively. The remaining institutions have two or fewer publications each (Figure 3). In terms of scientific output by country, China stands out as the main contributor with 11 publications, followed by Bangladesh and Brazil with 9 publications each, and Australia with 7 publications (Figure 4).

Of the total 64 publications registered in the Scopus database, scientific articles are the predominant type of document, representing 91% of the total output in this line of research. Reviews rank second with 5%, while the remaining 4% is distributed among editorials, conferences, and short surveys (Figure 5).

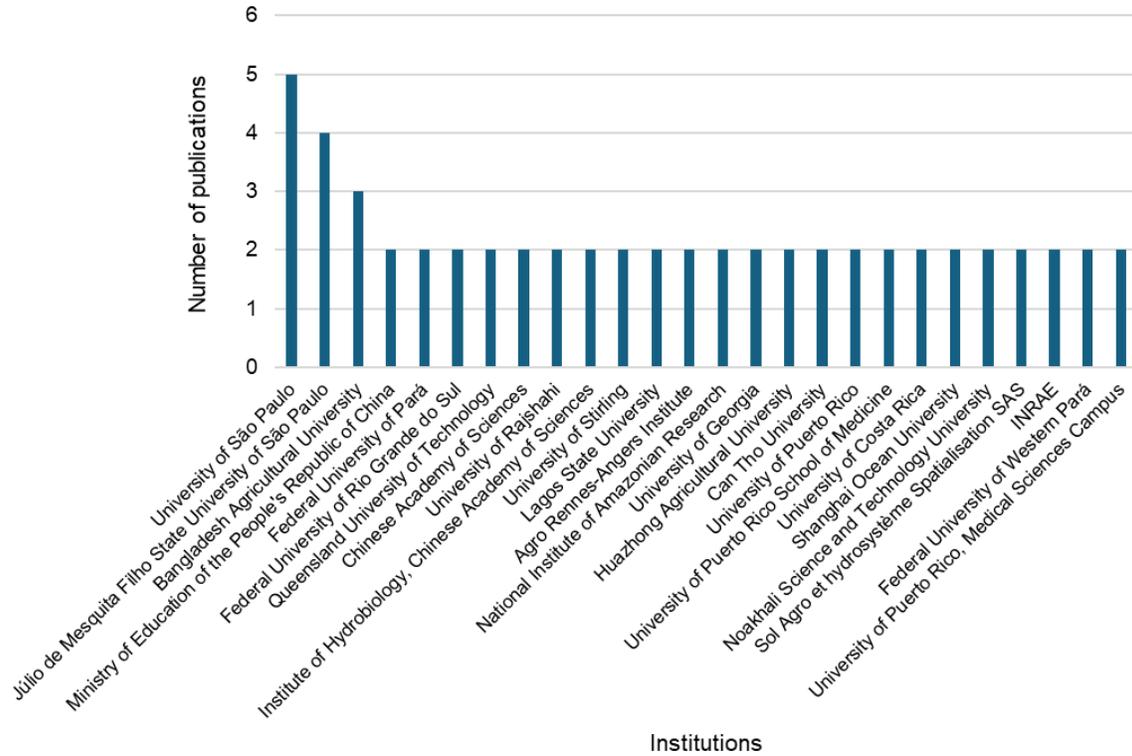


Figure 3. Affiliations of the authors of scientific publications related to the effect of climate change and anthropogenic factors on the genus *Macrobrachium*.

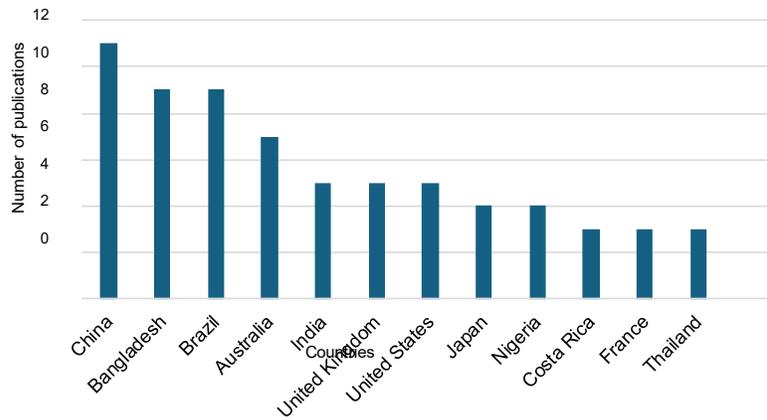


Figure 4. Countries producing scientific publications related to the effect of climate change and anthropogenic factors on the genus *Macrobrachium*.

