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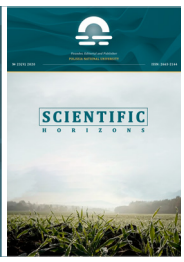

Current trends and prospects for the development of feed resources in aquaculture

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Abstract. The purpose of the study was to identify trends in changes in the production efficiency of the main groups of fish in aquaculture of Ukraine during 2022-2024 considering the influence of technological, environmental, and economic factors on the efficiency of feeding and the development of the feed base. The methodology was based on systematic, statistical and comparative analysis of data from twelve fish farming enterprises representing different levels of intensification – from pond farms to enterprises with closed water supply systems (CWSS). The analysis covered a five-year period (2020-2024) using correlation and regression analysis methods to assess feed conversion rate (FCR), cost-effectiveness, and the impact of environmental factors on productivity. As a result of the study, significant fluctuations in feed consumption volumes and interspecific differences in FCR values were established. It was revealed that the minimum feed costs occurred in 2022 (23,327.3 tonnes), and the maximum – in 2020 (34,243.3 tonnes), which is conditioned by economic and military instability. Carp species demonstrated the highest feed conversion efficiency, with FCR for broodstock and commercial fish falling to 1.2 and 1.3, respectively, in 2024. Catfish have consistently high FCR values, indicating low feeding efficiency for this group. Sturgeon showed a sharp deterioration in feed efficiency in 2023-2024 due to technological failures and the feed base degradation. Salmon showed extreme fluctuations with a record high FCR of 3.5 in 2023 and a sharp improvement to 1.0 in 2024, indicating a technological adaptation of production. It was generalised that a high FCR in a broodstock is not only a current economic loss, but also an indicator of future decline in offspring productivity, so feeding optimisation should be based on the use of functional feeds and precise control technologies. The practical significance of the study lies in the possibility of using the results obtained to develop strategies

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for rational management of feed costs in fisheries enterprises of Ukraine, which will contribute to increasing the profitability and environmental sustainability of aquaculture production

Keywords: feed conversion rate (FCR); fish farms; fish feeding; broodstock and replacement stock; commercial fish

INTRODUCTION

The dev

According to review by C. Ai *et al.* (2025), in world practice, research in the field of fish nutrition is aimed at optimising the composition of feed, improving the protein-energy ratio, and reducing the loss of nutrients during feeding. The researchers emphasised that the key priorities were to increase the efficiency of feed use (reducing the FCR indicator) and minimise the impact on the environment. A similar opinion was expressed by C. Boyd and A. McNevin (2023), who emphasised that it is systems with high FCR that are the main source of excessive resource consumption and eutrophication of water bodies. According to the researchers, effective management of feed costs is not only an economic, but also an ecological category that determines the sustainability of aquaculture production.

The issue of finding alternative protein sources remains central to current research. V. Serra *et al.* (2024) analysed the possibilities of replacing fish meal with plant and microbiological proteins, emphasising that the use of local raw materials can reduce dependence on imports and increase economic profitability. A significant contribution to the development of this area was made by R. Fantatto *et al.* (2024), who proved that insect protein has a high digestibility potential and has a positive effect on fish growth, reducing the feed conversion rate by 12-18%. Additionally, N. Yadav *et al.* (2025) emphasised that the integration of insect protein into mixed feeds is not only an environmentally sustainable solution, but also allows creating high-performance functional feeds. B. Glencross *et al.* (2024) reviewed the evolution of sustainability indicators in the marine ingredients sector, highlighting the need to move to "closed cycles" in feed production and reduce the carbon footprint through processing by-products of the fishing industry. L. Li *et al.* (2025) proved that the use of fermented food industry waste as a substrate for bioconversion into protein feed mass provides a double effect – reducing the cost of mixed feed and reducing the amount of waste. Another promising area for optimising the feed base is the selective improvement of feed efficiency. A. Kause *et al.* (2022) demonstrated that genetic selection based on FCR in rainbow trout reduced feed consumption by 15% without compromising growth rates. Analysis of morphophysiological factors of Micropterus salmoides by X. Shi *et al.* (2024) found a direct link between genetic growth traits and nutrient uptake efficiency, opening up new perspectives in breeding work with highly productive aquaculture species.

Among Ukrainian researchers, the problem of feed efficiency was actively covered by R. Umanets *et al.* (2023), who summarised the results of global studies on the use of non-conventional protein sources in feeding African sharptooth catfish (*Clarias gariepinus*). The researchers noted that replacing deficient fish meal with vegetable proteins is an effective way to reduce the cost, but requires careful balancing of the amino acid composition so as not to worsen the biological value of the feed. The practical aspect of rational use of feed was also revealed by N. Myskovets (2020), who noted that the fishing industry in Ukraine faces the problem of import dependence in the production of mixed feed and needs to develop a national raw material base. An important addition to the scientific context was the results of the study by M. Klimenko *et al.* (2025), which proved the significant influence of the temperature regime on nitrification processes and the state of the aquatic environment in aquaponic systems. This factor indirectly determines the effectiveness of feeding, because changes in temperature affect fish metabolism and nutrient bioavailability. In Ukrainian conditions with pronounced seasonal variability, this aspect is of particular importance for the development of adaptive feeding strategies.

