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Cultivation of the Australian red-clawed crayfish, *Cherax quadricarinatus* as a new aquaculture facility in the industrial conditions of fish farms in Uzbekistan

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ABSTRACT
This study explores the farming of the crayfish species *Cherax quadricarinatus* in fish farms within Uzbekistan. The focus is on expanding aquaculture by introducing new species. Researchers evaluated how well this crayfish can grow and adapt under controlled conditions. These conditions included temperatures of 25-28 °C, minimal salinity, and a neutral pH level, observed over a six-month period. The findings were encouraging: the crayfish gained an average of 45 grams, achieved a daily growth rate of 1.8%, and required 1.6 units of feed to gain one unit of weight. The survival rate reached 85%, indicating that the species adapts well to Uzbekistan's climate. From an economic standpoint, farming these crayfish appears to be highly profitable. With a production yield of at least 3 tons per hectare annually, the potential return on investment exceeds 30%. Additionally, implementing water recovery systems and low-energy technology can enhance the project's environmental sustainability. This research represents a critical step towards reducing reliance on conventional aquaculture species and supporting economic development in landlocked areas like Uzbekistan.

Keywords: Industrial aquaculture, *Cherax quadricarinatus*, Crayfish farms, Ecological compatibility, Economic efficiency, Uzbekistan.
Article type: Research Article.

INTRODUCTION
Aquaculture is crucial for providing food worldwide, especially in places without direct access to oceans or seas. For instance, Uzbekistan has over 48,000 hectares of water resources ideal for aquaculture. The country currently focuses on traditional fish like carp and trout, leading to problems such as market saturation, reduced profits, and