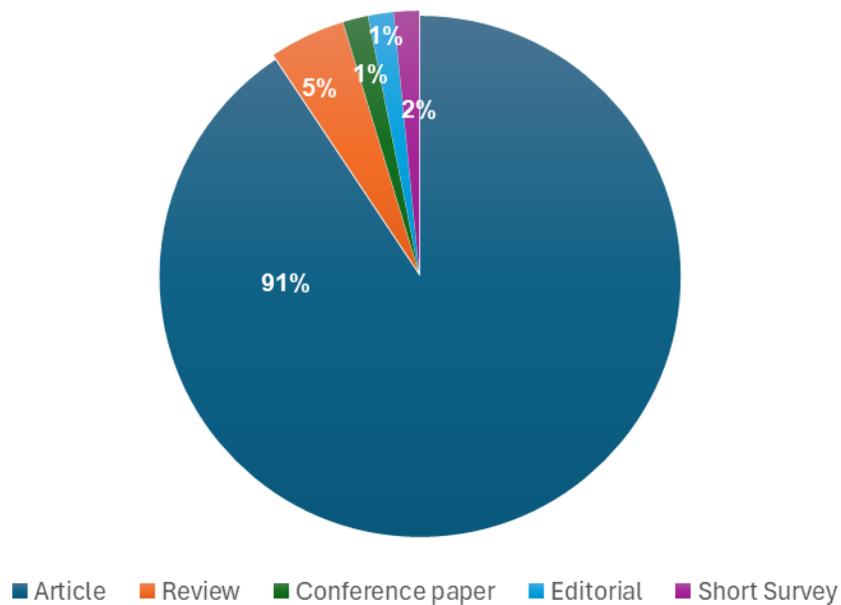


Figure 5. Type of scientific document published and related to the effect of climate change and anthropogenic factors on the genus *Macrobrachium*.

The thematic distribution of scientific publications in SCOPUS related to the impact of climate change and anthropogenic factors on species of the genus *Macrobrachium* reflects a multidisciplinary approach, with a greater concentration in the biological and environmental sciences (Figure 6). The area of Agricultural and Biological Sciences accounts for 32% of publications, highlighting the relevance of this genus in aquaculture systems, biodiversity, and ecosystem services. Environmental Sciences ranks second with 30%, highlighting the interest in understanding how changes in aquatic ecosystems, induced by climate change and human activities, affect *Macrobrachium* populations.

Other notable areas include Biochemistry, Genetics, and Molecular Biology (7%), which refers to studies related to physiological adaptations, genetic responses, and toxicology. The contribution of Medicine (5%) may be related to studies that assess food safety and human health risks from the consumption of species exposed to environmental contaminants. Other disciplines, such as Engineering and Economics, Econometrics, and Finance, although representing a smaller percentage (1-2%), highlight the importance of technical and economic analysis in the sustainability of the exploitation of this genus (Figure 6). Overall, this distribution reflects the need for an integrated approach to address the impacts of climate change and anthropogenic activities.

