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A New Approach to Sustainable Aquaculture Management – Impact of Fish Feed on Aquaculture Farm Costs

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***Abstract*— Analysing feed efficiency and identifying the most cost-effective feeding strategies are critical aspects of the fish farming process, as they play a pivotal role in promoting the sustainable development of aquaculture. In fish farming, as in other livestock sectors, the quality of the product is closely linked to the feed, its quality and the impact of the feed on the profitability of the enterprise — the utilisation and cost of the feed. Animal feed is formulated using a diverse range of ingredients specifically designed to fulfil the nutritional requirements necessary for supporting an animal's physiological functions, including immune system maintenance, growth and reproduction. The sustainability of fish feed is a critical concern in the aquaculture industry, given the emerging demand for fish products and the environmental pressures associated with traditional feed sources. The reliance on fishmeal and fish oil, derived from wild fish stocks, raises significant issues, including overfishing and habitat degradation. On average, consumption of fish feed grows by 3% each year. Therefore, the Development of alternative feed ingredients that are Both Economically viable and environmentally friendly is essential for the future of aquaculture. The purpose of this study is to assess the importance of fish feed in aquaculture on the basis of environmental, economic and social parameters and the perception of Latvian fish farmers regarding the importance of fish feed in aquaculture. A partially structured questionnaire was used to collect data. Both descriptive and indicative methods were used for statistical analysis of the collected data. Collected data was analysed using Linear Regression model. Linear Regression is used to study the linear relationship between a dependent variable in fish feed type and independent variable the farms used fish feed costs. The results showed that the type of extruded fish feed reduce the cost of feed for fish in aquaculture farms.**

***Keywords*— *aquaculture; fish farms; feed type; sustainability*.**

I. INTRODUCTION

The sustainability of fish feed is a critical concern in the aquaculture industry, given the increasing demand for fish products and the environmental pressures associated with traditional feed sources. The reliance on fishmeal and fish oil, derived from wild fish stocks, raises significant sustainability issues, including overfishing and habitat degradation [1]. Therefore, the development of alternative feed ingredients that are both economically viable and environmentally friendly is essential for the future of aquaculture.

The economical production of a healthy, high-quality product with rich survival, growth, reproductive performance, spawning success, and body composition in fish culture depends on proper nutrition [2]. Since feed usually accounts for half of the variable production cost in aquaculture, nutrition is essential. The creation of new, balanced commercial diets that support the best possible growth and health for fish has led to a significant advancement in fish nutrition in recent years [3].

In fish farming, as in other livestock sectors, the quality of the product is closely linked to the feed that is fed to the animals, its quality and the impact of the feed on the profitability of the enterprise — the utilisation and cost of the feed. Animal feed is formulated using a diverse range of ingredients specifically designed to fulfil the nutritional requirements necessary for supporting an animal's physiological functions, including immune system maintenance, growth and reproduction [4].

Factory-produced fish feed is divided into 3 categories — pelleted, extruded and grain. One of the primary advantages of pelleted feed is its lower production cost compared to extrusion technology; however, pelleted feed

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also has several limitations, many of which can be mitigated through the use of extrusion technology [5].

One of the major disadvantages of pelleting is the rapid sinking rate (about 10 to 15% of pelleted feed is lost due to sinking), which means higher feed costs, a less profitable product and a higher environmental impact due to pollution [6]. In addition, the nutrients in pellets dissolve more quickly in water, making the pelleted feed a lower quality fish feed than extruded feed [5].

In fish farms, fish need to be fed several times a day. The feed is eaten, digested and used metabolically to provide fish with energy and ensure growth and other physiological processes [7]. Oxygen (O_2) is taken in through the gills and is used to provide energy and break down proteins. This process produces carbon dioxide (CO_2) and ammonia (NH_3) as waste products. Undigested feed enters the water with faeces, suspended solids and organic matter. Carbon dioxide and ammonia are also released into the water through the gills. Thus, as the fish consume food and oxygen, the water system becomes polluted with faeces, ammonia and carbon dioxide, with significant environmental impacts [7].

