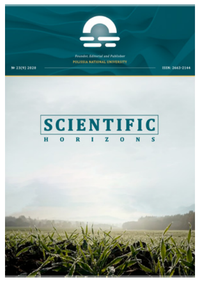
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 28(6), 23-35



UDC 502.55:574.5
DOI: 10.48077/scihor6.2025.23

Impact of anthropogenic factors on the population structure of non-fish seafood in reservoirs of Azerbaijan

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Article's History:
Received: 22.11.2024
Revised: 01.05.2025
Accepted: 28.05.2025

Abstract. The aim of the study was to establish the impact of anthropogenic factors on population size and structure. The article presented the results of a comprehensive empirical study aimed at assessing the influence of anthropogenic factors on the structure and abundance of shrimp (*Palaemon elegans, Palaemon adspersus*) and freshwater crayfish (*Astacus leptodactylus, Pontastacus eichwaldi*) populations in the conditions of Shamkir and Mingachevir reservoirs of Azerbaijan. In the period from June to August 2024, field surveys were conducted at sites with different degrees of pollution. The assessment included analyses of the density of individuals, age and sex composition, juvenile abundance and mortality, and spatial distribution of populations. For freshwater crayfish, the average density of *Astacus leptodactylus* ranged from 12 individuals/m^2 (clean zones of the Shamkir reservoir) to 5 individuals/m^2 (polluted zones of the Mingachevir reservoir). The number of *Pontastacus eichwaldi* varied from

Suggested Citation:
Guliyeva, F., Guliyeva, S., Bilgin, A., & Guliyeva, L. (2025). Impact of anthropogenic factors on the population structure of non-fish seafood in reservoirs of Azerbaijan. *Scientific Horizons*, 28(6), 23-35 doi: 10.48077/scihor6.2025.23.

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7 to 2 individuals/m^2. The share of juveniles in the population structure in clean areas reached 42% (*Palaemon elegans*) and 40% (*Astacus leptodactylus*), while in polluted areas it decreased to 15-20%. Mortality of juveniles up to 40% was recorded in sites with organic pollution. An imbalance in the sex composition was observed in areas with high levels of pollution: in *Palaemon adspersus* and *Pontastacus eichwaldi* the proportion of males exceeded 55%, while in clean areas females predominated or an equal ratio was maintained. The greatest decrease in the abundance of all species was observed in the Mingachevir reservoir – up to 60% for *Pontastacus eichwaldi*, which indicates the high sensitivity of the species to complex anthropogenic impact. The results showed that chemical pollution, recreational load and poaching are the determining factors of population degradation. A direct correlation between the level of anthropogenic impact and the decrease in abundance, disturbance of age and sex structure was established. Indicator indicators for monitoring the state of freshwater ecosystems were proposed. The obtained results can be used for development of monitoring programmes and ecological-restoration measures in aquatic ecosystems of Azerbaijan

Keywords: bottom invertebrates; monitoring of environment; technogenic load; freshwater ecosystems; bioindication

INTRODUCTION

The relevance of this study is due to the need to assess the impact of anthropogenic factors on aquatic ecosystems, which is especially important in the context of accelerated pollution of water bodies and climate change. The Shamkir and Mingachevir reservoirs, which are important ecosystems for the region, are exposed to various pollutants such as heavy metals and organic substances, which leads to changes in the abundance and population structure of aquatic inhabitants. Shrimp and freshwater crayfish, being sensitive indicators of water quality, are good subjects for studying the effects of pollutants. The problematic issue of the study is the insufficient assessment of the impact of anthropogenic pollutants on the state of populations of these species in specific water bodies of Azerbaijan, which limits the development of effective methods for the protection of water body ecosystems and sustainable use of their resources. It is important not only to quantify the populations, but also to analyse the impact of pollutants on age and sex structure, as well as on mortality of juveniles, which allows a deeper understanding of ecological changes in these reservoirs and the formation of recommendations for their protection.

Thus, F.R. Gulieva and L.V. Gulieva (2021) revealed that economic activities in the area of Mingachevir and Varvarinskoye reservoirs contributed to the reduction of species diversity of non-fish aquatic organisms. According to the results, the disruption of trophic relationships and reduction in the number of key invertebrates occurred under the influence of pollution and changes in the hydrological regime. In a study by S. Hasanova (2024) recorded the deterioration of aquatic environment as a result of wastewater and industrial emissions. The author found that anthropogenic pressure led to changes in the species composition and decrease in the abundance of certain groups of non-fish organisms. In the generalised analysis presented by R. Abbasov *et al.* (2022), it was shown that urbanisation and expansion of agricultural areas increased the pressure on water bodies in Azerbaijan. The authors stated that such processes reduced the stability of aquatic ecosystems and caused structural changes in hydrobiont populations. Based on data on Lake Naivasha, E. Mutethya and E. Yongo (2021) analysed the consequences of anthropogenically caused penetration of invasive species and recorded their impact on native invertebrate populations. The researchers found that the introduction of alien organisms contributed to the displacement of native species and disrupted the balance of the ecosystem.

