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The Effects of a Fish Farming Scenario Using QUAL2E Modelling at Fırtına Creek (Black Sea Region)

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Abstract

In this study, a water quality model of Fırtına Creek was used as an evaluative tool to estimate the spatial distribution of several water quality related variables together with the nutrient loads that are transported to the Eastern Black Sea. Fırtına Creek is an important habitat within the Eastern Black Sea ecosystem due to the fact that it is the primary spawning area for Black Sea Trout (*Salmo trutta labrax*, Pallas 1811). It can also be considered as an important water resource because of its relatively high flow rate and the water quality, which indicates that the stream is still not seriously polluted. Studies performed in this river indicate that external activities along the Fırtına Creeks watershed (such as road construction and pollution from a hydroelectric dam construction) have led to various changes within the ecosystem. In this study, the possible effects of three additional fish farms with a production capacity of 50 tons, located on the Fırtına Creek within 1 km distance from each other were evaluated in terms of their effects on the streams water quality. QUAL2E was used as the water quality modelling and analysis tool. The water quality data gathered from various data sources and the model were used to estimate dissolved oxygen (DO), biological oxygen demand (BOD_5) and nutrients along the stream.

Key words: Mathematical modelling, nutrient loads, QUAL2E, Fırtına Creek, Eastern Black Sea

Introduction

Eutrophication and oxygen depletion are among the primary problems addressed in water quality studies. Depletion of dissolved oxygen and the stimulation of undesired aquatic growth due to excessive inputs of various nutrients may cause severe problems in water quality (Chapra, 1997). Nutrients within the water develop specifically from the application of fertilizers on agricultural land, forest areas, and urban surface run-off (Erturk *et al.*, 2004).

Mathematical modelling, which forms an integral part of the decision-making process for water resources management, has been in use since the late 1960s as a tool in environmental sciences. Models and simulations allow the rapid evaluation of pollution in terms of cause and effect relationships. The main advantage is that modelling enables analyses of different future scenarios in present time (Erturk, 2005). Therefore, model results can be considered as important inputs for the decision making process, because they provide the possibility to forecast the environmental effects of future investments and to optimize the environmental precautions.

Fırtına Creek in the Eastern Black Sea region has the widest watershed area among the other streams in its vicinity and is comprised of a combination of numerous small streams scattered around the skirts of Kaçkar Mountains (Figure 1). The main small streams feeding Fırtına are Durak, Hemsin, Hala, Polovit and Tunca. Fırtına Creek, 68 km in length, has the highest flow rate within the region due to the regional climate characteristics (Erturk and Sivri, 2005) and its relatively large watershed area.

Fırtına Creek is an important habitat within the Eastern Black Sea ecosystem due to the fact that it is the primary spawning area for Black Sea trout (*Salmo trutta labrax*, Pallas 1811). It can also be considered as an important water resource because of its relatively high flow rate and the water quality, which indicates that the stream is still not seriously polluted. However, recent studies related to Black Sea trout have insinuated a potential danger of extinction due to the distortion of spawning and migrating areas. These suggest that in order to preserve the natural spawning habitat of this species, measures to protect and support the reproduction of the Black Sea trout must be taken (Celikkale *et al.*, 1999).

Studies indicate that other pollutants coming from surrounding settlement and agricultural areas around Fırtına Creek, including chemical fertilizers from tea fields may lead to negative effects. Also, possible future negative effects may result from planned hydroelectric power tribunes (Aydin and Yandi, 2002). As a result, the trout entering into Fırtına Creek will face additional dangers from these tribunes as well. It is important to note that during the construction phase, the surrounding river beds, fauna, and flora will definitely be negatively influenced (Tabak *et al.*, 2002).

