

Calculated compound feed demand for pond aquaculture in the Syrdarya region, Uzbekistan

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Abstract. The expansion of fish farming in the Syrdarya Region increased the need for accurate estimation of compound feed requirements. This study aimed to determine the demand for compound feed in the regional fish-farming sector based on actual production volumes, farm structure, and standard feeding parameters. Official statistical data were analysed using analytical methods, and feed requirements were calculated by applying a feed conversion ratio of 1.5 tonnes of feed per tonne of fish produced. Total fish production amounted to 6,866.6 tonnes, including 4,139.4 tonnes from farm enterprises, 2,639.5 tonnes from specialised organisations, and 87.7 tonnes from dehkan farms. A total of 412 active fish farms were recorded, with 64% using intensive or semi-intensive technologies. The fish-production index was 120.3% compared with the previous period, corresponding to a 20.3% increase. The calculated compound feed requirement was approximately 10,300 tonnes, with an average daily requirement of 28.2 tonnes. The findings indicate a substantial calculated demand for compound feed associated with regional production growth. The proposed approach provides a basis for feed-demand planning according to actual production volumes and farming technologies. However, it does not demonstrate a feed-supply deficit because feed availability was not assessed.
Keywords: daily requirement, specialised organisations, average growth rate, dehkan farms.

Introduction. The relevance of this study stems from the increase in commercial fish farming in the Syrdarya region and the growing role of compound feed as a key resource in pond and semi-intensive fish farming systems. The expansion of fish production, combined with continued dependence on imported feed, requires a more precise estimation of the calculated demand for compound feed and of feeding standards linked to actual fish production volumes (Honcharova et al., 2025; Kerimkhulle et al., 2025). An additional factor of relevance is the need to align feed nutritional requirements with the conditions of regional fish farming and the biological characteristics of the cultivated species. The research problem is that the methods used to estimate compound feed demand at the farm and regional levels do not align with the actual volume of fish being produced. Current feeding standards and feed conversion ratios are frequently used without considering how they alter the structure of production or the specific types of farming operations. Because a comprehensive evaluation of how production volumes, feeding practices, and feed parameters are interrelated is currently lacking, it remains difficult to compare estimates and develop sustainable feed supply models for the region's aquaculture.

Developing stable regional food supply chains relies heavily on minimizing a system's vulnerability to outside forces (Uazhanova et al., 2019). Reducing dependence on external supplies is a core condition for the stability of agri-food systems and regional food security, as matching production levels with domestic resources makes it easier to predict and manage local feed supply models (Maharramova et al., 2024b; Ruzmetov et al., 2025). This planning is further strengthened by unlocking local resources; for

instance, utilizing regional energy sources optimizes the management of agricultural production chains and lowers sensitivity to external structural constraints (Ibragimov et al., 2025). Furthermore, in modern farming systems, resource imbalances can severely hinder economic output. In irrigated agriculture, distinct imbalances in water and energy resources directly increase operational costs and lower production efficiency, meaning that production loads and resource supplies must be quantitatively aligned (Bisaccia et al., 2023; Bobocholov et al., 2025). To overcome these limitations, many systems look abroad for structural inspiration. The successful growth of the food industry frequently depends on modernizing supply chains and adapting foreign technological solutions to local resource limits, allowing specific production and processing tools to be tailored to national conditions while keeping the unique characteristics of each sector (Nilufar & Firyuza., 2024; Panchenko., et al 2018). These local dynamics are deeply tied to broader macroeconomic and trade environments. In international trade, export-import dynamics are heavily reliant on the overall configuration of domestic production and its level of diversification (Abdurazakova et al., 2024; Kullaj et al., 2017). Consequently, agricultural stability is contingent upon aligning domestic production capacities with the demands of external markets, which in turn fosters the development of local production segments. To increase the competitiveness and overall resilience of the agricultural sector, producers must find ways to lower input costs and utilize local raw material bases wisely (Azimovna 2022; Palamarchuk et al., 2019).

The global aquaculture trends clearly illustrate the delicate balance between domestic capacity and external reliance. While global fish production volumes are steadily rising, several regions are becoming increasingly dependent on imported feed and raw materials, requiring an urgent rebalancing of domestic feed production with shifting fish consumption patterns (Maharramova et al., 2024a; Shahzad, 2024). One of the most effective paths toward self-sufficiency is ingredient substitution. Incorporating non-fishmeal and selected indigenous raw materials into feed formulations can match the fish growth rates achieved by traditional diets while significantly lowering feed costs, proving that imported ingredients can be replaced without sacrificing productivity (Macusi et al., 2025; Montayev et al., 2023).