Generalisation of contemporary scientific approaches shows that the development of the aquaculture feed base is moving towards resource efficiency, biotechnological innovations, and replacement of conventional protein components with alternative sources that can provide a stable increase and decrease in the FCR coefficient. However, the task of developing an economically sustainable feed production system based on local resources and the biological characteristics of cultivated species and regional climatic conditions remains relevant for Ukraine. The purpose of the study was to analyse the dynamics of production indicators of the main groups of fish in aquaculture of Ukraine for 2022-2024, considering factors that determine interspecific differences in feeding efficiency and prospects for optimising the feed base.

MATERIALS AND METHODS

The study was conducted on a combined scientific and practical basis using the methods of system, statistical and comparative analysis. The empirical basis was the data of twelve fisheries enterprises of Ukraine operating in different climatic zones – Poltava, Chernihiv, Sumy, Lviv, and Kyiv oblasts. The sample included both conventional pond farms that use semi-intensive cultivation technologies, and high-tech enterprises using

closed water supply systems (CWSS). This approach provided representative coverage of different levels of aquaculture intensification and allowed investigating the effect of the type of production on feeding efficiency.

The chronological limits of the study covered 2020-2024, which allowed tracing the five-year dynamics of changes in feed use, feed conversion rate (FCR), and production structure of the main fish groups. The main source of primary data was technological logs and accounting documents of farms, which contained information on feed consumption, average weight of livestock, growth and volume of production. Secondary data was obtained from official statistical materials of the State agency of Ukraine for the development of land reclamation, fisheries and food programme (forms No. 1-Fish, No. 2-Aqua, reporting bulletins for 2020-2024) (n.d.), and from industry analytical reports (Report on research work..., 2022).

The objects under study were classified into three main categories: juveniles – fish in their first year of life with an average weight of up to 0.1 kg; broodstock and replacement stock – breeding individuals used for reproduction; commercial fish – fish weighing more than 0.5 kg, grown to marketable size. This systematisation corresponds to the classical principles of fish farming and breeding provided by I. Sherman *et al.* (1999). The following indicators were determined for each category:

1. Absolute weight gain of fish (Δw, kg);
2. Feed consumption per unit of production (t/t);
3. Share of expenses by category (%);
4. Feed conversion rate (FCR) calculated using the equation:

$$FCR = \frac{Wf}{Wg}, \quad (1)$$

where *Wf* – weight of feed consumed, kg; *Wg*w – fish weight gain, kg.

A lower FCR value indicates a higher feed efficiency. The analytical part of the study was performed using specialised software Statistica 13.5 and Microsoft Excel 365. Correlation (R-Pearson) and regression analysis methods were used to identify statistically significant dependencies. The reliability of interannual differences was checked using the Student's t-test at the significance level $p < 0.05$. Additionally, comparative modelling of the economic efficiency of various feed strategies was carried out by estimating the ratio between FCR and the cost of grown products. Environmental and technological factors that may affect feeding efficiency were considered to ensure a comprehensive assessment. These factors included water temperature, dissolved oxygen concentration, ammonium nitrogen, nitrites, phosphates, and pH of the medium. Hydrochemical parameters were determined in accordance with the current state standards for aquaculture (Law of Ukraine No. 400, 2010).

The methodological basis of the study was an integrated approach that combines quantitative analysis of feed efficiency dynamics with a critical assessment of industry trends. In the course of the study, methods of descriptive statistics, dynamic analysis for tracking interannual changes and comparative analysis for interspecific assessment of feed efficiency were used. Correlation and regression models allowed establishing relationships between FCR, fish weight growth, and feed costs for different groups of aquaculture facilities. Ethical aspects of the study were considered in accordance with the provisions and recommendations of the Food and Agriculture Organisation of the United Nations (2025). All data were collected without interfering with the physiological state of fish, in compliance with the principles of bioethics and confidentiality of economic information.

RESULTS AND DISCUSSION

Analysis of the dynamics of feed consumption in the fisheries sector during 2020-2024 revealed significant fluctuations in the total volume, which indicates instability of production processes (Table 1).