A common implication of the above mentioned studies is that the effects on the water being discharged from these newly constructed sites should

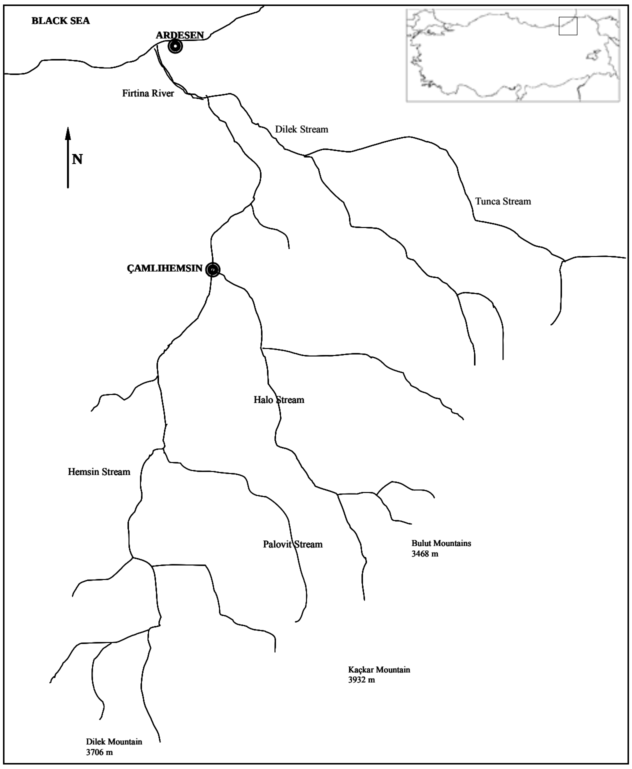

Figure 1. Location of Fırtına Creek.

be thoroughly investigated. Taking into consideration that the potential negative effects of these construction sites on the surrounding environmental ecosystem may lead to extinction of Black Sea trout, it is imperative that complexity of this issue should be taken seriously (Kurtoglu, 2005). Main aim of this study is to conduct a situational analysis and develop a basic water quality model using QUAL2E, while analyzing present effects. In addition, the model was used to analyze a scenario related to construction of three additional fish farming facilities with relatively high capacity.

Materials and Methods

Data Analysis

Two sets of data were collected for this study. The first set of data was collected first hand by the authors on site at Fırtına Creek via obtaining monthly samplings from the source, mid-point where the scenario is based, and the location of discharge. The second set of data was collected via previous studies in the area (Aydin and Yandi, 2002; Tabak *et al.*, 2002).

The average monthly flow rates, which were used for the QUAL2E simulations were calculated using the daily flow gauging data from State Hydraulic Works (Eruz *et al.*, 2005), which are given in Figure 2. According to this figure, Fırtına Creek has the highest flow rate among the other rivers discharging to Eastern Black Sea. Due to this high flow rate and relatively high slope, high current velocities are present in the Fırtına Creek.

During the spring season, high precipitation combined with snow melts because the observed peak flows in Figure 2. Monthly variations in water temperature, dissolved oxygen, BOD_5 and nitrate nitrogen are illustrated in Figures. Monthly water temperature varied from 4 to 18ºC (Figure 3), while dissolved oxygen concentrations were close to saturation concentrations throughout the year (Figure 4). Relatively low temperatures less than 20ºC even in the summer and high dissolved oxygen concentrations are favourable conditions for salmonid species. Low BOD_5 concentrations, as seen in Figure 4, indicate that Fırtına Creek is not heavily polluted by domestic wastewater and rural runoffs. The nitrate nitrogen concentration variations ranged between 1.5–3.5 mg/L (Figure 5). The variation of nitrate between the May-September intervals was fairly stable; however, the highest value of nitrate was observed in April as 3.5 mg/L (Figure 5). These high concentrations indicate the increase of nutrient loads into the stream because of two reasons. The first reason is the possible increase of inflows into the system after snowmelt. The second reason is related to increased fertilization during the growth reason of agricultural products (Sivri, 1999).