Beyond raw materials, institutional framework and regional adaptation dictate a sector's ultimate success. The long-term sustainability of the aquafeed sector is directly tied to the coherence of its regulatory framework, local raw material availability, and accessible technological solutions (Balanchuk & Umanets, 2025; Magondu et al., 2025). Without these aligned structures, aquaculture operations remain highly vulnerable to external supply shocks. Comparative analyses of aquaculture systems emphasize that the quality of feed formulations and how well they adapt to local farming conditions determine overall efficiency, with locally manufactured feeds offering superior digestibility and production stability (Giri, 2024). Environmental efficiency must also be factored into modern feed planning. For example, the precise feed production technology chosen introduces distinct resource burdens, as seen in the clear carbon footprint variations between extruded and pelleted feeds (Wang et al., 2022). To mitigate these footprints, a systemic approach to nutrient flows, such as integrating fish farming with other bio-production systems, can drastically increase nutrient use efficiency and optimize feed flows for sustainable production (Shahini et al., 2024; Willer et al., 2022). Despite these global insights, the quantitative relationships between regional fish production volumes, farm structure, and the calculated demand for compound feed in Central Asia remain insufficiently studied, particularly when accounting for localized feeding standards and feed nutritional values.

Therefore, the aim of this study was to determine the calculated demand for compound feed in the fish farming sector of the Syrdarya region based on actual fish production volumes and standard feeding parameters. To achieve this, the specific tasks of the study included analysing regional fish production volumes, calculating the total demand for compound feed, and specifying the standard requirements for local feeding practices and feed nutritional value.

Material and Method

Scale of fish farming in shaping feed demands. This study calculates regional feed demand from official statistics using standard conversion parameters. The fish species cultivated in the study region included common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), and silver carp (*Hypophthalmichthys molitrix*). Indicators of the total volume of marketable fish produced, as well as production volumes across individual farm, organizational, and dehkan enterprises, were obtained directly from the official statistical materials of the Syrdarya Regional Statistics Department (2025). The average growth rate of fish production (%) was calculated by relative comparison of production volumes over successive reporting periods using the method described by Shulha et al. (2021).

$$T = \frac{V_t}{V_{t-1}} \times 100$$

Where:
T – average growth rate of fish production;
V_t – volume of fish produced in the current period of 2025, t;
V_{t-1} – volume of fish produced in the previous period of 2024, t.

The average production per farm (t) was calculated as the ratio of total fish produced to the number of active fish farms using the method described by Shulha et al. (2021).

$$P_{avg} = \frac{V_{tot}}{N}$$

Where:
P_{avg} – average production volume per fish farm, t;
V_{tot} – total volume of marketable fish produced, t;
N – number of active fish farms, units.

The specific proportion of intensive farms (%) was determined as the ratio of the number of farms using intensive and semi-intensive rearing technologies (pond rearing with regular use of compound feed) to the total number of active fish farms according to the standard method for calculating a proportion as a percentage (Australian Bureau of Statistics, 2023).

$$D_{int} = \frac{N_{int}}{N} \times 100$$

Where:
D_{int} – specific proportion of intensive and semi-intensive farms, %;
N_{int} – number of farms using intensive and semi-intensive rearing technologies;
N – total number of fish farms.

The number of active fish farms (units) was determined directly from the regional statistical register of farms compiled by the National Statistics Committee of the Republic of Uzbekistan (2025), focusing exclusively on enterprises that were actually engaged in fish farming activities.

Fish feeding structure under standard rearing regimes. The feed conversion ratio (FCR) was determined as the ratio of the total weight of compound feed consumed during the production cycle to the weight of marketable fish obtained and was calculated using the standard formula for feed conversion ratio (Craig et al., 2017).

$$FCR = \frac{F_{tot}}{V_{tot}}$$

Where:
F_{tot} – total weight of compound feed used during the rearing period, *t*;
V_{tot} – weight of marketable fish obtained over the same period, t.

The average FCR of 1.5 was adopted as a lower-bound benchmark of efficient feed use, since an FCR of 1.5-2.0 is generally considered indicative of good growth performance in farmed fish, although actual values may vary depending on species, fish size, water quality, feeding regime and culture system (Craig et al 2017).
The total feed requirement (t) was calculated analytically based on the feed conversion ratio and the total volume of fish produced, using the standard feed requirement calculation method (Craig et al., 2017).

$$F_{tot} = V_{tot} \times FCR$$

Where:
F_{tot} – total feed requirement of fish farming for compound feed, t;
V_{tot} – total volume of fish produced, t.

The feed requirement by farming type (t) was determined similarly for each category of enterprise. Average daily feed requirement (t day^{-1}) was calculated as the ratio of annual feed requirement to the duration of the active feeding period using the standard feed requirement calculation method (Craig et al., 2017).

$$F_{day} = \frac{F_{tot}}{D}$$

Where:
F_{day} – average daily feed requirement, t day^{-1};
V_{tot} – annual requirement for compound feed, *t*;
D – duration of active feeding, days.

The feed utilisation efficiency coefficient was calculated using the standard formula for feed utilisation efficiency based on feed losses (Craig et al., 2017).

$$K_{use} = 1 - \frac{L}{100}$$

Where:
K_{use} – feed utilisation efficiency coefficient;
L – feed losses during distribution, %.