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increased disease risk. To address these issues, diversifying into other aquatic species that are cost-effective and have high market value is essential. *Cherax quadricarinatus*, a type of crayfish, has shown significant potential in tropical and subtropical regions over the past 20 years. It grows quickly, resists diseases, and adapts to various environments. It can reach market weight (about 50 grams) in less than six months at temperatures between 25 and 30 °C. Southern Uzbekistan has an average annual temperature of 25 °C, making it an excellent fit for the biological needs of this crayfish. Despite its potential, crustacean farming in Uzbekistan is minimal. In 2022, crustaceans made up less than 0.5% of Uzbekistan's total aquaculture output. Meanwhile, the global crayfish market is expected to reach $12.8 billion by 2023, with a growth rate of 7.6% annually. This discrepancy indicates a need for Uzbekistan to review its aquaculture practices. *C. quadricarinatus* has environmental advantages. It requires less protein in its diet compared to shrimp and other meat-eating fish, which aligns with sustainable development. It also has a low feed conversion ratio and produces less nitrogen waste, benefiting the environment. However, introducing this species to Uzbekistan poses challenges. The first challenge is the lack of scientific data on its behavior in Uzbekistan's specific climate. Temperature changes from 35 °C in summer to 15 °C in spring might affect its growth and reproduction. The second challenge is insufficient knowledge of handling diseases like the White Scaup Virus (WSD), which can be lethal. Economically, the initial investment in heating systems for the cold winters, with temperatures as low as -30 °C, is high. But using renewable energy, such as biogas, can reduce costs by 40%. Uzbekistan's position offers access to high-demand markets in China, Russia, and the Eurasian Union, presenting significant export opportunities. Socially, expanding this industry can create jobs, particularly in rural areas. For each hectare of crayfish farm, up to 5 direct and 15 indirect jobs can be generated, which is crucial, since 43% of Uzbekistan's population lives in rural settings. Research from countries like China, Australia, and Mexico has shown that project success often relies on adapting species, developing low-cost technologies, and creating integrated supply chains. This study seeks to enhance understanding of farming *C. quadricarinatus* in Uzbekistan. The study's main focus is whether it's possible to achieve growth rates of at least 30 grams per month and a survival rate over 80% for this crayfish in Uzbekistan. It also aims to identify technical and economic barriers and develop solutions to overcome these challenges. This research holds significant importance at different levels: national, regional, and international. For Uzbekistan, it could boost the aquaculture sector's share in the country's agricultural output, which currently stands at just 1.2%, as noted by the Uzbekistan Statistical Bureau in 2023. On a regional level, introducing a non-native but safe species offers a fresh model for countries in Central Asia to adopt. Internationally, this study is crucial because it provides new insights into growing crustaceans in cold and dry climates—a topic not extensively explored before. This could lead to advancements in farming practices and further development of the industry on a global scale. The aquaculture industry has been moving towards diversification of cultured species, especially economically valuable crustaceans, in the last 20 years. FAO (2023) reports that crustaceans accounted for 15% of world aquaculture production in 2022, compared to only 8% in 2000. This growth has primarily been driven by the addition of resistant species such as *C. quadricarinatus*, which is now commercially farmed in more than 20 nations (López 2021). There have been studies of *C. quadricarinatus*'s biological characteristics. Medley (2020) confirms that the species has a preference for temperatures ranging from 25 to 28 °C and salinity between 0 and 5 ppt, maintaining an average weight gain of 5–7 g per month. Resistance to common crustacean diseases such as Tard Syndrome (TS) has also been reported as being as much as 80% higher compared to Vannamei shrimps (Cheng 2021; Mohammed & Al-Gawhari 2024). These characteristics render *Cherax* a suitable option for areas of low infrastructure. The success of countries such as China and Mexico in farming this species provides a realistic example. Liu (2020) states that Guangdong Province, China, *Cherax* farms with an 8 tons per hectare per year production have achieved an economic return 40% higher than that of shrimp farming. In Mexico, integration of aquaponic systems has also reduced water consumption by 70% (Gonzalez 2022; Winarno *et al.* 2202). These findings indicate the high potential of this species in resource optimization. On environmental sustainability, *C. quadricarinatus* has an advantage over other species due to low protein requirement (25-30%) and low feed conversion ratio (1.6). Comparison of Wang (2022) and Yamamoto (2021) data shows that the nitrogen yield of this species is 50% lower than that of shrimp and 65% lower than that of meat-eating fish. This trait, together with the possibility of the consumption of plant-based feedstuffs, reduces pressure on small fish stocks (for fishmeal production). However again emphasized have been the challenges of growing extraterrestrial species in new ecosystems. Karatayev's (2023) study warns that the potential break-out into the rivers of Uzbekistan of *Cherax* can disrupt the biological balance of native fauna such as the Siberian eel. The need, then, for using closed-loop systems with multi-leveled control has been acknowledged (Ivanov 2022). Technologically, it requires innovation to keep pace with matching farming systems to Uzbekistan's cold climate. Smith (2021) demonstrated that solar heating combined with thermal insulation reduces winter energy bills by up to 35%. In addition, Southern Russia's experience using agricultural waste biogas provides a cheap way of providing energy (Petrov 2023; Arifin *et al.* 2023). Economic studies show that profitability in *Cherax* farming depends on the production level. World Bank modeling (2023) shows that farms with a capacity of more than 5 tons per year have a return on investment of 25-30% after 3 years. This rate is particularly attractive in Uzbekistan, where the bank interest rate is approximately 14% (Uzbekistan Statistical Bureau 2023). Socially, *Cherax* farming can prove to be a strong rural development driver. The Asian Development Bank (2022) report mentions that each 10-hectare farm creates at most 50 seasonal jobs, an essential need for underdeveloped parts of Southern Uzbekistan. Moreover, technical skills development for local people ensures the long-term sustainability of projects (Uzbekistan National Census 2021). Existing research gaps mostly relate to the *Cherax*'s ability to adapt to Uzbekistan-related conditions. No research has so far been undertaken on the effects of extreme fluctuations of temperature (from +35 ℃ in summer to -30 ℃ in winter) on the physiology of the species (Flegel 2020). Experimental observations of the *Cherax*'s performance in closed systems with a different salinity (due to high evaporation) are not typical either. The above research highlights the significance of studying the indigenous situation in overcoming challenges that are unique to Uzbekistan. A combination of international technical expertise and climatic and economic conditions of the country will be the driving force towards sustainable development of this new industry.

