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IMPACT OF THE WATER TEMPERATURE INCREASE IN THE DOSPAT DAM ON THE KEY INDICATORS CHARACTERIZING AQUACULTURE EFFICIENCY

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Abstract

Climate change is among the main challenges for achieving sustainable development of aquaculture. It is likely to cause changes in the temperature and hydrological regimes of inland waters. Air temperatures in the region of Dospat Dam have been rising over the past 15 years. This impacts the water temperature in the dam and on rainbow trout (*Oncorhynchus mykiss*) farming in it. The average water temperatures measured in the surface layer in the 1970s (10.18 ±6.79 °C), and the 1980s (10.16 ±7.07 °C) were lower than the ones today (12.40 ±7.12 °C). Higher summer temperatures of the water in the dam have an unfavourable impact on the key biological indicators which determine the aquaculture efficiency, such as fish growth (*AG*, g), survival rate of fish (*SR*, %) and feed conversion ratio (*FCR*). The water temperatures in July and August are above 18–20 °C. This period is marked by the lowest fish growth and the lowest survival rate of fish. At the same time, feed conversion ratio is 3.3:1 which is higher than recommended in feed charts and it is economically inefficient. Global warming is likely to have a negative impact on the development of cold-water aquaculture in Bulgaria. It will result in a longer production cycle and higher costs.

Key words: climate change, rainbow trout, feed conversion ratio, fish growth, survival rate.

Introduction

The importance of aquaculture for ensuring high-quality nutritional protein has been on the increase over the past decades. It was estimated that by 2030 over 62 % of the fish consumed will come from aquaculture (Kobayashi et al. 2015). The most widely farmed cold-water species in the world over the past 10 years has been rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) (Sae-Lim et al. 2015, Zhelyazkov 2015, Singh et al. 2016). The species is of major economic importance in Bulgaria and has good market potential.

The adverse impact of climate change and the increase of water temperature may have a negative effect on fish farming in temperate climate zones, including Bulgaria (De Silva and Soto 2009). According to United Nations Economic Commission for Europe (2017), in Bulgaria the vulnerability to the expected changes in rainfall is highest in the sectors of tourism, agriculture and aquaculture.

Aquaculture production process is based on the interaction of the species biological requirements with the environmental variables and the economic environment in which it is implemented. The major biological parameters which characterize aquaculture efficiency are fish growth (*AG*, g), survival rate (*SR*, %) and feed conversion ratio (*FCR*) (Noble et al. 2012, Sae-Lim 2013, Besson et al. 2016, Janssen et al. 2017). From an economic point of view, fish growth and survival rates are the major factors affecting revenue, costs of feed and fingerlings for stocking. The feed intake affects mainly feeding costs.

Physiological and biochemical processes of fish are directly related to water temperature (Jobling and Baardvik 1994). Fish growth mainly depends on water temperature, the amount of dissolved oxygen in it and the daily feed intake (Muradian 2016).

Rainbow trout can survive in water temperatures of 0–27 °C, but a narrower range 9–14 °C is required for the normal functioning of its physiological processes. At temperatures of 7–18 °C the appetite is optimal (Woynarovich et al. 2011). At higher temperatures, cold-water species demand more energy to maintain the metabolism, which reduces their growth rate. The impact of global warming and temperature increase on freshwater fish varies based on the season (Morgan et al. 2001). Although temperature increase in winter may be beneficial for the trout growth, temperatures of 18–23 °C in summer are moderately challenging for the survival of the species but ones of 25–28 °C are considered crucial (Rebl et al. 2020). When the temperatures exceed 20 °C, the digestive system of rainbow trout does not use the nutrients fully and most of the feed consumed is only partially utilized (Fornshell and Hinshaw 2008). This results in a higher *FCR* in summer, which is often economically inefficient. Feed intake and digestion may slow down or stop at low water temperatures (Belkovskiy et al. 1991, Hubert and Chamberlain 1996). The lowest temperature at which species growth has been recorded is 3 °C (Fornshell and Hinshaw 2008). According to FAO (2005–2021), the optimal water temperature for intensive rainbow trout aquaculture is below 21 °C.