In a study by C. Waldock *et al.* (2025) documented that pollution of water bodies caused changes in the trace element composition of tropical fish communities, affecting the entire trophic structure. The authors emphasised that similar processes may have occurred in other ecosystems, including reservoirs, where anthropogenic interference was observed. When analysing the consequences of the transformation of coastal landscapes, T. Pšeničková and J. Horák (2022) found a reduction in abundance and simplification of the structure of hydrobiont populations. The researchers recorded that deforestation and the creation of artificial reservoirs had a long-term negative impact on the ecological parameters of aquatic communities. In particular, A. Febriana and B.I. Utary (2024) found that conversion of mangrove forests in the Tanjung Luar village area caused habitat degradation and reduction of biological resources. According to the authors, the disturbance of the natural balance was accompanied by the loss of breeding habitat for many invertebrate species, affecting the entire structure of coastal ecosystems. A large-scale study by W.M. Jubb *et al.* (2023) analysed the effects of hydraulic structures and water level fluctuations on fish migrations in river systems. The authors found that combined anthropogenic impacts disrupted the reproduction and movement of aquatic organisms, contributing to changes in the spatial structure of their populations, including invertebrate's dependent on stable hydrological regimes.

In analysing the relationship between natural resources and socio-economic behaviour of communities, S. Gaja-Svasti *et al.* (2022) documented that in the Mun River Basin, wild fish and invertebrates remained the most important element of the diet and source of income for villagers. The authors emphasised that changes in the aquatic environment caused by anthropogenic interventions were directly reflected in the decreasing availability of these resources and the transformation of traditional lifestyles. Summarising data from the Mekong region, I.G. Baird and Z.S. Hogan (2023) noted that the construction of hydropower plants entails a significant reduction in fish biodiversity and degradation of aquatic habitat. As part of their review, it was shown that non-fish species, particularly those sensitive to water level fluctuations and bottom substrate quality, were also at risk of extinction under the impact of regulated flows. Sustainable aquaculture production was addressed in a study by S.M. Colombo *et al.* (2023), which examined the potential for closed-loop feed systems for "blue" food resources. The authors found that feed rationalisation and reduction of pressure on natural aquatic populations can contribute to the recovery of non-fish organisms subjected to anthropogenic depletion.

In the context of fisheries conservation, I. Mayer and M. Pšenička (2024) examined the use of reproductive technologies to conserve teleosts in the face of declining abundance. The researchers demonstrated that technological reproduction can serve as a compensatory mechanism for the loss of natural populations, including non-fish components of ecosystems that are closely related to spawning conditions and microenvironment. The aim of the study was to analyse changes in the structure of non-fish seafood populations under the influence of anthropogenic factors in reservoirs of Azerbaijan. The objectives of the study were to identify key anthropogenic factors, assess their impact on non-fish seafood and analyse changes in population structure.

MATERIALS AND METHODS

The study was conducted from June to August 2024 in the Shamkir and Mingachevir reservoirs of Azerbaijan. The climate of the region was characterised by dry and hot summers with average daily air temperatures from +28 to +35°C and night temperatures from +20 to +25°C. The average annual precipitation was 200-300 mm, most of which occurred in the spring months. The hydrological regime of both reservoirs is subject to significant anthropogenic influence due to the presence of large industrial enterprises, recreational areas and settlements in the adjacent territories. This was the reason for selecting these reservoirs as sites for assessing the impact of anthropogenic factors on aquatic ecosystems and hydrobiont populations. Shrimp: stone shrimp (*Palaemon elegans*) and grass shrimp (*Palaemon adspersus*), as well as freshwater crayfish: Slender-clawed crayfish (*Astacus leptodactylus*) and Caspian crayfish (*Pontastacus eichwaldi*) were selected as research objects. The species were selected due to their high sensitivity to changes in the hydrochemical regime of water bodies and widespread occurrence in aquatic ecosystems of Azerbaijan. These species have indicator properties that allow to objectively assess the level of ecological state of water bodies and the degree of anthropogenic impact.

To assess the impact of anthropogenic factors, two categories of sites were studied: clean (control sites with minimal human impact) and heavily polluted. Sampling was carried out monthly from June to August 2024 by hand collection and using standard invertebrate traps. Each site was surveyed in three replicates and then the mean population density (number of individuals per square metre) was calculated. Shrimp and crayfish densities were determined by counting the number of captured specimens in a defined area of the reservoir bottom (1 m^2). The authors adhered to the standards of the Guidelines for the treatment of animals in behavioural research and teaching (2012). For this purpose, a control area (1 × 1 metre square) was allocated at each site, after which the captured individuals were counted, recorded and then the average density was calculated using the formula (1):

$$D = \frac{N}{S}, \tag{1}$$

where D – population density (individuals/m^2); N – number of captured individuals in the study area; S – plot area (m^2).

The sex composition of populations (proportion of females and males) was determined by visual examination of each specimen using a "Leica EZ4" binocular microscope (Germany). The sex of each captured specimen was recorded, and then the proportion of individuals of each sex (% of the total population size) was calculated (2):

$$P = \frac{n_p}{N} \times 100\%, \tag{2}$$

where P – proportion of females or males (%); n_p – number of individuals of a particular sex (females or males); N – total number of individuals surveyed.

To assess the age structure, morphometric analysis was carried out using electronic caliper "Mitutoyo" (model CD-15APX, Japan) with measurement accuracy up to 0.01 mm and electronic scales "Ohaus Scout STX2202" (USA) with accuracy up to 0.01 g. The obtained data allowed to distinguish age groups: juveniles, adults and older individuals. Mortality of juveniles was assessed by comparing the number of juveniles in contaminated sites and control (clean) zones. The number of juveniles was recorded separately for each site (individuals per m^2). Mortality was calculated according to the following formula (3):

$$M = \frac{(N_c - N_p)}{N_c} \times 100\%, \tag{3}$$

where M – juvenile mortality (%); N_c – number of juveniles in control (clean) areas (individuals/m^2); N_p – number of juveniles on polluted areas (individuals/m^2).

