*Biosystems Engineering* (2007) **96** (4), 581–591
doi:10.1016/j.biosystemseng.2007.01.006
AP—Animal Production Technology



# Water Temperature Regimen Analysis of Intensive Fishfarms associated with Cooling Effluents from Power Plants

J.C. Gutiérrez-Estrada; I. Pulido-Calvo

Dept. Ciencias Agroforestales, Univ. Huelva, EPS, Campus Universitario de La Rábida, 21819 Palos de la Frontera (Huelva), Spain;
e-mail of corresponding author: juanc@uhu.es

*(Received 26 April 2006; accepted in revised form 19 January 2007; published online 12 March 2007)*

This work analyses the effect that the electrical market liberalisation has on the variation of water temperature regimes in intensive aquaculture plants, and more specifically, the fishfarms which take advantage of the cooling effluents from power plants. Data were obtained from a facility devoted to the European eels growth which takes the warm water from the cooling effluent from the Puente Nuevo thermal power plant (Córdoba, Spain). The results indicate that the liberalisation of the electrical network has a significant influence on the form and quantity of energy generated by the thermal power plant, and consequently on the thermal regimes of the cooling effluent. A decrease in the mean water temperature (mean water temperature before liberalisation = 25·5 °C and after liberalisation = 24·3 °C) and an increase of variation range of water temperature (standard deviation before liberalisation = 1·7 °C and after liberalisation = 2·5 °C) inside the fishfarm were observed (without modify the management scheme of the production system) when the electrical market liberalisation was implemented. The growth potential of reared eels estimated from a growth capacity index (GCI) showed significant differences between the mean values in the regulated and liberalised electrical markets. The decrease in the value of GCI was 6·67% when the electrical market liberalisation was implemented.


## 1. Introduction

Water temperature is one of the most important factors for the intensive aquacultural industry, since profitability largely depends on the time between the beginning of production and withdrawal of the harvest shares (stock subset of commercial size). Thus, it is easier to obtain growth rates that allow harvest share extraction of commercial sized fish in a minimal time, if the temperature of water is kept around the physiological ideal temperature of the reared species. Nevertheless, maintaining the water temperature at the physiological ideal during a harvest cycle requires an additional cost of electrical energy. The alternative is to locate the fishfarm close to a source of warm water. In this respect, authors such as Nash and Paulsen (1981), Lund (1986), Coll (1991), Veil (1998) and Lund *et al.* (2005) indicate the great potential of the cooling effluents for agricultural and aquacultural applications. In the aquacultural industry, this technology (based upon the use in fish hatchery and farming operations thermally polluted cooling water discharged from an electric power plant) is contributing to the rapid growth of inland aquaculture.

In Spain, there are 48 generating plants that need water cooling. Only four plants (8%) use the warm water effluent for commercial or experimental fish rearing purposes. These cases are related to the thermal power plants of Puente Nuevo (Córdoba), Litoral (Almería), Alcudia (Mallorca) and San Roque (Cádiz). This reveals the high potential of installation of new fishfarms associated with cooling effluents of power plants.

In this type of fishfarm, a key aspect is the flow regimen of warm water because rapid and high changes of water temperature promptly produces physiological and behavioural changes in fish. This stress status changes the blood composition and increases/decreases the breathing and the heartbeat frequency, causing a decrease of the immune system effectiveness and an increase of the susceptibility to diseases and attack of parasites (Palackova *et al.*, 1990). Therefore, some possible consequences of the high and rapid changes of water temperature are the direct and indirect unfavourable effects on growth rates, mortality rates and final yield.

The continuity of the flow of warm water from a power station to a fishfarm is directly dependent on the continuity of the electricity generation. This is itself dependent on a large number of factors, but in general, generating stations which are cheaper to run are likely to provide the most constant supply of warm water. In some European countries, including the United Kingdom, power stations are listed in the order of merit, and the most efficient and economic are known as 'base load' stations. In Spain, the Law of the Electrical Sector, Law 54/1997 (BOE, 1997) recognises the right to free installation and its functioning is organised according to the principle of free competition. For this reason, it is necessary to take into account the electrical production system of the generating plant as well as the possibility of exploiting this source of warm water. The producers of electric power carry out their economic offers of energy sale by means of a market operator. The latter determines the functioning order of the production units (*e.g.* thermal, nuclear power plants) starting from the cheapest offer up to equalising the demand for energy in this programming period (BOE, 1997). Those plants that produce cheaper energy will generate electricity in a more consistent way and be associated with a more consistent flow of warm water with few variations in their temperature regimes.