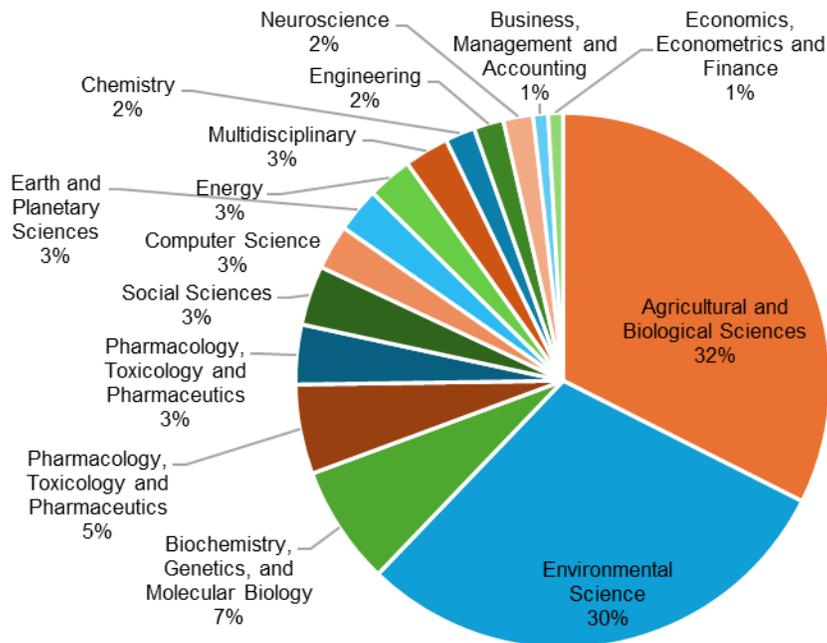


Figure 6. SCOPUS subject areas related to scientific publications on the effect of climate change and anthropogenic factors on the genus *Macrobrachium*.

Based on the results obtained in the literature review, it was determined that the potential negative anthropogenic effects on crayfish species, including *M. tenellum*, are habitat modification, pollution, and illegal and destructive fishing practices.

Chemical calculation

The results obtained through the calculation of the CS and PDCAAS show that only the amino acids methionine/cysteine, with an index of 0.94, were limiting (Table 1). In general, these results allow us to conclude that the muscle protein of *M. tenellum* is a good source of protein with high nutritional value, suitable for meeting the protein requirements of children under two years of age and therefore for any age group. The protein quality of *M. tenellum* is similar to that of fish commonly consumed by the population.

Table 1. AA requirement in children under two years of age, muscle AA profile (mg/g protein), CS and PDCAAS of *Macrobrachium tenellum* and some fish used as human food.

EAA (mg/g protein)	AA Requirements for children under two years old	AA profile of <i>M. tenellum</i> protein	CS	PDCAAS			
			<i>M. tenellum</i>	<i>M. tenellum</i>	Tilapia	Carp	Tuna
Histidine	18	25	1.39	1.17	1.22	1.54	1.47
Isoleucine	25	40	1.60	1.34	1.74	1.73	1.66
Leucine	51	80	1.57	1.32	1.47	1.50	1.44
Lysine	55	96	1.75	1.47	1.54	1.57	1.50
Methionine/Cysteine	25	28	1.12	0.94	1.52	1.52	1.45
Phenylalanine/Tyrosine	47	100	2.13	1.79	1.77	1.46	1.40
Threonine	27	63	2.33	1.96	1.65	1.53	1.46
Valine	32	39	1.22	1.02	1.42	1.51	1.45

Social perception

Of the 120 surveys conducted, 80.0% of participants recognize the shrimp, and 18.5% still catch it; however, 65.8% no longer consume it, and 40.7% perceive a clear reduction in its abundance. Among the factors identified as causes, the most notable are pollution (87.4%), increased water temperature (76.6%), and, to a lesser extent, the presence of hydraulic barriers (35.3%). Destructive fishing using toxic substances was identified as a serious problem by 80.7%, and 84% recognized fishing during closed seasons as a frequent practice. Despite this, 81.5% consider the conservation of the species to be a priority, although most are unaware of the current regulations.

The literature review identified and analyzed various scientific documents that directly or indirectly address the effect of climate change and anthropogenic factors that have, or may have, a negative impact on native shrimp populations and other species that share the same ecosystems and habitats.

