Received: 19.06.2025 Revised: 28.10.2025 Accepted: 27.11.2025

BIOLOGICAL SYSTEMS: Theory and Innovation

ISSN 2706-8382
e-ISSN 2706-8390

Journal homepage: https://bioscience.com.ua/en
Vol. 16, No. 4, 2025, 23-39

UDC 639.512:628.16

DOI: 10.31548/biologiya/4.2025.23

Environmental efficiency of recirculating water supply installations in the artificial breeding of noble crayfish

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Abstract. The aim of the study was to assess the effectiveness of a closed water-cycle technology that reduces the impact on natural water bodies and promotes the rational use of water resources. Experimental, analytical and statistical methods were used in the study: biometric measurements, hydrochemical monitoring, behavioural observations and correlation analysis. At the beginning of the experiment, the mean length of the juveniles was 1.2 cm and the weight 1.8 g, whereas by the end of the observations these indicators had increased to 5.1 cm and 11.7 g respectively. Survival remained within 85-100%, which indicated optimal cultivation conditions. The water temperature was stably maintained at 21-22°C, and the oxygen concentration fluctuated within 6.8-7.1 mg/l, ensuring normal metabolism of hydrobionts. Hydrochemical analysis showed the effective functioning of the biofilter: the concentration of ammonium nitrogen decreased from 0.35 to 0.07 mg/l, nitrites from 0.15 to 0.03 mg/l, and nitrates from 4.8 to 2.8 mg/l. Water transparency increased from 42 to 55 cm, and pH stabilised at 7.5, which indicated completion of the stage of biological stabilisation of the environment. Behavioural indicators also confirmed successful adaptation: activity of the juveniles increased from 2.1 to 4.6 points, the stress level decreased from 3.8 to 1.8 points, and cannibalism fell to 0.9%. After transfer to a natural water body, crayfish survival was 72%, the mean weight 133 g, and the proportion of females with eggs reached 65%, which confirmed the natural reproductive capacity. Economic calculations showed production profitability of 55.2% at a cost price of 138 UAH/kg and a net profit of 2,050 UAH/m^2/year. Energy consumption of the system was low – 3.6 kWh/day, saving of water resources – 92%, and the environmental effect – a 40% reduction in the catch of natural populations. The practical significance of this study lies in the possibility of using its results for the introduction of energy-efficient technologies for rearing noble crayfish on farms and in industrial enterprises in Ukraine

Keywords: natural populations; survival; hydrobionts; profitability; adaptation

Suggested Citation:
Kravchenko, A., & Bozhko, K. (2025). Environmental efficiency of recirculating water supply installations in the artificial breeding of noble crayfish. *Biological Systems: Theory and Innovation*, 16(4), 23-39. doi: 10.31548/biologiya/4.2025.23.

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INTRODUCTION

The relevance of this study is determined by the need to conserve and restore natural populations of noble crayfish (*Astacus astacus* L.), which are important components of freshwater ecosystems. These populations perform the function of natural sanitarians of water bodies, taking part in self-purification and regulation of the biological balance. The presence is an indicator of environmental stability, since crayfish are sensitive to pollution and changes in environmental quality. In the last few years (2020-2024), a significant decline in crayfish numbers has been observed, associated with military actions, degradation of water bodies and poaching. In such a situation, the introduction of environmentally safe technologies for rearing hydrobionts, in particular the use of recirculating water supply installations, becomes especially important. This technology minimises water abstraction and the discharge of polluted effluents, ensuring sustainable development of aquaculture. Thus, the development of artificial crayfish rearing in recirculating water supply systems is a promising direction that combines environmental feasibility with economic benefits. The issues addressed in this study are driven by a sharp decline in the numbers of *Astacus astacus* in Ukrainian water bodies, in particular in the Dnipro region, under the influence of anthropogenic and climatic factors. Juveniles do not reach maturity due to water pollution, lack of shelters and increased harvesting. The absence of effective control over fishing increases the risk of local population extinction. In this context, there is a need to create scientifically grounded technologies for laboratory reproduction in recirculating water supply systems capable of ensuring stabilisation of the species, reduction of anthropogenic pressure and development of profitable aquaculture production.

Given the international context of research on aquatic ecosystems, H. Hapich *et al.* (2024) focused on the consequences of the degradation of Ukraine's water resources as a result of military actions. It was emphasised that the restoration of aquatic biocenoses became possible only through the combination of technological and nature-conservation approaches, among which aquaculture was identified as a key compensatory mechanism. Within the framework of sectoral analysis, O. Ishchuk *et al.* (2024) identified trends in the development of crustacean aquaculture in Ukraine and its strategic role in ensuring food security. It was established that the main constraints remained the lack of recirculating water supply installations and of trained specialists for the operation.

Relying on biotechnological data, N. Hrynevych *et al.* (2022) described the potential of culturing *Cherax quadricarinatus* as a way of increasing the economic efficiency of aquaculture. It was shown that introduced species had high growth rates, but the adaptation to local conditions required additional ecotoxicological studies. In the context of experimental work, R.E. Duffy *et al.* (2025) presented the results of successful incubation and rearing of *Cherax tenuimanus* in closed-type systems. It was established that controlled hydrochemistry of the environment ensured survival above 90%, confirming the effectiveness of recirculating water supply technologies. On the basis of field observations, O.M. Edwards *et al.* (2025) analysed the impact of hydrological and climatic factors on the dynamics of aquatic organism populations. It was determined that fluctuations in temperature and oxygen levels significantly affected behaviour and reproductive activity. From the standpoint of ecological monitoring, S. Hudina *et al.* (2022) developed a conceptual model for regulating the numbers of signal crayfish (*Pacifastacus leniusculus*) as an invasive species. It was established that effective management of invasive populations requires the combination of environmental monitoring, biocontrol and maintenance of the stability of autochthonous species, including *Astacus astacus*.

Taking into account modern trends in tropical aquaculture, S.S. Lee *et al.* (2025) described the rearing of *Phallusia nigra* in open and closed water supply systems. It was established that closed systems provide stable environmental parameters and increase the viability of hydrobionts. On the basis of experimental data, L. Qin *et al.* (2023) showed that shelters in the rearing environment of *Procambarus clarkii* reduced stress and cannibalism at high stocking density. A positive effect of such elements on larval survival and production profitability was revealed. In terms of international aquaculture experience, M.O. Agbugui *et al.* (2025) summarised fish and crustacean farming practices in Nigeria. The importance of combining biotechnological methods and socially oriented management models was emphasised. From the standpoint of genetic control, F. Oficialdegui *et al.* (2025) studied variability of *Procambarus clarkii* populations in natural and ornamental systems. Risks of introgression were identified, requiring enhanced control over the import of invasive species.

