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Optimization of the depth of the cages in the Dospat Dam by studying two environmental limiting factors in the rearing of rainbow trout (*Oncorhynchus mykiss,* Walbaum, 1792)

Martina Stancheva

Wildlife Management Department, University of Forestry, 10 St. Kl. Ohridski Blvd., 1797 Sofia, Bulgaria. E-mail: martina_vas.nik@abv.bg

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Abstract

Aquaculture is one of the fastest growing livestock sectors for food production. In the future, sustainable and efficient development of this sector can be achieved only through a more rational use of resources. Optimization of the rearing process in rainbow trout (*Oncorhynchus mykiss*) cage farm, located in the Dospat Dam, by determining the optimal net cages depth, is an opportunity to reduce the costs for nets, save labour time for nets cleaning and reduce fish stress during the harvesting. The research of two environmental factors – water temperature (°C) and oxygen saturation (%) is important for the determination of the rainbow trout nets cage's depth. The results show that the longest period of the year with favourable conditions for the culture of the species in the dam is at a depth of 9 m. Here, water temperature and oxygen saturation are outside the optimal ranges for rainbow trout only in 11 weeks of the year, compared to 22 weeks at 1 m and 27 weeks at 20 m. Based on these results and taking into account the shape of the nets of the cages that are used in the aquafarm, the optimal depth of the rainbow trout nets in the Dospat Dam is 10 m.

Key words: aquaculture, water temperature, oxygen saturation, efficiency, costs.

Introduction

Rainbow trout (*Oncorhynchus mykiss*, Walbaum, 1792) is the most widely introduced and cultured cold-water species in the world (Singh et al. 2016, Zhelyazkov and Stratev 2019). In Bulgaria, rainbow trout is the main object of cold-water aquaculture, too (Stoyanova and Staykov 2017, Uzunova 2020). In the past 5 years, its production varies between 4000 and 5000 t annually.

Trout farming is growing and to reduce costs and continue the industry forward, research and management improvement are needed (Pucher et al. 2015, Craveiro et al. 2019). In Bulgaria breeding of trout species is concentrated mainly in the mountainous and semi-mountainous regions, as the most commonly used intensive production systems are raceways and net cages. The last one is more economically efficient (Sedgwick 1990, Stoyanova et al. 2016). The biggest rainbow trout cage aquafarm in Bulgaria is situated in the Dospat Dam.

A few economic analyses of farms that produce trout in cages shows that, the most important share of capital in the total assets are building-pool-cage and changing and maintaining the net cages (Karabulut et al. 2017, Myrli and Khawaja 2019). To reduce the costs and to ensure the economic efficiency of fish cages, it is important to determine the optimum submergence depth of them (Huang et al. 2008, Liu et al. 2019). It usually varies from 3 to 15 m (Salie et al. 2008, Yüngül et al. 2016, Dirican 2021). Transportation of fish from one facility to another causes stress to fish (Tacci et al. 2015). The deeper the cage is 20 m, the longer it takes fish to be hauled to the surface during the harvesting, resulting in fish drawing longer together into a confined space and causes it additional stress. It leads to negative effects (damage to fish health and meat quality) and economic losses (Stevenson 2007, Wu et al. 2021). On the other hand, the frequent changing of nets for on-shore cleaning is a capital- and labour-intensive process (Hodson et al. 1997). Costs and problems associated with mooring also increase with depth (Beveridge 2004). Determining the most appropriate depth for the cages in the Dospat Dam can lead to the optimization of the technological process and reduce the costs of the farm (Hadzhinikolova and Iliev 2011).

Rainbow trout occurrence in lakes and dams mostly depends on the dissolved oxygen and water temperature (Swales 2009). To define the depth of the net, it is necessary to establish its vertical distribution.

Water temperature (°C), oxygen saturation (%) and the amount of dissolved oxygen ($mg \cdot L^{-1}$) in the water are interrelated, and in general the saturation is a function of temperature. Using a stepwise linear regression model for randomly selected cages Stancheva (2021a) tested the effect of these factors on rainbow trout growth cultured in the Dospat Dam and established that the temperature and oxygen saturation has the greatest influence on it.