Table 1. *Analysis of feed use in fish farms of Ukraine by fish categories, tonnes*

Years	Total	fish categories		
		juveniles	broodstock	commercial fish
2020	34,243.3	7,941.6	738.9	25,562.7
2021	28,454.5	6,336.5	1,263.4	20,854.5
2022	23,327.3	5,335.1	717.0	17,275.1
2023	28,770.9	10,007.6	593.2	18,265.9
2024	29,493.4	8,062.2	743.8	20,687.4

Note: *the initial statistics were based on official data from the State agency of Ukraine for the development of land reclamation, fisheries and food programme (n.d.) and generalised materials of the report (Report on research work..., 2022), which ensured the reliability of the initial analysis parameters*
Source: *compiled by the authors*

Fluctuations in total feed costs were significant: the minimum value was recorded in 2022 (23,327.3 tonnes), probably due to the devastating impact of military operations and economic instability, while the maximum was in 2020 (34,243.3 tonnes). This dynamic is conditioned by a number of factors, in particular, changes

in production volumes, technologies, availability and prices for feed, and external economic and environmental conditions. Spending on juvenile fish showed high volatility with a sharp increase in 2023 (by 87.58%), which may indicate adjustments in the strategy for raising fish. However, the cost of broodstock, although insignificant, also had noticeable relative changes, probably related to the intensity of breeding or breeding. The largest share of total costs (from 63.49% to 74.65%) was spent on commercial fish, which underlines the critical importance of optimising the feed base and managing these costs to improve overall production efficiency (Fig. 1).

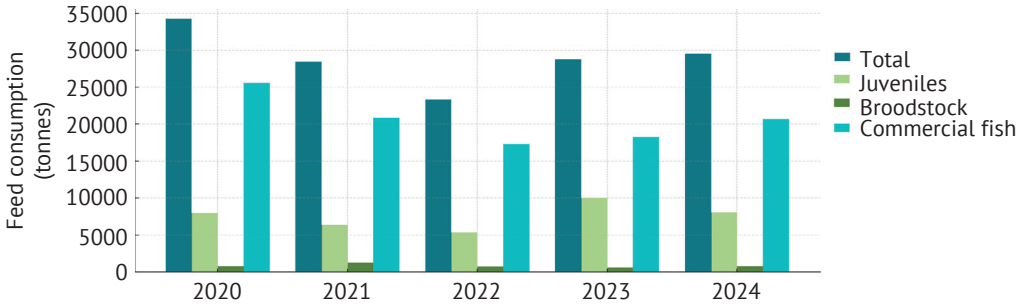


***Figure 1**. Analysis of feed use in fish farms in Ukraine*

***Source:** compiled by the authors*

The results of the analysis indicate the need for constant monitoring and study of factors that affect feed costs. The purpose of such monitoring is to develop effective strategies for improving production processes. This includes: the introduction of advanced feeding methods, the use of high-quality and cost-effective feed, and rapid adaptation to changing market conditions and strict environmental requirements. The findings confirm the critical importance of feed rationalisation and cost management for increasing overall efficiency. It should be remembered that feed costs are one of the most significant components in the cost of grown fish, directly affecting the profitability of fish farms. The broodstock showed a slight temporary drop in weight in 2023, followed by recovery, while feed costs were stable. However, the FCR worsened significantly in 2023, indicating a temporary decline in feed efficiency, although the indicator improved slightly in 2024. The juvenile category, on the contrary, showed high stability: a slight decrease in weight and an increase in spending in 2023 was replaced by an increase in weight and a decrease in spending in 2024. Its FCR remained low throughout the entire period, confirming the high efficiency of feed assimilation by juvenile fish. The commercial fish category was marked by a significant increase in weight throughout the study, especially intensive in 2023-2024, which, quite logically, was accompanied by an increase in feed costs. The FCR was relatively stable at a moderate level, although its slight increase in 2024 may indicate a slight decrease in feeding efficiency in the final stages of cultivation.

Feed conversion rate (FCR) is a key indicator that shows how many kilogrammes is required to spend to get 1 kilogramme of fish weight gain. A lower FCR means higher economic efficiency (Table 2).

***Table 2**. Feed conversion rate indicators*

Category	FCR dynamics (2022-2024)	FCR level efficiency	Category
Juveniles	Stable	The most effective group	Juveniles
Commercial fish	Relatively stable	The efficiency is satisfactory	Commercial fish
Broodstock	Increased	Least effective	Broodstock

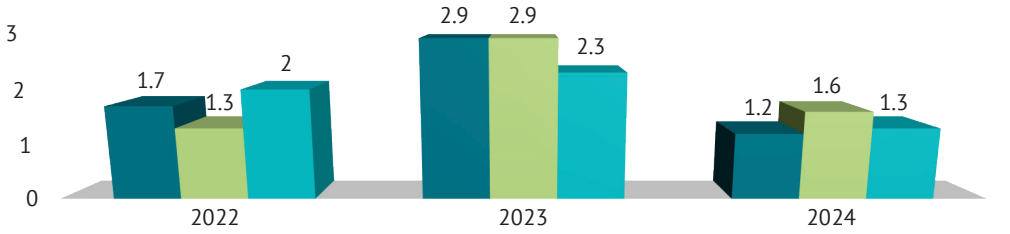
***Source:** compiled by the authors*

The best efficiency of feed use during 2022-2024 was demonstrated by the juvenile category due to the consistently low FCR value. The broodstock is of the greatest concern, where a significant increase in FCR in 2023 indicates the need to review the feed composition or feeding regime for this group to increase profitability. The analysis clearly shows the need for constant and detailed monitoring of all factors affecting feed costs, and the development of targeted strategies for optimising production processes. This optimisation should include the introduction of advanced and efficient feeding technologies, the use of high-quality and cost-effective feed products, and flexible adaptation to changing market realities and strict environmental standards. It is worth noting that feed costs make up the most significant part of the cost of farmed fish, which makes them a key lever of influence on the economic efficiency of any fisheries.