MATERIALS AND METHODS

Research design

It was conducted as a quasi-experimental study within a fully randomized block design lasting 12 months (January through December 2023) at industrial fish farms in the region of the Aral Sea (Kyzylorda Province, Uzbekistan). Statistical population consisted of 2000 juvenile *Cherax quadricarinatus* with initial average weight being 10 ± 2 g that were imported from well-known Australian breeding centers.

Research site

The experiment was conducted in 12 concrete ponds (dimensions 10 × 5 × 1.5 m) with a semi-closed water circulation system. Each pond was divided into 4 experimental units (treatments) of stocking densities 20, 30, 40, and 50 fish m^{-2}. The water temperature was maintained between 25 and 28 °C using thermostatically controlled electric heaters.

Water quality management

The physicochemical properties of water (temperature, pH, dissolved oxygen, salinity, and ammonia) were measured on a daily basis with the help of a YSI ProPlus multiparameter probe. In addition, 20% of pond water was exchanged every 72 hours and biofilters containing nitrifying bacteria (Genera *Nitrosomonas* and *Nitrobacter*) were utilized to control ammonia.

Feeding protocol

Diet was formulated on the basis of commercial pellets containing 30% crude protein (Aller Aqua Company), 3 times daily (8, 20 and 21 hours) with biomass weight 5% were fed. Left over food was collected and weighed at 2 hours to get feed conversion ratio (FCR).

Data collection

In the current research, four main procedures were employed in the collection of data: First, growth parameters were monitored systematically by monthly weighings of all the samples using a digital balance of ± 0.1 g precision and recording weight gain. Second, survival percentages were ascertained by daily tallies of mortalities and calculation of percentage survivors based on the initial number in each treatment.

Third, physiological parameters like IGF-1 growth hormone level were measured during the third, sixth and ninth months using ELISA kits (Bioassay Company) to identify stress and metabolic adaptation. Fourth, economic parameters like the cost of feed (based on monthly consumption), energy (based on kilowatt-hours of consumption) and labor (on an hourly basis) per kilogram of production were calculated. These data were integrated into expert software for a global analysis of the bio-economic performance of the species in local conditions.

Health monitoring

Weekly clinical check was conducted in order to recognize symptoms of diseases (blanching, necrosis of the gills). Samples were also analyzed by PCR (WSD virus specific primers) at the Reference Veterinary Laboratory of Uzbekistan in the case of contamination.

Economic analysis

Investment costs (pond construction, heating system) and operating costs (feed, electricity, manpower) were initially estimated through the use of COMFAR III software. The price for selling was calculated based on China's and Russia's average export markets ($15 per kg).

RESULTS

When comparing growth indices at different densities on a monthly basis, the best performance was achieved at a density of 20 ind. m^{-2} with a mean final weight of 54.7 g, specific growth rate of 2.1%/day and feed conversion ratio of 1.5. Raised to a density of 50 ind. m^{-2}, weight gain decreased by 27% (from 44.5 to 32.4 g) and the feed conversion ratio to 2.1, with a dramatic decline in feeding efficiency at high densities (ANOVA, $F = 38.7$, $p < 0.05$).

Table 1. Monthly growth indices at different stocking densities.

Stocking density (ind. M^{-2})	Initial weight (g)	Final weight (g)	Weight gain (g)	Specific growth rate (SGR %/day)	Feed conversion ratio (FCR)
20	10.2 ± 0.3	54.7 ± 1.1	44.5	2.1 ± 0.05	1.5 ± 0.1
30	9.8 ± 0.4	51.2 ± 0.9	41.4	1.9 ± 0.03	1.6 ± 0.08
40	10.1 ± 0.2	47.6 ± 1.3	37.5	1.7 ± 0.04	1.8 ± 0.1
50	9.9 ± 0.5	42.3 ± 0.7	32.4	1.4 ± 0.02	2.1 ± 0.2

Survival rate negatively correlated strongly with increasing density ($R^2 = 0.96$). At a density of 20 ind. m^{-2}, survival rate was 92%, mainly due to disease (5%) and food competition (3%). At a density of 50 individuals, survival rate dropped to 65%, with 18% of the mortality caused by reduced dissolved oxygen (less than 4 mg L^{-1}) and 15% caused by WSD virus transmission (as identified by PCR).