For quantitative assessment of anthropogenic pollution, water and bottom sediment samples taken monthly at each location were used. Concentration of heavy metals (Pb, Zn, Cu) was determined by atomic absorption spectrophotometer "Analytik Jena novAA 400P" (Germany). The content of pollutants in water and bottom sediments was measured by infrared spectrometer "Infracal ATR-SP" (USA). Organic pollution (nitrates, nitrites and ammonium nitrogen) was analysed using a spectrophotometer "Hach DR3900" (USA). Noise impact from recreational activities (motor boats, fishing and tourism) was measured with a noise meter model "Testo 815" (Germany). Measurements were made monthly during daytime (from 10:00 to 16:00) at each study site, after which the average noise level in decibels (dB) was calculated. The obtained data were processed by analysis of variance (ANOVA) in Statistica 12 software. For visualisation it was used graphs built in Microsoft Excel and Python with Matplotlib library, showing population density, mortality of juveniles and reduction of species abundance at polluted areas.

RESULTS

Quantitative indicators of shrimp populations in Shamkir and Mingachevir reservoirs. The average density of *Palaemon elegans* shrimp in the Shamkir Reservoir varied from 12 to 25 individuals per square meter. The highest number of individuals was observed in coastal areas with aquatic vegetation and minimal pollution, where the density reached 25 individuals/m². In contrast, areas located near industrial enterprises and recreational zones were characterised by a lower abundance of this species – approximately 12-15 individuals/m². In the Mingachevir Reservoir, the density of *Palaemon elegans* was lower, ranging from 8 to 18 individuals per m². The maximum density of 18 individuals was observed in areas with low anthropogenic impact, far from populated areas, whereas near sites of intensive fishing and industrial activity, the population density decreased to minimal values – 8-10 individuals per m². The species *Palaemon adspersus* showed a noticeably lower population density in both reservoirs. In the Shamkir Reservoir, the density of this species varied from 9 to 17 individuals per m². The highest concentration of individuals was characteristic of coastal, shallow-water areas with shelters and a rich food base. In moderately polluted areas, the density decreased to 10-12 individuals/m², while in zones of pronounced anthropogenic pollution, it was less than 9 individuals/m².

In the Mingachevir Reservoir, the situation proved even less favourable for *Palaemon adspersus*: the population density ranged from 6 to 14 individuals per m². The lowest abundance of this species was noted in areas with high levels of industrial and domestic effluent pollution (6-7 individuals/m²), indicating a pronounced sensitivity of this species to the negative impact of pollutants. When studying the age and sex structure of the shrimp, differences in the distribution of age groups and sex ratio of the populations were revealed. For *Palaemon elegans* in the Shamkir Reservoir, juveniles (less than one year old) accounted for 42%, adults (1 to 2 years old) – 48%, and the proportion of older individuals (over 2 years old) was low – only about 10%. A similar pattern was observed in the Mingachevir Reservoir, however, the proportion of juveniles was smaller (35%), while adults constituted up to 55%. *Palaemon adspersus* demonstrated a different pattern of age distribution. In the Shamkir Reservoir, juveniles accounted for approximately 30%, while adults were the dominant age group, reaching 60%. Older age groups were rarely encountered (10%). In the Mingachevir Reservoir, the proportion of juveniles was even lower (25%), and adults higher (65%), indicating difficult reproduction and premature aging of the population.

In addition to abundance and age composition, significant differences in the sex ratio of shrimp were identified. In *Palaemon elegans*, a predominance of females was observed – on average 55-60% of the total population in both reservoirs. *Palaemon adspersus* had an almost equal sex ratio (50:50%), however, in areas with increased pollution, a slight predominance of males was noted (up to 55%). A comparative analysis of individual distribution showed unevenness in populations across the reservoir areas. The highest abundance of both species was characteristic of remote and ecologically clean zones with low levels of anthropogenic impact. Areas with intensive human economic activity were characterised by a decrease in the total shrimp abundance by 25-40% from the average values across the reservoirs (Table 1).

Table 1. *Quantitative indicators of shrimp populations in Shamkir and Mingachevir reservoirs*

Type of shrimp	Reservoir	Density (individuals/m²)	Juveniles	Adults	Older individuals	Proportion of females	Proportion of males
Palaemon elegans	Shamkir	12-25	42%	48%	10%	60%	40%
	Mingachevir	8-18	35%	55%	10%	55%	45%
Palaemon adspersus	Shamkir	9-17	30%	60%	10%	50%	50%
	Mingachevir	6-14	25%	65%	10%	45%	55%

Source: *developed by the authors*

Thus, it was found that anthropogenic impacts significantly change the quantitative indicators and structure of shrimp populations in Shamkir and Mingachevir reservoirs, with *Palaemon adspersus* species being the most vulnerable. The results obtained can be used to develop measures for the protection and rational use of shrimp resources in water bodies of Azerbaijan.