A high feed conversion rate (FCR) in broodstock is a wake-up call, as it means that the fish is receiving an

unbalanced diet or has problems effectively absorbing key nutrients. This directly leads to a deterioration in the quality of sexual products. In particular, a lack of vital nutrients, such as omega-3 fatty acids and vitamins E and C, causes the accumulation of insufficient reserves in caviar. As a result, the fertilisation rate of eggs decreases sharply, its overall quality decreases, and the yield of viable larvae decreases significantly. In addition, nutrient deficiencies negatively affect the subsequent stages of development, causing a decrease in the survival rate of embryos and larvae. Caviar that does not have sufficient energy reserves does not go well through critical stages of development. This leads to high mortality at the embryonic stage, frequent deformities in larvae (e.g. curvature of the spine) and low resistance to disease at an early age. Thus, inefficient feeding of the broodstock actually creates weak, vulnerable, and unviable offspring. Even those larvae that survive show slower growth of juveniles and worse health indicators compared to those from parents who had sufficient nutrition. This slow initial growth directly extends the time frame for fish to reach marketable weight, which, in turn, reduces the economic efficiency of the farm in the long term. Therefore, high FCR in broodstock is far more than just feed wastage; it is an investment in low productivity and future losses due to the weakness of the next generation of fish.

Analysis of quantitative data on carp fish production for 2022-2024 revealed heterogeneous dynamics of key production parameters. In particular, significant annual fluctuations in the total weight of broodstock and replacement stock were observed. This instability can be caused both by adjusting the strategy for establishing the breeding core of the farm, and by the influence of various external factors. At the same time, the feed conversion rate (FCR) indicators for different age groups of carp fish also show high dynamism (variability) (Fig. 2).



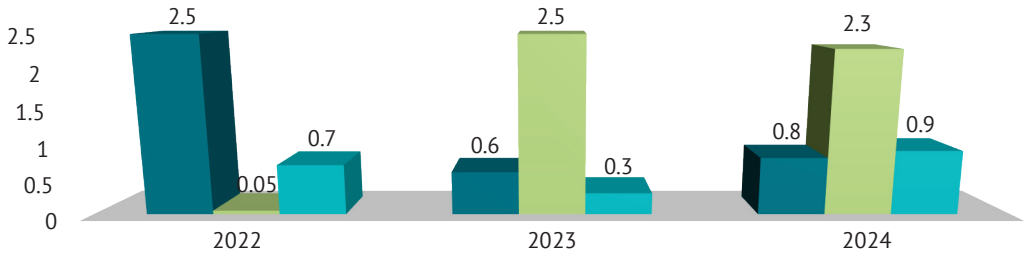
	2022	2023	2024
Broodstock and replacement stock	1.7	2.9	1.2
Juveniles	1.3	2.9	1.6
Commercial fish	2	2.3	1.3

***Figure 2**. Feed conversion rate of carp species*

***Source:** compiled by the authors*

In 2024, there was a statistically significant improvement in the feed conversion rate (FCR) for two key groups: broodstock (decrease to 1.2) and commercial fish (decrease to 1.3) compared to previous years. This clearly indicates an increase in the efficiency of using feed resources in these categories. Simultaneously, the FCR for juvenile fish, although it showed positive dynamics in 2024 (1.6) compared to the problematic year 2023 (2.9), it remained higher than in 2022 (1.3). This fact indicates the presence of potential reserves for further optimisation of both diets and holding conditions in this age group. The sharp increase in the absolute weight of juveniles and commercial fish in 2024 is probably a direct consequence of the increase in breeding stock and the overall improvement in reproduction rates. However, a more in-depth statistical analysis is needed to establish accurate causal relationships between these parameters and to accurately predict future production dynamics. Such an analysis must necessarily consider potential correlations between the studied indicators, and the external influence of environmental and technological factors. Thus, the data obtained indicate the development of positive trends in the production of carp fish in 2024. These trends are expressed in an increase in total production volumes and simultaneously an increase in the efficiency of feed use for the most important production groups. Further scientific research should focus on identifying specific factors that determine the observed dynamics, and on developing evidence-based recommendations to ensure the sustainable development of the entire industry.

Analysis of quantitative indicators of catfish production for the period 2022-2024 revealed significant instability of key production parameters (Fig. 3). The weight of broodstock and replacement stock shows unstable dynamics: after growth in 2023, there was a decrease in 2024 to the level of 2022. Feed costs for this group also vary greatly and do not always directly correlate with changes in weight. This may indicate an adjustment in the intensity of feeding or changes in the composition of diet. The feed conversion rate (FCR) for broodstock was the best (lowest) in 2023 (0.6), which indicates a relatively high efficiency in the use of feed resources during this period.