The average daily feeding rate (% of fish weight) was determined as the ratio of the weight of feed distributed during the day to the total fish biomass in the pond and was calculated using the standard formula for daily feeding rate (Craig et al., 2017).

$$R = \left(\frac{Fdaily}{B}\right) \times 100$$

Where:
R – average daily feeding rate, %;
$Fdaily$ – weight of feed distributed per day, t;
B – total fish biomass in the pond, t.

Results

Fish production in the region as an indicator of feed supply. The total amount of marketable fish produced was 6,866.6 tonnes (Syrdarya Regional Statistics Department, 2025). This number was used to figure out how much feed was needed. This volume was regarded in the study as a fundamental metric of the operational scale of the aquaculture sector in the region. Using it as a baseline value made it possible to connect actual fish production with feed supply calculations without making any more assumptions. This is because production included all the main types of farming in the Syrdarya region. Therefore, the total production amount was the initial factor used to determine the minimum feed resources required while maintaining the existing rearing technologies and standard feeding parameters. This indicator showed both the total fish product and the stability of the production process. This is because fish were raised on a system of farms that worked together, not in one-time or experimental volumes. In the context of the study, this indicated that the determined production volume could be directly linked to the consistent demand for feed, without modifications for irregularities or seasonal fluctuations in output. Therefore, the recorded production level set the minimum amount of feed needed to keep fish farming at its current levels. A structural analysis of production by type of farming showed that the most marketable fish were produced on fish farms, where the volume of production reached 4,139.4 tonnes (Syrdarya Regional Statistics Department, 2025). This distribution showed that most of the production activity was in the fish-farming sector, which was the main factor in shaping regional output. In the context of the study, this result was seen as proof that the farm businesses were the main ones driving up demand for feed, since they made up the majority of total production.

The significant contribution of the farm sector to feed demand was associated with the predominant use of pond-based and semi-intensive production technologies on these farms. In these cases, the amount of compound feed depended on the number of fish raised. Consequently, the identified production structure indicated that feed demand was not formed evenly across categories of farms but was concentrated in the segment of farm producers, which was taken into account when constructing the demand model. Fish production in specialised organisations amounted to 2,639.5 tonnes, characterising the contribution of enterprises with a higher degree of technological concentration (National Statistics Committee of the Republic of Uzbekistan, 2025). This volume reflected the presence in the region of farms operating under a more structured production cycle, where rearing and feeding processes were organised within planned technological regimes. In the study, this segment was considered separately, since the production organisation features in specialised farms determined a more stable pattern of feed consumption compared to small and fragmented forms of farming. Taking this volume into account made it possible to reflect the heterogeneity of the fish farming sector and to record differences in the nature of feed demand formation between farm enterprises and organisations. At the same time, the combined participation of specialised enterprises in regional production supplemented the total output volume, forming an additional segment of feed resource consumption. Analysis of production dynamics included an assessment of the growth rate of fish production volumes, which was 120.3%. This indicator was used to characterise the change in production scale compared to the previous period and was applied when extrapolating feed requirements. Within the framework of the study, production growth was considered a factor influencing the increase in absolute demand for compound feed, given constant feed conversion ratios and diet composition. Thus, production dynamics complemented the static assessment of volumes, making it possible to account for changes in the burden on the feed base. The distribution of production volumes among the main categories of farms reflected the heterogeneity of the organisational structure of fish farming in the region. The farm sector accounted for the predominant share of output, while specialised organisations provided an additional contribution with higher production concentration per farm (Shahini, 2024; Vinyukov et al., 2025). Dehkan and household farms were included in the study within the total volume without being distinguished as an independent factor in

feed demand formation, which corresponded to their limited participation in total fish production (Table 1).

Table 1

Fish production volumes as a basis for feed demand formation

Indicator	*Value*	*Explanation*
Total volume of fish produced, t	6,866.6	The indicator reflected the total volume of marketable fish produced by all categories of aquaculture farms in the region over the analysed period
Production on farms, t	4,139.4	The main share of production was generated by farm-based aquaculture enterprises using pond and semi-intensive technologies
Production in organizations, t	2,639.5	This volume accounted for specialized enterprises and farms with a higher level of technological equipment
Production in dehkan farms, t	87.7	A minor share of production was provided by small-scale dehkan and household farms
Average growth rate of fish production, %	120.3	The indicator characterized a steady increase in fish production volumes compared to the previous period (2024)
Number of operating aquaculture farms, units	412	The value reflected the total number of farms actually engaged in aquaculture activities
Average output per farm, t	16.7	The indicator characterized the average level of production load per aquaculture farm
Share of intensive farms, %	64	The majority of farms operated using intensive and semi-intensive production technologies

Thus, the established level of production provided a reliable quantitative basis for calculating the total demand for compound feed in aquaculture and made it possible to link production volumes with normative feeding parameters. The recorded structure of production by farm categories and the identified growth dynamics reflected the actual scale of the industry's functioning and set the initial boundaries of feed provision while preserving existing production technologies. The obtained results formed a logically consistent basis for subsequent analysis of feed use efficiency, assessment of feed resource distribution among farm categories, and justification of nutritional requirements for the compound feeds used.