Climate change

Climate change, driven by anthropogenic activities, is altering global temperatures, which could have a direct effect on aquatic species such as *M. tenellum*. Staines (2007) points out that increased water temperatures could influence growth, reproduction, and survival rates. As temperatures rise, the development and survival patterns of this species are likely to be altered, which could have long-term consequences for its populations. Barange & Perry (2009) clearly

outline the potential impacts of climate change on continental aquatic ecosystems. The impacts on water range from a general increase in temperature affecting thermal stratification, hydrological cycles, and seasonal patterns to changes in species distribution due to alterations in the habitat or changes in water flows and their physicochemical composition. This could lead to impacts on biodiversity through alterations in migration patterns (very important in amphidromous shrimp such as *M. tenellum*), physiology, and reproductive behavior, such as the spawning season. Adapting the findings of Ferrer-Miranda *et al.* (2023) from the general findings of their work to the specific impact that climate change could have on native shrimp populations in relation to fisheries, it can be concluded that increased water temperatures and changes in hydrological flows will alter their life cycles from reproduction to recruitment. These changes will cause populations to move to less impacted habitats, which could reduce their availability to coastal communities that depend on them as a source of food and economic livelihood. On the other hand, in aquaculture, increased temperature and climate variability will directly affect water quality and disease incidence, jeopardizing the sustainable production of these species under farming conditions.

Habitat modification due to barriers and hydrological changes

The studies analyzed in this research indicate that habitat modification can significantly affect the movement patterns of *M. tenellum*, such as the construction of barriers and dams that can affect the migratory patterns of the species (Guzmán-Arroyo *et al.*, 2009). If we add to this the growth of informal human settlements on riverbanks, the result is a dramatic change in the habitat of this and other species, which may compromise the availability of resources and the conditions necessary for their reproduction and long-term survival. In the case of dams and reservoirs, Rodríguez-Uribe *et al.* (2014) observed that these structures can obstruct the seasonal migrations of *M. tenellum*, affecting its behavior and recruitment patterns. Olivier *et al.* (2013) conducted a study of the effects of river control structures on the migration of *M. ohione* (a species very similar to *M. tenellum*) in the Mississippi River and demonstrated that these barriers significantly reduce the recruitment rates of juveniles upstream. Peña-Almaraz *et al.* (2021), using artificial barriers designed in the laboratory, observed that juvenile *M. tenellum* can climb barriers with an inclination of up to 90° when these have adequate roughness. However, this inclination does represent a high degree of difficulty that can cause upstream migration to come to a standstill. Peña-Almaraz *et al.* (2024) also studied the counter-current swimming ability of different sizes of *M. tenellum* under different water flows in an experimental system. Their results show that, although this species is capable of coping with diverse water flows, it cannot overcome fast flows such as those formed in the diversion channels of dams and reservoirs, which could also affect its seasonal migrations and subsequent recruitment. Castillo (1999) mentions in his report that the modification of watercourses can significantly alter aquatic habitats, potentially causing species to suffer displacement or a reduction in abundance.

This, together with human activities that modify the hydrological regime, such as watercourse diversions, can affect the habitat conditions of *M. tenellum*. Habitat fragmentation also promotes the isolation of subpopulations, which can reduce genetic diversity and make populations more vulnerable to stochastic events (Andrade, 2010). Furthermore, by restricting the movement of organisms, their ability to adapt to environmental changes such as global warming is limited (Yáñez-Arancibia & Day, 2010).

Overfishing and illegal and destructive fishing practices

Macrobrachium tenellum is a species caught by artisanal fishing, which in some cases can have negative effects on its populations, since, in the absence of real government inspection, ovigerous females or individuals smaller than the permitted size are caught. Although this species has a closed season from August to October each year, during the breeding season (for both *M. americanum* and *M. tenellum*) (D.O.F. 2010), artisanal fishermen do not respect this period and carry out their fishing without any major problems (personal communication with fishermen from Tomatlán, Jalisco).