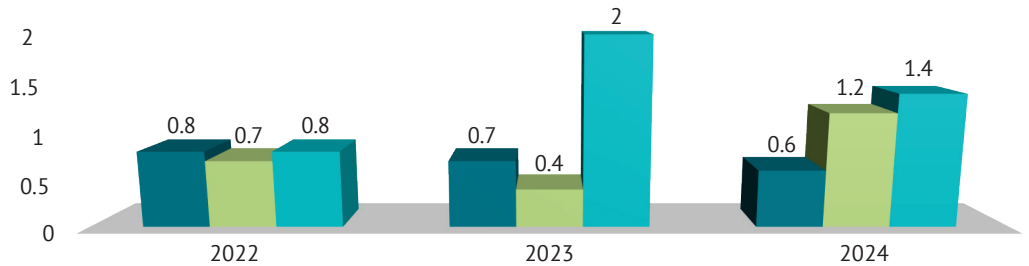
	2022	2023	2024
Broodstock and replacement stock	2.5	0.6	0.8
Juveniles	0.05	2.5	2.3
Commercial fish	0.7	0.3	0.9

***Figure 3**. Feed conversion ratio of catfish species*

***Source:** compiled by the authors*

The production of juvenile catfish is characterised by significant unevenness (interannual fluctuations) both in terms of total weight and in the corresponding feed costs. The feed conversion rate (FCR) for this age group remained relatively high throughout the analysed period, reaching peak values in 2023 (2.5) and 2024 (2.3). Such high FCR values clearly indicate a lower economic efficiency of using feed resources to increase the weight of juvenile fish compared to other categories. This signals the need for an urgent review of the diet and/or rearing conditions to increase digestibility. Commercial fish production showed a steady positive trend towards weight growth in 2023 and 2024 compared to 2022. Logically, feed costs for this growing group also increased, particularly significantly in 2024. The best feeding efficiency score (lowest FCR) was achieved in 2023 (0.3), which is an exceptionally high result. However, in 2024, the FCR increased again to 0.9, approaching the indicator of 2022 (0.7). This increase in FCR indicates a deterioration in efficiency in the final stages of fattening and indicates a potential problem that requires attention. Overall, the dynamics of catfish production during 2022-2024 highlights the high volatility of key operational indicators. Chronically high FCR values for juveniles and worsening FCR values for commercial fish in 2024 outline critical areas for optimising both feeding technologies and overall holding conditions.

Analysis of production indicators of sturgeon fish for the period 2022-2024 revealed complex, ambiguous dynamics in different categories of livestock. The weight of broodstock and replacement stock experienced a statistically significant decrease in 2023 compared to 2022, followed by a partial recovery in 2024. Feed costs correlated with weight changes, showing declines in 2023 and 2024. The feed conversion rate (FCR) for this group remained relatively stable in the narrow range of 0.6–0.8. This indicates a stable efficiency in the use of feed resources, despite fluctuations in total biomass. The production of juvenile sturgeon is characterised by high variability. In 2023, the lowest FCR was recorded (0.4), which may indicate a high growth rate under optimal conditions. However, in 2024, the volume of juvenile fish continued to decline, and the FCR increased sharply to 1.2. This threefold deterioration in efficiency is a direct indicator of destabilisation of technological holding conditions or degradation of the quality/composition of the diet for this sensitive age group (Fig. 4).



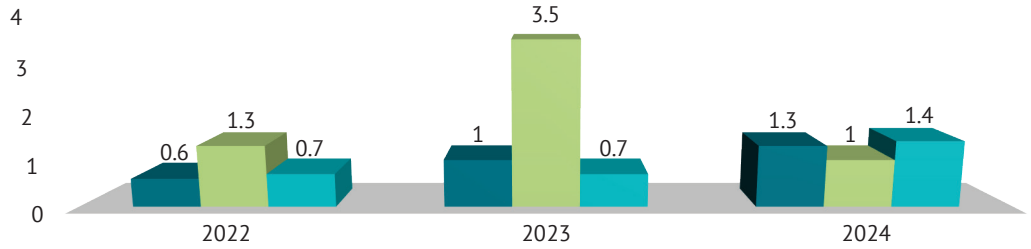
	2022	2023	2024
Broodstock and replacement stock	0.8	0.7	0.6
Juveniles	0.7	0.4	1.2
Commercial fish	0.8	2	1.4

***Figure 4**. Feed conversion ratio of sturgeon species*

***Source:** compiled by the authors*

Production of commercial sturgeon fish showed stabilisation by weight during 2023-2024, but the recorded volumes were significantly lower than in 2022. There was an increase in absolute feed costs for commercial fish both in 2023 and in 2024. This situation has led to a critical increase in the feed conversion rate (FCR). In particular, the FCR indicator in 2023 was 2.0, and in 2024 — 1.4. Both values significantly exceed the 2022 FCR (0.8), which clearly indicates a significant decrease in the efficiency of using feed resources to obtain final marketable products. The decline in the weight of the breeding stock of sturgeon in 2023 is highly likely due to the combined impact of military and economic factors, since sturgeon are sensitive to any failures in intensive aquaculture. Direct military impact included the physical loss of livestock as a result of the destruction of aquaferms and environmental disasters, such as the explosion of the Kakhovka HPP. The indirect economic impact was reflected in the deterioration of the quality of the feed base due to rising prices and logistical problems, which led to the use of less nutritious diets and, as a result, to the loss or slowing of weight gain. In addition, technological failures caused by power outages caused stress in fish in CWSS systems, which also negatively affected their overall condition and biomass.