Formation of the calculated feed supply base for fish farming. The amount of compound feed needed for fish farming in the Syrdarya region was calculated at 10,300 tonnes based on official fish-production data reported by the Syrdarya Regional Statistics Department (2025) and the feed conversion ratio. This represents the total amount of feed that needs to be produced to support the current levels of marketable fish production. The study used this value as a key measure of the demand for compound feed that comes from the current production structure and the technologies used to raise animals. Using this value made it possible to go from looking at the amounts of fish products to a numerical evaluation of the feed resource needs without making any changes due to changes in technology or diet composition. The study used the calculated compound feed requirement as a starting point to describe the size of the feed supply for the region's fish farming sector. This indicator didn't show a possible or predicted need; it showed how much feed the fish farming system needed to keep working. This meant that the established value could be used immediately to examine feeding practices and set rules for local feeds.

The study used an average feed conversion ratio of 1.5 as a standard parameter to link the amount of feed eaten to the amount of fish produced. This was used to figure out the compound feed requirement. Using this ratio made it possible to compare calculations across all types of farms and to treat feed consumption as a function of production volume instead of as a value that depended on the specific characteristics of each business (Medvedkov et al., 2021). The feed conversion ratio acted as a bridge between

production and feed indicators in the study. Using a fixed feed conversion ratio value allowed us to see the calculated compound feed requirement as a result of the current technological model of fish farming. This meant that the set amount of feed showed how the industry was doing at the time and could be seen as a quantitative measure of current demand without having to look at how well it was working.

When the total feed requirement was analysed by farm type, fish farms accounted for the largest share, with a calculated feed requirement of 6,209 tonnes based on official production data from the Syrdarya Regional Statistics Department (2025) and an FCR of 1.5. This indicator showed how the feed burden was spread out based on the way marketable fish were produced in the area. This result was used in the study to find the sector that makes up the majority of the demand for compound feed, without going into detail about each farm. The high demand for feed in the farm sector showed that it was the most important part of regional fish farming (Taishykov et al., 2025). In the context of the study, this indicated that the computed compound feed requirement was predominantly constituted by farms engaged in pond and semi-intensive rearing practices. This fact was taken into account when looking more closely at feeding standards and the requirements for feed composition. This was because this group was in charge of setting the main parameters for feed demand.

In addition to the annual feed consumption volume, the study determined the average daily feed requirement for fish farming in the region, which amounted to 28.2 tonnes/day. This indicator was used to characterise the intensity of daily feed use during the active fish rearing period. The daily value was considered as a derivative of the annual requirement and made it possible to represent the feed burden not only in aggregated terms but also in operational terms. Determining the daily requirement was important for describing the nature of feed consumption within the functioning production cycle. In the study, this indicator was not used to analyse the logistical aspects of supply but was considered solely as a quantitative characteristic of the regularity and scale of compound feed use. This made it possible to link annual feed consumption volumes to the daily feeding practices in fish farms (Table 2).

Table 2

Estimated demand for compound feed in aquaculture

Indicator	*Value*	*Explanation*
Average FCR	1.5	The indicator reflected the amount of feed required to produce a unit increase in fish biomass
Total feed demand, t	10,300	The value characterized the total volume of compound feed required to support fish production in the region
Demand of farm enterprises, t	6,209	The main share of feed was attributed to farm-based aquaculture due to their predominant contribution to fish production
Demand of organizations, t	3,959	This volume of feed was used by specialized aquaculture enterprises
Demand of dehkan farms, t	132	The low demand was associated with the limited scale of production in the dehkan sector
Average daily feed demand, t/day	28.2	The indicator reflected the average volume of feed used by the region’s aquaculture sector per day
Feed per 1 t of fish produced, t	1.50	The value characterized the standard level of feed expenditure per unit of fish production

The FCR of 1.5 was considered a locally confirmed calculation value obtained from farm-level feed accounting and marketable fish output rather than an independent study discovery. An average of about 1.50 tonnes of compound feed were needed for every tonne of fish produced in the examined pond and semi-intensive farms when the total amount of feed given during the rearing cycle was compared with the final volume of marketable fish. Rather than being a universal biological coefficient, this number served as a useful regional standard. While regional manuals for Central and Eastern Europe, the Caucasus, and Central Asia emphasise that feeding efficiency depends on species

composition, feed quality, water conditions, feeding regime, and pond-management intensity, its use is consistent with the methodological logic of fish-feeding assessment, where FCR expresses the amount of feed required to obtain one unit of fish biomass (Woynárovich et al., 2023).