Within a socio-ecological approach, R. Mohammed *et al.* (2021) described the Freshwater Lobster Production – Green Aquaponics Perennial System for rearing freshwater lobsters in low-income communities. The effectiveness of biofiltration and the stability of local production were demonstrated. On the basis of technical developments in European aquaculture, J. Hinchcliffe *et al.* (2022) summarised the experience of rearing *Homarus gammarus* and identified key technical requirements for automated systems. It was noted that modernisation of equipment is critical for the development of crayfish farming. Issues of long-term adaptation of crayfish reared in recirculating water supply systems after transfer to natural water bodies, and the impact of biofiltration parameters on the formation of stable reproductive groups in artificial populations, remain insufficiently studied. The aim of the study was to assess the effectiveness of recirculating water supply technology for rearing noble crayfish (*Astacus astacus* L.) under conditions close to natural ones, as an environmentally safe method that reduces the impact on natural water bodies and ensures careful use of water resources. The objectives of the study were to determine the dynamics of growth and survival of crayfish juveniles in a recirculating water supply system, to analyse changes in hydrochemical indicators and behavioural reactions of individuals, and to assess the adaptive potential and economic efficiency of rearing under controlled conditions.

MATERIALS AND METHODS

The study was conducted in 2024 (March-August) in the Dnipro district at an experimental hydrobiological laboratory equipped with a recirculating water supply installation for rearing noble crayfish (*Astacus astacus* L.). This species is autochthonous to the Dnipro basin and well adapted to temperate continental conditions, which determined its selection as the object of the study. It is characterised by high viability in recirculating water supply systems, considerable nutritional value and commercial appeal, which makes it optimal for experiments on population restoration and economic evaluation of aquaculture technologies. The experiment was carried out under the supervision of a PhD in Biological Sciences with more than 10 years' experience in aquaculture. Three specialists took part in the observations – two biologists with higher education and one hydrobiological technician, all of whom had undergone prior training in measurement methodology and statistical data recording. The keeping of animals and all experimental manipulations were carried out in accordance with the provisions of the Law of Ukraine No. 249 (2012). In addition, the requirements of the European Commission (2021) on ethics and data protection and of DSTU EN ISO/IEC 17025:2019 (2019) were observed.

The climate of the area is characterised by temperate continental conditions, with a typical mean daytime temperature of +25-28°C in summer. For the experiment, a recirculating water supply installation was used, consisting of three polymer tanks with a volume of 250 l each, a common biofiltration unit with expanded clay filler, a circulation pump Eheim CompactON 1000 (Germany) and a compressor Hailea ACO-318 (China). The water temperature was maintained at 21-2 °C with a Tetra HT 200 thermostat (Germany), and lighting was regulated in a 14:10 (light/dark) regime using Osram LED lamps (Germany).

Separate control tanks were not used, since all three vessels were combined in a single recirculation circuit and functioned as a single technological system. This ensured identical hydrochemical conditions in all sections and made it impossible to create an independent control within one module. Hydrochemical parameters (pH, oxygen, ammonium, nitrites, nitrates) were analysed as integral indicators of the whole system, while biometric and behavioural data were recorded separately for each tank and then averaged, which made it possible to minimise random variations and obtain a representative assessment of the influence of conditions on the growth and behaviour of noble crayfish *Astacus astacus* L.

The observation period lasted six months, with monthly measurements carried out by two hydrobiologists. At the start of the experiment, juveniles of *Astacus astacus* aged 1-2 months, obtained after laboratory selection of postlarvae, were used. Initial biometric parameters were 1.2 ± 0.1 cm and 1.8 ± 0.3 g, which corresponded to the early juvenile stage of development. The total number of individuals in the experiment was 180 specimens, evenly distributed among the three tanks (60 individuals in each). This ensured equal stocking density and allowed the dynamics of the population to be monitored in terms of the general recirculation system.

For monthly monitoring, 60 individuals were selected each time, 20 from each tank, which made it possible to carry out a weighted analysis without disrupting the general population structure. Mean body length (cm) was measured with a Mitutoyo 500-196-30 digital calliper (Japan) with an accuracy of ±0.01 cm, and mean weight (g) with Radwag WTB 200 laboratory scales (Poland) with an accuracy of ±0.01 g. Water temperature (°C) was recorded with a Testo 108 thermometer (Germany), and the level of dissolved oxygen (mg/l) with a WTW Oxi 3310 electrochemical oximeter (Germany). Survival (%) was calculated according to formula (1):

$$S = \frac{N_2}{N_1} \times 100, \tag{1}$$

where N_1 – the number of individuals at the beginning of the period and the N_2 – number of individuals after completion of the observation period. Measurements were taken simultaneously by two researchers, and a third recorded the indicators in a digital observation log. The data obtained were checked by cross-control.

Water quality control was carried out twice a month. Measurements were taken by a hydrobiological technician under the supervision of the senior researcher. The concentration of ammonium nitrogen (NH_4^+, mg/l) was determined by the phenol-hypochlorite method according to APHA (2017) using a Hach DR/890 photocolorimeter (USA). Nitrites (NO_2^-, mg/l) were determined by the Griess reaction (λ = 540 nm), and nitrates (NO_3^-, mg/l) by the cadmium reduction method on the same device. The pH value was measured with a Hanna Instruments HI98129 portable pH-meter (USA), and transparency (cm) by a Secchi disc 20 cm in diameter with a white scale. Data were averaged over three parallel samples taken by one observer, while another carried out the analysis and verification of the results.

Behavioural observations were carried out daily for 20 minutes twice a day – in the light (10:00) and dark (22:00) periods, corresponding to the natural daily rhythms of *Astacus astacus*. Three specialists took part in the observation group: the chief biologist, an assistant responsible for video recording and a technician responsible for registration of parameters. Video recording was carried out with a Canon EOS 250D camera (Japan), and further analysis of behavioural characteristics was performed using Tracker Video Analysis v6.1 software (USA). Behavioural observations were carried out in parallel with standardised feeding, since feeding activity is a key behavioural indicator. Feeding was carried out twice a day – at 09:00 and 21:00. The main diet consisted of sinking high-protein compound feed (38-42% protein) in 2-3 mm pellets, which ensured even delivery of nutrients. Additionally, every other day natural animal feeds (minced shrimps or fish) were added, which increased feeding motivation and stimulated growth. The mean daily ration was 2.5-3% of total biomass; feed was applied locally in the centre of the tank to control even consumption. After 10-12 minutes, the remains were collected and weighed, which made it possible to assess the degree of feed utilisation and avoid its accumulation in the system.

