Journal of Environmental Biology
January 2007, 28(1) 67-72 (2007)

Estimation of stream temperature in Firtina Creek (Rize-Turkiye) using artificial neural network model

Nuket Sivri*[1], Niyazi Kilic[2] and Osman N. Ucan[2]

[1]Istanbul University, Engineering Faculty, Environmental Eng. Dep., 34320, Istanbul, Turkiye
[2]Istanbul University, Engineering Faculty, Electrical Electronics Eng. Dept., 34320, Istanbul, Turkiye

(Received: January 25, 2006 ; Revised received: July 15, 2006 ; Accepted: August 11, 2006)

Abstract: *Water temperature is one of the most important environmental variables in aquatic ecosystem. Temperature changes may have positive or negative effects on organisms. High water temperatures have caused mortalities in salmonid fishes. Therefore, monitoring and prediction of potential adverse changes in water temperature is very important. Here, we have developed and tested an artificial neural network (ANN) model to predict stream temperature of Firtina Creek in Black Sea region, using local water temperature, dissolved oxygen, pH and other available meteorological data (air temperature, rainfall). Thus, enabling define suitable habitat for native Sea Trout (Salmo trutta labrax, Pallas 1811) under past drought or other adverse environmental conditions.*

Key words: *Water temperature, Artificial neural network (ANN), Firtina Creek, Sea trout, Salmo trutta labrax*

Introduction

Stream water temperature is one of the most important parameters in aquatic ecosystem studies. It is vital in relation to chemical processes as well as influencing many biological processes, such as growth and mortality of aquatic organisms. Variations in stream water temperatures are also significant in limnological studies. For example, water temperature determines the rate of decomposition of organic matter and the saturation concentration of dissolved oxygen (Nemerow, 1985). Perturbations of the thermal regime in a stream can significantly impact the utilization of fish habitats, and stream water temperature can be one of the limiting factors in determining the habitat potential of a stream (Boyee, 1982).

Stoneman and Jones (2000) have clearly demonstrated the importance of water temperature at distinguishing sites with differing trout biomasses. High stream temperatures in the range of 23-25^{0}C have been observed to adversely effect mortality of salmonid fishes (Lee and Rinne, 1980; Saila *et al*., 2004). As in many other studies, water temperature appeared to have effect on migratory behavior of sea trout (Trepanier *et al*., 1996). It is possible that temperature has an effect at very high or very low levels and that the temperature range in our study was too narrow to exert detectable effects. Studies related to the effects of climate warming on fish thermal habitat have been conducted at a national level in USA, which indicate that stream habitat for cold and cool water fishes would be substantially reduced (approximately 50%), based on an estimated doubling of the current atmospheric carbon dioxide concentration (Eaton and Scheller, 1996).

Although river discharge is the factor most frequently cited as controlling the rate of upstream migration, it is recognized that temperature and other environmental factors, such as turbidity, can modify the effect of discharge. As stated by Peters *et al.* (1973), the flow rate of river is important since it is the dominant stimulus which leads to the upstream migration of fish (Banks, 1969).

One of the well known genus is *Salmo trutta,* which forms resident populations in the upper streams of rivers and occurs in North Africa, Europe, West Asia and Anatolia and it is a considerable potential species for recreational fishery. However, in most parts of these areas, river systems have undergone great changes in their ecology and morphology in recent years and river damming and degradation of spawning habitats have caused a decline in the stocks of *S. trutta* sizes (Kara and Alp, 2005).

Specimens of the trout *Salmo trutta labrax*, are found only in North East Anatolia and they live in small creeks, lakes and river basins in the Black Sea region. According to the oldest record of the considered fish, the origin of this species is from the Crimean region of the Black Sea. This trout completes all its life stages in a river, and the red spots on their skin never disappear (Aras *et al*., 2003). The ideal growth environment of salmonid species is in clear rivers, which have temperature between 7-19ºC and are abundant in oxygen. The similar envirsonmental factors are also effective in *Salmo trutta labrax*.