Indicators of freshwater crayfish populations in Shamkir and Mingachevir reservoirs. The average population density of freshwater crayfish, *Astacus leptodactylus*, in the Shamkir Reservoir ranged from 5 to 12 individuals per square metre. The maximum density for this species (12 individuals/m²) was recorded in areas with clean water and natural shelters – such as stones, snags, and dense aquatic vegetation. In territories affected by sewage and domestic waste, the crayfish abundance decreased to 5-6 individuals per m². In the Mingachevir Reservoir, the average density of *Astacus leptodactylus* was lower, varying between 3 and 9 individuals per m². The highest abundance was observed in areas remote from industrial influence, whereas zones of intense pollution were characterised by a minimal abundance – 3-4 individuals per m². The density of the second species studied, *Pontastacus eichwaldi*, in the Shamkir Reservoir was within the range of 3 to 7 individuals per square metre. A high density (7 individuals/m²) was recorded only in isolated areas with minimal anthropogenic impact and the presence of a good food base. Areas with pollution and constant human presence showed a sharp decrease in density to 3-4 individuals/m². In the Mingachevir Reservoir, the density of *Pontastacus eichwaldi* was the lowest, amounting to only 2 to 5 individuals per m². The lowest abundance (2 individuals/m²) was recorded in zones with significant domestic waste pollution.

The age structure of the *Astacus leptodactylus* population in the Shamkir Reservoir was characterised by a high proportion of juveniles (up to 2 years old) – 40%. Adults (from 2 to 4 years old) constituted about 45%, and older individuals (over 4 years old) – 15%. In the Mingachevir Reservoir, the percentage of juveniles decreased to 30%, adults increased to up to 50%, and the proportion of older individuals increased to 20%, reflecting negative conditions for successful juvenile reproduction. The age composition of the *Pontastacus eichwaldi* population in the Shamkir Reservoir consisted of 25% juveniles, 60% adults, and 15% older individuals. In the Mingachevir Reservoir, juveniles accounted for only 20%, adults – 65%, and older individuals – 15%. The sex composition of crayfish populations was close to an equal ratio. In the Shamkir Reservoir, both species studied had an equal proportion of females and males – approximately 50:50%. However, in the Mingachevir Reservoir, especially in polluted areas, an increase in the proportion of males to 55% was observed, likely due to different resistance of the sexes to pollution. During the annual observation period, the *Astacus leptodactylus* population in the Shamkir Reservoir decreased by 15%. In the Mingachevir Reservoir, the decline in the abundance of this species reached 20%. The *Pontastacus eichwaldi* population decreased even more significantly – by 20% in the Shamkir Reservoir and by 25% in the Mingachevir Reservoir. The main factors for this reduction were the deterioration of water quality and the destruction of natural habitats due to anthropogenic pollution and fishing. In areas with high levels of organic and chemical pollution, an increase in juvenile mortality of both species by 25-30% was recorded compared to clean areas. This led to a sharp imbalance in age structure and a deterioration of reproductive potential (Table 2).

***Table 2**. Indicators of freshwater crayfish populations in Shamkir and Mingachevir reservoirs (for the observation period 2024)*

Type of crayfish	Reservoir	Density (individuals/m²)	Juveniles	Adults	Older individuals	Proportion of females	Proportion of males	Annual population decline	Juvenile mortality in polluted areas
Astacus leptodactylus	Shamkir	5-12	40%	45%	15%	50%	50%	-15%	25%
	Mingachevir	3-9	30%	50%	20%	45%	55%	-20%	30%
Pontastacus eichwaldi	Shamkir	3-7	25%	60%	15%	50%	50%	-20%	25%
	Mingachevir	2-5	20%	65%	15%	45%	55%	-25%	30%

***Source:** developed by the authors*

The results indicate the critical impact of pollution and poaching on the structure and abundance of freshwater crayfish in both reservoirs. The greatest damage was caused to juveniles, which significantly reduced the ability of populations to natural recovery and sustainable development.

Effects of specific anthropogenic factors on the abundance and population structure of shrimp and freshwater crayfish populations. Among the main factors, industrial wastewater containing heavy metals (lead, zinc, copper), domestic organic effluents, and intensive poaching caused the greatest damage. The abundance of *Palaemon elegans* shrimp in areas of the Shamkir Reservoir with elevated heavy metal content (especially lead and zinc) decreased from 25 to 17 individuals/m² (a 32% reduction). A similar situation was observed in the Mingachevir Reservoir, where pollution caused a reduction in the abundance of this species from 18 to 11 individuals/m² (a 39% reduction). Furthermore, domestic organic effluents discharged into the water body also caused a 25-30% reduction in the population abundance of this species compared to clean areas (Khudiiash *et al.*, 2023).

For the grass shrimp, *Palaemon adspersus*, the greatest reduction in abundance was recorded in areas polluted by organic domestic effluents. In the Shamkir Reservoir, the abundance of this species decreased from 17 to 11 individuals/m² (a 35% reduction), and in the Mingachevir Reservoir – from 14 to 8 individuals/m² (a 43% reduction). This indicated the species' high sensitivity to organic pollutants (Koretsky & Kononenko, 2024). The age structure of both shrimp species also underwent significant changes under the influence of pollution. For instance, the proportion of juveniles of the grass shrimp in polluted areas of the Mingachevir Reservoir decreased from 25% to 15%, while the juvenile mortality increased to 40% compared to 15% in control areas. In the Shamkir Reservoir, for *Palaemon elegans*, the proportion of juveniles decreased from 42% to 30%, and mortality increased from 15% to 32%. The populations of freshwater crayfish were also significantly reduced under the influence of anthropogenic factors. For example, the abundance of the slender-clawed crayfish (*Astacus leptodactylus*) in the Shamkir Reservoir, due to the impact of heavy metals and poaching, decreased from 12 to 8 individuals per m² (a 33% reduction). In the Mingachevir Reservoir, domestic organic effluents had an even greater impact, reducing the population abundance of this species from 9 to 5 individuals per m² (a 44% reduction).