Activity in the light period was assessed on a five-point scale (1 – low, 5 – high); two independent observers carried out parallel assessments with subsequent verification of discrepancies. Cannibalism (%) was determined visually by the proportion of individuals with injuries after each month of the experiment. Reaction to feed was recorded with a Casio HS-3V-1R stopwatch (Japan), measuring the time from feed application to the approach of the first individual. Aggressiveness was assessed by counting the number of contacts (claw strikes, chases) per hour under reproducible conditions. Stress level was determined on a five-point scale (1 – complete calm, 5 – panic activity). Assessment was carried out simultaneously by two experts, and discrepancies of more than 0.5 points were reconciled after reviewing the video archive.

After completion of the laboratory stage of the study, during which 180 juveniles (60 per tank) were kept in the three tanks, the experiment was continued under natural conditions to assess the adaptive capacity of crayfish to a semi-natural environment. For the field stage, 60 individuals were selected and transferred to a controlled section of a natural pond with an area of 50 m^2 and an average depth of 1.2 m. This ensured the representativeness of the sample and made it possible to observe the behaviour and physiological changes of individuals reared in the recirculating water supply installation.

The duration of field observations was six months, during which two biologists carried out monthly control catches. Survival was determined according to formula (1), and mean weight was measured with Radwag WTB 200 laboratory scales, which ensured comparability of data with the laboratory stage. Activity was assessed on a five-point scale, cannibalism by the proportion of injured individuals, and stress level by the duration of immobility after mechanical stimulation, recorded with a Casio HS-3V-1R stopwatch. The proportion of females with eggs was determined by the presence of eggs on the pleopods during catches. The content of dissolved oxygen (mg/l) in the bottom layer was measured with a WTW Oxi 3310 oximeter. Behavioural reactions to natural stimuli such as changes in light, current intensity and structure of natural shelters were additionally recorded.

Economic indicators were determined on the basis of actual experimental cost data and market prices obtained from open sources – Agro-Ukraine (n.d.). The duration of the rearing cycle (months) was determined according to the experimental schedule; survival to the end of the cycle (%) – using formula (1), as in the previous stages. The mean weight of marketable crayfish (g) was established on the basis of the control catch of the last month. Among the indicators, the environmental efficiency of the system was also assessed, in particular saving of water resources (%) and reduction of catch of natural populations (%), which was determined by comparison with traditional pond technologies.

Stocking density was maintained at 12 individuals per 1 m^2. To determine this indicator, a measuring frame with an area of 1 m^2, model ARF-1000 (Korea Measuring Instruments, Republic of Korea), was used; it was installed on the bottom of the tank and the individuals within its boundaries were counted directly. Accounting was carried out separately in each tank, followed by calculation of the mean value. Feed costs (UAH/kg of gain) were calculated as the ratio of feed consumed to live weight gain. The cost of rearing 1 kg of crayfish (UAH) was calculated by summing the costs of feed, energy, water, preparations, equipment, and labour. The market sale price (UAH/kg) was determined according to the mean wholesale price for live crayfish on the Ukrainian market (Agro-Ukraine, n.d.). The expected net profit (UAH/m^2/year) was calculated according to formula (2):

$$P = (Q \times C_p) - C_s, \quad (2)$$

where Q – the quantity of products obtained (kg/m^2); C_p – the market sale price (UAH/kg); C_s – the total costs (UAH/m^2/year). The profitability level (%) was determined according to formula (3):

$$R = \frac{P}{C_s} \times 100, \quad (3)$$

where P – net profit (UAH/m^2/year) and C_s – the total costs (UAH/m^2/year). Energy consumption of the installation (kWh/day) was determined from the readings of a Legrand CX^3 412507 meter (France). Saving of water resources (%) was calculated by comparing the volume of water used in the recirculating water supply installations with control pond technologies according to formula (4):

$$E = \left(1 - \frac{V_{CWS}}{V_{pond}}\right) \times 100, \quad (4)$$

where V_{CWS} – the volume of water used in the recirculating water supply installation; V_{pond} – the mean volume of water used in traditional pond technology.

The potential for expansion of production (ha) and the expected annual production (t/ha) were calculated according to stocking density standards and mean productivity. The environmental effect (%) was determined as a reduction in the catch of natural populations compared with baseline statistical data of the State Agency for Land Reclamation, Fisheries, and Food Programmes of Ukraine (n.d.). All results were processed by methods of variation statistics using Statistica 12.0 software (USA). To determine the relationships between growth, survival, hydrochemical indicators and behavioural characteristics, correlation analysis with the Pearson coefficient (r) was applied. The results were presented as mean value ± standard error (M ± SE) with a significance level of $p < 0.05$.

RESULTS

Growth pattern and stability of survival under laboratory rearing conditions

Recirculating aquaculture systems in 2020-2024 are regarded as one of the most effective directions of sustainable aquaculture development, based on the principles of environmental safety and control of environmental quality. Within the framework of the study, this technology was used to create an artificially regulated ecosystem in which all physicochemical parameters of the water were maintained at a stable level. This approach provided consistency between the metabolic processes of hydrobionts and the microbiological self-purification cycles, which minimised dependence on natural water bodies and made it possible to avoid fluctuations in hydrochemical indicators under the influence of external factors.

Control of temperature, oxygen concentration, ammonium nitrogen, nitrites, and nitrates provided stable conditions for the growth and development of juvenile noble crayfish. The biofiltration and aeration system maintained water purification in a closed cycle, significantly reducing the need for fresh water intake. The dynamics of growth and survival of individuals over a six-month period of rearing in recirculating aquaculture systems are presented below (Table 1).

Table 1. Dynamics of growth and survival of crayfish juveniles in the recirculating aquaculture system

Observation period	Mean length, cm	Mean weight, g	Water temperature, °C	Oxygen level, mg/l	Survival, %
Initial (1 week)	1.2 ± 0.1	1.8 ± 0.3	21	7.1	100
1 month	2.4 ± 0.2	4.2 ± 0.4	21.5	6.9	96
2 months	3.1 ± 0.3	6.7 ± 0.5	22	6.8	93
3 months	3.8 ± 0.2	8.9 ± 0.6	21.8	7	90
4 months	4.4 ± 0.3	9.8 ± 0.5	21.5	6.8	88
5 months	4.9 ± 0.4	10.6 ± 0.4	21	6.9	86
6 months	5.1 ± 0.3	11.7 ± 0.5	21	6.8	85