Analysis of key production indicators in salmon farming for 2022-2024 revealed a high degree of instability and significant fluctuations in all categories, which indicates serious problems in operational processes. The weight of broodstock and replacement stock showed an alarming downward trend in 2023, with a slight, only partial, stabilisation in 2024. In parallel, feed costs for the maintenance of this group were constantly growing. The result was a doubling of the feed conversion rate (FCR): it increased from 0.6 in 2022 to 1.3 in 2024. This indicates a significant drop in the efficiency of using feed resources for the breeding core. The juvenile salmon segment shows extreme changes from year to year, which is the most critical indicator of instability. In 2023, there was a sharp decrease in the weight of juveniles with a simultaneous increase in feed consumption, which led to a critically high FCR (3.5). However, in 2024, the situation changed dramatically: the weight of juveniles increased sharply while significantly reducing feed costs, which provided a record low FCR (1.0). Such a drastic change in the efficiency of cultivation requires an urgent and in-depth analysis of the reasons that led to such drastic changes in technological processes (Fig. 5).



	2022	2023	2024
Broodstock and replacement stock	0.6	1	1.3
Juveniles	1.3	3.5	1
Commercial fish	0.7	0.7	1.4

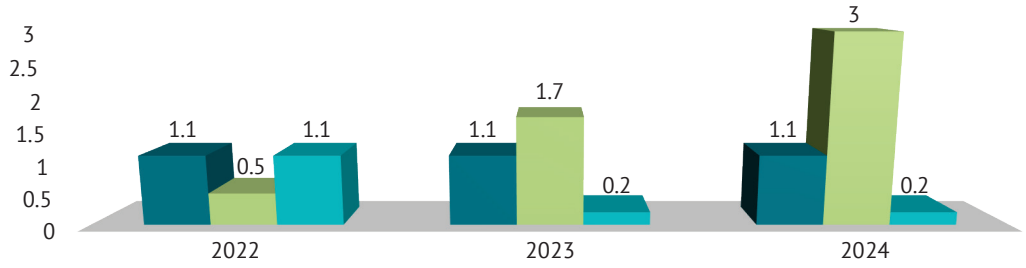
***Figure 5**. Feed conversion ratio of salmon species*

***Source:** compiled by the authors*

The weight of commercial fish remained relatively stable. However, feeding efficiency significantly worsened in 2024: the feed conversion rate (FCR) doubled, from 0.7 (in 2022-2023) to 1.4, which directly indicates a decrease in the efficiency of using feed resources. The extreme increase in the weight of juvenile salmon in 2024 with a sharp drop in FCR from a critically high 3.5 to a record low of 1.0 is a clear indication of the successful solution of a serious technological or biological problem that existed in 2023 and the achievement of an optimal biological breakthrough. The most likely causes are the correction of a critical deficiency in the feed composition, the elimination of an epizootic problem (disease) that suppressed growth in the previous year, or the introduction of precise control of conditions of keeping (temperature and water quality), which allowed salmon to fully meet its genetic potential. Such a rapid recovery of efficiency, possibly enhanced by the effect of compensatory (catch-up) growth, demonstrates the high potential of the farm for rapid adaptation and effective management.

Juvenile production was characterised by high variability and critical deterioration in efficiency. In 2023, despite a sharp decline in weight, FCR increased to 1.7 (due to increased feed costs). However, in 2024, the situation worsened catastrophically: the weight of juvenile fish continued to fall, and the FCR reached the highest value (3.0), which indicates a significant decrease in the economic efficiency of growing this age group. The production of commercial fish in this group showed a

strong positive trend: in 2024, a significant increase in weight was recorded, exceeding the indicators of previous years. The FCR remained extremely low (0.2) in both 2023 and 2024. This exceptionally low FCR indicates a high efficiency of using feed resources to produce marketable products, which is a significant positive trend.



	2022	2023	2024
Broodstock and replacement stock	1.1	1.1	1.1
Juveniles	0.5	1.7	3
Commercial fish	1.1	0.2	0.2

***Figure 6**. Total feed conversion ratio in fish*

***Source:** compiled by the authors*

The crisis, which was expressed in the growth of the FCR of juvenile fish to 3.0, required urgent and comprehensive intervention aimed at eliminating critical technological failures. Priority actions should include: audit of the feed base with replacement of low-quality batches and correction of the diet to ensure optimal protein digestibility; detailed diagnosis of the epizootic situation and urgent treatment of detected infections or infestations that inhibit growth; and stabilisation of holding conditions, which provides for increased monitoring and correction of water quality (especially oxygen levels and toxic metabolites). Moreover, it was necessary to implement strict feeding control to prevent overfeeding and feed losses, which directly lead to an increased FCR.