This work intends to analyse the impact of electric power market liberalisation and its effect on the parameters of water temperature and yield in fishfarms associated with a thermal power plant. The analysis was carried out in an intensive eel fishfarm located in southern Spain which did not change the operation scheme of the production system before and after electric power market liberalisation.

## 2. Fishfarm description

Hidrorecursos S.A. is a fishfarm located in the north of the province of Córdoba (southern Spain) which concentrates all its production in the growth of European eels. Placed on the left side of the Puente Nuevo reservoir, it takes the necessary water for its production from two main sources: (a) the Puente Nuevo reservoir (cold water); and (b) the cooling channel of the Puente Nuevo thermal power plant (warm water) (*Fig. 1*). Generally, the cooling channel of the Puente Nuevo thermal power plant is never empty because although the electricity generation is zero, the thermal plant has a minimum maintenance operation level. Only in periods of technical stop (for important reparations) the channel is empty.

The water flow inside the installation is of two types, with some of the culture tanks included in an open flow system and the other tanks in a recirculation system. In the open system, there are two series of 12 circular tanks of $3{\cdot}2\,m^3$ (series C and D), corresponding to the nursery area and a series of 14 rectangular tanks of $110\,m^3$ (series G) that corresponds with the growth area. In the recirculation system, there are two series of 12 circular tanks of $3{\cdot}2\,m^3$ (A and B series) that belong to the nursery area and 20 rectangular tanks of $16\,m^3$ (series E and F) that belonging to the pre-growth area. The recirculation process is possible thanks to the action of three filtration units (biofilters). Two of them are associated with the series A and B, respectively, whereas the third one filters the water proceeding from both pre-growth series. The water renovation rate of the system is $10\%\ day^{-1}$.

## 3. Material and methods

The necessary information for the analysis has been obtained from two main sources: (a) the fishfarm central computer where the automatic measures of the mean daily water temperature are stocked; and (b) the Puente Nuevo thermal power plant. Basically, the series of water temperatures in the rearing tanks (January 1997–July 2000) has been extracted from the first source, whereas, the second one has provided the data series of energy generated by the power plant (January 1997–July 2000).

The fast Fourier transform (FFT) technique was used to extract the periodic components from the data series from the Puente Nuevo thermal plant (Lo *et al.*, 1975; Otnes & Enochson, 1978; Park, 1998). Since these are discrete time series the sampling frequency has been established between 0 and 0·5 in order to avoid the frequencies rebound effects of frequencies (aliasing) (Bloomfield, 1976). The FFT provides a pair of values for every wave frequency (Fourier coefficients), which are considered as a complex number with a cosinusoidal component (real part) and a sinusoidal one (imaginary part). Both values can be combined for the periodogram calculation (Park, 1998).

The growth of any fish species is highly related to the water temperature. For this reason, the effect of water