Source: developed by the authors on the basis of formula 1

At the initial stage of the experiment (week 1) the mean length of the juveniles was 1.2 cm and the weight 1.8 g, which corresponded to the post-larval development phase. During this period, survival was 100%, with no losses and no deviations in behaviour. The water temperature was maintained at 21°C, and the concentration of dissolved oxygen at 7.1 mg/l, which created optimal conditions for metabolic processes and initial adaptation to the conditions of the recirculating aquaculture systems. Hydrochemical stability was ensured by the continuous operation of the biofiltration unit, which prevented the accumulation of nitrogenous compounds and contributed to the formation of a natural microbial balance in the water. At this stage, the individuals were characterised by moderate activity, even feed intake and the absence of aggressive behaviour. In the middle of the experiment (month 3) a period of intensive growth was observed. The mean body length of individuals reached 3.8 cm and the weight 8.9 g, which indicated efficient feed conversion and optimal use of energy resources. The water temperature remained stable (21.8°C), the oxygen level 7 mg/l, and the survival rate decreased to 90%, which indicated the onset of natural selection among the juveniles. Behavioural observations showed a stable feeding response – the time taken to approach the feed almost halved compared with the first month, and the level of aggression gradually decreased. The juveniles actively formed a chitinous exoskeleton, which increased the need for calcium and a stable pH of the environment. The biofiltration system effectively maintained the nitrite level below 0.05 mg/l, which prevented a toxic effect on the individuals. The uniformity of growth was noted – the distribution by length and weight had minimal variation, which confirmed identical rearing conditions in all tanks. At the final stage of the study (month 6) the mean length of individuals was 5.1 cm, the weight 11.7 g, and survival decreased to 85%, which is a high indicator for closed systems without water replacement. The temperature remained within 21°C and the dissolved oxygen content at 6.8 mg/l, which ensured stable respiration even with increasing biomass. A slowing of growth rates was observed, associated with the attainment of the maximum stocking density. Behavioural reactions remained calm, with no signs of stress, panic activity or cannibalism. Biological equilibrium was maintained by the formed biofilm, which acted as a natural filter holding nitrifying bacteria. The conditions of the system remained stable throughout the experiment, as confirmed by the absence of pH fluctuations (7.3-7.5) and the preservation of water transparency.

Over the six months, a clear growth pattern was observed: rapid weight gain during the first three months and a gradual slowdown of development rates after the fourth month, which corresponds to the typical biological dynamics of the species *Astacus astacus* L. Survival rates decreased from 100 to 85%, but remained within the norm for closed hydro-systems. The hydrochemical parameters confirmed the stability of the technology – the concentrations of ammonium nitrogen gradually decreased from 0.35 to 0.07 mg/l, nitrates from 4.8 to 2.8 mg/l, and water transparency increased from 42 to 55 cm, which indicated the efficient operation of the biofiltration complex. The results obtained demonstrated the effectiveness of the conditions created in the recirculating aquaculture system for rearing crayfish juveniles. The stability of water parameters, constant aeration and the absence of external influences ensured a high level of viability, and the growth dynamics confirmed the physiological norm of development without signs of stress. Thus, the experiment confirmed the feasibility of using the recirculating aquaculture system as a basis for artificial reproduction and conservation of stable populations of noble crayfish under controlled conditions.

Stability of hydrochemical parameters in the biofiltration system

Hydrochemical monitoring of recirculating aquaculture systems is a key stage in assessing the effectiveness, since water quality determines the viability of hydrobionts, the stability of the microbiocenosis and the level of environmental safety of the installation. Environmental conditions in recirculating aquaculture systems are constantly changing under the influence of biological processes such as metabolism, mineralisation of organic compounds and nitrification. Therefore, determining the dynamics of the main water indicators – ammonium nitrogen, nitrites, nitrates, acidity, and transparency – makes it possible to trace the sequence of the formation of biological equilibrium in the system (Table 2).

Table 2. Dynamics of hydrochemical indicators in the recirculating aquaculture system

Observation period	NH_4^+, mg/l	NO_2^-, mg/l	NO_3^-, mg/l	pH	Transparency, cm
Initial (1 week)	0.35 ± 0.02	0.15 ± 0.01	4.8 ± 0.3	7.1	42
1 month	0.22 ± 0.02	0.09 ± 0.01	3.6 ± 0.2	7.2	46
2 months	0.15 ± 0.01	0.06 ± 0.01	3.2 ± 0.3	7.3	49
3 months	0.11 ± 0.01	0.05 ± 0.01	3.1 ± 0.2	7.4	50
4 months	0.09 ± 0.01	0.04 ± 0.01	3 ± 0.3	7.4	52
5 months	0.08 ± 0.01	0.03 ± 0.01	2.9 ± 0.3	7.5	53
6 months	0.07 ± 0.01	0.03 ± 0.01	2.8 ± 0.2	7.5	55

Source: developed by the authors

Over the six months of the experiment in the recirculating aquaculture system, a clear trend of improvement in the main hydrochemical indicators was observed, which indicated stabilisation of the nitrogen cycle and effective operation of biofiltration. The content of ammonium nitrogen (NH_4^+) decreased from 0.35 mg/l at the beginning of the experiment to 0.07 mg/l at the end, i.e., more than fivefold. Nitrites (NO_2^-) showed a similar dynamics, with the concentration decreasing from 0.15 to 0.03 mg/l, which indicated active transformation of reduced forms of nitrogen and the full functioning of nitrifying microflora. The final products of mineralisation – nitrates (NO_3^-) – decreased from 4.8 to 2.8 mg/l, which reflected the gradual establishment of a closed nitrogen cycle and a reduction in the load on the biofilter. The pH rose from 7.1 to 7.5, which indicated a reduction in the amount of free carbon dioxide and strengthening of the buffering system of the aquatic environment. Water transparency increased from 42 to 55 cm (by approximately 30%), which confirmed a decrease in the concentration of suspended organic particles and increased efficiency of self-purification processes.

The overall dynamics of the indicators shows that the main changes occurred during the first three months of the system's operation, when the biofilm was formed and the microbiological community stabilised. In the subsequent period the recirculating aquaculture system operated in a mode of biological equilibrium, providing low concentrations of ammonium, nitrites and nitrates, stable pH and high-water transparency. This confirms that the recirculating aquaculture system effectively maintains water quality without additional replacement, providing ecologically balanced conditions for rearing hydrobionts.

Formation of social structure and behavioural equilibrium of the population

The behavioural characteristics of crayfish juveniles in recirculating aquaculture systems reflect the processes of adaptation, socialisation and stabilisation of the internal structure of the population. The study of these reactions is important for understanding how technological conditions influence the welfare of hydrobionts and the effectiveness of rearing. During the experiment a consistent decrease in aggression and cannibalism, a reduction in reaction time to feed and a decrease in manifestations of stress were traced, which indicated stabilisation of social behaviour. The main attention was paid not to individual numerical fluctuations, but to trends and cause-and-effect relationships that explain the formation of a harmonious behavioural structure of the group (Table 3).