In this study, we have estimated various environmental factors using an artificial model of the brain, known as Artificial

Corresponding author: E-mail: sivrin@yahoo.com or nuket@istanbul.edu.tr, Tel.: +90 212 473 70 70 / 17651 or +90 212 473 70 70 / 17502, Fax: +90 212 473 71 80,

Neural Network (ANN). ANNs are particularly well suited for problems in which large datasets contain complicated nonlinear relations among many different inputs. ANNs are able to find and identify complex patterns in datasets that may not be well described by a set of known processes or simple mathematical formula. (Rounds, 2002). Here, we have developed and tested an ANN model to predict stream temperature of Firtina Creek in Black Sea, using local water temperature, dissolved oxygen (DO), pH and other available meteorological data (air temperature, rainfall). Then we are able to define suitable habitat for Black Sea Trout under past drought or other adverse environmental conditions.

Materials and Methods

Study area: Province of Rize is situated on the North East of Turkey and is a rapidly growing residential, retirement and resort area. The study has been conducted in Firtina Creek, east of Rize on Southeast coast of Black Sea (Fig. 1). It is a special basin in the Eastern Black Sea ecosystem, not only for its water quality and flow rate but also as a major spawning and nursery area for Black Sea Trout *Salmo trutta labrax*. Firtina Creek in the Eastern Black Sea region has the widest basin area and contains the combination of a large number of small streams scattered around the skirts of Kackar mountains. The main small creeks feeding Firtina are Durak, Hemsin, Hala, Polovit and Tunca. Firtina Creek is 68 km long, has the highest flow rate in the region due to the temperate climate and run off into the Black Sea in 2 km west of town Ardesen.

It is well known fact that there has been a substantial decline in the stock of sea trout, which is native and protected species of the Firtina Creek. Several factors are effective for this decrement. Since the species is an anadromous form, changing in flow direction and building structures negatively affects the fish movements. In addition, rainbow trout farming along the creek and escapes from these farms force the food competition for slow growing species. Another effect is, that market price of this fish is higher than others; this puts over fishing pressure on the species. In order to enrich the population of *Salmo trutta labrax*, rehabilitation of Firtina Creek becomes very important (Tabak *et al.*, 2002).

Aydin and Yandi (2002) have found negative effects of the contamination coming from a few settlement areas around Firtina and chemical fertilizers and pesticides from tea plant fields. Additionally, possible effects of a planned river type dam project for electricity generation in the area are also emphasized in the same study. In this dam project, the plant contains a tunnel system and accordingly by blocking the stream, the water will be directed through the tunnel. The hydroelectricity plant to be built in Firtina Creek is planned to be bigger than that of Ikizdere in the region. Therefore, the sea trout entering into Firtina Creek will face additional danger from this plant as well. During construction phase, river bed and the surrounding fauna and flora will definitely be affected. Along the river there are trout farms and restaurants and their numbers are increasing. The amount of production depends on the flow rate and the quality of the water. Unfortunately, the effects of the wastes and pollutions coming from these places on the ecosystem of the region have not been studied enough (Tabak *et al.*, 2002).

Fig. 1: Location of Firtina Creek

Recent studies on Black Sea trout have signaled the danger of extinction because of the distortion of spawning grounds and migrating routes. Sea trout certainly needs special conservation program and the Firtina Creek has vital importance since it has small self sustaining stock. (Tabak *et al.*, 2002, Çelikkale *et al.*,1999).

Data analysis: Artificial Neural Network (ANN) or simply Neural Networks (NN) are highly parallel systems that process information through many interconnected neurons that respond to inputs through modifiable weights, thresholds and mathematical transfer functions. Each unit processes the pattern of activity it receives from other units, than broadcasts its response to still other units. An important advantage of ANNs over traditional statistical models is that, they impose fewer and more flexible constraints in their application. ANNs are particularly well suited for problems in which large dataset contain complicated nonlinear relations among many different inputs. ANNs are able to find and identify complex patterns in datasets that may not be well described by a set of known processes or simple mathematical formula (Saila *et al.*, 2004; Rounds, 2002; Soyupak *et al.*,2003).

In ANN, neurons usually operate in parallel and are configured in regular architectures. They are often organized in layers and feedback connections both within the layer and toward adjacent layers are allowed. The strength of each connection is expressed by a numerical value called a weight, which can be updated. They are also characterized by their time domain behavior, which is often referred as dynamics. In general, neuron could be modeled as a non linear activated function of which the total potential inputs into synaptic weights are applied. The artificial model of neuron consists of the three elements (Sahin *et al.*, 2004). These are:

1. A set of synapses or connection links, each of which is characterized by a weight or strength of its own.
2. An adder for summing the input signals, weighed by the synapses of the neuron.
3. An activation function or transfer functions for limiting the amplitude of the output of a neuron.