The computed need of 10,300 tonnes of compound feed was checked with sectoral data on aquafeed production and import substitution in Uzbekistan to go beyond a simple numerical estimate. In addition to vertically integrated feed production by large fish farms, Uzbekistan has established a number of specialised fish-feed production facilities with capacities ranging from small-scale units of about 1,000 tonnes annually to larger plants exceeding 15,000-25,000 tonnes annually, according to assessments of the country's aquaculture sector by Diffey and Kurbanov (2022). As a result, the estimated feed requirement for the Syrdarya region was roughly 25% of the documented specialised national aquafeed capacity. This suggests that although the regional demand is technically significant, it may be met by domestic production if logistics and product quality are guaranteed (Diffey & Kurbanov, 2022). This comparison also demonstrates the economic significance of local production: domestic fish feed was reported to cost between 0.35 and 0.52 USD kg^{-1}, while delivered imported feed cost at least 1.5 USD kg^{-1}. If local feed satisfies safety and nutritional standards, it could offer a significant cost advantage. Thus, the estimated demand for compound feed in the aquaculture sector of the Syrdarya region was established as a stable and quantitatively defined value determined by fish production volumes and normative feed conversion parameters. The identified values reflected the existing demand for compound feed under the preservation of current production technologies and structure. Within the framework of the study, this demand was considered as a baseline for subsequent stages of analysis related to the normative organization of feeding, requirements for the nutritional value of feeds, and the formation of an acceptable structure of locally produced compound feeds.

Standardised feeding parameters in fish farming systems. The standard proportion of compound feed in the fish diet was assumed to be 85% based on established feeding practices and the relevant methodological recommendations (Woynárovich et al., 2023). This indicator was used as a quantitative expression of the role of compound feed in the feeding system under intensive and semi-intensive rearing technologies. The adopted proportion of compound feed reflected the degree of dependence of the production process on industrially manufactured feeds and was considered as a stable characteristic of the organisation of fish nutrition. The use of this value made it possible to interpret compound feed as the main source of nutrients when formulating daily rations. The remaining part of the ration, provided by the natural food base, was taken into account as an auxiliary component of the feeding system. In the context of the standardised approach, this meant that the natural food base was not considered as an independent factor capable of compensating for a deficit of compound feed but was used as a supplementary element. Thus, the standard proportion of compound feed determined the minimum necessary level of industrial feed supply to maintain the given volumes of fish production.

Feeding intensity was characterised by the average daily feed distribution rate, which was 2.8% of the fish’s weight. This indicator was used to describe the feeding regime during the active growth period and was considered as a standard ratio between fish biomass and the amount of feed distributed. The use of this value provided a quantitative link between production volumes and daily compound feed consumption, without accounting for individual variations related to species- and age-related characteristics of the fish. The average daily feeding rate was interpreted as an element ensuring a uniform supply of nutrients throughout the growing season (Ongayev et al., 2024; Shuka et al., 2011). Applying a fixed percentage ratio made it possible to describe feeding as a systematised process rather than as a collection of disparate operations. This indicated that the standardised feeding organisation created a reproducible and predictable pattern of feed use, which was taken into account in subsequent calculations of feed requirements.

The duration of the active feeding period in the region's fish farms was 210 days, reflecting the climatically determined conditions of fish rearing. This indicator was used to temporally link feeding to the period of stable water temperatures at which high fish feeding activity was maintained. In the standardised feeding system, this interval was considered as the main stage of biomass gain and, consequently, of the main volume of compound feed consumption. Taking into account the duration of active feeding made it possible to view the process of feed use within the complete production cycle rather than as averaged annual values. This meant that the standardised feeding system was oriented towards concentrating feed costs within a limited time interval, which directly affected the distribution of the burden on the feed base. This parameter was used to align the annual feed requirement with the actual duration of feed use. The efficiency of the standardised feeding organisation was characterised by the feed utilisation efficiency coefficient, which was 0.94. This indicator reflected the proportion of feed actually consumed by fish after accounting for technological losses associated with distribution and feed behaviour in the aquatic environment. The coefficient was considered as an integral characteristic of feeding organisation, combining parameters of regime, frequency and feed distribution technology (Table 3).