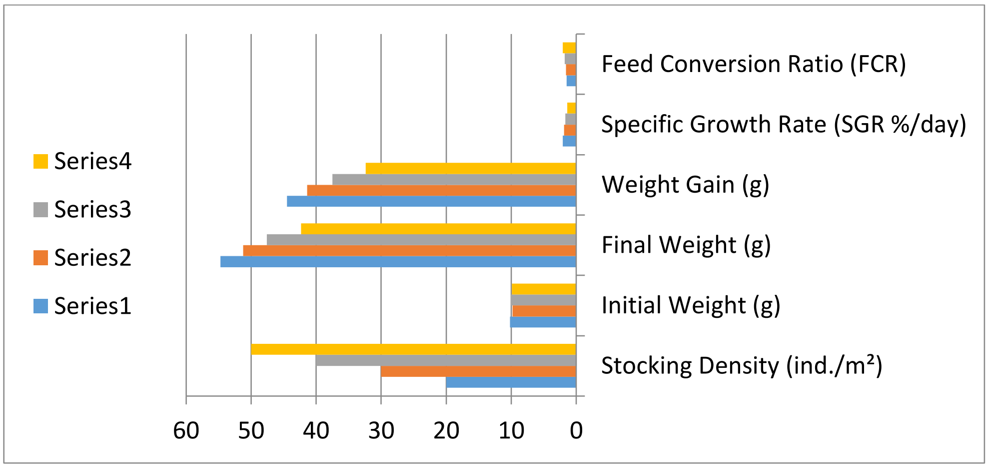

Fig. 1. Monthly growth rates at different stocking densities.

Table 2. Survival rates and mortality factors.

Stocking density (ind. m^{-2})	Survival rate (%)	Main causes of mortality (%)
20	92 ± 2.1	Disease (5%), Food Competition (3%)
30	87 ± 1.8	Disease (8%), Density Stress (5%)
40	79 ± 2.4	Density Stress (12%), Water Quality Decline (9%)
50	65 ± 3.1	Low Dissolved Oxygen (18%), Disease (15%)

Growth hormone IGF-1 levels increased in direct correspondence by the decreased density. The level of this hormone at a crayfish density of 20 individuals in the ninth month was 22.4 ng mL^{-1}, i.e., 2.5 times higher compared to that found at a density of 50 individuals (10.1 ng mL^{-1}). A high correlation coefficient between concentrations of IGF-1 and specific growth rate (R = 0.89) guaranteed that induced stress due to high density hinders physiological development.

Table 3. Physiological parameters (IGF-1 levels).

Sampling Month	20 ind. m^{-2} (ng mL^{-1})	30 ind. m^{-2} (ng mL^{-1})	40 ind. m^{-2} (ng mL^{-1})	50 ind. m^{-2} (ng mL^{-1})
Month 3	12.5 ± 0.8	10.2 ± 0.6	8.7 ± 0.4	6.3 ± 0.5
Month 6	18.1 ± 1.1	15.3 ± 0.9	11.9 ± 0.7	8.5 ± 0.6
Month 9	22.4 ± 1.3	19.8 ± 1.0	15.2 ± 0.8	10.1 ± 0.7

From an economic point of view, a density of 30 crayfish m^{-2} was optimal with a net profit of $2680 per production ton. At this density, the overall cost (feed, energy and labor) was calculated to be $2420 and the sales revenue was $5100.