The neuron model could also include an externally applied bias, denoted by b_k. The bias b_k has the effect of increasing or lowering the net input of the activation function depending on whether it is positive or negative, respectively. Mathematically the neuron k will be described by the following equations:

$$u_k = \sum_{j=1}^{m} w_{k,j} x_j \qquad (1)$$

where $\{x_1,....,x_m\}$ are the input signals; $\{w_{k,1},....,w_{k,m}\}$ are synaptic weights of neuron k. The activation function, denoted by $f(v)$, defines the output of a neuron which considerably influences the behavior of the network:

$$v_k = u_k + b_k \qquad (2)$$

$$y_k = f(v_k) \qquad (3)$$

where threshold value and *f* is activation function are generally used in ANN. These are:

Piecewise linear function:

$$f(v_k) = \begin{cases} 1 & v_k \geq \frac{1}{2} \\ v & \frac{1}{2} > v_k > -\frac{1}{2} \\ 0 & v_k \leq -\frac{1}{2} \end{cases} \qquad (4)$$

threshold function:

$$f(v_k) = \begin{cases} 1, & if\ v_k \geq 0 \\ 0, & if\ v_k < 0 \end{cases} \qquad (5)$$

sigmoid function:

$$f(v_k) = \frac{1}{1+e^{av_k}} \qquad (6)$$

where a is the slope of the activation function.

The monitoring data belonging to the years 2001 and 2002, is designed to meet the requirements of training and testing the neural network. This data base is divided into two parts as training and test sets. In ANN approach, the effects of all input/output parameters can be evaluated and various outputs can be obtained for different environments. In ANN, the number of input/output parameters, number of neurons in hidden layer and the type of nonlinear activation function, learning rate, and sum squared error (SSE) criteria affect the performance of the structure.

Results and Discussion

Data set of Firtina Creek of North Eastern Turkey was measured to develop the predictive annual stream temperature variation. The problem was modeled by applying ANN described in the previous section. Three variables of the inputs were taken from Firtina Creek. They were daily records of stream temperature, pH, and dissolved oxygen. The other two inputs were obtained from weather station, which are monthly average records of air temperature and rainfall.

In this study, Multi Layer Perceptron (MLP) model of ANN approach was used to predict stream temperature of Firtina Creek. Here, MLP was chosen because of the complexity of the case. All the data are normalized into the range {-1.0, 1.0}. This was carried out by determining the maximum and minimum values of each variable over the whole data period and calculating normalized variables using equation (7) as below.

$$x_{norm} = 2*\left[\frac{(x - x_{min})}{(x_{max} - x_{min})}\right] - 1.0 \qquad (7)$$

The neuron number of hidden layer is an important factor. Here, various ANN models were tested changing the number of neurons in the hidden layer between 2 and 20. As a result, a 3 layer network with 5 inputs, 12 hidden neurons and a single output (estimated stream temperature of Firtina Creek) has been chosen. Fig. 2 shows the ANN architecture. The black circles are processing units in all the layers representing artificial neurons and gray ones are simple nodes.

During the training procedure, monthly average five inputs values of 2001 were taken. After satisfactory results have been found out, we focused on the same parameters collected

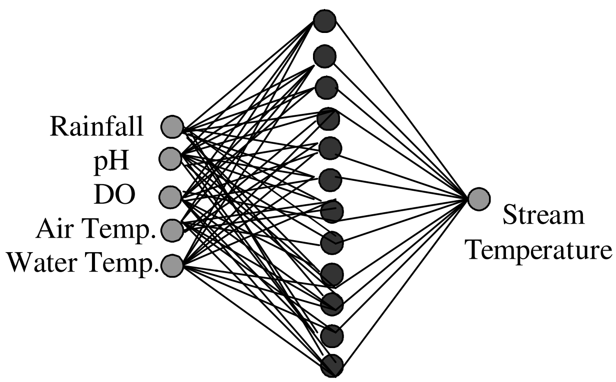

Fig. 2: MLP-ANN structure

during 2002 and 2003. Here, since only stream temperature was studied, we have not given other parameters in both testing and training steps. The sigmoid function was chosen in equation (6) as an activation function, which was found as the best optimization function in meteorological data by Gardner and Dorling (1999), Boznar *et al.* (1993). In this study, we have compared various inputs, hidden and output layers with different neuron numbers as in Table 1 and proposed a suitable ANN structure with three layered MLP.