Model Selection

Water quality models have been developed during the past three decades. According to Jorgensen

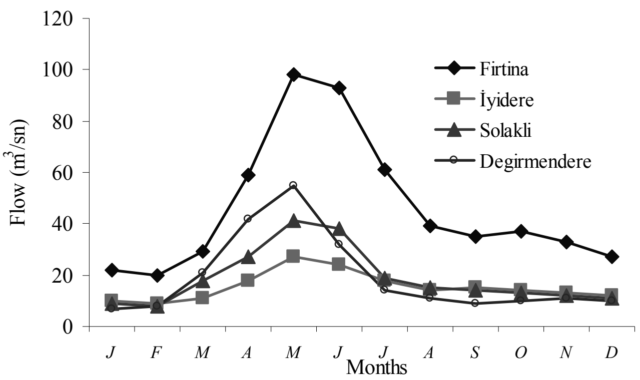

Figure 2. Monthly flow rates.

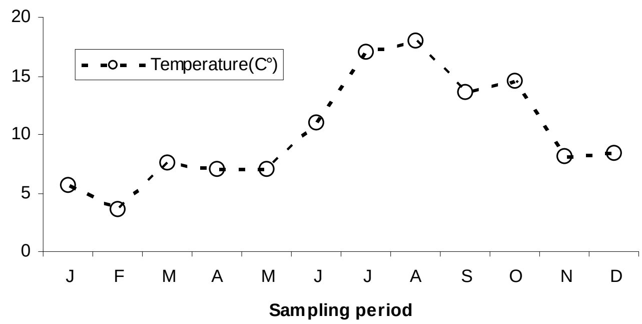

Figure 3. Monthly variation of water temperature.

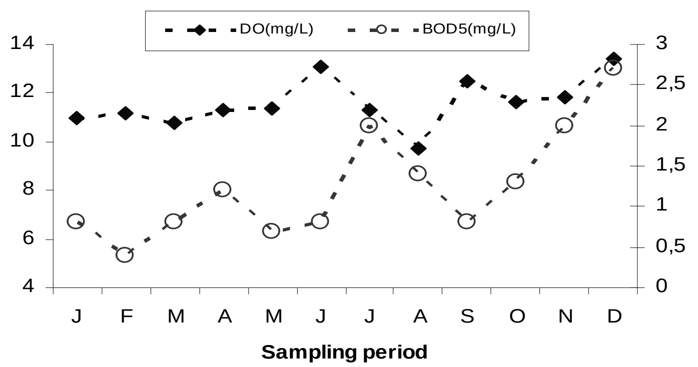

Figure 4. Monthly variation of dissolved oxygen and BOD_5**.**

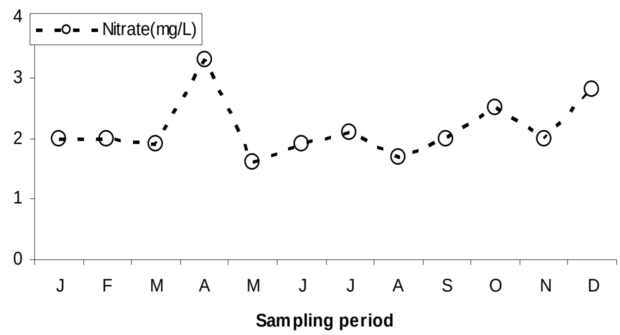

Figure 5. Monthly variation of nitrate.

(1999), more than 4000 ecological models have been used in aquatic ecosystem research and environmental management. QUAL2E/UNCAS (Brown and Barnwell, 1987), WASP (Ambrose *et al.*, 1993), CE-QUAL-RIV1 (Environmental Laborotory, 1995), CE-QUAL-W2 (Cole and Wells, 2002), and EPD-RIV1 (Martin and Wool, 2002) are some examples of widely used models, which have been applied to various streams in water quality studies and were found to be reliable; especially in nutrient modelling and Total Maximum Daily Load (TMDL) calculations. There are also modifications of QUAL2E, such as MODQUAL, QUAL2K and TMDL (Erturk *et al.*, 2004).