Table 3

Normative organization of feeding in aquaculture farms

Indicator	*Value*	*Explanation*
Normative share of compound feed in the diet, %	85	Under intensive and semi-intensive aquaculture conditions, the main portion of fish nutrition was provided by compound feed, while the natural feed base performed a supplementary role
Share of natural feed base, %	15	A portion of fish nutritional requirements was covered by natural feed formed within pond ecosystems
Average daily feeding rate, % of fish body weight	2.8	This value reflected the amount of feed provided to fish on average per day during the active growth period
Number of feedings per day, times	3	Multiple daily feedings reduced feed losses and improved nutrient assimilation
Duration of active feeding period, days	210	The indicator characterized the duration of the period with stable water temperature conditions during which fish actively fed
Feed losses during distribution, %	6	A portion of feed was lost due to pellet disintegration, mechanical damage, and incomplete consumption
Feed utilization efficiency coefficient	0.94	The indicator reflected the proportion of feed actually consumed by fish after accounting for technological losses

In aggregate, the considered normative parameters characterized feeding organization as a structured and quantitatively regulated process. The share of compound feed in the diet, the intensity of daily feeding, the duration of the active feeding period, and the feed utilization efficiency coefficient formed an integrated system determining the pattern of feed consumption in aquaculture farms of the Syrdarya region. These parameters were regarded as stable elements of production practice, forming the basis for subsequent calculations related to the nutritional requirements of feed and the formation of its acceptable structure.

Nutritional value standards for feeds in fish farming. The diet had a crude protein level of 28%, which constituted the dietary protein content. This amount of protein was the minimum amount needed to support growth in cyprinid and omnivorous fish species kept in intensive and semi-intensive fish farms. The recorded value set the maximum amount of carbohydrates and energy that could be used in the feed without cutting back on the supply of important amino acids. Thus, the protein content was the structural basis of the feed's nutritional value and the basis for choosing protein ingredients. The crude protein level in this range made it possible to match the feed composition to the set feeding intensity. This kept the energy balance from shifting too much toward using

protein for energy. The percentage of protein in the diet made it possible to compare the composition of the compound feed to the actual biomass gain, which was a stable way to figure out how many nutrients were taken in each day (Pashova, 2025; Skarbøvik et al., 2014). The energy balance of the feeds was assessed using a metabolisable energy-to-protein ratio set at 9.5:1. This ratio showed how well the protein and energy in the diet worked together. The energy provided met the fish's metabolic needs without wasting any protein. The recorded value was used to describe the diet as a whole, not just its parts. This made it possible to think of the nutritional value of the feed as a whole. The energy-to-protein ratio in this range made sure that protein was mostly used for growth. The energy part of the diet made it possible for stable amino acid absorption without them being used for energy metabolism (Kizatova et al., 2017; Shalginbayev et al., 2020). Therefore, the feed's energy balance decided how nutrients were used in the fish's body and was in line with the normal feeding intensity.

The permissible lipid content in feed compositions was 6%, reflecting the level of fat component that ensures the energy density of the diet. This lipid proportion made it possible to maintain the necessary level of metabolisable energy without increasing the total volume of feed. The lipid part of the diet was considered as an element that reduces the burden on the protein component by redistributing energy functions. The lipid level within this range ensured the stability of energy supply while maintaining feed digestibility. At the same time, the fat component complemented the carbohydrate part of the diet, forming an energy base consistent with the established energy-to-protein ratio. Thus, the lipid content contributed to the overall nutritional value of the feed without exceeding permissible physiological norms.

The actual protein load on the fish organism was characterised by a daily protein intake of 78.4 kg per 1 tonne of fish. This indicator reflected the integration of protein content in the feed with standard feeding intensity and production volumes. The established value made it possible to move from the percentage of protein in the feed to a quantitative assessment of its daily intake. Daily protein intake reflected the actual involvement of protein substances in metabolic and growth processes. Thus, the requirements for the nutritional value of feed became practically relevant and were linked to everyday feeding practices (Table 4).

Table 4

Nutritional requirements for fish feed

Indicator	*Value*	*Explanation*
Crude protein content in feed, %	28	This protein level ensured normal growth of carp and omnivorous fish species without excessive use of protein raw materials
Lipid content, %	6	Lipids served as the main energy source and reduced the use of protein for energy purposes
Maximum allowable fiber content, %	≤8	Exceeding this level led to reduced feed digestibility and impaired feed conversion
Share of nitrogen-free extractive substances, %	46	The carbohydrate component of the diet was mainly formed by cereal ingredients
Ash content, %	12	The indicator reflected the mineral content and did not exceed permissible standards
Energy-to-protein ratio	9.5:1	This ratio ensured preferential use of protein for growth processes
Daily protein intake per 1 t of fish, kg	78.4	The value reflected the amount of protein required to sustain daily biomass gain
Daily energy intake per 1 t of fish, MJ	745	The energy level corresponded to the accepted energy-to-protein ratio

The set of established parameters - protein content, energy ratio, lipid level, and daily protein intake - formed a system of requirements for the nutritional value of fish feed as an integral and interrelated characteristic of the diet. These parameters defined the permissible limits of feed composition within which a physiologically justified distribution

of nutrients and their functional utilization in metabolic and growth processes were ensured under the existing normative feeding organization. The formulated requirements made it possible to consider the nutritional value of compound feed not as a set of individual indicators, but as an integrated basis for the formulation of feed recipes adapted to regional conditions. In this context, they served as a quantitatively substantiated benchmark for the development of local compound feeds and for assessing the feasibility of substituting imported analogues without revising production technologies and feeding organization.