The optimal water temperature for rainbow trout is 12–18 °C (Purser and Forteath 2003). Growth rates are markedly reduced as the temperature is 4 °C (Hilton and Slinger 1981). The minimum temperature at which the growth of the species is reported is about 3 °C (Fornshell and Hinshaw 2009). At temperatures above 20 °C the digestive system does not use nutrients well and feed is only partially digested (Hinshaw 2000). High temperatures impaired the immunity, digestion, and growth of rainbow trout (Jiang et al. 2021).

For trout species, oxygen saturation is recommended to be over 70 % (Purser and Forteath 2003). There was no difference in growth or feed conversion ratio in the cultivation of rainbow trout in over-saturated water (180 %) with oxygen (Edsall and Smith 1990, Doulos and Kindschi 1990).

The present work aims to study the two most important environmental factors for rainbow trout rearing – water temperature and oxygen saturation in the different depth layers of the Dospat Dam and to determine the depth conditions that are favourable for culturing the species.

Materials and Methods

The study was conducted in the Dospat Dam (41°39’40” N and 24°09’05” E) which is situated in the Western Rhodopes

Mountains at 1200 m a.s.l. It was built on the Dospatska River in 1969 for the production of hydroelectrical power. Its flooded area is 22 m^2 and the catchment area is 432.30 km^2. Its length is 19 km and the average width is 1.3 m. The depth of the dam in some places exceeds 50 m. One of the largest farms for breeding rainbow trout in net cages in inland waters on the Balkan Peninsula is located in the dam. The aquafarm consists of over 150 cylinder shape with a conical base cages of 3 different diameters – 15 m, 22 m, and 30 m and its area is 3.5 ha. The cages are located in a 35 m area depth of the dam and the nets are at a depth between 15 and 20 m. Fish are grown from fingerlings (5 g) to market size (300–400 g). For the study period, the main chemical factors on which the welfare of rainbow trout depends (pH, ammonia, nitrates, sulphates, nitrogen, phosphorus, etc.) are within the permissible limits for the species. The water samples have been performed in licensed laboratories according to the respective standards.

To establish the water temperature regime and to determine the oxygen saturation of water in the Dospat Dam for the period 2017–2019, data from the aquafarm and personal reports were used (Table 1).

The measurements were made in the area of the cages 3 times a week in situ at each meter depth from 1 to 20 m. The values were reported with an electronic thermometer and combined oximeter FiveGo/F4. For the needs of aquafarm management, the results are present for weeks, and changing water temperature and oxygen saturation in depth was monitored at every 3 meters. The data for water temperature and oxygen saturation are averaged from 2017, 2018, and 2019, because no statistically significant difference ($\chi^2 = 2.229$, $p = 0.3279$) was found between their values in these years.

The obtained data were analyzed statistically using Microsoft Excel 2016 and Statistica 8.0 (Weiß 2007).

Results and Discussion

The water temperature in the Dospat Dam is outside the optimal range for rainbow trout for two periods of the year. During the winter (January–March), between the 2nd and 11th weeks, the average water temperature maintained below 4 °C (3.1 ±0.6°C, mean ±SD) in all depth layers from 1 to 20 m (Fig. 1). At these temperatures the digestion is delayed, due to which the consumption of feed with high protein content often causes severe liver damages to rainbow trout, which can lead to serious fish losses (Boyadzhiev 2011).

The second unfavourable period for species rearing is in the summer. The highest temperatures are between the 28th and 35th week of the year (Fig.1). Water temperature in these weeks in each meter depth up to 9 m exceeds 20 °C. The average temperature is 20.8 ±0.5 °C and the absolute water temperature maximum (22.9 °C) is recorded on 10.08.2019 at 1 m depth. Similar temperature values

Table 1. The number of measurements of water temperature and oxygen saturation in different depth layers of the Dospat Dam.