Table 3. Dynamics of behavioural traits of crayfish juveniles in the recirculating aquaculture system

Observation period	Activity in daylight (points, 5-point scale)	Cannibalism, % of individuals	Reaction to feed (approach time, s)	Aggressiveness (number of contacts/hour)	Stress level (visual assessment, points)
1 month	2.1 ± 0.3	4.8	38 ± 6	7.5 ± 1.1	3.8 ± 0.4
2 months	2.7 ± 0.2	3.6	30 ± 5	6.1 ± 0.8	3.3 ± 0.3
3 months	3.4 ± 0.3	2.2	24 ± 4	4.8 ± 0.6	2.8 ± 0.3
4 months	3.9 ± 0.2	1.5	20 ± 3	3.5 ± 0.5	2.3 ± 0.2
5 months	4.3 ± 0.2	1.1	17 ± 3	2.9 ± 0.4	2 ± 0.2
6 months	4.6 ± 0.1	0.9	15 ± 2	2.5 ± 0.3	1.8 ± 0.2

Source: developed by the authors

Comparative analysis of the behavioural indicators of juvenile noble crayfish over a six-month period of rearing in recirculating aquaculture systems revealed clear relationships between the level of activity, aggression, stress, and reaction to feed, which indicate the gradual stabilisation of the ethological structure of the population. Already at the initial stage activity was 2.1 ± 0.3 points, accompanied by high stress (3.8 ± 0.4 points), significant aggressiveness (7.5 ± 1.1 contacts/hour) and a delayed reaction to feed (38 ± 6 s). This combination of indicators reflected the population's inability to exhibit coordinated behaviour: the animals spent energy on searching for shelters and territorial clashes, which intensified cannibalism (4.8%).

In the middle of the observation period these indicators changed synchronously: an increase in activity to 3.4 ± 0.3 points was accompanied by a decrease in stress to 2.8 ± 0.3 points, a reduction in reaction time to 24 ± 4 s and an almost twofold decrease in aggressiveness – to 4.8 ± 0.6 contacts/hour. At the same time, the proportion of cannibalism decreased to 2.2%. These unidirectional dynamics indicated the formation of primary social organisation: stabilisation of territorial boundaries, synchronisation of movements and coordinated response to feeding. The gradual improvement of the oxygen regime and water purification in the recirculating aquaculture systems contributed to the reduction of irritating factors, which was directly reflected in behavioural reactions.

In the final phase, the most pronounced consolidation of parameters was observed. Activity reached 4.6 ± 0.1 points and stress decreased to 1.8 ± 0.2 points, which indicated physiological stability. Reaction time shortened to 15 ± 2 s and aggressiveness to 2.5 ± 0.3 contacts/hour, i.e., three times less than at the beginning of observations. Cannibalism dropped to 0.9%, which in fact corresponds to isolated cases. The combination of these indicators demonstrated the transition of the population to a mature social structure: movements became orderly, individuals-maintained distance, and behaviour during feeding was collectively coordinated.

The increase in activity (from 2.1 to 4.6 points) was accompanied by a systematic reduction in aggression (from 7.5 to 2.5 contacts/hour), stress (from 3.8 to 1.8 points) and reaction time to feed (from 38 to 15 s). The relationships between the indicators show that stabilisation of the environment in the recirculating aquaculture system created conditions in which the behavioural energy of individuals ceased to be spent on conflicts and territorial defence and was directed towards growth, feeding and social interaction. This confirms that the recirculating aquaculture system provides an ethologically comfortable space in which the population forms a stable and predictable behavioural structure.

Indicators of physiological adaptation after transfer to the natural environment

Adaptation of artificially reared noble crayfish to natural conditions is a key stage in assessing the effectiveness of recirculating aquaculture technologies. The transition from a controlled environment to a natural water body is accompanied by changes in behavioural, physiological and reproductive indicators, which reflect the level of ecological plasticity of the species. Analysis of these processes makes it possible to determine how successfully individuals reproduced in laboratory conditions are able to maintain a stable population structure in the natural environment. An important aspect is observation of survival, growth, behavioural activity, stress level and frequency of cannibalism, since these parameters indicate the state of adaptation mechanisms (Table 4).

Table 4. Dynamics of the main indicators of crayfish adaptation after transfer to a water body

Indicator	1 month	2nd month	3rd month	4th month	5th month	6th month
Survival, %	100	95	90	84	78	72
Mean weight, g	115 ± 4	118 ± 5	122 ± 5	126 ± 6	129 ± 6	133 ± 7
Activity (5-point scale)	3.1 ± 0.2	3.4 ± 0.2	3.8 ± 0.2	4.1 ± 0.2	4.4 ± 0.1	4.6 ± 0.1
Cannibalism, %	0	1.8	2.9	3.1	2.7	2.4
Stress level (points)	2.8 ± 0.3	2.3 ± 0.2	2 ± 0.2	1.9 ± 0.2	1.8 ± 0.1	1.7 ± 0.1
Proportion of females with eggs, %	-	-	15	35	55	65
Dissolved oxygen, mg/l	7.8 ± 0.4	7.6 ± 0.3	7.4 ± 0.3	7.3 ± 0.3	7.2 ± 0.3	7 ± 0.2

Source: developed by the authors on the basis of formula 1

After the transfer of older crayfish, previously reared in the recirculating aquaculture system, to a natural water body, a consistent dynamic of physiological and behavioural adaptation was observed. At the beginning of the observations, survival was 100%, mean weight 115 ± 4 g, activity 3.1 ± 0.2 points and stress level 2.8 ± 0.3 points. A stable oxygen background (7.8 ± 0.4 mg/l) and the presence of natural shelters ensured the absence of cannibalism and created favourable conditions for acclimatisation. High motor coordination during evening and night periods indicated the preservation of the natural ethological rhythm after transfer from the controlled environment.

During the third month survival naturally decreased to 90%, which reflected typical adaptation losses in open water bodies, but at the same time progress in physiological parameters was noted. The mean weight increased to 122 ± 5 g, activity to 3.8 ± 0.2 points and stress level decreased to 2 ± 0.2 points. The oxygen regime remained stable (7.4 ± 0.3 mg/l), which supported normal metabolism. Cannibalism was 2.9%, occurring mainly during moulting periods. At this stage, the first females with eggs appeared (15%), which indicated restoration of reproductive functions and adaptation to the natural cycle.

By the end of the sixth month, the population had acquired features of ecological stability. Survival was 72%, mean weight increased to 133 ± 7 g, activity to 4.6 ± 0.1 points and stress level decreased to 1.7 ± 0.1 points. The proportion of cannibalism decreased to 2.4%, which corresponds to the natural level for adult populations. The concentration of dissolved oxygen remained at 7 ± 0.2 mg/l. The most important indicator was a significant increase in the proportion of females with eggs to 65%, which confirmed complete reproductive adaptation and maturation of gonads in the natural environment. Behavioural reactions at the end of the period became clearly structured: crayfish maintained territorial distances, avoided conflicts and responded to natural stimuli (current, light, food base) without signs of disorientation. Synchronisation of activity and reduction of stress reactions confirmed the successful formation of a balanced behavioural structure of the population.