The Fırtına Creek is a small shallow creek with high current velocities where each cross-sectional segment is well mixed. Therefore, in using a one-dimensional transport model, Equation 1, where C is the concentration of a water quality constituent, A_x is the cross section area, V is the current velocity, S_c is the external load, D_L is the longitudinal dispersion coefficient and R represents all the water quality kinetics, is deemed appropriate.

$$\frac{\partial C}{\partial t} = \frac{1}{A_x}\frac{\partial}{\partial x}\left(A_x D_L \frac{\partial C}{\partial x}\right) - \frac{1}{A_x}\frac{(A_x V)}{\partial x} + \frac{S_c}{A_x \Delta x} + R \quad \text{Equation 1}$$

Equation 1 should be solved numerically to obtain spatial or temporal variations of water quality variables. Variations in flow rate and temperature within one month were found statistically not significant. Therefore, for this study, it was decided to solve Equation 1 for the steady state of each month instead of using a fully constructed dynamic model. For this study, dissolved oxygen, BOD_5 and forms of nitrogen (organic nitrogen, ammonium nitrogen and nitrate nitrogen) were primary variables of concern. Therefore, QUAL2E water quality model code simulating rate and transport of these variables were used.

QUAL2E can be run in steady-state and quasi-dynamic modes. In the quasi-dynamic mode, QUAL2E can simulate diurnal variations of water quality parameters; however, it cannot simulate the effect of dynamic loads and can only process steady-state river hydraulics. The model subdivides a river into reaches and computational elements, as shown in Figure 6. According to this model, the computational elements are assumed to be completely mixed (Brown and Barnwell, 1987). Several programming operations were required to integrate QUAL2E into the decision support system tools developed for this study.

The water quality constituent interactions are illustrated in Figure 7. Detailed information about QUAL2E kinetics can be found in reports of Brown and Barnwell (1987), Chapra (1997) and Lung (2001).

Model Inputs

The model inputs include the model network, geographic features of the watershed (such as location and elevation), meteorological properties, headwater and side flows (incrementing inflows), hydraulic and geometric properties of channels in the model network, estimated loads from the watershed and the model coefficients.

The model network composed of the main branch of the Fırtına Creek was modelled with QUAL2E, which consists of three reaches (5 km each) and 30 computational elements (500 m each)

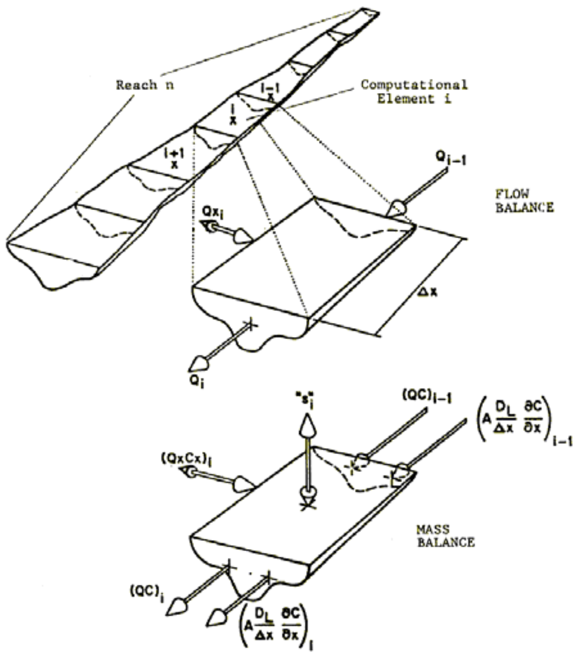

Figure 6. QUAL2E computational network.