Anthropogenic factors had the most significant negative impact on the population of the Caspian crayfish (*Pontastacus eichwaldi*). In the Shamkir Reservoir, under the influence of organic pollutants (nitrates and nitrites), the abundance decreased from 7 to 4 individuals per m² (a 43% reduction). In the Mingachevir Reservoir, characterised by high levels of domestic organic effluents, the abundance of the Caspian crayfish decreased most sharply – from 5 to 2 individuals per m² (a 60% reduction). Besides water pollution, a significant negative factor was noise pollution from recreational activities (fishing, tourism) (Shumka *et al.*, 2020). In areas with high noise levels, the abundance of freshwater crayfish additionally decreased by 15-20%, and the proportion of older and adult individuals decreased by 40-50%, which indicated the negative influence of noise and fishing on the reproductive potential of populations (Table 3).

***Table 3**. Effects of specific anthropogenic factors on the abundance and population structure of shrimp and freshwater crayfish populations*

Type	Reservoir	Anthropogenic factor	Numbers, clean areas (individuals/m²)	Numbers, polluted areas (individuals/m²)	Headcount reduction	Main pollutants	Proportion of juveniles in clean areas	Proportion of juveniles in polluted areas	Juvenile mortality in polluted areas
Stone shrimp (Palaemon elegans)	Shamkir	Heavy metals (Pb, Zn, Cu)	25	17	32%	Lead (Pb), Zinc (Zn)	42%	30%	32%
Stone shrimp (Palaemon elegans)	Mingachevir	Petroleum products, domestic wastewater	18	11	39%	Organics	35%	20%	35%
Grass shrimp (Palaemon adspersus	Shamkir	Organic domestic wastewater	17	11	35%	Organics	30%	18%	32%
Grass shrimp (Palaemon adspersus)	Mingachevir	Domestic wastewater	14	8	43%	Organics	25%	15%	40%
Slender-clawed crayfish (Astacus leptodactylus)	Shamkir	Heavy metals, poaching of fish	12	8	33%	Lead, Zinc, Poaching	40%	30%	35%
Slender-clawed crayfish (Astacus leptodactylus)	Mingachevir	Organic domestic wastewater	9	5	44%	Organics	30%	20%	40%
Caspian crayfish (Pontastacus eichwaldi)	Shamkir	Nitrates, nitrites	7	4	43%	Nitrates, nitrites	25%	15%	35%
Caspian crayfish (Pontastacus eichwaldi)	Mingachevir	Domestic wastewater	5	2	60%	Organics	20%	10%	40%

***Source:** developed by the authors*

Thus, water pollution and anthropogenic factors had a significant negative impact on the quantitative indicators and population structure of the studied species. Freshwater crayfish and shrimp species *Palaemon adspersus* were the most sensitive to pollution.

Distribution of shrimp and crayfish populations in relation to anthropogenic impacts. In the clean areas of the Shamkir and Mingachevir Reservoirs, a uniform distribution of *Palaemon elegans* shrimp was observed. The maximum density (25 individuals per m²) was noted in areas of the Shamkir Reservoir little affected by anthropogenic factors, characterised by the presence of natural shelters and a rich food base. In areas with a moderate level of pollution and increased anthropogenic pressure, the density of this species decreased to approximately 17 individuals per m², while the most polluted areas subjected to active recreational activity were characterised by a reduction in abundance to 10-12 individuals per m². *Palaemon adspersus* exhibited even greater sensitivity to pollution and other anthropogenic factors, including poaching and noise pollution (Shumka *et al.*, 2023). The maximum abundance of this species was recorded in the coastal zones of the Shamkir Reservoir (17 individuals/m²), where favourable habitat conditions, such as clean water and abundant shelters, were observed. In polluted areas, the shrimp abundance decreased to 11 individuals/m², and in the most polluted areas of the Mingachevir Reservoir, the density was only 8 individuals/m².

For freshwater crayfish, the spatial structure of populations was even more sensitive to anthropogenic impact (Kurovska, 2024). The slender-clawed crayfish (*Astacus leptodactylus*) reached maximum density in clean zones of the Shamkir Reservoir, distant from industrial facilities, where the abundance was up to 12 individuals per m². In areas with water polluted by heavy metals and organic substances, the abundance decreased to 8 individuals per m², and in the Mingachevir Reservoir – to 5 individuals per m². The Caspian crayfish (*Pontastacus eichwaldi*) showed the most pronounced dependence on anthropogenic impact among the studied crayfish species. In the Shamkir Reservoir, its density varied from 7 individuals/m² in clean areas to 4 individuals/m² in polluted territories. In the Mingachevir Reservoir, this indicator was even lower, amounting to only 2-3 individuals per m² in areas with high levels of oil and organic pollution. This indicated that the Caspian crayfish proved to be the most sensitive to the negative influence of anthropogenic pollution.

Analysis of the spatial distribution showed that the most vulnerable were the juveniles of all investigated species. In polluted areas, the proportion of juveniles significantly decreased, leading to a noticeable imbalance in the age structure and a deterioration of reproductive potential (Bilyalov *et al.*, 2025). In the most polluted zones of the Mingachevir Reservoir, the mortality of shrimp and crayfish juveniles exceeded the figures in clean areas by 2-2.5 times. It was also established that noise pollution caused by active human recreational activity (boating, fishing, tourism) intensified the negative impact of pollution. In areas with high noise levels, the density of shrimp and crayfish populations additionally decreased by 15-20%, and the abundance of older age groups – by up to 50% (Fig. 1).