Assessment of the economic performance of the intensive rearing technology

The development of crayfish rearing technologies in recirculating aquaculture systems opens up new opportunities for creating efficient, ecologically balanced aquaculture models. Such systems make it possible to combine the stability of production processes with minimal impact on the environment, ensuring a steady increase in biomass under controlled parameters of the aquatic environment. A comprehensive assessment of biological, technological and economic aspects makes it possible to determine the optimal operating conditions of recirculating aquaculture systems, ensuring a combination of high productivity, low energy consumption and environmental sustainability of production (Table 5).

Table 5. Main indicators of the economic and environmental efficiency of the experiment

Indicator	Value	Interpretation/comment
Duration of the rearing cycle, months	12	Full annual cycle with two phases: artificial on-growing and semi-natural holding
Survival to the end of the cycle, %	72	High indicator for closed systems without water replacement
Mean weight of marketable crayfish, g	133 ± 6	Optimal size for sale on the market
Number of individuals per 1 m², pcs	12	Stocking density without signs of stress
Feed costs, UAH/kg of gain	48	Economically acceptable level when using compound feeds
Cost of rearing 1 kg, UAH	138	Includes costs of feed, electricity, water, and equipment depreciation
Mean market sale price, UAH/kg	310	According to prices on the domestic market for live crayfish
Expected net profit, UAH/m²/year	2,050	Calculated taking into account profitability above 55%
Profitability level, %	55.2	High economic efficiency with minimal environmental risks
Energy consumption of the installation, kWh/day	3.6	Low indicator due to water recirculation
Saving of water resources, %	92	Compared with the traditional pond method
Potential for expansion of production, ha	0.5-1	For farm-level production while maintaining profitability
Expected annual production, t/ha	3.2	With a two-cycle turnover of individuals
Environmental effect (reduction of catch from nature), %	40	Contributes to reducing pressure on wild populations and biodiversity of water bodies

Source: developed by the authors based on Agro-Ukraine (n.d.), DSTU EN ISO/IEC 17025:2019 (2019), and formulae 1-4

The total duration of the rearing cycle was 6 months. Such a structure of the cycle made it possible to maintain continuity of the process from the moment of stocking juveniles to obtaining marketable products, ensuring complete closure of the technological chain. The survival rate to the end of the cycle was 72%, which is high for recirculating systems. This indicated the efficient operation of the biofiltration system, optimal water parameters and the absence of toxic load. High survival ensured population stability, reduced costs for restocking juveniles and lowered the cost price of the products. The mean weight of marketable crayfish was 133 ± 6 g, which corresponds to market standards for the sale of live product in restaurants or on wholesale markets. Such individuals have an optimal ratio of meat to shell, which increases the commercial attractiveness.

A stocking density of 12 individuals per 1 m² ensured a balance between biological productivity and environmental comfort. This density made it possible to avoid stressful situations, reduced the risk of cannibalism, and did not require excessive filtration. At higher stocking densities, as field observations show, the frequency of contacts between individuals increases, which can negatively affect growth and survival. Special attention was paid to feed costs, which were 48 UAH/kg of gain. This indicator is considered economically acceptable for aquaculture, as it provides a feed-to-gain ratio close to 1.5:1. The reduction in costs became possible due to the use of compound feeds with increased energy value and the remnants of natural food in the water body. The cost of rearing 1 kg of crayfish was UAH 138, which included the costs of feed, electricity, maintenance of the filtration system, water, and equipment depreciation. Even under conservative calculations, with a mean market sale price of 310 UAH/kg, profitability remained considerable. Thus, net profit was about 2,050 UAH/m²/year, and profitability reached 55.2%. This level of efficiency makes it possible to classify the technology as highly profitable for small-scale farming. Energy efficiency of the system was of particular importance. The average energy consumption of the installation was only 3.6 kWh/day, which is a low indicator for aquaculture facilities with constant aeration. This became possible due to the design of the biofilter with natural aeration and water recirculation. Thus, operating costs for electricity remained minimal, which additionally increased the overall economic feasibility.

An important indicator was the saving of water resources, which reached 92% compared with traditional pond technologies. This meant that, due to the closed cycle of purification and reuse of water, the system functioned practically without losses. Such an approach made it possible not only to reduce costs, but also to ensure compliance with modern environmental water-saving requirements. From the point of view of scaling up, the potential for expansion of production was 0.5-1 ha for farm-level production while maintaining profitability. Calculations showed that at such a scale it is possible to achieve an annual production of up to 3.2 t/ha, i.e., about 3,200 kg of marketable crayfish with a two-cycle turnover of individuals. This made it possible to transform the experimental model into a stable farm with a fully closed biotechnological process.

Assessment of the environmental effect showed that the introduction of the system can reduce the catch of natural crayfish populations by approximately 40%, which has a direct positive impact on river and lake ecosystems. A reduction in poaching pressure, in turn, contributes to the restoration of natural spawning grounds and improvement of biodiversity. In addition, water leaving the system after biofiltration did not contain excess organic substances, which prevented eutrophication or deterioration of the quality of natural waters. An important indicator of environmental sustainability is the energy intensity of the process, which remained within natural balances and did not require constant use of fuel resources. Owing to this, the system had the potential to be integrated into local energy-saving programmes, including power supply from solar panels or biogas plants. Thus, the comprehensive assessment proved that the proposed technology combined high biological productivity, a minimal level of water consumption, low energy costs and significant profitability. It can be adapted to the conditions of different regions – from private households to industrial farm systems. The overall result showed that a cycle duration of 12 months, survival of 72%, profitability of 55%, energy consumption of 3.6 kWh/day and water saving of 92% form a balanced model of economic and environmental management. At the same time, the environmental effect – a 40% reduction in catch from natural water bodies – confirmed that the system is not only economically advantageous, but also contributes to the conservation of biodiversity. Consequently, the use of the recirculating aquaculture system has the potential to become a key direction in the development of modern, environmentally oriented aquaculture business, which combines technological innovation, economic feasibility and nature-conservation effect. Such a system makes it possible not only to ensure stable production of high-quality hydrobiological products, but also to reduce pressure on natural water bodies, contributing to the gradual restoration. Thanks to minimal water consumption, low energy intensity, controlled microclimate and the possibility of multiple use of resources, the installation creates a closed ecological cycle within which all by-products of production can be repeatedly involved in the economic process.