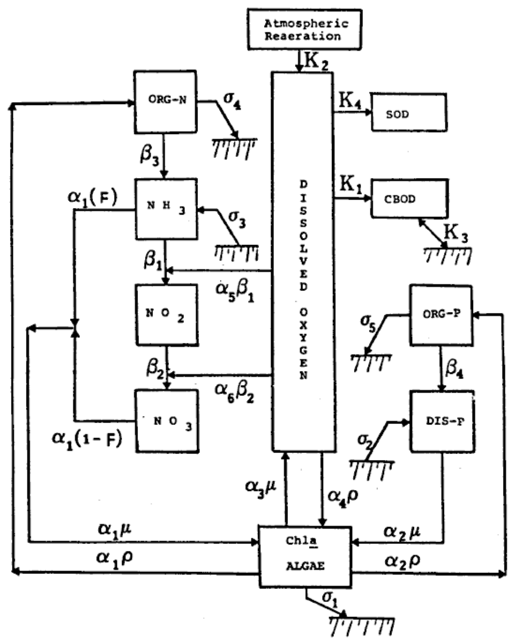

Figure 7. QUAL2E water quality constituent interactions.

(Figure 8). Geographical features of the watershed were extracted from the existing physical maps and monthly averaged meteorological parameters were used as meteorological input. As stated previously in the data analysis section, flows from State Hydraulic Works (DSI) were used to generate monthly flow related model inputs. Side flows were estimated by hydrological calculations and water budget analyses, which were then, checked with DSI flow data. Detailed calculations were made by Yenigun *et al.* (2005) to estimate point and diffuse pollution loads. Model coefficients were obtained by model calibration and verification explained in the following section. Input values for January are given at Table 1.

Model Calibration and Verification

The model was calibrated for the winter season and verified for the middle and late spring, when agricultural loads reach their maximum because of manure applications and relatively high surface runoffs. Model calibration for the winter is illustrated on Figure 9, 10 and 11. As seen from these Figures, QUAL2E reproduced the spatial distribution of the related water quality variables successfully.

Scenario Analyses for Fish Farming

It is a well known fact that there has been a reduction in *Salmo trutta labrax* stock in the Fırtına Creek (Aydin and Yandi, 2002; Tabak *et al.*, 2002). Several factors are responsible for this decline: creek species being anadromous, changing direction of water flow due to works along the creek basin, establishment of concrete structures along the basin, and recreational activities including white water rafting that negatively affects fish mobility. Cultured trout species that escape from current fish farms in the creek generate food competition and perdition among the slower growing species.

It is known that there are several fish farming facilities within the creek (URL 1). There have been various speculations about the possible effects of establishing the three fish farms, each of 50 ton capacity and located within 1 kilometre distance from each other. However, this is currently not permitted by the local government. Taking this information into consideration, suitable areas for fish farming were chosen from the map and a modelling scenario was created. Calculations were based on the following specifications: a farm of 150 tons capacity requires about 150-225 tons of feed with feed conservation ratio of 1.0-1.5. Fish feed contains 45% protein, 10% fat and about 20% carbohydrates. Waste loads were calculated according to these assumptions. In the study, bi-annual trout growth was aimed at 250 grams (Yildirim and Korkut, 2004).

For the scenario analysis, spring and summer seasons, which are more critical for water quality, were taken into consideration. During spring, Fırtına Creek receives most of its nutrient loads from agricultural areas and the summer may be a critical

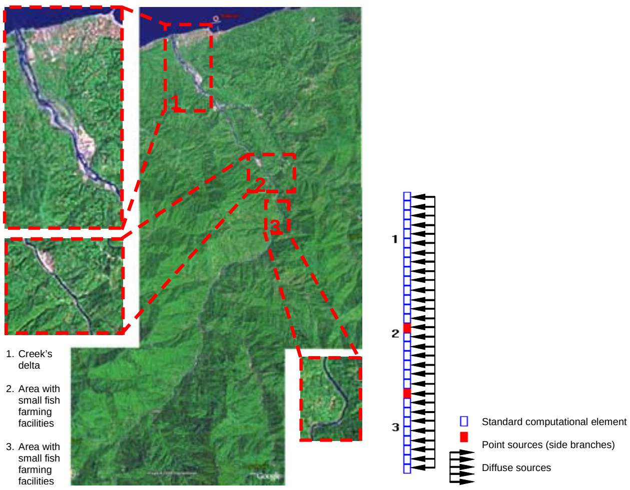

Figure 8. Model Network For Firtina Creek.