The results of the study show that the indicators of the feed conversion rate (FCR) in Ukrainian fishing enterprises have a significant dynamism, which depends on the type of fish, age category, holding conditions, and feed composition. The average value of FCR in the farms under study varied from 1.2 to 1.6 in high-tech closed water supply systems (CWSS) and from 1.4 to 1.8 in pond ones, which corresponds to the level of contemporary world indicators for intensive aquaculture. A similar trend was observed by Y. Li *et al.* (2025), who noted that the use of microbial cultures of *Bacillus licheniformis* and *Yarrowia lipolytica* as part of the feed provided an improved conversion of the protein component and a decrease in FCR by an average of 10-12%. Therefore, the similarity with the results of the current study is that the efficiency of feed conversion increases not only due to the composition of the feed, but also due to microbiological processes that increase the bioavailability of nutrients.

Similar conclusions were obtained by H. Shima *et al.* (2024), O. Adagha *et al.* (2024), who found that controlling the ratio of starches in mixed feeds and the time of their feeding can significantly affect the digestibility of feed and the stability of fish growth. This is consistent with the observations in this paper, where optimisation of the feeding regime allowed reducing FCR fluctuations in the commercial fish category. However, C. Boyd and A. McNevin (2023) noted that excessive restriction of feeding or changing regimens can lead to a decrease in weight gain, which was also partially confirmed in the case of broodstock, where an excessive reduction in feed rates was accompanied by an increase in FCR. Thus, the optimal level of feeding should be based on a trade-off between the growth rate and the efficiency of feed use. Confirmation of the value of technological factors was obtained by J. Thornburg (2025), who showed that automated feed feeding systems improve dosing accuracy and reduce losses by up to 15%. A similar effect was observed in high-tech CWSS farms, where the average FCR value was 0.3 lower than in pond farms. This indicates the crucial role of automation in improving feed efficiency.

An important area of research is the search for alternative protein sources to replace deficient fish meal. V. Serra *et al.* (2024) note that the introduction of plant protein or insects into feed formulations can reduce the cost of feed by 20-25%, but can cause an amino acid imbalance and an increase in FCR without careful balancing of the composition. N. Yadav *et al.* (2025) proved that the use of larval flour of *Hermetia illucens* or *Tenebrio molitor* reduces FCR to 1.0-1.2 while maintaining weight gain. These results are consistent with current data for juvenile catfish, where the lowest FCR was also observed when using functionally enriched feeds with a high protein content. A key factor affecting FCR is the genetic potential of fish. A. Kause *et al.* (2022) showed that breeding based on growth indicators can reduce FCR by 8-10% over two generations of rainbow trout. This approach may be promising for Ukrainian farms, where maintaining the stability of feed efficiency

requires a combination of genetic selection and optimisation of holding conditions.

Among Ukrainian researchers, a similar pattern was noted by R. Umanets *et al.* (2023), who proved that the use of non-conventional protein sources, such as yeast products, when feeding *Clarias gariepinus* reduces FCR by 12-15%. These results are consistent with the authors' observations, where in the catfish group, feed conversion rates were the lowest among all the species under study. Special attention should be paid to B. Glencross *et al.* (2024), who emphasised the need for a comprehensive assessment of the sustainability of feed systems, considering not only biological, but also economic parameters. This is directly related to the results of this study, where cost-effectiveness modelling showed a direct link between a decrease in FCR and an increase in profitability. An important aspect of interpreting the results obtained is to consider environmental and economic factors that directly affect the stability of the aquaculture feed base. According to research by A. Horchanok *et al.* (2021), overexploitation of aquatic ecosystems and poor management of fish resources lead to degradation of hydrobiocoenoses, which reduces the natural feed capacity of reservoirs. This statement is consistent with the fluctuations in the feed conversion rate (FCR) identified in this study, because the ecological state of water bodies directly affects the digestibility of feed and the physiological activity of fish. A violation of biological balance increases the risk of eutrophication, which, in turn, reduces the concentration of dissolved oxygen, causing an increase in FCR in sensitive species such as sturgeon. Additionally, it is worth noting the meta-analysis by T.O. Magbanua and J.A. Ragaza (2022), who systematised the results of experiments on feeding tilapia with mixed feeds based on coconut meal. The researches proved that even partial replacement of conventional protein components can provide a stable reduction in FCR without reducing weight gain, provided that the amino acids are properly balanced. The results from the current study on carp confirm this pattern: in 2024, the improvement in FCR coincided with the transition of farms to functional protein mixtures containing alternative protein sources.