Depth, m	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Sample, n	224	224	224	165	162	162	162	162	162	162
Depth, m	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Sample, n	161	161	160	160	160	160	160	134	131	79

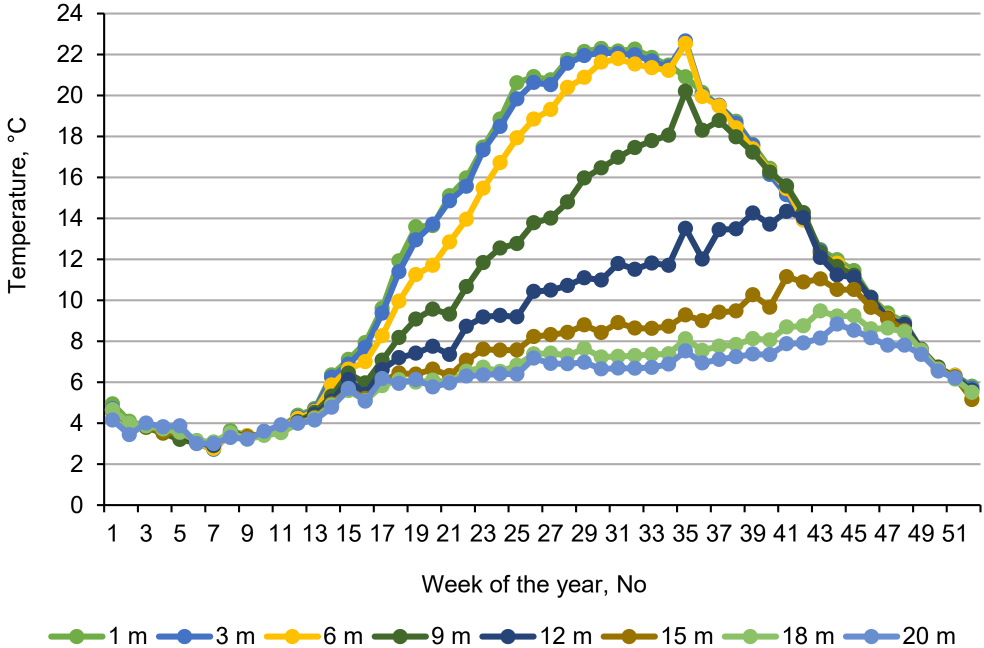
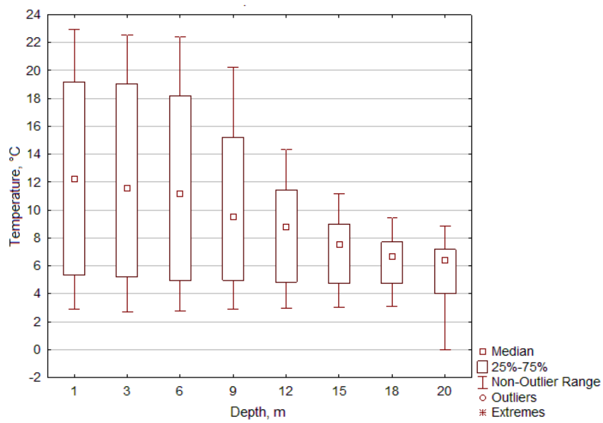


Fig. 1. Dynamics of water temperature in the Dospat Dam in different depth layers by weeks.

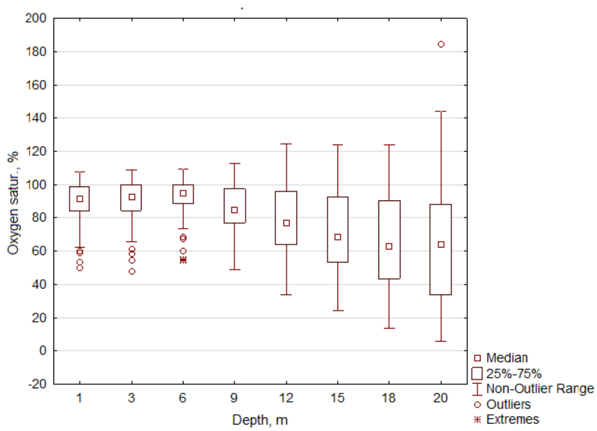
(22 °C and 23 °C) for the surface layer are reported respectively by Naumova and Zhivkov (1988) and Hadzhinikolova and Iliev (2011). High water temperatures in the Dospat Dam in July and August have a negative impact on the most important aquaculture efficiency parameters – fish growth, survival rate and feed conversion ratio (Stancheva 2021b).