DISCUSSION

The results obtained showed that the use of the recirculating water supply installation provided stable conditions for the growth and development of river crayfish over the six months of the experiment. In the first week the juveniles were in the adaptation phase, but even at this stage one hundred per cent survival was recorded, which indicated the effectiveness of the conditions for the initial start-up of the system. The gradual increase in body length from 1.2 to 5.1 cm and in mass from 1.8 to 11.7 g demonstrated uniform growth without sharp fluctuations, which pointed to a balanced ratio between feed supply and the physicochemicalparameters of the environment. Overall, the temperature regime was maintained within 21-22°C, and the level of dissolved oxygen at 6.8-7.1 mg/l, which corresponded to the optimal conditions for the metabolism of *Astacus astacus*. Survival decreased only to 85% at the end of the experiment, which confirmed the minimal impact of stress factors and the absence of critical deviations in the operation of the system. The biofiltration complex effectively maintained chemical balance, reducing the concentration of ammonium nitrogen from 0.35 to 0.07 mg/l, nitrites from 0.15 to 0.03 mg/l, and nitrates from 4.8 to 2.8 mg/l. The parallel increase in pH to 7.5 and the rise in water transparency to 55 cm confirmed the stability of the functioning of the biocenosis of the filter. It was established that the formed self-regulating system maintained a closed nitrogen-exchange cycle without external intervention. This made it possible to minimise water consumption and to ensure a clean rearing environment. Crayfish cultivation reduced the pressure on natural populations and could significantly decrease the scale of poaching. With an increase in the volumes of legal rearing, the market price of crayfish decreased, which reduced the attractiveness of illegal harvesting.

Taking into account the influence of technological factors on the health of aquaculture organisms, the studies by L. Owens & J. Elliman (2025) and R. Wood *et al*. (2025) highlighted the issue of monitoring the status of crustacean and amphibian populations in altered environmental conditions. L. Owens & J. Elliman investigated the emergence of pathogens in rearing systems for *Cherax quadricarinatus* in Australia, establishing a relationship between holding conditions and the frequency of infectious outbreaks. R. Wood *et al*. applied environmental DNA methods to detect residual amphibian populations, demonstrating the advantages of molecular control. In contrast to these works, the present study did not require external genetic or microbiological intervention, since the stability of the recirculating water supply installations was maintained by natural biofiltration. In addition, the survival achieved at the level of 85-100% and the absence of pathogens confirmed the environmental safety and effectiveness of the closed purification cycle.

Considering the experience of studies of natural and artificial populations of aquatic invertebrates, the works of V.C. Terrell *et al*. (2023) and G. Kwikiriza *et al*. (2025) considered issues of population reproduction and the risks of aquaculture impacts on natural ecosystems. V.C. Terrell *et al*. established the dynamics of reproduction of *Rana areolata* under natural conditions, whereas G. Kwikiriza *et al*. emphasised the danger of escapes from aquaculture systems, which threatened the gene pool of local species. The present study demonstrated a different approach – a fully closed technological system without contact with the natural environment, which eliminated invasive risks. The experimental model provided stable population growth, a controlled hydrochemical regime and the possibility of completing the full life cycle without negative impacts on external aquatic ecosystems.

With regard to studies devoted to rare and protected crustacean species, the research of R.B. McCormack & N.S. Whiterod (2024) and C.C. Bloomer *et al.* (2024) examined the biological characteristics and conservation factors of indigenous species *Euastacus gamilaroi* and *prairie crayfish*. R.B. McCormack & N.S. Whiterod analysed threats to population degradation in natural waterbodies caused by disruption of the hydrological regime and human activity. C.C. Bloomer *et al*. noted that the application of conservation practices can contribute to stabilising population numbers, but these approaches did not provide for experimental control of environmental parameters. In comparison with these works, the present study was distinguished by experimental depth, clear regulation of hydrochemical indicators and practical orientation. Owing to the creation of a self-regulating recirculating water supply system, it was possible to achieve biological equilibrium, high survival and reproductive potential, which determines the prospects of this technology for the future restoration of natural populations.

Considering the results of studies devoted to the invasive potential of aquaculture species, the works of P.J. Haubrock *et al*. (2021) and A. Max-Aguilar *et al*. (2021) analysed the ecological risks and genetic diversity of *Cherax quadricarinatus*. P.J. Haubrock *et al*. determined that the expansion of cultivation of this species creates a threat to biodiversity in tropical regions due to its high adaptability and potential to escape into natural waterbodies. A. Max-Aguilar *et al.* assessed the genetic variability of populations in Mexico in order to create a breeding programme, but the study was limited to the population level without analysing the impact of holding conditions. The present study, on the contrary, was aimed at working out the technological parameters of keeping in a closed system, which completely eliminated ecological risks. The results obtained proved that stable indicators of growth, survival and hydrochemical balance can be achieved without the involvement of invasive species, providing an environmentally safe alternative to open systems.

Taking into account works oriented towards new monitoring methods and integrated rearing approaches, J.A. Greenhalgh *et al*. (2024) and Y. Wei *et al*. (2023) investigated various models combining environmental control and innovative technologies in aquaculture systems. J.A. Greenhalgh *et al*. showed that the use of environmental DNA can optimise species conservation strategies, but this approach remained exclusively diagnostic. Y. Wei *et al.* examined the Chinese integrated "rice-crayfish" system, which emphasised economic benefits, while at the same time noting difficulties with maintaining stable water quality. Unlike these works, the present study achieved a balance between technological stability and environmental sustainability: the closed system ensured stable hydrochemical parameters, consistent survival and minimal environmental impact, which makes it a more manageable and reproducible model.

Bearing in mind generalised data on intensification and physiological adaptation of crustaceans, the works of M.G. Emerenciano *et al*. (2022) and J.R. Latournerié-Cervera *et al*. (2025) considered various aspects of feeding, physiology and crustacean responses to environmental changes. M.G. Emerenciano *et al*. summarised advances in shrimp culture, emphasising the effectiveness of intensified systems, but without a detailed analysis of the environmental consequences. J.R. Latournerié-Cervera *et al*. examined the phenology of *Cambarellus montezumae* in Mexican waterbodies, revealing a relationship between water quality and population activity. In comparison with these works, the present study was of a more comprehensive nature, combining physiological, hydrochemical and biotechnical aspects. The stability achieved in growth indices, oxygen levels and water transparency confirmed that the presented recirculating water supply installation system can provide the complete life cycle of crayfish without ecological risks and without interference with natural populations.

Taking into account studies aimed at trends in fisheries, M. Eilitta *et al.* (2023) and G. Araujo *et al*. (2022) examined the ecological and technological challenges of modern aquaculture. M. Eilitta *et al*. analysed the population ecology of introduced crayfish in Zambia, establishing that invasive species adapt rapidly and displace local fauna, creating risks for natural biotopes. G. Araujo *et al*. summarised current trends in fish farming, emphasising the transition to technologically intensive systems, but without a detailed ecological assessment of the impact. Unlike these works, the present study focused on endogenous populations of *Astacus astacus* in a controlled environment without ecological risks. The achievement of stable growth indicators, high survival (85-100%) and a closed nitrogen cycle confirmed the advantage of the laboratory model over open or invasion-dependent systems.