The number of neurons for hidden layer was altered between 2 to 20 in testing results, the best performance of sum square error (SSE) was found as 0.005 for normalized stream temperature (ST). The highest correlation coefficient (r) was 0.89 between predicted and observed ST as in Fig. 3. The stream temperature values were trained for hidden layer neuron number as in Fig. 4. Satisfactory results were obtained. Hence, the best

Table - 1: Comparison of the obtained reached SSE in training and correlation outputs (r) between predicted and observed in testing for various ANN model structure (ST: Stream Temperature)

ANN model structure	Sum square error (SSE)	Predicted observed ST (r)
5-10-1	0.0063	0.84
5-12-1	0.005	0.89
5-14-1	0.011	0.71
5-16-1	0.008	0.73
5-18-1	0.0061	0.75
5-20-1	0.33	0.65

suited model for ANN was found as (5,12,1) corresponding number of neurons in input, hidden and output layers respectively. The learning rate was also found as 0.1 over the whole ANN models. In testing, annually observed and predicted stream temperature for ANN model output were evaluated in Figure 5.

Although, Firtina Creek ecosystem can tolerate inputs during the spring, the summer model showed that decrease of creek's flow rate and increase in temperature resulted in decrement of DO. Simulation results related to these scenarios have shown that even though probable establishments will not

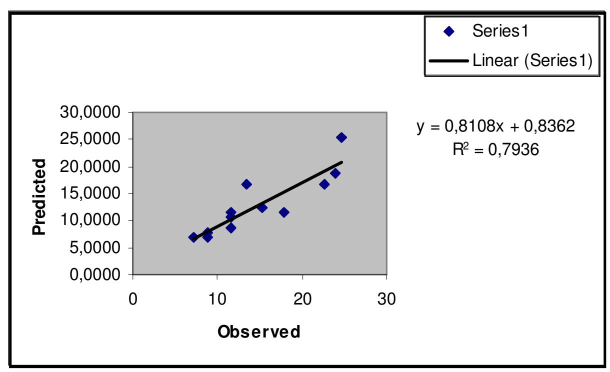

Fig. 3: Regression lines for ANN predicted of stream temperature and observed stream temperature for test data set

have significant effects, their effect on ecosystem is still expected to be noticeable (Tabak *et al.*, 2002). Constructions on streams, which cause changes in flow together with the ecological balance and may result in some sudden decreases in the natural fish population. Starting from the data, after the evaluation of different ideas and alternative solutions, a decision with multiple alternatives should be reached. This definitely indicates the importance of model developing studies and speculating on the results they yield.

Water temperature is a primary important parameter for sustaining a healthy natural fish population. The optimum growth environment of salmonid species is clear rivers, which