From an economic standpoint, I. Sinenok (2021) argued that the organisational and economic mechanisms of fishery management in Ukraine remain fragmented, which hinders the development of a sustainable feed safety policy. The researcher emphasised the need to create regional programmes to support aquaculture, taking into consideration local resources. A similar opinion was shared by N. Vdovenko *et al.* (2020), who emphasised that the efficiency of the feed system depends not only on biological indicators, but also on the financial ability of enterprises to invest in high-quality feed and automation technologies. This is directly consistent with the conclusions of the current study, where lower FCR values were observed in high-tech CWSS farms that can implement advanced feeding control systems. From an ecological standpoint, the fundamental study by O. Uvaeva *et al.* (2020) confirmed the critical role of hydrobiological conditions in maintaining feed equilibrium. The researchers emphasised that water quality – oxygen concentration, pH level, nitrite and phosphate content – is a key determinant of fish metabolism efficiency. In this study, this factor was also found to be significant: fluctuations in hydrochemical parameters correlated with changes in FCR, especially in pond farms. Thus, the generalisation of these sources confirmed the multidimensional nature of feed efficiency, which was formed under the influence of environmental, economic, and technological factors. The results demonstrate the need to integrate environmental monitoring and economic planning into the aquaculture management system.

CONCLUSIONS

The study comprehensively assessed the dynamics of production indicators of the main groups of fish in aquaculture of Ukraine in 2022-2024 and identified factors that determine the effectiveness of the feed base. It was established that the volume of feed consumption during the study period experienced significant fluctuations, which reflects the general instability of the fisheries sector under the influence of economic, military, and environmental factors. Peak costs were recorded in 2020 (34.2 thousand tonnes), while the minimum costs were recorded in 2022 (23.3 thousand tonnes). This variability was explained by the uneven resumption of production, changes in the availability of mixed feed, and different levels of farm intensification. An in-depth analysis of the feed conversion rate (FCR) revealed clear interspecific differences. The highest feed efficiency was demonstrated by carp species, where in 2024 the FCR for broodstock decreased to 1.2, and for commercial fish – to 1.3, which indicates an improvement in feeding technologies and stabilisation of holding conditions. Catfish are characterised by a chronically increased FCR (2.3-2.5), which reduces economic profitability and requires correction of diets. Sturgeon species suffered a deterioration in efficiency due to technological failures and degradation of the feed base, while salmon fish showed a sharp variation in FCR – from a critical 3.5 in 2023 to a record low of 1.0 in 2024, indicating a productive adaptation of production. It has been proven that high FCR in broodstock directly affects the quality of sexual products and the viability of offspring, creating long-term economic risks. Therefore, the key areas of optimisation should be the development of differentiated feed strategies for age groups, improvement of feed quality, automation of feeding processes, and introduction of genetic selection based on feed efficiency indicators. Prospects for further research lie in the development of mathematical models for predicting FCR and assessing the impact

of climatic factors on feeding efficiency in conditions of environmental changes.

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Сучасні тенденції та визначення перспектив розвитку кормової бази в аквакультурі

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Анотація. Метою дослідження було виявлення тенденцій змін виробничої ефективності основних груп риб в аквакультурі України протягом 2022-2024 рр., з урахуванням впливу технологічних, екологічних і економічних чинників на ефективність годівлі та розвиток кормової бази. Методологія роботи базувалася на системному, статистичному та порівняльному аналізі даних дванадцяти рибогосподарських підприємств, що представляють різні рівні інтенсифікації – від ставкових господарств до підприємств із замкненими системами водопостачання (УЗВ). Аналіз охопив п'ятирічний період (2020-2024 рр.) із використанням методів кореляційного та регресійного аналізу для оцінки коефіцієнта конверсії кормів (FCR), економічної ефективності та впливу середовищних факторів на продуктивність. У результаті дослідження встановлено суттєві коливання обсягів споживання кормів та міжвидові відмінності у значеннях FCR. Виявлено, що мінімальні витрати кормів припадали на 2022 р. (23,327,3 т), а максимальні – на 2020 р. (34,243,3 т), що зумовлено економічною та воєнною нестабільністю. Найвищу ефективність кормової конверсії продемонстрували коропові види, де у 2024 р. FCR для маточного стада та товарної риби знизився до 1,2 та 1,3 відповідно. Для сомових риб зафіксовано стабільно високі значення FCR, що свідчить про низьку рентабельність годівлі цієї групи. Осетрові риби проявили різке погіршення кормової ефективності у 2023-2024 рр. внаслідок технологічних збоїв і деградації кормової бази. Лососеві риби продемонстрували екстремальні коливання з рекордно високим FCR 3,5 у 2023 р. та різким поліпшенням до 1,0 у 2024 р., що засвідчує технологічну адаптацію виробництва. Узагальнено, що високий FCR у маточного стада є не лише поточною економічною втратою, а й індикатором майбутньої зниження продуктивності потомства, тому оптимізація годівлі має базуватися на використанні функціональних кормів і точних технологій керування. Практична цінність роботи полягає у можливості використання отриманих результатів для розробки стратегій раціонального управління кормовими витратами в рибогосподарських підприємствах України, що сприятиме підвищенню рентабельності та екологічної стійкості аквакультурного виробництва

Ключові слова: коефіцієнт конверсії корму (FCR); рибні господарства; годівля риб; маточне та ремонтне поголів'я; товарна риба