Rising water temperature in summer may affect water quality in dams, resulting in harmful algal blooms and problems with the level of dissolved oxygen (Fischlin et al. 2007, Bates et al. 2008). There are other production parameters (e.g. rearing density in cages, change of batches) affecting the profitability of the farm also dependent on the temperature regime and growth potential of the fish (Besson et al. 2017). Some diseases (e.g. furunculosis) affecting salmonids are likely to become more prevalent at higher temperatures (Marcos-Lopez et al. 2010, Kibria et al. 2017). One of the frequent problems in cold-water aquaculture in summer is heat stress. The elevation of cortisol as stress-respond in fish may suppress their immune function (Bonga 1997, Mommsen et al. 1999, Webster et al. 2020, Islam et al. 2021), affect growth (Bernier and Peter 2001) and survival rate (Barton and Iwama 1991, Huang et al. 2018). The heat shock response in rainbow trout arises at 21 °C (Shi et al. 2015, ZhiCheng et al. 2019).

Forecasted temperature changes are expected to increase economic uncertainty in aquaculture because ecological problems result in higher production costs for the farm (Bethke 2015, Cubillo et al. 2021). The impact of climate change on cultured rainbow trout is poorly known in Europe and the risk assessment for this species is still challenging (CERES 2017).

The aim of the present study is to establish if the water temperature in Dospat Dam fluctuates over time and does it impact the major biological indicators in rainbow trout cage aquafarm.

Material and Methods

The study was conducted between 2017 and 2019 in the largest aquafarm in Bulgaria situated in the waters of Dospat Dam. The farm covers an area of 3.5 ha with 150 floating net cages in which rainbow trout is reared. Fingerlings (5–20 g) are stocked in spring and summer. The production cycle is all year round and continues until the fish reach harvest weight. Rainbow trout market size in Bulgaria is 300–400 g. Feeding is carried out twice a day by hand using quality extruded feed with high protein content (>40 %). The daily feed ratio determining is according to recommended feeding levels of the feed producers and depends on the fish weight and the daily water temperature.

Dospat Dam was built in 1969 on the Dospatska river in the Western Rhodope Mountains. It is situated at 1200 m a.s.l. and covers an area of 18.3 km^2 (41°39’40”N 24°09’05”E). The length of the dam is 19 km and its average width is 3 km. Its flooded area is 22 km^2. The catchment area covers 432.30 km^2, the average annual flow is 249.07 million m^3, the fill volume is 449.22 million m^3 and the usable volume is 447.13 million m^3 (National Electricity Company 2021). The height of the wall from the base is 60 m and the average depth where the cage farm is situated is 35 m. The climate in the region is mountainous with a strong Mediterranean influence. The average year-round air temperature is 9–13 °C. Springs arrive later, summers are cool and wet, and autumns – long and warm. Winter temperatures remain below 0 °C, which results in long-lasting snow cover.

To establish the change of water temperature in the dam, literature data for the temperatures in two periods 1970–1978 (Zhivkov 1987) and 1980–1982 (Boyadzhiev 2007) was used. The third period of study is between 2011 and 2019 when the water temperature was measured at every meter of depth from the surface layer up to 20 m of depth. The majority of the measurements were taken near the cages using combined dissolved oxygen meters (WTW Oxi 1970i and FiveGo/F4).

We used the Julian calendar for operational planning purposes in the aquaculture. We divided the seasons of the year by weeks: spring – weeks 12–24, summer – weeks 25–37, autumn – weeks 38–50 and winter – weeks 51–11 of the year. The weeks are numbered from 1 to 52 for the first year and from 53 to 104 for the second one because the production cycle usually covers two years’ period.

The growth performance of two batches of fish was studied in the period 2017–2019. They were divided into groups according to the season of fingerlings stocking the cages – stocked in spring and stocked in summer. Fifteen cages were chosen for the study, in which the growth rate, average individual weight, and survival rate of the same fish were traced from initial stocking until harvest at 300–400 g (Table 1).

Table 1. Data of the cages used in the research.