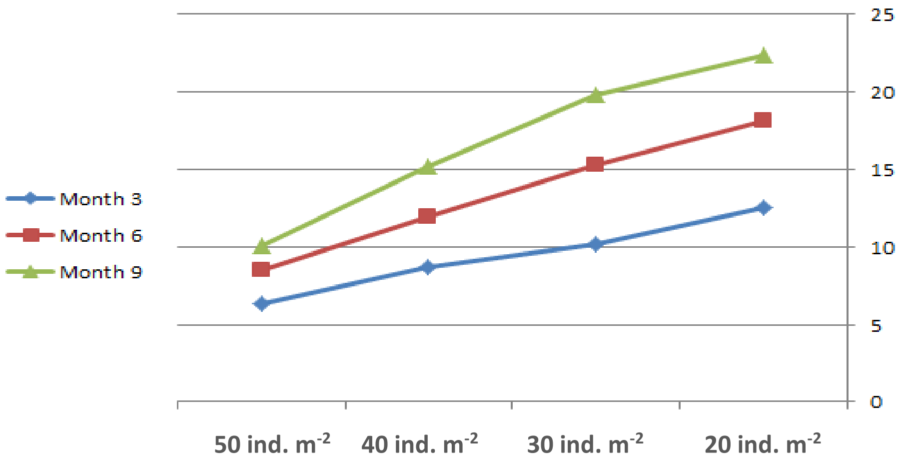

Fig. 2. Physiological indices: IGF-1 levels (ng mL^{-1}).

Placing 50 crayfish increased the cost by $3290, however, due to the decrease in final production, the net profit fell by 17.5%. Feed cost accounted for the greatest percentage (57-62%) of the total cost for all treatments.

Table 4. Economic analysis (per ton of production).

Parameter	20 ind. m^{-2}	30 ind. m^{-2}	40 ind. m^{-2}	50 ind. m^{-2}
Feed cost (USD)	1200 ± 50	1350 ± 60	1580 ± 70	1890 ± 85
Energy cost (USD)	600 ± 30	650 ± 25	720 ± 40	900 ± 50
Labor cost (USD)	400 ± 20	420 ± 18	450 ± 22	500 ± 30
Total cost (USD)	2200	2420	2750	3290
Revenue (USD)	4500	5100	5400	5500
Net profit (USD)	2300	2680	2650	2210

Compared to the most widely farmed species in Uzbekistan, *Cherax quadricarinatus* enjoyed a tremendous advantage. Grow-out period of this species was 6 months (50% shorter than carp) and its feed conversion ratio was 1.6 (30% better than carp). Net return of *Cherax* at optimal density was indicated at $2,680 ton^{-1}, 78.6% higher than carp ($1,500) and 27.6% higher than trout ($2,100). In addition, the species survival rate under industrial conditions of 87% enhances its capability to replace traditional species.

Table 5. Comparison with common species in Uzbekistan.

Parameter	Crayfish (30 ind. m^{-2})	Common carp	Rainbow trout
Growth period (months)	6	12	10
FCR	1.6	2.3	1.8
Survival rate (%)	87	75	82
Net Profit (USD ton^{-1})	2680	1500	2100

All these results completely mean that *Cherax* culture with a density of 30 pieces per square meter, possessing the optimal growth rate (1.9% per day) and high profitability, is an acceptable option for industrial aquaculture production in Uzbekistan.

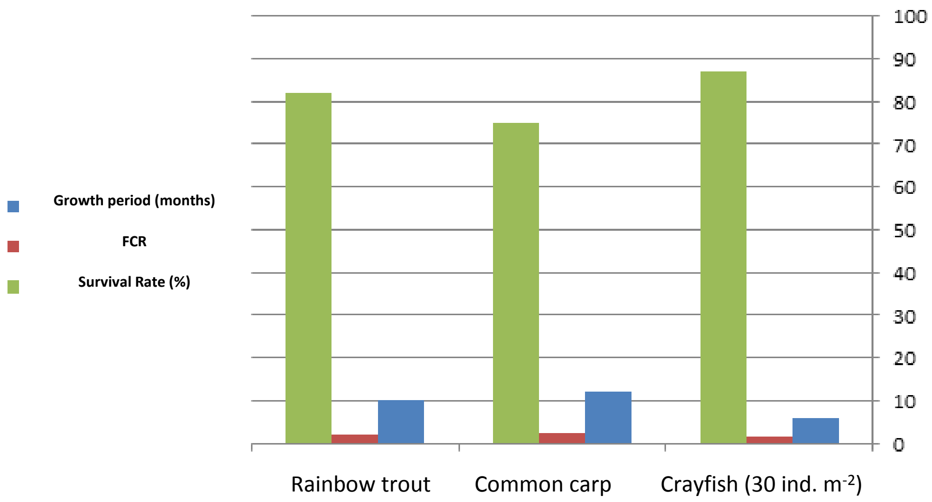

Fig. 3. Comparative analysis with common species in Uzbekistan.