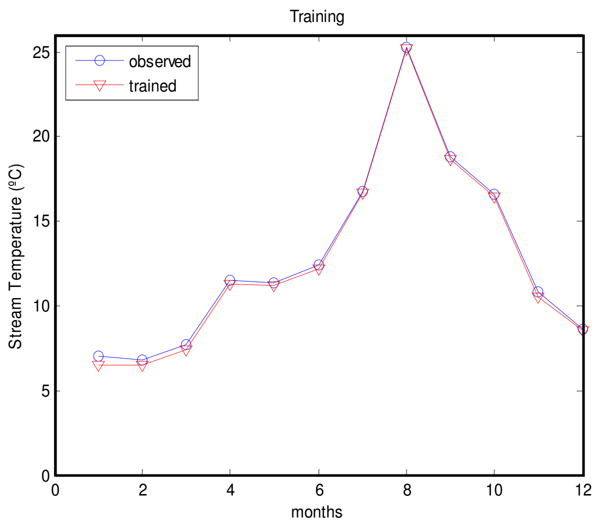

Fig. 4: ANN outputs for (5,12,1) model structure, training set of ANN for 2002

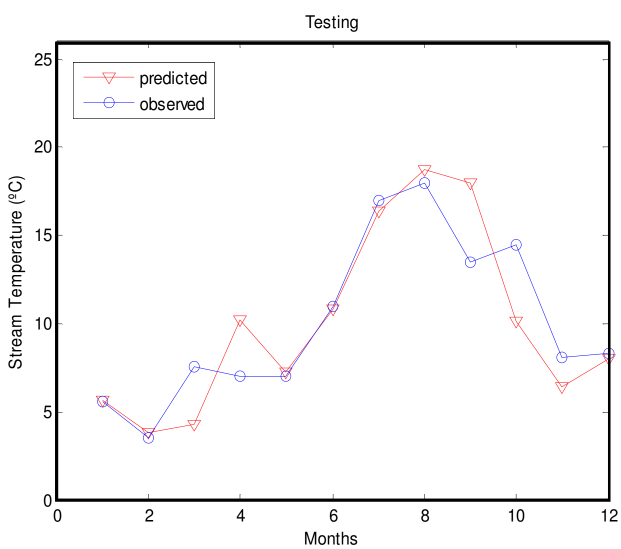

Fig. 5: ANN outputs for (5,12,1) model structure, testing of ANN for 2003

have temperature between 7-19ºC and are abundant in oxygen. In particular, Edwards (1989) and Lelek (1980) have reported that Firtina Creek has an ideal environment for trout species. Celikkale (1999) has defined that trout can tolerate water temperatures up to 22ºC, however, pH, dissolved oxygen and other water quality criteria can effect this tolerance depending on the changes/fluctuations in water temperature. Fish growth increases with increasing water temperature up to an optimum point, after that it starts decreasing.

It was found that the water temperature of rivers effects fish growth linearly between a minimum of 3.3ºC and a maximum of 12.8ºC (Elliot, 1994). Maisse and Bagliniere (1999) reported that fish in temperate waters grow faster compared to fish at high altitudes and in regions where the winter lasts longer. Reproduction occurs most intensely from the middle of October to the end of November. In summer months, reproduction continues until the end of December in rivers and their tributary where water temperature is high. Members among Black Sea trout maintain their reproduction starting from around the end of August to the middle of December. For this reason, the importance of the usefulness of the results found is increasing. It may be possible to predict the data for the following year with the data on hand. This helps to plan fish aquaculture and identify the areas where mature fish leave their eggs, and eliminate the negative effects on fish stocks. Accurate predictions should be made to support the maintenance of the natural environment of *Salmo trutta labrax*, a species endemic to the Black Sea.

The temperature of stream water is complex and includes air temperature, rainfall and time of runoff. The relations between pH, dissolved oxygen and other measurable stream variables are often strong, though typically nonlinear and specific to an individual watershed (Quilty *et al.*, 2004). ANNs are ideal for modeling temperature based on these relations. Artificial neural networks are well suited to modeling the nonlinear relations between water quality (physical, chemical etc) and meteorological (air temperature, rainfall etc) variables. The results of the neural network training were considered to be very accurate and the validation test also indicated very satisfactory prediction accuracy (Saila *et al.*, 2004). In our ANN approach, the effects of all input/output parameters can be evaluated and various outputs can be obtained for different environments and predicted stream water temperatures of Firtina Creek. These predictions are important not only for the people who work on fish aquaculture but also for making decisions about established or soon to be established Fishery Policies.

Acknowledgments

We thank to Prof. Dr. Ibrahim Okumus for suggesting corrections and to Dr. Ilker Z. Kurtoglu for providing update information on our study region.

References

Aras, N.M., H.I. Haliloglu, O. Ayik and H. Yetim: Comparison of fatty acid profiles of different tissues of mature trout (*Salmo trutta labrax*, Pallas, 1811) caught from Kazandere Creek in the Çoruh Region, Erzurum, Turkey. *Turk. J. Vet. Anim. Sci.*, **27**, 311-316 (2003).

Aydin, H. and I. Yandi: The general status of spawning areas of Blacksea trout in the east Blacksea regions (*Salmo trutta labrax* Pallas, 1811). *E.U. JFAS.*, **19 (3-4)**, 501-506 (2002).

Banks, J. W.: A review of literature on the upstream migration of adult salmonids. *J. Fish Biol.*, **1**, 85–136 (1969).

Boyee, K. D.: A guide to stream habitat analysis using the instream incremental methodology. Instream flow information paper 12. U.S. fish and wildlife service EWS/OBS-82/26. 248 p, (1982).