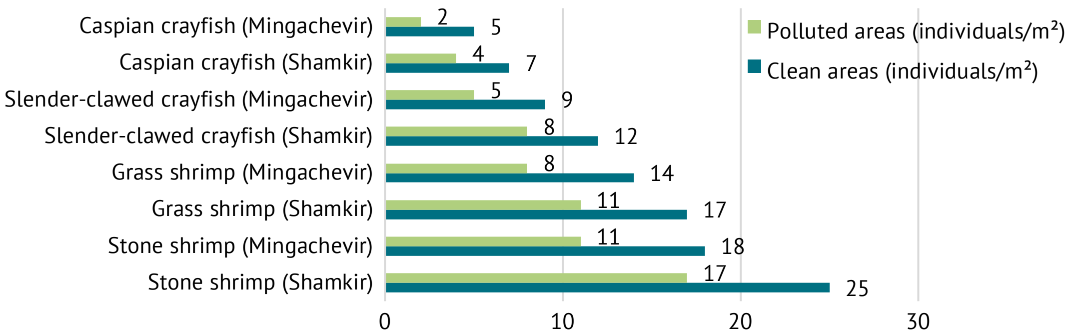

***Figure 1**. Distribution of shrimp and crayfish populations in relation to anthropogenic impacts*
***Source:** developed by the authors*

Thus, the results clearly demonstrated a direct dependence of spatial structure and population size on the level and type of anthropogenic impact. The greatest changes were observed in areas with complex impact of pollution (oil products, heavy metals, organics) and active recreation. The results of the study showed a significant decrease in the number of shrimp and crayfish populations in the polluted areas of the Shamkir and Mingachevir reservoirs, especially in the species *Palaemon adspersus* and *Pontastacus eichwaldi*, where the influence of anthropogenic factors led to a decrease in juveniles, imbalance of sex ratios. The greatest changes were observed in Mingachevir reservoir, where the level of pollution reached critical indicators for the ecosystem.

DISCUSSION

The conducted study established that anthropogenic factors exert a significant negative impact on the structure and abundance of shrimp (*Palaemon elegans,* *Palaemon adspersus*) and freshwater crayfish (*Astacus leptodactylus, Pontastacus eichwaldi*) populations in the Shamkir and Mingachevir Reservoirs. In polluted areas of both water bodies, the density of all studied species was significantly lower compared to clean zones: for *Palaemon elegans* in polluted areas of the Shamkir Reservoir, density decreased from 25 to 17 individuals/m² (by 32%), and for *Palaemon adspersus* – from 17 to 11 individuals/m² (by 35%). In the Mingachevir Reservoir, the abundance of *Palaemon elegans* decreased from 18 to 11 individuals/m² (by 39%), and *Palaemon adspersus* – from 14 to 8 individuals/m² (by 43%). The Caspian crayfish proved particularly vulnerable, with its abundance in heavily polluted areas of the Mingachevir Reservoir dropping to 2 individuals/m², representing a 60% reduction. The proportion of juveniles in polluted areas also significantly decreased for all species: for *Palaemon elegans* and *Palaemon adspersus*, the proportion of juveniles in polluted areas of Mingachevir decreased from 35-42% to 15-18%, accompanied by increased mortality (up to 50%). Simultaneously, shifts in sex structure were observed: males predominated in polluted areas, especially for *Palaemon adspersus* and *Pontastacus eichwaldi*, which may indicate differential resistance of sexes to toxicants. Thus, the spatial distribution, age, and sex composition of populations clearly correlated with the intensity of anthropogenic impact, confirming its destructive influence on the water bodies' ecosystem.

Research by L. Sehnal *et al.* (2021) and D.D. Backović and N. Tokodi (2024) addressed two different directions related to the response of aquatic organisms to technogenic loads. D.D. Backović and N. Tokodi focused on the biotoxicological aspect, investigating the spread of cyanobacteria and cyanotoxins in freshwater bodies, including aquaculture systems. It was emphasised that these compounds significantly disrupt metabolic functions and reduce the reproductive activity of aquatic organisms. Meanwhile, L. Sehnal *et al.* dedicated their work to the analysis of the microbiome of aquatic vertebrates, focusing on its role in immune defence and adaptation to polluted environments. Both approaches covered molecular and physiological levels but did not include population or spatial parameters. In contrast to these authors, the presented study allowed for establishing quantitative relationships between environmental pollution and the demographic structure of shrimp and crayfish populations, which enhances the applied significance of the obtained results in the context of bioindication and monitoring.

On the other hand, studies by R.N. Wanjari *et al.* (2024) and C. Zanghi and C.C. Ioannou (2025) concentrated on the physicochemical properties of the environment and their impact on ecosystem stability and functioning. C. Zanghi and C.C. Ioannou demonstrated that an increase in water turbidity leads to disruption of visual signals in fish, which entails a decrease in hunting efficiency and changes in the structure of trophic networks. At the same time, R.N. Wanjari *et al.* applied ecological modelling methods to analyse reservoir stability and interactions between abiotic and biotic components. Both studies presented important systemic conclusions but did not address specific changes in the structure of individual populations. Unlike these authors, the current work examined the quantitative parameters of indicator species populations and recorded patterns of decline in abundance and juveniles depending on the degree of pollution, which expands the possibilities for assessing the real vulnerability of aquatic ecosystems.