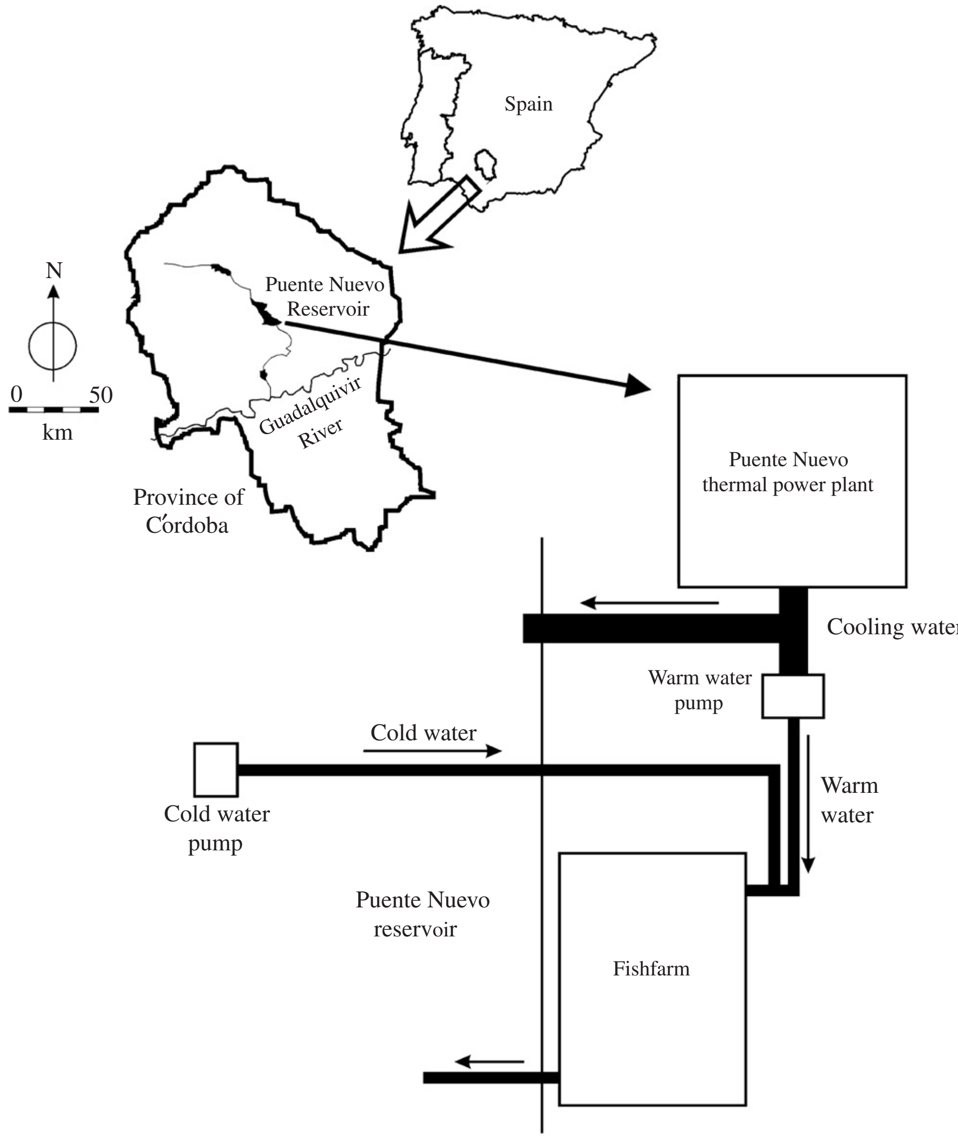


*Fig. 1. Geographical location of Hidrorecursos S.A.; schematic representation of the water flow in the fishfarm*

temperature variation on fish growth must be evaluated. Gutiérrez-Estrada (2003) and Gutiérrez-Estrada *et al.* (2004) determined the experimental relationship between water temperature $T$ and the growth capacity index ($I_{GC}$) for European eel for the rearing conditions of Hidrorecursos S.A. by means of a polynomial equation:

$$\text{IF } T \leqslant 12{\cdot}9\,^{\circ}\text{C OR} \geqslant 29{\cdot}9\,^{\circ}\text{C THEN } I_{GC} = 0 \quad (1)$$

$$\text{IF } 12{\cdot}9\,^{\circ}\text{C} < T < 29{\cdot}9\,^{\circ}\text{C THEN } I_{GC} = 8{\cdot}2167 - (1{\cdot}4918\,T) + (0{\cdot}0857\,T^2) - (0{\cdot}0015\,T^3) \quad (2)$$

where $I_{GC}$ is the growth capacity index.

A value for $I_{GC}$ of 1 is the maximum growth capacity (water temperature = 24·5 °C) and a value for $I_{GC}$ of 0 (water temperature $\leqslant$12·9 °C or water temperature $\geqslant$29·9 °C) means that there is no growth (*Fig. 2*). In this paper, this relationship was used to estimate the influence of water temperature changes on variation growth over time.