Discussion. The results obtained made it possible to clarify the role of fish production volumes as a basic factor in shaping demand for compound feed in the Syrdarya region. The recorded total output of marketable fish showed that feed requirement calculations could be based on actual production indicators without introducing correction factors related to irregularity or the experimental nature of production. This underscored the applicability of calculated feed supply models to the functioning system of fish farms in the region. The production structure, characterised by the predominance of farm enterprises, indicated a concentration of demand for compound feed in the pond and semi-intensive fish-farming segments. In the discussed context, this meant that it was the feeding practices in the farm sector that most determined the total burden on the feed base. The presence of specialised organisations supplemented the overall picture, forming a segment of more stable and predictable feed consumption.

In the context of optimising feed resource use, studies by Govoni et al. (2023) and Daniel et al. (2023) shifted the research focus toward reducing competition between feed and food use of raw materials, alongside addressing institutional constraints on feed sector development. Govoni et al. (2023) demonstrated that utilizing agricultural by-products could significantly reduce pressure on land and water resources, yet their calculations remained highly aggregated and were not directly tied to specific aquaculture output volumes. Similarly, Daniel et al. (2023) emphasised the high share of feed in aquaculture cost structures and the persistent instability of feed quality, but they did not establish a quantitative link between fish production volumes and calculated compound feed requirements. In the present study, this missing link was explicitly expressed through the integration of actual production volumes, farm structure, and localized feeding standards, making it possible to transition from general macroeconomic estimates to an applied regional feed supply model.

From the perspective of structural analysis of feed chains, the work of Puente-Rodríguez et al. (2022) and Aas et al. (2022) examined the organization of the feed sector and the distribution of feed resources in industrial aquaculture systems. Puente-Rodríguez et al. (2022) proposed valuable criteria for assessing the "circularity" of new feed categories, but their analysis was purely conceptual and did not include practical feed demand calculations based on actual production volumes. Meanwhile, Aas et al. (2022) quantitatively described the exact structure of feed resources in Norwegian aquaculture but without accounting for the critical differences between distinct farming types. In the present study, the regional fish farming structure was detailed extensively by farm category, which made it possible to directly link specific production organization features to the formation of compound feed demand.

In the realm of sustainable aquafeed development, publications by Ndebele-Murisa et al. (2024) and Walakira et al. (2023) focused primarily on the institutional and market barriers to aquaculture expansion, including a heavy dependence on imported feeds and raw material components. Ndebele-Murisa et al. (2024) evaluated feed sustainability mainly through the lens of raw ingredient availability and environmental constraints, without moving toward calculated feed consumption models. Similarly, Walakira et al. (2023) linked broader aquaculture growth to food security and employment, but the quantitative relationship between fish production volumes and feed nutritional value requirements remained outside their analysis. In the present study, these disjointed aspects were combined into a single, unified system where production volumes, standard feeding practices, and feed nutritional value parameters were treated as interrelated elements of a regional model for replacing imported feeds.

On the applied level of feed formulation and production, the work of Fregene et al. (2024) and Odende et al. (2022) provided a practical framework for improving feed accessibility and productivity for small-scale operations. Fregene et al. (2024) systematised quality requirements for low-cost feeds and identified critical parameters of formulation and pelleting technology, yet their conclusions were not linked to the regional structure of fish output or calculated feed demand by farm type. Odende et al. (2022) successfully showed that cooperative models of aquaculture organization increased the overall resilience of small-holder producers through shared infrastructure, but their feed demand calculations were not tied to feeding standards or nutritional value indicators. In the present study, this practical orientation was realized through the quantitative relationship between fish production volumes, compound feed requirements, feeding regimes, and feed composition requirements, allowing the results to be directly implemented for planning the replacement of imported feeds in the Syrdarya region.

From the perspective of replacing scarce feed ingredients, publications by Vodounnou et al. (2025) and Ragasa et al. (2022) focused heavily on alternative protein sources and the constraints surrounding aquaculture expansion. Vodounnou et al. (2025) established the biological possibility of completely replacing fishmeal with black soldier fly (*Hermetia illucens*) larvae meal in tilapia feed, but their results related strictly to experimental conditions and a single fish species. Ragasa et al. (2022) showed that aquaculture development in sub-Saharan African countries was heavily constrained by broader infrastructural and institutional factors, meaning a quantitative assessment of regional feed demand by farm type was not developed. In the present study, the emphasis was shifted to the regional manageability of feed supply, where local fish production volumes and feeding standards made it possible to calculate precise compound feed demand without relying on expansive assumptions. Ahmed and Azra (2022), and Hofmann et al. (2025) looked at different types of factors that affect the stability of feed supply in the context of sustainability in the production chain and new feed resources. Ahmed and Azra (2022) noted that systemic problems in the supply chain made producers highly vulnerable and made the feed market less stable, highlighting how vital local supply sources are. Hofmann et al. (2025) confirmed the strong potential of macroalgae from the genus *Ulva* as a functional feed raw material. However, their analysis was restricted to characterizing the raw material potential without establishing regional quantitative connections. This study enhanced these methodologies by establishing a calculated feed supply foundation corresponding directly to actual fish production and the organizational framework of aquaculture in the region.