In a series of works by M.J. Thorstensen *et al.* (2022) and X. Miao *et al.* (2023), approaches aimed at studying the physiological state of aquatic organisms depending on environmental conditions were implemented. M.J. Thorstensen *et al.* developed non-invasive data collection methods for assessing the physiological state and movement of freshwater fish, reducing stress on the study subjects. X. Miao *et al.*, in turn, demonstrated that short-term keeping of silver carp in a clean natural environment improves its organoleptic and biochemical characteristics. Both works focused on physiological indicators; however, demographic characteristics and population stability were not assessed. The conducted study, however, allowed for recording a sharp decrease in density of up to 60-80%, an increase in juvenile mortality, and a distortion of sex structure in benthic crustaceans, which provides a more complete picture of the consequences of pollution at the population level.

Similarly, the works of D. Pandit *et al.* (2023) and A.G. Tacon *et al.* (2024) raised issues concerning the degradation of aquatic ecosystems from different perspectives. D. Pandit *et al.* investigated the decline in species diversity in Bangladesh water bodies and noted its impact on food security and the sustainability of small-scale fisheries, especially in socially vulnerable areas. A.G. Tacon *et al.* conducted an annotated literature review on the benefits and risks of consuming fish and seafood, drawing attention to the content of heavy metals and other pollutants. Despite their relevance and broad scope, neither study touched upon specific population changes due to pollution. This work filled that gap by establishing quantitative dependencies between the intensity of anthropogenic impact and population viability parameters – density, age composition, and sex structure – thereby creating a scientific basis for biomonitoring and restoration of aquatic bioresources.

Of particular note are the studies by K. Amoah *et al.* (2024) and L. Zhang *et al.* (2024), which considered two different approaches to assessing the state of aquatic organisms. K. Amoah *et al.* conducted molecular and immunobiological characterisation of four *Bacillus* strains isolated from the gut of hybrid grouper, demonstrating their antagonistic action against pathogens and their potential to improve fish health in aquaculture systems. Meanwhile, L. Zhang *et al.* focused their efforts on monitoring fish species diversity in coastal waters using DNA metabarcoding technology and passive water sampling. While both studies made significant contributions to the development of molecular ecology and monitoring, neither covered the analysis of spatial and age structure of populations under conditions of chemical pollution. In contrast, the presented study provides a clear focus on changes in the demographics and structure of crayfish and shrimp populations depending on the level of water body pollution, including an assessment of density, sex composition, and juveniles, which allows for conclusions to be drawn at the ecosystem sustainability level.

Among the works concerning the adaptation of organisms to changing conditions, the research by H.C. Vieira *et al.* (2022) and S. Rahayu *et al.* (2024) are noteworthy. S. Rahayu *et al.* analysed the current state and prospects of probiotic application in Chinese aquaculture, highlighting their impact on immune resistance, growth, and reduction of pathogen load in aquatic organisms. At the same time, H.C. Vieira *et al.* proposed a method of transplant testing for fish in field conditions to assess the toxicological load of the aquatic environment. Although both approaches are aimed at studying the response of organisms to external factors, they remain limited to the analysis of physiological and behavioural parameters at the level of individual organisms. In contrast, the present study presents spatial and quantitative indicators of populations in natural conditions, allowing for the consideration of the sustainability not of individual organisms, but of entire biocoenoses and their ability to self-maintain under conditions of complex pollution.

Equally interesting and conceptually significant are the studies by O.A. Anyanwu *et al.* (2023) and M. Reverter *et al.* (2025), which address the socio-ecological consequences of anthropogenic pressure on water resources. M. Reverter *et al.* presented a retrospective review of the aquaculture industry's contribution to the development of antimicrobial resistance, linking this to the excessive use of antibiotics and the global spread of resistant strains. O.A. Anyanwu *et al.*, in turn, conducted an interdisciplinary study dedicated to the perception of fish consumption in polluted marine environments in Indonesia. The authors showed that the population experiences an internal conflict between the traditional value of fish as a food source and the awareness of potential contamination risks. Both studies focus on the global and social aspects of ecological degradation but do not include a specific analysis of the consequences of pollution for population dynamics and structure. In contrast, the conducted study complements general assessments with empirical data on real changes in the spatial distribution, mortality, and reproduction of indicator species, which increases the accuracy of diagnosing the ecological state of freshwater bodies.

In the works of F.C. Sarker *et al.* (2022) and C. Van Driessche *et al.* (2024), issues concerning the conservation of freshwater biodiversity and the monitoring of fishing communities in a transformed environment were considered. F.C. Sarker *et al.* conducted an inventory of the ichthyofauna of the floodplain ecosystems of Sylhet (Bangladesh), highlighting the richness of species composition and the environment's susceptibility to seasonal and anthropogenic stress. Measures to strengthen the protection and management of water resources were proposed. In turn, C. Van Driessche *et al.* used DNA metabarcoding to assess spatio-temporal changes in the composition of fish communities in the Scheldt estuary. Trends of species shifting in response to environmental changes were identified; however, the analysis did not include the structural characteristics of individual populations. Unlike these works, the presented study provided an assessment of the density, sex, and age composition of benthic invertebrates, demonstrating a direct correlation of these parameters with the level of pollution and recreational pressure, which significantly expands the applied value of the obtained data.

In the studies by A.A. Mamun *et al.* (2021), and T.O. Sogbanmu and A.B. Dauda (2024), the consequences of industrial aquaculture and the possibilities of using local fish species in toxicological assessments were considered. A.A. Mamun *et al.* showed that export-oriented coastal fish farming can benefit vulnerable populations in terms of food security, but if uncontrolled, it can be accompanied by ecological risks. In turn, T.O. Sogbanmu and A.B. Dauda systematised the use of local Nigerian fish species in laboratory ecotoxicological tests, emphasising their significance for assessing the impact of pollutants. Both approaches were oriented towards economic or experimental practice but did not include field assessments of population stability under conditions of real pollution. Unlike them, the presented study applied a comprehensive population-ecological approach, documenting structural changes and demographic consequences of pollution for benthic invertebrates in freshwater ecosystems. The reviewed studies covered a wide range of aspects from biodiversity and physiology to food security and molecular monitoring methods. However, most of them either focused on individual organisms or described general ecosystem processes without analysing population structure and dynamics.