To ensure nutrient uptake, digestion, absorption, and transport to the cells of the animal's body, more and more feed additives are being used in fish feed [8]. The range of feed additives used in fish feed is very diverse and focuses on the quality of the feed. Feed additives in fish feed include pellet binders, antioxidants and feed preservatives (anti-mould and anti-microbial compounds). Enzymes are also used to improve the availability of certain nutrients (protease, amylase) and to prevent the presence of certain antibodies (phytase, non-starch polysaccharide enzymes) [9].

The effectiveness of probiotics in aquaculture depends on their origin and application [10]. The combination of probiotics with prebiotics also contributes to improving the health and growth results of fish [11]. In his study, Wei highlights the positive effects of combining probiotics with medicinal herbs, which can improve the growth results, immune system and disease resistance of fish species [12]. This synergy between probiotics and plant extracts can improve feed efficiency and overall fish health, making it valuable in the diet of fish.

Several studies have reported that the gastrointestinal tract of fish is sensitive to stress. Some of the most common signs are degeneration of the intestinal mucosa and impaired feed intake. Fish health is closely associated with a balanced gut microflora, which plays a crucial role in digestion, nutrient absorption, and disease resistance [13;14;15]. To maintain a healthy gut microflora, fish feed is supplemented with dietary supplements, probiotics, immunostimulants, phytogenic substances, and organic acids [10]. The health of fish also has economic implications, because if fish are sick, they cannot be caught and consumed, reducing income and sales for aquaculture businesses.

The suitability of fish feed is also determined by the way the fish are farmed. In recirculating systems, only extruded feed is recommended for fish, but in freshwater ponds, supplementary feed is used. Extruded feed is safe and one of its advantages is that it is formulated according to the actual biological needs of the fish. Extruded feeds are available in different pellet sizes to suit each stage of fish development. Its composition is combined to provide specific feed for juveniles, breeders, commodity fish, etc. In a recirculation system, a high feed utilisation is desirable to minimise waste and faeces, thus also reducing the load on the water treatment system [16].

On a professionally managed farm, all the feed that is fed is used in full, minimising the uneaten part. Feed conversion is a measure of how many kilograms of feed are used for each kilogram of fish produced. The fish farmer is seeking more production at a lower load on the filter system. Uneaten feed is money wasted, which also hampers the operation of water treatment system [17].

The aim of the study was to investigate which type of fish feed is more economically viable for fish farms in Latvia. Other studies have reported that fish feed costs account for 30–50% of the total costs of a business [23], which is a significant share. The present study also aims to find out also how much of the total cost is accounted for by feed costs in fish farms in Latvia.

II. MATERIALS AND METHODS

A survey prepared for Latvian aquaculture operators was used to collect the data. The survey consisted of structured and open-ended questions to investigate the costs of fish feed incurred by aquaculture enterprises and the link between the costs and the type of fish feed used by the enterprise. In 2024, there were 61 economically active aquaculture entrepreneurs in Latvia. 30 aquaculture entrepreneurs (n=30) took part in the survey, representing 50% of the Latvian aquaculture entrepreneurs.

Multiple linear regression method was used to analyse the data, which involves two linearly related variables, one dependent variable (Y) and one independent variable (X), which are linearly related to each other [18,19,20]. The main objective of linear regression is to fit a linear equation to the observed data, thus allowing the effects of the predictor variables to be predicted and interpreted. In this study, the dependent variable (Y) is the type of fish feed used in the aquaculture enterprise and the independent variable (X) is the cost of fish feed. The aim of the regression analysis was to test a general underlying model linking two variables and to show the relationship between X and Y to predict Y for a given value of X [20].The linear regression method assumes that the relationship between the predictor and target variables is linear: a constant unit of change in one implies a constant unit of change in the other. This simplicity usually makes linear regression the optimal choice for analyses with small samples, and also makes these models relatively easy to interpret and understand.

Analysis, synthesis, the logical construction method, the induction and deduction methods were employed to execute the research tasks. Scientific literature review was used as well.