Table 1. Input values for January

Reach No	Reach Name	Begin River (km)	Total element	Manning Coef.	BOD Decay (1/day)	Reaeration coef.	O-N hydrolysis	NH_3 oxidation	Temp (°C)	DO (mg/L)	BOD_5 (mg/L)
1	Upper Firtina	15	10	0.2	0.3	1	0.1	0.3	5.3	12.4	0.8
2	Middle Firtina	10	10	0.2	0.3	1	0.1	0.3	5.3	12.4	0.8
3	Lower Firtina	5	10	0.02	0.3	0.5	0.1	0.3	7	11.9	0.8

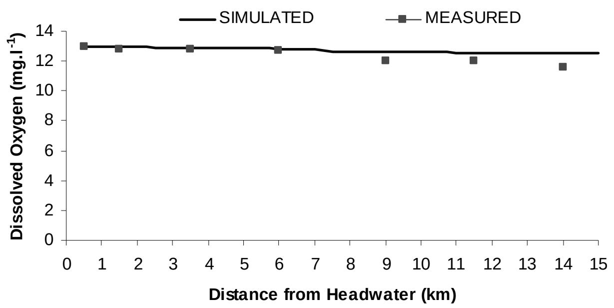

Figure 9. Model calibration for dissolved oxygen.

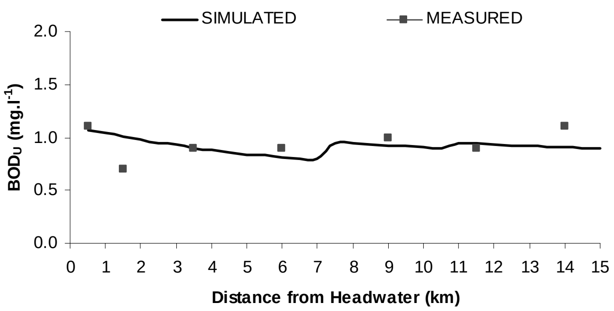

Figure 10. Model calibration for ultimate biological oxygen deman.

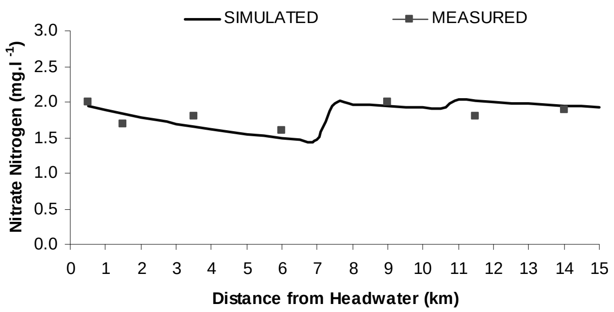

Figure 11. Model calibration for nitrate nitrogen.

season for the water quality due to temperature increase and decreased flow rates. Changes related to DO, BOD_5, temperature and nutrients are supported by the model findings (Figure 12).

Results and Discussion

The results obtained from the steady-state simulation indicate that additional fish farms of large capacities may have apparent effects on the Fırtına Creek, especially in decreased dissolved oxygen and increased biochemical oxygen demand and nutrient concentrations.

Construction of three 50 tons capacity trout farms located at 1 km distance from each other was analysed for the DO, BOD_5, and nutrient effects in Fırtına Creek. During the spring season, where the flow rate is high, the effects of agricultural loads were found to be more important than the loads resulting from existing establishments. However, it was found that Fırtına Creek could tolerate the effects of establishment loads due to high flow rates in the spring system.