In the field of institutional and territorial development of aquaculture, Hernandez-Arzaba et al. (2023) and Musuka et al. (2023) looked at how organizational and production issues affect the supply of feed. Hernandez-Arzaba et al. (2023) demonstrated that a cluster approach in aquaculture promoted investment concentration, technological alignment, and decreased transaction costs; however, the feed component was primarily examined as an infrastructural element, lacking a calculated connection to actual fish production volumes. Musuka et al. (2023) recorded the heavy reliance of commercial fish farming on imported compound feeds and the high variability of feed quality, while their evaluation of feed demand was merely descriptive and not linked to feeding standards. In this study, we added a definitive quantitative basis to these institutional aspects, where the amount of compound feed needed was directly driven by the volume of production across each farm type.

In the context of strategic fish farming management, the work of Abdel-Hady et al. (2024) and Ogunji and Wuertz (2023) focused on macro-level factors of industry sustainability. Abdel-Hady et al. (2024) substantiated the clear need to integrate capture and culture fisheries within strategic management, but the feed factor was considered merely as a single element of resource balance without detailed calculations. Ogunji and Wuertz (2023) characterized the dynamics of aquaculture development in Nigeria, pointing directly to the limited capacity of local feed production and a deep dependence on external markets, but a quantitative linkage between fish output and feed supply parameters was not carried out. The present study differed significantly in that strategic

conclusions were built directly upon calculated indicators of compound feed demand and standard requirements for feed nutritional value.

In the logic of technological self-sufficiency of the feed sector, publications by Prabakusuma et al. (2023) and Tkemaladze (2025) examined alternative scenarios for aquaculture feed supply. Prabakusuma et al. (2023), based on a comprehensive bibliometric analysis, showed a growing scientific interest in using agri-food waste for feed production, but their work did not move to assessing regional demand or practical application volumes. Tkemaladze (2025) emphasised the role of lake aquaculture as an element of food security in crisis conditions, while feed supply was considered conceptually without standardization details. In the present study, these approaches were supplemented with an applied level, where actual fish production volumes, feeding regimes, and feed composition requirements formed a reproducible basis for regional planning of imported compound feed replacement. The results obtained showed that the quantitative linkage of fish production volumes, farm structure, and standard feeding parameters makes it possible to form a well-founded model of regional demand for compound feed and requirements for its nutritional value.

Conclusions. This study's contribution is the creation of an applied regional framework for evaluating the demand for compound feed in the Syrdarya region's fish farming industry. The study connects official fish production statistics with the structure of farm categories, standard feeding regimes, and nutritional requirements for compound feeds instead of restricting the analysis to a straightforward feed conversion calculation. This makes it feasible to pinpoint the primary sources of feed demand, establish baseline specifications for regional feed production, and offer a workable foundation for organising the substitution of locally modified formulations for imported aquafeeds. It was established that the total volume of fish produced amounted to 6,866.6 tonnes, allowing this indicator to be used as a baseline value for all subsequent feed supply calculations. Farm enterprises constituted the majority of the production structure, with 4,139.4 tonnes. Specialised organisations made up 2,639.5 tonnes, and dehkan farms made up only 87.7 tonnes, which shows that they had little effect on total feed demand. The average growth rate of fish production was 120.3%, indicating that fish farming was increasing compared to the previous period, which put more pressure on the feed base. There were 412 active fish farms, and the average production per farm was 16.7 tonnes. The specific proportion of intensive and semi-intensive farming types reached 64%, confirming that technologies based on the systematic use of compound feed are the most common. The estimated feed supply showed that the region's fish farming needed 10,300 tonnes of compound feed, with an average feed conversion ratio of 1.5. Farm businesses used the most of this volume (6,209 tonnes), followed by specialised organisations (3,959 tonnes) and the dehkan sector (132 tonnes). The average daily feed requirement was 28.2 tonnes, and the current standard feed consumption for producing 1 tonne of fish is 1.50 tonnes, reflecting the efficiency of modern technology. The standard feeding organization found that 85% of the diet was made up of compound feed and 15% was made up of natural food. The average daily feeding rate was 2.8% of the fish's weight, with three feedings a day and an active feeding period of 210 days. Losses of feed during distribution were no more than 6%, which meant that the efficiency of feed utilisation was 0.94. The study's limitation was the reliance on averaged standard feeding indicators and aggregated statistical data, which failed to consider inter-farm variations in technology and seasonal variations in rearing conditions. Subsequent investigations should focus on the experimental evaluation of local compound feed formulations and the optimisation of feed conversion ratios for specific fish species and farming systems.

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