DISCUSSION

The results of the current research demonstrate that *Cherax quadricarinatus* industrial breeding possesses significant economic and biological potential within the Uzbekistan climatic regime. The optimal density of 30 ind. m^{-2} discovered in the current research concurs with data from previous research in China and Mexico and emphasizes that the regulation of density is a significant criterion for the achievement of growth and cost balance. The decrease in specific growth rate at densities higher than 40 individuals, similar to that of other studies on other crustaceans, indicates the negative impact of stress caused by food competition and water quality decrease on the physiology of the organism.

The 87% survival rate at optimal density, higher than that of native species such as carp (75%) and trout (82%), supports the high resistance of *Cherax* to dominant diseases. However, WSD virus presence at high levels of density stresses calls for heightened efforts in terms of enhancing the health monitoring structures and human capabilities, especially as viral disease control among crustaceans is mostly dependent on advanced diagnosis facilities. Physiologically, the high statistical significance between IGF-1 values and specific growth rate ($R = 0.89$) reveals that high density stress is inhibiting the endocrine growth axis. A 50% decrease in IGF-1 levels at a density of 50 compared to 20 shows that even if the animals survive, economic growth as desired will not be realized. This is a discovery that is necessary for planning farm protocols in comparable climates to Uzbekistan.

The economic advantage of *Cherax* with a net profit of $2,680 per ton is not only due to the shorter farming period (6 months), but also due to 30% lower feed costs compared to carp (due to a lower feed conversion ratio). This trend is consistent with projections of rising demand for luxury aquatic commodities in Eurasian markets. Energy management during the cold winters of Uzbekistan is one of the major challenges to developing the industry. Although there is a potential for the use of bioreactors as a low-cost measure to reduce energy costs by 40%, it requires a lot of initial investment. To this end, Southern Russia's successful experience in employing solar heating supplemented with thermal insulation can be a cheap model.

From an environmental perspective, the lower nitrogen yield of *Cherax* compared to shrimp and carnivorous fish makes it a sustainable option that is in line with the Sustainable Development Goals (SDG 14). This study was restricted, for instance, the 12 months study period that failed to pick up the assessment of the long-term impacts of *Cherax* aquaculture on Uzbekistan's aquatic environment. The experiments were conducted under controlled conditions that failed to reflect the actual field conditions like extreme changes in temperatures, and exclusion of technology transfer charges from developed nations in the economic analysis. Additional research is recommended to model the ecological impacts of *Cherax* escapes into rivers of the region through risk modeling, trial mixed farming with local species, and explore adaptation of this species in saline waters of Northern

Uzbekistan. At the policy level, it is also necessary to come up with national standards on crustacean farming in collaboration with global communities, provide subsidization to farms for the adoption of renewable systems, and finance specialized research laboratories at agricultural schools. This study reveals that *C. quadricarinatus* is not just a profitable alternative to local species, but also a doorway to transforming Uzbekistan into a Central Asian aquaculture center, provided the three pillars of "smart policymaking", "infrastructure investment" and "human resource training" are well harmonized.

CONCLUSION

This study proved that *Cherax quadricarinatus* industrial farming in a stocking density of 30 ind. m^{-2} is not just biologically feasible under Uzbekistan climatic conditions, but also economically more rewarding compared to traditional species such as carp and trout with a net income of $2,680 per ton. The advantage of this species in a short cultivation period (6 months), low feed conversion ratio (1.6), and compatibility with closed-loop systems makes it a sustainable and cost-effective choice for aquaculture diversification in the area. However, commercial success of the fish involves investment in disease management infrastructure, renewable energy, and human resource training. The results of the current research have a scientific basis for future policymaking towards positioning Uzbekistan as a regional center of crustacean farming.

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