No cage	Initial body weight, g	Number of fish	Year of stocking
	Spring stocking		
I	5.8	80,000	2018
II	5.8	76,480	2018
III	6.2	81,597	2018
IV	5.9	90,832	2018
V	5.5	71,445	2018
VI	5.5	71,237	2018
VII	7.7	31,402	2018
VIII	5.0	115,200	2017
	Summer stocking		
I	10.4	52,730	2018
II	10.8	52,300	2018
III	12	55,016	2018
IV	12	36,400	2018
V	10	36,600	2018
VI	10	36,500	2018
VII	13	47,000	2018

We examined the growth performance of the fish stocked in spring separately from the ones stocked in summer. The control measurements of the fish cages stocked in spring were taken in the following weeks: 16, 21, 22, 27, 31, 36, 42, and 47, and of the fish cages stocked in summer: 25, 28, 37, 38, 42 and 47. A Pentair VAKI Fish Pump, which is a fish sorting machine with digital software control, was used to measure the weight and number of the fish in each cage. The custom VAKI software counts and measures, with accuracy over 99%, fish weighting between 0.1 g and 800 g.

Fish absolute growth (*AG*, g) was calculated using the formula (1) (Busacker et al. 1990):

$$AG = Y_2 - Y_1, \tag{1}$$

where: Y_1 is initial fish weight, g; Y_2 is final fish weight, g.

The extent of the survival rate (*SR*, %) within the study period was calculated using the formula (2):

$$SR = \frac{N_F}{N_I} \cdot 100\,, \tag{2}$$

where: N_F is number of fish at the end of the period; N_I is number of fishes at the beginning of the period.

The feed conversion ratio (*FCR*) was calculated using the formula (3) (Okumuş et al. 1999):

$$FCR = \frac{FC}{A_2 - A_1}\,, \tag{3}$$

where: *FC* is feed consumption, kg; A_1 is total fish weight at beginning of the period, g; A_2 is total fish weight at end of the period, g.

Descriptive analysis was used to determine the mean value and the standard deviation of the water temperature values. We used correlation analysis to determine the impact of water temperature on fish growth. The one-way analysis of variance (ANOVA) was applied to compare the change in fish weight by weeks. Linear regression was used for estimation of the impact of water temperature on the fish growth rate, survival rate and *FCR*, in which the dependent variables were the parameters determined and the independent variable was the water temperature. The correlation between the fish growth and the quantity of feed was estimated on log-transformed data. The statistical analyses were performed by using the MS Excel and the PAST software (Hammer et al. 2001).

Results and Discussion

Water temperature

The average annual water temperatures measured in the surface layer of the dam in the first (10.2 °C) and second period (10.2 °C) were lower than the ones in the third period (12.4 °C) (Fig. 1). The coldest month for the three periods is in February (1.9 ±1.19 °C), while the hottest ones are in July and August (20.5 ±1.59 °C).

From 1970 to 1982 water temperatures did not exceed 20 °C but in the last 10 years, the temperature in August was higher than 22 °C. Over a period of the last 40–50 years, the average monthly water temperatures have increased by 2 to 3 °C (Fig. 1).

Water temperatures are favourable for rearing farmed rainbow trout from the second half of March until the beginning of July as well as from the beginning of September until the beginning of January. In this period, temperatures were within the tolerance range of the species -4–20 °C. Water temperatures in July and August were above 20 °C, which is associated with a higher risk of adverse effects during rearing. Water temperatures fall below 4 °C from the middle of January until the middle of March and feeding may be discontinued.

Comparing with the results of Boyadzhiev (2007), rearing period of rainbow trout in the Dospat Dam is reduced from 9 to 8 months. At water temperatures of 5–15 °C, rainbow trout reach 250–500 g for 2.5–4.5 months (Woynarovich et al. 2011). However, as water temperatures in Dospat Dam vary quite broadly (2–22.3 °C), several periods fall outside the species' optimum range. In such conditions fingerlings (5 g) need about 12 months to reach a weight of 350 g. A longer production cycle results in higher costs. The present study confirms the predictions of declines in trout habitat of over 50 % given the projected climate warming scenarios (Hartman and Porto 2014, Vinnå et al. 2021).