Although the Fırtına Creek ecosystem can tolerate inputs during the spring and summer model (as shown in Figure 12 a and b), decreases in the creek's flow rate and increases in the temperature resulted in lower DO levels. The simulation results indicate that although potential establishments will not have observable and direct significant effects, their effects on the ecosystem are still expected to be noticeable.

Conclusion and Recommendations

Construction along the streams causes a

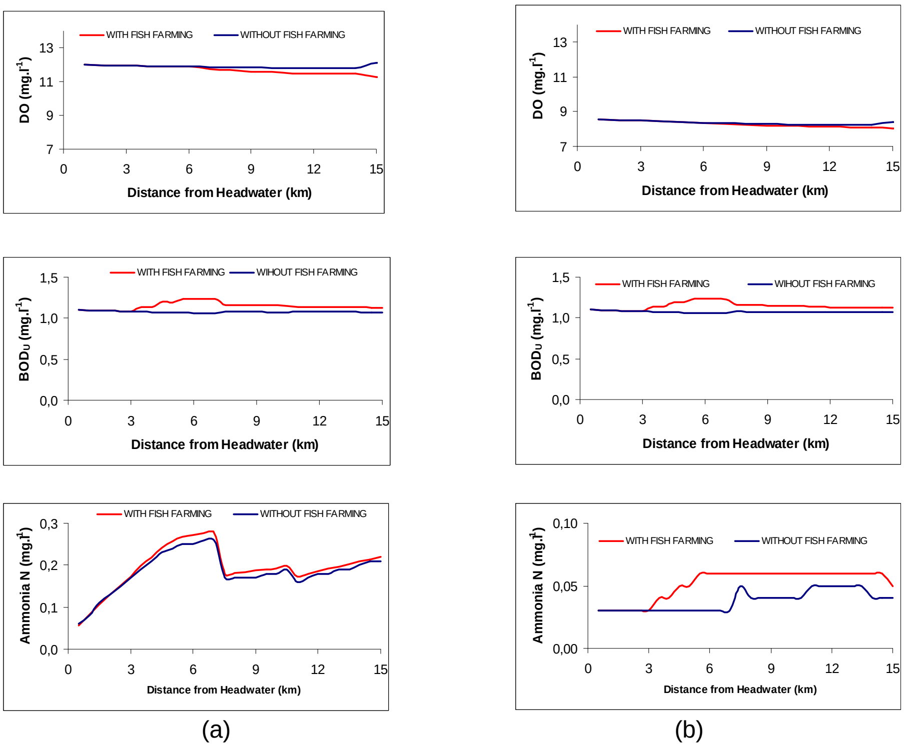

Figure 12. Simulation results for scenario analyses (a) for spring (b) for summer.

disruption in the water flow leading to the ecological balance, which may result in the sudden decreases of the natural fish population. For this reason, the protection of the natural species should be taken into consideration and a national fishing policy, regulations, and prohibitions should be defined. In addition, based on findings from the data, an evaluation of different ideas, protective measures, and a decision with multiple alternatives should be reached. This suggests and indicates the importance of model developing studies while speculating on the results they yield.

The steady state modelling approach followed in this study has proven to be useful for estimating the basic effects of fish farming on a stream ecosystem. However more comprehensive models and more data will be needed to obtain more precise and results. For the assessment of other effects of fish farming in Fırtına Creek, other analytic tools should be used. Therefore, from the model findings, it can be concluded that production farms may be considered as alternative protection measures against the danger of the extinction of the Black Sea trout.

In this study, the fish farming facilities were entered into the model as point sources of pollution. In reality, fish farms use water from streams and produce wastewater, reaching the creeks in turn and then going to other fish farms. A new approach, where fish farms will also be included into the model network and be simulated dynamically together with the stream ecosystem, will provide possibilities for better assessment of the Fırtına Creek ecosystem.

Acknowledgement

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