Given the works devoted to spatial distribution and modelling of the spread of aquatic organisms, N.J. Mecha & R.G. Dolorosa (2024) and J.A. Daniels *et al.* (2023) studied environmental and infrastructural factors determining population dynamics in open waterbodies. N.J. Mecha & R.G. Dolorosa investigated larval collection sites of lobsters *Panulirus spp*. in the Philippines, identifying key hydrological parameters but without reproducing controlled growth conditions. J.A. Daniels *et al.* created a model of the spread of invasive species in river systems, focusing on the impact of hydraulic structures. In contrast to these works, the present study had an experimentally controlled character: all hydrochemical parameters were kept stable, which ensured the complete absence of migration risks and made it possible to trace growth patterns in an isolated biosystem.

Taking into account studies oriented towards biodiversity conservation and the digitalisation of aquaculture, M.V. Alvanou *et al.* (2022) and W.K. Cheng *et al*. (2025) described the latest approaches to monitoring crustacean populations. M.V. Alvanou *et al*. summarised the status of crayfish conservation in Greece, identifying problems of degradation of natural waterbodies and proposing measures for stock replenishment, but without developing technological solutions. W.K. Cheng *et al*. presented the concept of "smart aquaculture", in which the condition of crayfish was assessed by means of computer vision and Internet of Things systems. In comparison with these studies, the present experimental work had a practically verified character: hydrochemical stability, steady growth and minimal biomass losses showed that even without complex digital algorithms, the recirculating water supply installation system is capable of ensuring high efficiency, biosecurity, and reproducibility of results under real conditions. Thus, the results obtained demonstrated that stable water parameters, high survival and the gradual increase in crayfish biomass confirmed the effectiveness of the presented recirculating water supply system as an environmentally safe and technologically balanced aquaculture model.

CONCLUSIONS

In the course of the study, the effectiveness of the recirculating water supply installation for rearing the river crayfish *Astacus astacus* L. under laboratory-controlled conditions was experimentally confirmed. Over six months of rearing, the average length of the juveniles increased from 1.2 ± 0.1 cm to 5.1 ± 0.3 cm, and the average mass from 1.8 ± 0.3 g to 11.7 ± 0.5 g. Survival during this period remained high – from 100% at the beginning of the experiment to 85% at the end. Water temperature was maintained within 21-22°C, and the level of dissolved oxygen at 6.8-7.1 mg/l. Hydrochemical control showed a decrease in the concentration of ammonium nitrogen from 0.35 to 0.07 mg/l, nitrites from 0.15 to 0.03 mg/l and nitrates from 4.8 to 2.8 mg/l, with an increase in pH from 7.1 to 7.5 and an increase in transparency from 42 to 55 cm. This confirmed the effective functioning of the biofilter and the formation of a stable internal ecosystem. Behavioural analysis showed a clear positive trend: the activity of the juveniles increased from 2.1 ± 0.3 to 4.6 ± 0.1 points, the stress level decreased from 3.8 ± 0.4 to 1.8 ± 0.2 points, the proportion of cannibalism fell from 4.8% to 0.9%, and the reaction time to feed decreased from 38 to 15 seconds. This indicated stable metabolism and the formation of a socially coordinated behavioural structure of the population.

To assess adaptation under natural conditions, juveniles from the stage of the recirculating water supply installations were not used, but adult crayfish, selected separately as a control group of the adaptation block. For this reason, the average mass of individuals in the first month after release was 115 ± 4 g and was not related to the mass of the juveniles reared in the laboratory. After release into the waterbody, over six months survival gradually decreased from 100% to 72%, while the average mass increased from 115 ± 4 g to 133 ± 7 g. The activity of adult crayfish reached 4.6 ± 0.1 points, the stress level decreased to 1.7±0.1 points, and the proportion of females with eggs rose to 65%, which indicated complete restoration of reproductive function and stable physiological adaptation in the natural environment. Economic analysis showed that the cost price of rearing 1 kg of crayfish in the laboratory-production cycle was UAH 138, with an average market price of 310 UAH/kg. The expected net profit reached 2,050 UAH/m^2/year, and profitability exceeded 55%. The results obtained demonstrate that recirculating water supply technologies not only ensure stable growth and high survival, but also significantly reduce pressure on natural waterbodies, promoting the rational use of water resources. A limitation of the study was the relatively short observation period under natural conditions and the absence of comparative data for other crayfish species. Further research should be directed towards studying the reproductive cycle, optimising feeding schemes and developing scalable models of closed systems for industrial use.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None.

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Екологічна ефективність установок замкнутого водопостачання при штучному розведенні річкового раку

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Анотація. Метою дослідження було оцінити ефективність технології замкненого водного циклу, що знижує вплив на природні водойми та сприяє раціональному використанню водних ресурсів. У дослідженні застосовувалися експериментальні, аналітичні та статистичні методи: біометричні вимірювання, гідрохімічний контроль, поведінкові спостереження й кореляційний аналіз. На початку експерименту середня довжина малька становила 1,2 см, маса – 1,8 г, тоді як наприкінці спостережень показники зросли до 5,1 см і 11,7 г відповідно. Виживаність зберігалася у межах 85-100 %, що свідчило про оптимальні умови культивування. Температура води підтримувалася стабільно на рівні 21-22°C, концентрація кисню коливалася в межах 6,8-7,1 мг/л, забезпечуючи нормальний метаболізм гідробіонтів. Гідрохімічний аналіз показав ефективну роботу біофільтра: концентрація амонійного азоту зменшилася з 0,35 до 0,07 мг/л, нітритів – з 0,15 до 0,03 мг/л, а нітратів – з 4,8 до 2,8 мг/л. Прозорість води зросла з 42 до 55 см, а pH стабілізувався на рівні 7,5, що свідчило про завершення етапу біологічної стабілізації середовища. Поведінкові показники також підтвердили успішну адаптацію: активність молоді збільшилася з 2,1 до 4,6 балів, рівень стресу знизився з 3,8 до 1,8 балів, а канібалізм скоротився до 0,9 %.Після переселення у природну водойму виживаність раків становила 72 %, середня маса – 133 г, а частка самиць з ікрою досягла 65 %, що підтвердило природну здатність до відтворення. Економічні розрахунки засвідчили рентабельність виробництва 55,2 % при собівартості 138 грн/кг та чистому прибутку 2050 грн/м^2/рік. Енергоспоживання системи було низьким – 3,6 кВт·год/добу, економія водних ресурсів – 92 %, екологічний ефект – зниження вилову природних популяцій на 40 %. Практична значимість даного дослідження полягає у можливості використання його результатів для впровадження енергоефективних технологій вирощування річкових раків у фермерських та промислових господарствах України

Ключові слова: природні популяції; виживаність; гідробіонти; рентабельність; адаптація