Impact of water temperature on fish growth

Over the entire rearing period 2017–2019, there has been a weak negative correlation between temperature and growth rate (r = -0.15, p = 0.02). Fish growth decreases with the increase of temperature

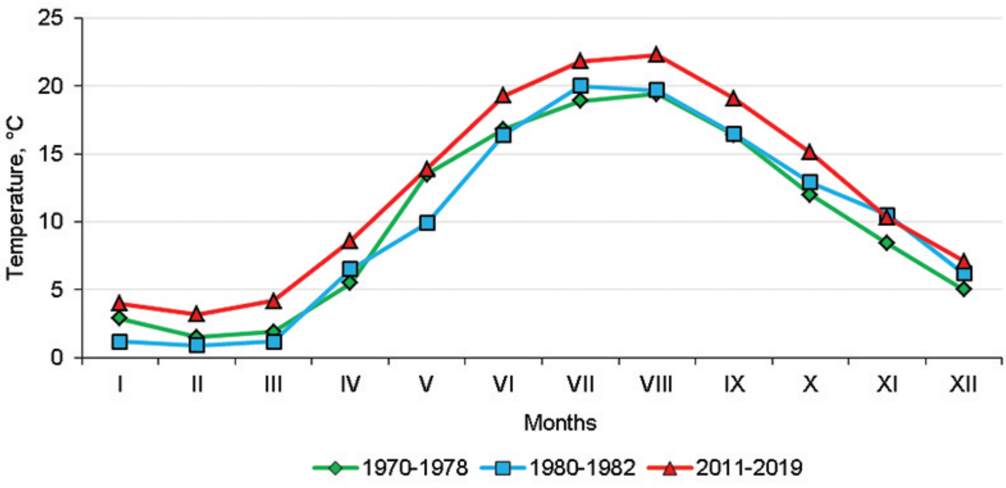


Fig. 1. Dynamics of water temperature in the period 1970–2019.

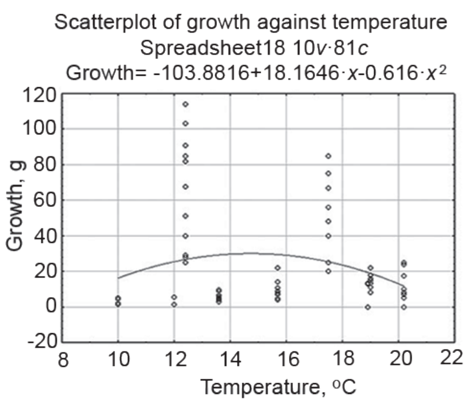
(Fig. 2). Two peaks of high absolute fish growth are formed at water temperatures of 12.4 °C and 16 °C, but beyond this temperature range, growth rates gradually decrease.

There is a weak negative correlation (r = -0.06, p = 0.58) between temperature and absolute fish growth in the cages stocked in spring, but it is statistically insignificant. However, if we compare the absolute fish growth mean values of the fish stocked in spring by weeks, there is a reliable difference between them (F = 8.529, p = 0.0091) (Fig. 3a). A strong negative correlation (r = -0.69, p < 0.0001) was found between temperature and growth of the fish in the cages stocked in summer (Fig. 3b).

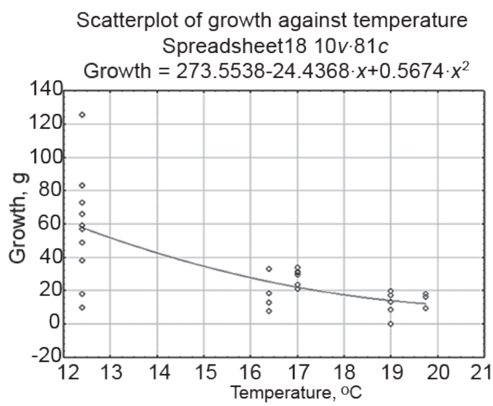
Following the course of the change in water temperature during the seasons, the fish go through the same water temperatures twice a year – once when the water warms up in the spring and a second time when it cools down in the autumn. In spring, the cages were stocked in week 16 when the water temperature was 10 °C, and by week 20 it was already 13.5 °C. Contrary to the expected fish growth peak at 12.4 °C, such did not occur at the moment of reaching that temperature (Fig. 3a). The likely reason for the different growth rates at identical temperatures in spring and autumn was the weight of the fish at those particular moments. In rainbow trout weighing ≤25 g the period of slow growth (hyperplasia) predominates and the period of fast growth (hypertrophy) increases with fish weight (Rowlerson and Veggetti 2001, Dumas et al. 2007).