A negative aspect of artisanal fishing for shrimp, including *M. tenellum*, is the use of poisons to facilitate their capture. This practice is banned by Mexican Official Standard NOM-064-SAG/PESC/SEMARNAT-2013, which regulates prohibited fishing systems, methods, and techniques in waters under federal jurisdiction in the United Mexican States. The regulation states that this technique harms the ecosystem, as the poison affects not only the target species but also all species present in the area of influence of the toxic substance used. Although it is an illegal practice, it is carried out clandestinely in many states of the country, even those without a coastline. Pasquel (2022) and Aguirre (2018) report the use of cyanide for fishing in rivers and reservoirs in communities in the state of Hidalgo. Residents have denounced this practice, which, in their view, has led to the near extinction of several species of acamayaz (shrimp) and other aquatic species. Cazarín (2019) mentions that, in some areas of Veracruz, *M. carcinus* (pigua) is already considered extinct due to overfishing and, in particular, the use of poisons to catch them. Similarly, Ibarra (2017) reports high mortality of aquatic species in Escuinapa, Sinaloa, as a result of the use of cyanide in fishing for species of commercial interest.

Pollution

Water pollution is one of the most significant threats to *M. tenellum* populations, mainly due to agricultural, industrial, and urban activities. Among the sources of pollution, agricultural pesticides and fertilizers are particularly concerning, as they can alter water chemistry and directly affect aquatic organisms. In this context, the presence of nitrites from fertilizers is of particular interest due to their high solubility and mobility, which facilitates their dispersion and the generation of negative impacts on aquatic ecosystems (Manenti *et al.*, 2019).

Liquid and solid waste effluents from industrial and urban areas are a constant threat that can introduce toxic contaminants into aquatic ecosystems. Effluents can contain heavy metals, hydrocarbons, and microplastics in water bodies (Becerril *et al.* 2007). According to González-Pisani *et al.* (2022), freshwater crustaceans are particularly susceptible to exposure to microplastic (MP) and nanoplastic (NP) particles. Studies have shown that MPs can be ingested and retained in the digestive system of these crustaceans, affecting their growth, reproduction, and defense mechanisms against oxidative stress. Genetic toxicity effects, including DNA damage, have also been observed, and bioaccumulation of microplastics in tissues has been documented to lead to long-term consequences for the health and structure of freshwater crustacean populations.

Contamination can also have negative effects on the digestive physiology of shrimp. The study by Cheng-Yu *et al.* (2017) on the plasticity of the intestinal microbiome in *M. nipponense* (also very similar to *M. tenellum*) showed that rapid changes in the environment can significantly alter the intestinal microbial composition of these crustaceans. This can make them susceptible to colonization by pathogenic bacteria and/or alterations in digestive physiology that result in nutritional pathologies. Although this study was conducted on another species of the genus *Macrobrachium*, its findings are relevant for understanding the potential impacts on *M. tenellum*.

Sociocultural and economic importance

River shrimp are a fundamental resource for coastal communities throughout Mexico. Anthropogenic impacts on their populations not only have ecological consequences but also important socioeconomic implications, affecting communities that depend on them both as a regular food source and as a means of economic livelihood through their commercialization (García-Guerrero *et al.*, 2013).

Cruz-Sánchez *et al.* (2019) conducted a study on the fishing of *Macrobrachium* shrimp in the Palizada River, Campeche, highlighting its sociocultural and economic relevance for local communities. Socioculturally, fishing has been passed down from generation to generation, with the vast majority of fishermen coming from families dedicated to this trade, reflecting its deep cultural roots. In addition, traditional knowledge of climate cycles and fishing seasons for species such as *M. acanthurus* (acamaya) and *M. carcinus* (pigua) underscores the historical relationship between these communities and the aquatic resources that constitute a significant source of income. Although no similar study has been conducted for *M. tenellum*, the personal experience of the authors of this paper allows us to assert that this species is an important source of income and food for many coastal and riverside communities on the Mexican Pacific slope.