III. RESULTS AND DISCUSSION

Based on the survey data on the total costs of the enterprise, it can be concluded that feed costs represent the largest share (48%), followed by purchase of juvenile fish (16%), energy (8%) and other costs (28%). See Figure 1 for the cost structure of Latvian aquaculture farms.

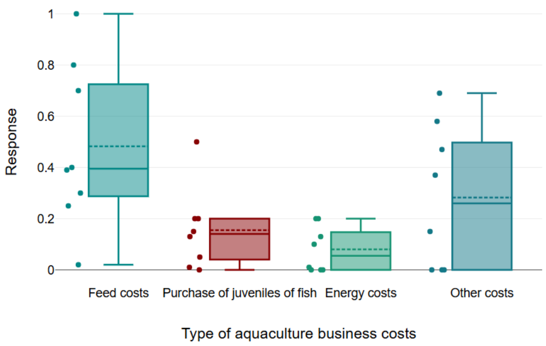


Fig. 1. Cost structure of Latvian aquaculture farms.

A multiple linear regression analysis was performed to examine the influence of the variables of fish feed type granular, extruded and grains on the variable Feed costs.

The regression model showed that the variables of fish feed granular, extruded and grains explained 13.794% of the variance from the variable feed costs. An ANOVA was used to test whether this value was significantly different from zero. Using the present sample, it was found that the effect was not significantly different from zero, F=0.12, p = 0.971, R^2 = 0.138.

Table 1 shows the results for each dependent variable in the model, including the constant (intercept). The unstandardized coefficient B indicates the expected change in the dependent variable Feed costs for each one-unit increase in the respective dependent variable.

TABLE 1 THE LINEAR REGRESSION MODEL COEFFICIENTS

Model	**Constant**	**Type of fish feed**		
		Granular	***Extruded***	***Grains***
B	0.525	-0.13	-0.225	-0.015
Beta	0	-0.186	-0.246	-0.021
Standard error	0.324	0.459	0.562	0.459
t	1.618	-0.283	-0.4	-0.033
p	0.204	0.795	0.716	0.976
lower bound	-0.507	-1.59	-2.013	-1.475
upper bound	1.557	1.33	1.563	1.445

Y-intercept of the regression line represents the expected value of the dependent variable when all dependent variables are zero. In this context, it means that when type of fish feed Granular, Extruded and Grains are zero, the independent variable Feed costs is expected to be around 0.525. The p-value is 0.204, indicating that the intercept is not statistically significantly different from zero. More precisely the null hypothesis that the coefficient of Constant is zero in the population is not rejected.

If the value of the variable Type of fish feed Granular changes by one unit, the value of the variable Feed costs changes by -0.13 units. The p-value is 0.795, indicating that this coefficient is not statistically significantly different from zero, which means we cannot confidently say that Type of fish feed Granular impacts the independent variable. More precisely the null hypothesis that the coefficient of Type of fish feed Granular zero in the population is not rejected.

If the value of the variable Type of fish feed Extruded changes by one unit, the value of the variable Feed costs changes by - 0.225 units. The p-value is 0.716, indicating that this coefficient is not statistically significantly different from zero, which means we cannot confidently say that Type of fish feed Extruded impacts the independent variable. More precisely the null hypothesis that the coefficient of Type of fish feed Extruded is zero in the population is not rejected.

If the value of the variable Type of fish feed Grains changes by one unit, the value of the variable Feed costs changes by - 0.015 units. The p-value is 0.976, indicating that this coefficient is not statistically significantly different from zero, which means we cannot confidently say that Type of fish feed Grains impacts the independent variable. More precisely the null hypothesis that the coefficient of Type of fish feed Grains is zero in the population is not rejected. When all dependent variables are equal to zero, the value of the variable Feed costs is 0.525.

The standardized coefficients betas are independent of the measured variable and are always between -1 and 1. The larger the amount of beta, the greater the contribution of the respective dependent variable to explain the independent variable Feed cost. In this model, the variable Type of fish feed Extruded has the greatest influence on the Feed costs. A scatter diagram shows the points (Xi, Yj) on a rectangular coordinate system. Figure 2 shows a Scatter diagram of fish feed.