Low fish growth during the first weeks after the spring stocking of fish can be anticipated, because at that moment rainbow trout weight was 5.93 ±0.12 g on average, being in a period of slow growth. At the same temperature in the autumn, the average weight is already between 96.5 and 162.3 g and the fish have entered a period of rapid growth and hyperplasia weakens for an account of hypertrophy (Dumas et al. 2007).

During the periods of the highest temperatures (weeks 31–35) there are cages with 'loss of weight' (Fig. 3a). Some authors (Uysal and Alpbas 2002, Borchel et al. 2014) also establish that the species' weight gain is reduced at temperatures

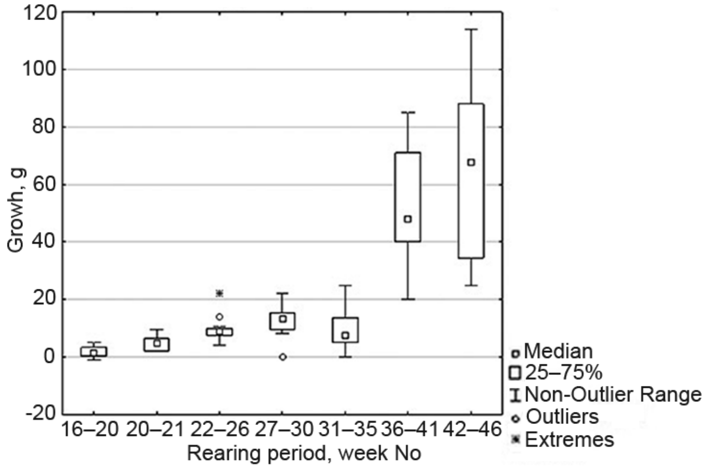


(a)

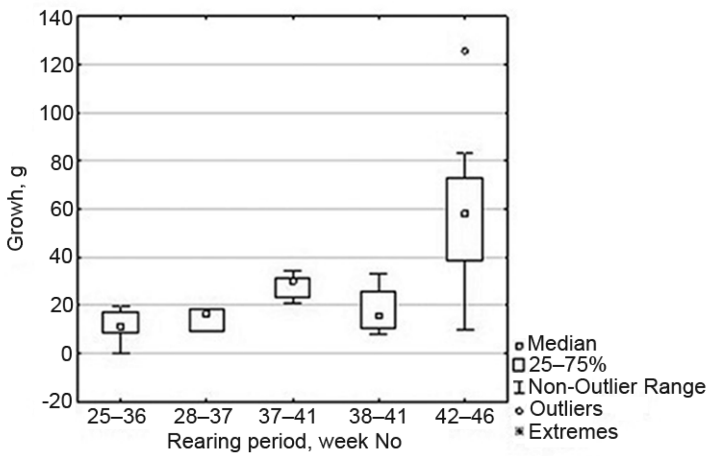


(b)

Fig. 2. Distribution of absolute fish growth in spring stocked group (a) and in summer stocked group (b) depending on water temperature.



(a)



(b)

Fig. 3. Growth of spring (a) and summer (b) stocked fish in different weeks of rearing.

above 22 °C. Reduced growth may be explained by the fact that the increase of temperature leads to increased metabolic costs for rainbow trout, as a result of which they have less energy left for growth (Hartman and Porto 2014). The highest absolute growth (65.27 ±30.61 g) in the fish stocked in spring was measured in autumn between weeks 42 and 46 at an average water temperature of 12.4 °C.