Ortega-Álvarez (2024) documents that river shrimp, particularly in Zacualpan, Colima, are of great socio-cultural and socio-economic importance. From a cultural perspective, their fishing and preparation are deeply rooted in community traditions, forming part of their identity and festivities such as “La Chacaliza.” This event, which combines community fishing, gastronomy, and religious rituals, highlights the connection between natural resources and local cultural expressions. Economically, the commercialization of river shrimp, known locally as chacal, provides supplementary income to families, especially during seasons of high demand. However, overfishing, pollution, and climate change threaten both the populations of these species and the continuity of the practices that revolve around them. Therefore, their conservation involves not only preserving a biological resource but also protecting a pillar of the region’s cultural and economic heritage.

Also on the Pacific coast, specifically in Baja California Sur (Gulf of California), Lizárraga-Hernández (2024) reported that river shrimp of the genus *Macrobrachium* represent a key element of the region’s sociocultural heritage. Since the time of the Jesuit missions, these crustaceans have been an important source of food for local communities, particularly in the oases, which have historically been settlement and development sites due to their access to water. Shrimp were part

of the diet of both the native inhabitants and the settlers, who recognized their abundance and quality during the rainy seasons. In addition to their nutritional value, these crustaceans are deeply linked to traditional practices and knowledge that have been passed down from generation to generation. The decline in their populations due to overexploitation and habitat alteration not only represents an ecological threat but also a significant cultural loss.

According to Martínez-Castro *et al.* (2024), freshwater shrimp stand out as an example of the economic and cultural potential that can be integrated into Social and Solidarity Economy (SSE) approaches in Oaxaca. This model seeks to promote productive activities that respect biodiversity and local traditions, generating income equitably and sustainably. The fishing and marketing of freshwater shrimp could align with the principles of the SSE, strengthening local and regional value chains based on cooperation and economic equity. However, overexploitation, habitat destruction, and pollution threaten both shrimp populations and the food security of the communities that depend on them.

Shrimp of the *Macrobrachium* genus are not only a biological resource but also a central element in the cultural identity and economic livelihood of numerous communities in Mexico. Their use illustrates the intrinsic relationship between natural resources and human traditions, reflected in activities passed down from generation to generation, such as fishing and the preparation of these crustaceans (Ortega-Álvarez, 2024). This cultural link not only strengthens social cohesion but also highlights the historical and symbolic relevance of shrimp. Economically, shrimp represent a key source of income, especially for coastal and riverside communities with limited resources (Cruz-Sánchez *et al.* 2019). However, growing pressure from factors such as overfishing, pollution, and habitat destruction threatens not only the stability of their populations but also the continuity of the cultural and economic practices that depend on them. The conservation of langostinos involves more than protecting a biological resource; it requires preserving an essential pillar of the cultural and economic heritage of communities. This requires a comprehensive approach that combines sustainable management measures, environmental education, and public policies that value and strengthen local value chains, ensuring that this valuable resource continues to benefit present and future generations. Without these actions, not only is biodiversity at risk of being lost, but also a unique cultural and economic legacy.

Social perception

Surveys showed that a large part of the local population recognizes a decline in shrimp availability but is unaware of fundamental aspects such as the existence of closed seasons or permitted fishing practices. This disconnect between local knowledge and formal regulations points to a failure in resource governance, a situation already documented in other studies on artisanal fishing in Mexico (Altieri, 2013; Cruz-Sánchez *et al.*, 2019; Pasquel, 2022).

In this context, the lack of effective control poses a concrete threat to the sustainability of shrimp harvesting and reduces the possibility of implementing participatory mechanisms. This reinforces the urgency of promoting conservation mechanisms that integrate environmental education, community monitoring, and institutional strengthening, as has been proposed for

coastal fisheries in the Pacific and Gulf of Mexico (Ortega-Álvarez, 2024; Martínez-Castro *et al.*, 2024).