The calculated regression coefficients refer to the sample used for the calculation of the regression analysis; therefore, it is of interest whether the individual coefficients only deviate from zero by chance or whether they also deviate from zero in the population. To test this, the null hypothesis was made for each coefficient that was equal to zero in the population. The standard error now indicates how much the respective coefficient will scatter on average when the regression analysis is calculated for a further sample. The test statistic t is then calculated from the standard error and the coefficient. scatter diagram of the two variables can be plotted. Figure 3 shows Pareto diagram of standardized effects.

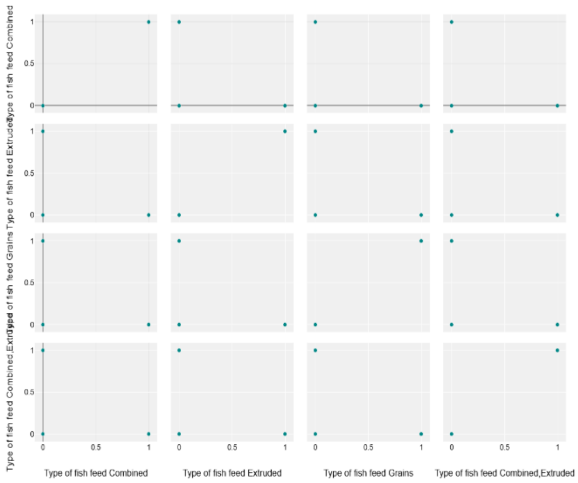
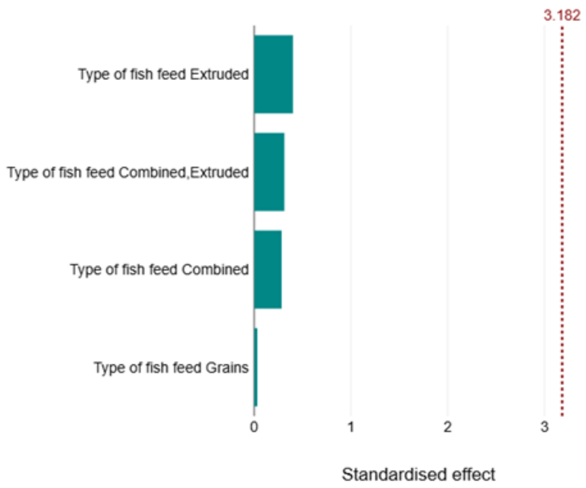


Fig.2 Scatter diagram of fish feed.



Note: p-value=0.5.

Fig.3 Pareto diagram of standardized effects.

IV. CONCLUSIONS

Analysing feed efficiency and identifying the most cost-effective feeding strategies are critical aspects of aquaculture, as they play a pivotal role in promoting the sustainable development of aquaculture. Mathematical optimisation tools, such as optimal control models, are needed to determine the optimal choice of growth factor, e.g., dose rate, throughout the growth cycle. They have been used in several aquaculture systems and are considered time-dependent due to their flexibility and simplicity.

In aquaculture, rationing can have both economic and environmental consequences, as any inefficiency in feed use can increase production costs and exacerbate negative externalities associated with feed consumption [21;22;23;24]. Excess feed can increase waste, leading to higher environmental impacts and loss of financial resources, while insufficient feed supply can reduce the digestive efficiency of fish due to feed competition and quantity imbalances [25]. From a productivity point of view, the ideal feed ration promotes optimal growth and feed conversion ratio (FCR).

Optimizing feed composition and feeding practices can lead to better growth performance and health in farmed fish, ultimately contributing to more sustainable aquaculture systems. The integration of sustainability into fish feed production also requires a comprehensive understanding of the nutritional needs of fish and the environmental impacts of various feed ingredients. The study confirmed that dependent variable Type of fish feed Extruded has the greatest influence on the independent variable Feed costs.

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