CONCLUSIONS

As a result of this study, a comprehensive assessment of the influence of anthropogenic factors on the structure, abundance and spatial distribution of shrimp (*Palaemon elegans, Palaemon adspersus*) and freshwater crayfish (*Astacus leptodactylus, Pontastacus eichwaldi*) populations in the Shamkir and Mingachevir reservoirs was carried out. In areas with minimal anthropogenic load (control zones) the density of shrimp populations varied from 12 to 25 individuals/m^2 for *Palaemon elegans* and from 9 to 17 individuals/m^2 for *Palaemon adspersus* in the Shamkir reservoir. In Mingachevir reservoir, the densities of these species ranged from 8 to 18 individuals/m^2 for *Palaemon elegans* and 6 to 14 individuals/m^2 for *Palaemon adspersus*. For freshwater crayfish in the Shamkir reservoir, population densities of *Astacus leptodactylus* ranged from 5 to 12 individuals/m^2 and *Pontastacus eichwaldi* from 3 to 7 individuals/m^2. In Mingachevir reservoir, the density of *Astacus leptodactylus* ranged from 3 to 9 individuals/m^2 and *Pontastacus eichwaldi* from 2 to 5 individuals/m^2. In polluted areas near sewage and recreational sources, shrimp abundance decreased to 11-17 individuals/m^2 and crayfish abundance to 2-5 individuals/m^2, representing a 32-60% reduction in density compared to control sites. The age structure of the populations showed significant changes: the proportion of juveniles in control conditions ranged from 25% to 42%, while in polluted areas it decreased to 15-20%. The mortality rate of juveniles in polluted areas reached 40-50%, especially in *Palaemon adspersus* and *Pontastacus eichwaldi*. A change in the sex composition was also recorded: the proportion of males was 55-78% in contaminated areas, while in clean areas it was 40-56%. The spatial structure of the populations showed a tendency towards habitat reduction and fragmentation, especially in the coastal zones of the Mingachevir reservoir, where maximum concentrations of organic pollutants were detected. Noise pollution, household rubbish and poaching also had an impact. Thus, a direct correlation between the level of anthropogenic impact and demographic characteristics of populations was established. The study confirmed that the decrease in density, mortality of juveniles and disturbance of the sex structure are reliable indicators of ecological disadvantage of water bodies. The prospects for further research on this topic include the development of more detailed monitoring programmes aimed at studying the long-term effects of anthropogenic impact on the ecosystems of Azerbaijan's reservoirs, as well as investigating the effectiveness of restorative measures to support the sustainability of non-fish seafood populations in these conditions.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Вплив антропогенних чинників на структуру популяції нерибних морепродуктів у водосховищах Азербайджану

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Анотація. Метою дослідження було встановити вплив антропогенних чинників на чисельність і структуру популяцій. У статті представлено результати комплексного емпіричного дослідження, спрямованого на оцінку впливу антропогенних чинників на структуру та чисельність популяцій креветок (*Palaemon elegans*, *Palaemon adspersus*) і річкових раків (*Astacus leptodactylus*, *Pontastacus eichwaldi*) в умовах Шамкірського та Мінгечаурського водосховищ Азербайджану. У період із червня до серпня 2024 року було проведено польові обстеження на ділянках із різним ступенем забруднення. Оцінка включала аналіз щільності особин, вікового та статевого складу, чисельності молодняка та його смертності, а також просторового розподілу популяцій. Для річкових раків середня щільність *Astacus leptodactylus* коливалася від 12 особин/м^2 (чисті зони Шамкірського водосховища) до 5 особин/м^2 (забруднені зони Мінгечаурського). У *Pontastacus eichwaldi* чисельність варіювала від 7 до 2 особин/м^2. Частка молодняка в структурі популяцій на чистих ділянках досягала 42 % (*Palaemon elegans*) і 40 % (*Astacus leptodactylus*), тоді як на забруднених ділянках – знижувалася до 15-20 %. Зафіксовано смертність молодняка до 40 % на ділянках з органічним забрудненням. На ділянках з високим рівнем забруднень спостерігався дисбаланс статевого складу: у *Palaemon adspersus* і *Pontastacus eichwaldi* частка самців перевищувала 55 %, тоді як на чистих ділянках переважали самки або зберігалося рівне співвідношення. Найбільше зниження чисельності всіх видів відзначено в Мінгечаурському водосховищі – до 60 % у *Pontastacus eichwaldi*, що свідчить про високу чутливість виду до комплексного антропогенного впливу. Результати засвідчили, що хімічне забруднення, рекреаційне навантаження та браконьєрство є визначальними чинниками деградації популяцій. Встановлено пряму залежність між рівнем антропогенного впливу та зниженням чисельності, порушенням вікової та статевої структури. Запропоновано індикаторні показники для моніторингу стану прісноводних екосистем. Отримані результати можуть використовуватися для розробки програм моніторингу та еколого-реставраційних заходів у водних екосистемах Азербайджану

Ключові слова: донні безхребетні; моніторинг середовища; техногенне навантаження; прісноводні екосистеми; біоіндикація