Nutritional quality

Macrobrachium tenellum is a source of high-quality protein with an amino acid profile comparable to that of commonly consumed fish (Espinosa-Chauran *et al.*, 2013). This crustacean not only provides essential nutritional benefits, but is also accessible to coastal communities with limited resources, considered an easy-to-cook option in multiple preparations, where it represents a vital component of their diet. In addition, its capture and commercialization generate complementary income in vulnerable regions, reinforcing its sociocultural and economic relevance (Pérez-Velázquez *et al.*, 2011). In this context, the loss of *M. tenellum* would deal a severe blow to the food security of local communities, especially in regions where protein options are limited (FAO, 2022). This could exacerbate social and economic inequalities, increasing dependence on less accessible and less healthy external food sources.

Resilience

Based on the points outlined above, the resilience of *M. tenellum* populations to climate change and anthropogenic activities appears to be severely compromised, although not completely ruled out.

Arguments against strong resilience:

Severe cumulative impacts: multiple factors negatively affecting river shrimp populations, such as climate change (temperature increase, hydrological alterations) and human activities (overfishing, pollution, and destructive practices). These impacts are not isolated but interact, intensifying their negative effects.

Habitat modification: Physical barriers such as dams and reservoirs hinder shrimp migration, limiting their life cycle. Although juveniles have some ability to adapt, prolonged restrictions can lead to population fragmentation and loss of genetic diversity, reducing the ability to adapt to environmental changes (Peña-Almaraz *et al.*, 2024).

Lack of effective regulation: Despite the existence of regulations, such as closed seasons and bans on destructive fishing, widespread non-compliance exacerbates the situation. The lack of rigorous enforcement of laws suggests that human actions will continue to be a significant pressure factor (FAO, 2007).

Climate vulnerability: Abrupt changes in water temperature and chemical composition directly affect vital processes such as reproduction, recruitment, and growth. These processes are fundamental to population recovery (Blanck and Lamouroux, 2007).

Arguments in favor of potential resilience:

Biological adaptability: *M. tenellum* has demonstrated some ability to cope with adverse conditions, such as climbing inclined barriers and tolerance to diverse water flows (Peña-Almaraz *et al.*, 2021; Peña-Almaraz *et al.*, 2024). This suggests a biological plasticity that could allow it to survive in certain circumstances.

Sociocultural and economic importance: The relevance of shrimp to local communities could encourage community actions for their conservation, such as reducing destructive fishing and environmental education (García-Guerrero *et al.*, 2013).

Research and sustainable management: Focusing on conservation strategies, such as fisheries regulation, aquaculture, and habitat restoration, could mitigate some negative effects, allowing for some degree of recovery (Santos-Romero *et al.*, 2021).

Although there are signs of adaptability (Vega-Villasante *et al.*, 2011; Rodríguez-Flores *et al.*, 2012), the cumulative impacts and magnitude of anthropogenic and climate threats appear to exceed the natural recovery capacity of *M. tenellum* populations. The resilience of these populations will depend largely on coordinated and effective human intervention. Without comprehensive management strategies, habitat restoration, and community education, the most likely scenario is continued decline that will compromise both the biodiversity and the sociocultural and economic benefits associated with this species.

Conclusions

Macrobrachium tenellum represents not only a source of high-quality protein for coastal communities with limited resources, but also an essential component of their socio-ecological systems. The results indicate that this species is facing increasing threats from climate change, pollution, overfishing, and habitat fragmentation. Through local knowledge, it was found that the population perceives a reduction in its availability, although it is unaware of the existence of current regulations, which limits the possibility of implementing participatory conservation actions. Therefore, it is urgent to adopt comprehensive strategies that combine sustainable management, environmental education, and inclusive policies that recognize the ecological, nutritional, and sociocultural value of this species.

Contribution of the authors

Work conceptualization, VVF, VCMA, and MMCE; Development of the methodology, MATY, VVF; Software management, MATY, MMCE; Experimental validation, VCMA, VVF, and MMCE; Analysis of results, MATY, VCMA, MMCE, and VVF; Data management, MATY, VVF; Writing and preparation of the manuscript, MATY; Editing, VCMA, VVF, and MMCE; Project manager, VCMA, VVF; Fund acquisition, VVF.

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Informed consent statement

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Conflict of interest

The authors declare that they have no conflict of interest.

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