Temperature is the main controlling factor affecting fish growth in the cages stocked in summer. The absolute growth of the fish differs significantly by weeks (F = 11.89, p = 0.0011). The highest growth rate (57.89 ±33.07 g) is between weeks 41 and 47 at a temperature of 12.4 °C, and the lowest (10.63 ±9.0 g) – between weeks 25 and 37 at a temperature of 20 °C (Fig. 3b). In the same period, there were also cages in which no increase but even decrease of fish weight was registered. It seems that the high water temperature in July and August slows down the growth of rainbow trout.

Comparing the growth performance of the fish stocked in spring and summer, it was evidently similar. In spring, the cages were stocked in week 16 when the water temperature was 10 °C, and by week 20 it was already 13.5 °C. Contrary to the expected growth rate peak at 12.4 °C, such did not occur at the moment of reaching that temperature (1.99 ±2.48 g). The possible reason for the different growth rates at identical temperatures in spring and autumn was the weight of the fish at those particular moments. Low fish growth during the first weeks after the spring stocking of fish can be anticipated, because at that moment rainbow trout weigh 5.93 ±0.12 g on average, and hence undergo a period of slow growth.

Both the fingerlings stocked in spring and those in summer display the lowest growth between weeks 26 and 36 when the water temperature is above 20 °C. Up to week 31 growth is commensurate with the quantity of feed intake. Afterwards fish growth declines regardless of the feed quantity offered.

Impact of water temperature on survival rate of fish

A significant negative correlation exists between the temperature and the fish survival rate (r = - 0.52, p = 0.0053) (Fig. 4).

The survival rate was highest (94.6%) at water temperatures between 12 and 15°C. At temperature exceeds 18 °C, survival rates decreased. The lowest survival rates (37.9 %) were measured at temperatures of 20–20.5 °C, probably as a result of heat stress. The survival rate of fish in the cages at the temperatures of the winter months was higher than those in summer, so higher temperatures probably affect rearing rainbow trout much more than low temperatures in winter (Fig. 4).

Hence, we may suggest that the ‘loss of weight’ of the fish and their lower survival rate observed in summer in Dospat Dam were due to heat stress causing protein denaturation in the cells, which is closely related to cellular responses to hyperthermia.

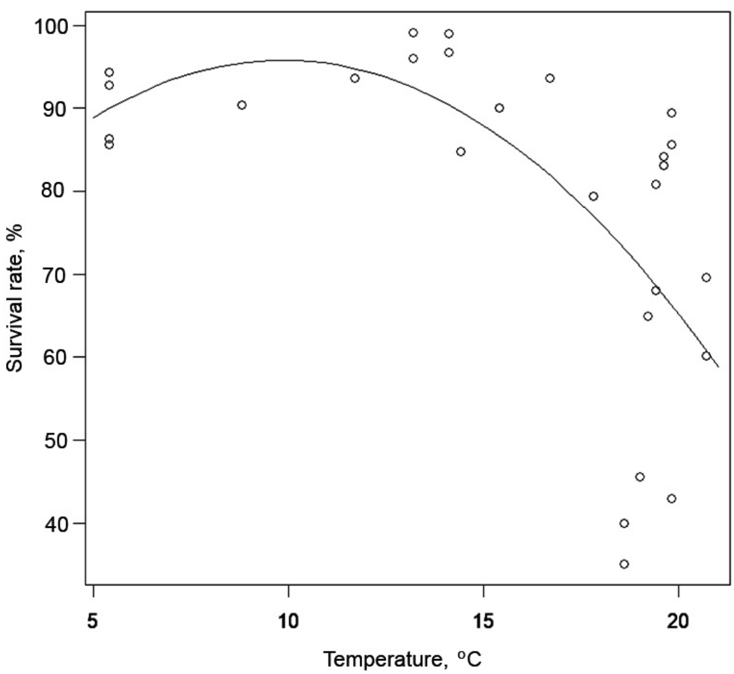


Fig. 4. Distribution of fish survival rate depending on water temperature.