Boznar, M., M. Lesjak and P. Mlakar: A neural network based method for short term predictions of ambient SO_2 concentrations in highly polluted industrial areas of complex terrain. *Atmospheric Env.*, **32**, 2627-2636 (1993).

Celikkale, M.S., E. Duzgunes and I. Okumus: Turkeys aquaculture sector: Potential, current situation, problems and solutions, Istanbul. Chamber of commerce. Publ. no. 1999-2, Intanbul, Turkey. pp. 414 (1999) In Turkish.

Eaton, E. J. and R.M. Scheller: Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography*, **41(1)**, 109-118 (1996).

Edwards, D. J. and S. Doroshov : Appraisal of the stergeon and seatrout fisheries and proposals for a rehabiliation programme, FAO-Turkey technical cooperation programme, FAO W/T7449 Rome. 38, (1989).

Elliot, J. M. : Quantitative ecology and the brown trout. Oxford univ. press, Oxford. pp. 286 (1994).

Gardner, M.V. and S.R. Dorling: Neural network modeling and prediction of NO_x and NO_2 concentrations in urban air in London. *Atmospheric Env.*, **33**, 709-719 (1999).

Kara, C. and A. Alp: Feeding habits and diet composition of brown trout (*Salmo trutta*) in the upper streams of River Ceyhan and river Euphrates in Turkey. *Turk. J. Vet. Anim. Sci.,* **29**, 417-428 (2005).

Lee, R. M. and J. N. Rinne: Critical thermal maxima of five trout streams in the southwestern United States. *Transactions of the American Fisheries Society*, **109(6)**, 632-635 (1980).

Lelek, A.: The occurence taxonomy and future of trouts in north east Turkey. Report for European committee for the conservation of nature and natural resources. pp. 102 (1980).

Maisse, G. and J.L. Bagliniere: Biology and ecology of the brown trout. Praxis publishing ltd, Chichester, UK (1999).

Nemerov, N.L.: Stream, lake, estuary and ocean pollution. Van Nostrand, Reinhold Company, I New York. (1985).

Peters, J. C., H. R. Farmer and P. J. Radford: A simulation model of the upstream movement of anadromous salmonid fish. *Reading Water Resources Board* 21. (1973).

Quilty, E., P. Hudson and T. Farahmand: Artificial neural networks for validation and correction of high frequency water quality data, 11th CWWA national conference in Calgary, April 3-6, (2004).

Rounds, S. A.: Development of a neural network model for dissolved oxygen in the Tualatin river, oregon. Proceeding of the second federal interagency hydrologic modeling conference, Las Vegas, Nevada, July 29 - August 2002: ISBN: 0-9779007-0-3, USA, (2002).

Sahin, U., O.N. Ucan, B. Soyhan and C. Bayat.: Modeling of CO distribution in Istanbul using artificial neural networks. *FEB.*, **13 (9)**, 839-845 (2004).

Saila, S., M. Cheeseman and D. Poyer: Maximum Stream temperature estimation from air temperature data and its relationship to Brook Trout (Salvelinus fontinalis) Habitat requirements in Rhode Island, Wood Pawcatuck watershed association (WPWA), (2004).

Soyupak, S., F. Karaer, H. Gürbüz, E. Kivrak, E. Sentürk, A. Yazici: A neural network based approach for calculating dissolved oxygen in reservoirs. *Neural Comput. and Applic.,* **12,** 166-172 (2003).

Stoneman, C. L. and M.L. Jones: The influence habitat features on the biomass and distribution of three species of southern Ontario stream salmonids. *Transactions of the American Fisheries Society,* **129**, 639-657 (2000).

Tabak, I., M. Aksungur, M. Zengin, C. Yilmaz, , N. Aksungur, A. Alkan, B. Zengin and D.S. Misir: The bioecological characteristics of the Blacksea Trout (*Salmo trutta labrax*, Pallas, 1811) and its culture possibility, Project final report, TAGEM/ HAYSUD/ 98/12/01/007. pp.191 (2002).

Trepanier, S., M.A. Rodriguez and P. Magnan: Spawning migrations in landlocked Atlantic salmon: Time series modelling of river discharge and water temperature effects. *J. Fish Biol.*, **48**, 925–936 (1996).