The environment is a very important variable in aquaculture because it affects fish production and should be taken into account to make a reliable management decision (Casini et al. 2015). The analysis of the vertical dynamics of water temperature and oxygen saturation in different depth layers can be used as a tool to determine the most effective depth for rainbow trout cages in the Dospat Dam (Fig. 2a, b).

By going into depth water temperature decreases both in value and retention period (Fig. 2a). In the summer samples at a depth of 1 m, the average water temperature is 21.6 ±0.7 °C, which is above the temperature tolerance (21 °C) for rainbow trout farming, according to FAO (2023). These temperatures persist for 11 weeks (between the 25th and 36th week) at 1 m depth, and at 9 m the temperature is above 20 °C (20.2 °C) for only 1 week (35th week). Rainbow trout is highly susceptible to heat stress. It occurs when the water temperature exceeds 21 °C. The increase in temperatures may cause problems with the survival rate of fish and the occurrence of diseases due to a weakened immune system (Huang et al. 2018). For the entire study period, water temperatures above 20 °C were not measured in the depth layers between 12 m to 20 m.



a



b

Fig. 2. Dynamics of the two environmental limiting factors in different depth layers in Dospat Dam: a) Dynamics of water temperature, b) Dynamics of oxygen saturation.

Rainbow trout growth does not differ significantly when farmed at 92 % and 79.4 % saturation, a difference occurs at 52.1 % when growth performance and survival rates are significantly lower (Welker et al. 2019). The water oxygen saturation in the dam at depths up to 9 m throughout the year is 90.3 ±12.9 %, which is above the required minimum (70 %) (Purser and Forteath 2003) for rainbow trout farming (Fig. 2b). In most unfavourable weeks in terms of water temperature (between the 25th and 35th week), the saturation remains high (96.8 ±7.06 %), which is in the optimal range for the species. Below the recommended 70 %, but within the allowable limits (40 %) for the species, saturation falls to 61.1 ±5.41 % in the period between the 48th and 51st week. This confirms the data of Hadzhinikolova and Iliev (2011) that at a depth of up to 10 m, there is no problem with oxygen levels for rainbow trout farming.

After a depth of 9 m, the average values of both factors decrease. The water temperature is below the optimal range (12–18 °C) for rainbow trout, resulting in the reduction of daily feed intake and respectively fish growth. It leads to a longer farm production cycle and higher costs (Stancheva 2021b). Oxygen saturation of water also decreases as the lowest reported levels at 12 m (33.7 %) are below the minimum required (40 %) and reach the minimum 5.7 % at a depth of 20 m, resulting in hypoxia and fish death (Williams et al. 2019). These fluctuations in the water temperature and oxygen saturation after 9 m depth are probably due to the thermocline existing at a depth of 8–15 m (Hadzhinikolova and Iliev 2011).

On this basis, the most effective depth for the site of cages is determined, as well as the most risky periods for rearing trout in terms of environmental factors. The longest period with favourable conditions for breeding rainbow trout in the Dospat Dam is at a depth of 9 m (Fig. 3). At this depth,