Impact of water temperature on feed conversion ratio (*FCR*)

A moderate negative correlation with a high degree of reliability existed between the water temperature and the *FCR* (r = -0.55, p < 0.00001). The average feed conversion ratio calculated for the farm was 1.9:1 and it fluctuates during the different seasons and rearing periods (Table 2).

The *FCR* in weeks between 31 and 35 was 3.3:1, which exceeded the stand-

Table 2. Feed conversion ratio (*FCR*) in different periods of fish rearing.

Rearing period, No week	Water temperature, average °C ±SD	*FCR* ±SD
22–26	16.7 ±1.93	2.26 ±1.06
27–30	20.2 ±0.51	1.30 ±0.36
31–35	21 ±0.36	3.30 ±2.35
36–41	17.5 ±2.11	1.36 ±0.52

Note: the data are collected from spring and summer stocked cages.

ard values for the rainbow trout (1.0–2.0). The high feed conversion ratio results in higher costs for obtaining a unit of yield, which reduces production efficiency. In comparison, a net cage fish farm in the Almus Dam in Turkey reports *FCR* of 1.63 in summer and autumn at temperatures of 17.6–19.8 °C during the study period (Kayim et al. 2007). Another similar study calculates *FCR* as 1.57 (Rad and Koksal 2001). The combined data for spring and summer stocked fish batches show that despite the high quantity of feed used in the summer months, the weight gain of fish decreases during this period (Fig. 5).

The study of Hartman and Porto (2014) also established decreasing feeding efficiency from 1.03 at 20 °C to 1.3 at 22 °C. It may be explained by the fact that at water temperatures above 18–20 °C the proteins that make up the enzymes begin to inactivate, thereby inhibiting the metabolism of fish (Stevenson 1987).

In the conditions of Dospat Dam, a high cost of feed per kilogram of growth is probably due to a lower energetic efficiency of feed, used during the periods of high summer temperatures. Another reason for the high *FCR* during those weeks might be the lower fish survival rate than it is planned in feeding process of the farm.

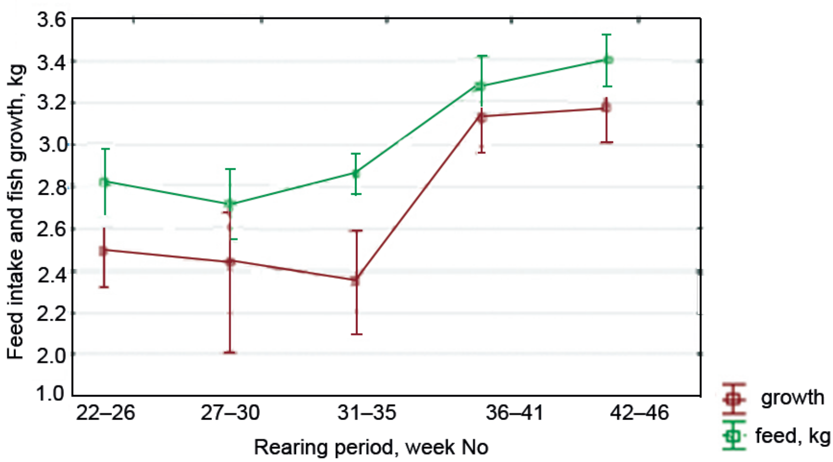


Fig. 5. Combined data of spring and summer batches of feed intake and weight gain of fish by weeks.

Conclusion

Climate change and rising water temperature, particularly during the summer months, in Dospat Dam has an adverse effect on the three main indicators characterizing the production efficiency of rainbow trout aquaculture. The absolute growth and the survival rate of fish are the lowest in July and August, when the water temperatures are above 18 °C. Low feed efficiency in these months leads to higher production costs. In the increasingly warmer climate, the all-year round farming of cold-water species such as rainbow trout in the Dospat Dam is becoming harder and risky.

In the future, the year-round use Dospat Dam for cold-water aquaculture needs could continue if the possibilities of biotechnology and selective breeding programs are used to create more temperature-resistant rainbow trout strains. Another possibility is breeding economically valuable fish species in the dam, adapted to warmer water during the warmer months of the year but more research is needed.

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