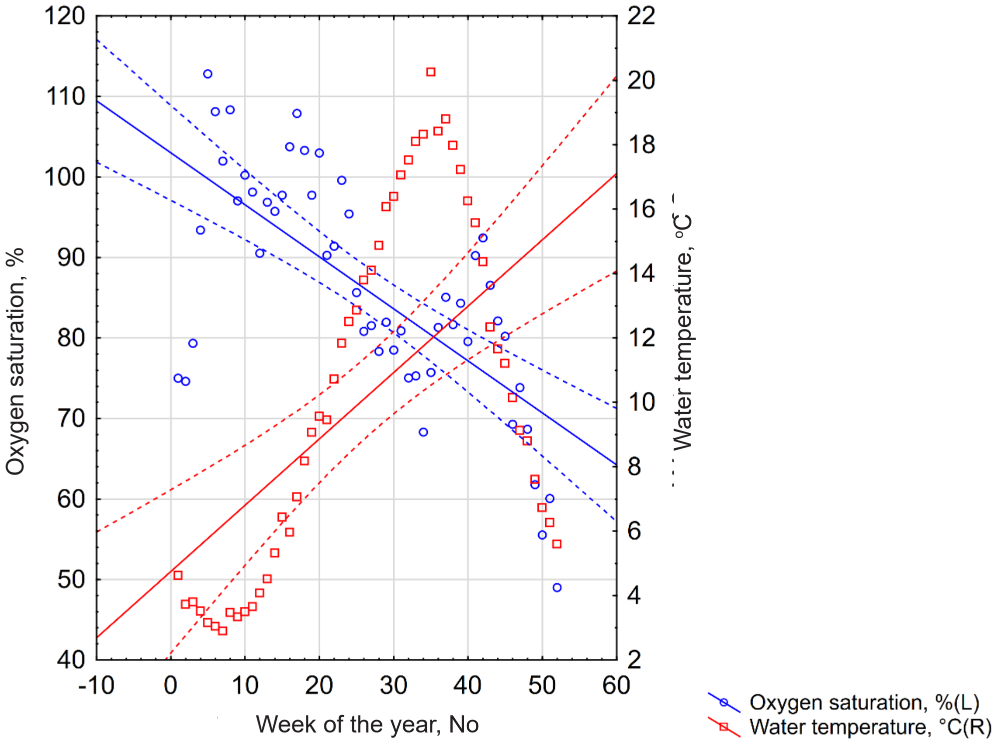


Fig. 3. Average values of water temperature and oxygen saturation at 9 m depth by weeks for the period 2017–2019.

the number of weeks in which the indicators do not meet the requirements of the trout is 11 weeks, for comparison, at 20 m they are 27 weeks, and at 1 m – 22 weeks. Water temperature and oxygen saturation are within the tolerance range for growing the species throughout the year at a depth of 9 m. Here, as in the other layers, temperatures are below 4 °C between the 2nd and 11th weeks, but the unfavourable summer period, with water temperatures above 20 °C, is only one week.

The results obtained apply to the entire water area of the dam, because according to Hadzhinikolova and Iliev (2011), there are no significant differences between the water indicators measured at different stations in the dam.

The technical efficiency of the aquafarm is related to the production technology (Farrel 1957, Brümmer et al. 2002). Optimizing the depth of the net cages will reduce the cost associated with this capital- and labour-intensive process. The cost of nets varies depending on the width of the mesh and the material that they are made of. For example, the cost of a 22 m diameter cage net used in the Dospat Dam, is about € 12 kg^{-1}, and the weight of such a net is approximately 250 kg, i.e. € 3000. For a cage with a diameter of 15 m, the price of the net is about € 2300. Reducing the depth of the cages, in addition to the price of the nets, also reduces the volume of nets that need to be cleaned. This is labour-intensive maintenance activity and it is time- and water-consuming, and the efficiency of living labour is expressed primarily by saving time (Piralkov 2003).

According to FAO (2015) the depth of cages should be no more than 40 up to 50 % of the cage diameter, i.e. 7.5 m depth for cages with a diameter of 15 m, 11 m for cages with a diameter of 22 m and 15 m for cages with diameter 30 m. The depth of the cages may depend on the net shapes, too. Cage net shapes may be cylindrical or conical. A cylindrical shape maximizes the volume of the cage. In our case, the nets have cylinder shape with a conical base (Oliveras 2003). To use the maximum volume of the base net in the optimum environmental conditions, we recommend the depth of the base net to be up to 9 m plus 1 m depth of the net cone base height. In the specific conditions of the Dospat Dam and the nets‘ shape that is used, the optimal depth of rainbow trout nets is 10 m. The nets should be not more than 12 m, because after that the conditions for rearing the species are unfavourable and risky. It also confirms Beveridge's thesis (Beveridge 1996) that a cage depth of 3–10 m would be acceptable for most species.

Conclusion

To develop sustainable aquaculture in the future, producers need to look for opportunities to optimize production, which will reduce costs and resource use. This can be achieved by adapting technological processes to the specific needs and conditions – environmental, economic, and technological. The research of the two main environmental factors for rainbow trout rearing and optimization of the cages' depth give an opportunity to improve the production technology and reduce the costs and labour intensity in the future farming of the species in the Dospat Dam.

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