## 4. Results

### 4.1. *Energy production in the thermal power plant*

The temporal variation of the energy generated by the Puente Nuevo thermal plant during the period between January 1997 and July 2000 is shown in *Fig. 3*. The energy production during the year 1997 lightly fluctuates in the first months of the year, though from the

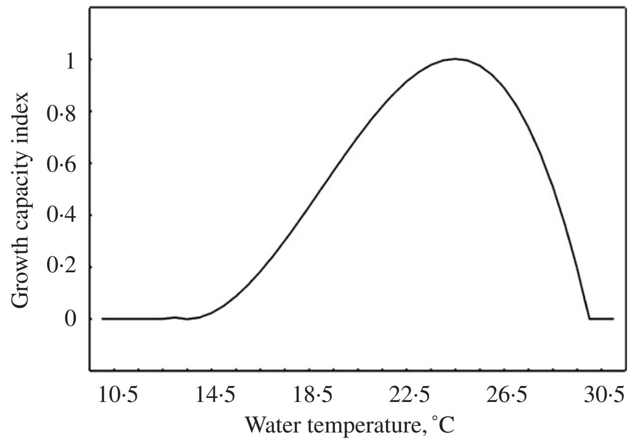


*Fig. 2. Relationship between water temperature and the growth capacity index for European eel for the rearing conditions of Hidrorecursos S.A*

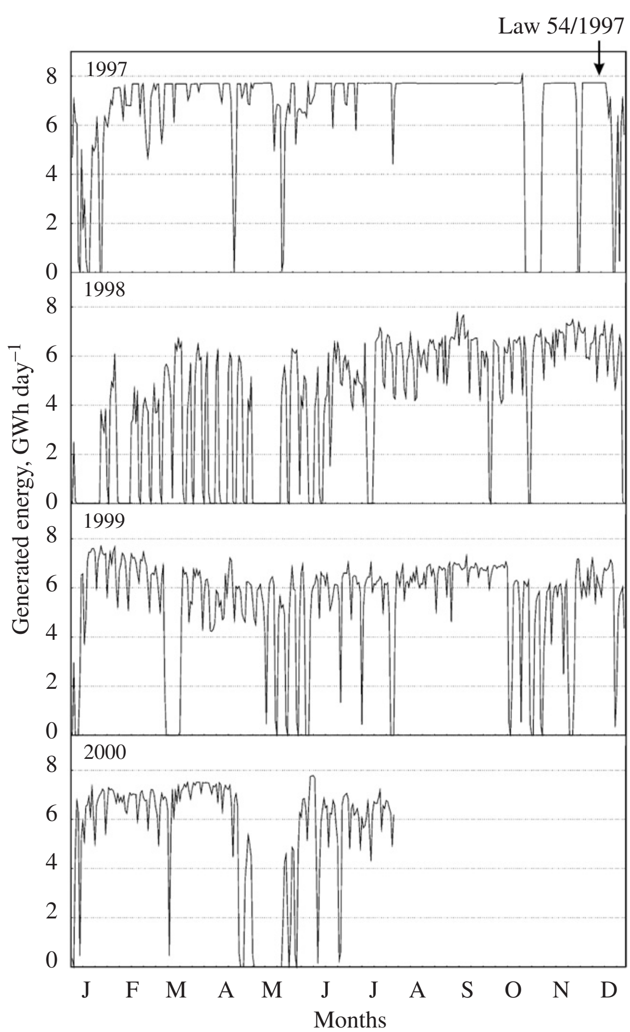


*Fig. 3. Generated energy ($GWh\ day^{-1}$) by the Puente Nuevo thermal power plant between January of 1997 and July of 2000*

beginning of February it becomes stable. Exactly from this moment there is only one technical stop in October which separates periods where the produced energy is close to its possible maximum. From the time the Law of the Electrical Sector, Law 54/1997 (BOE, 1997), comes into force at the end of November 1997, the production of energy would decrease considerably. In the first months of 1998, the mean production stabilises about 2·1 GW h, occurring from this moment a constant increase up to reaching the maximum annual values. This trend goes on in the years 1999 and 2000. In this period three technical stops occurred: May 1998, March 1999 and May 2000.

The Fourier transform of the data shows the presence of coefficients with absolute values, which are significantly far from the value zero, indicating strong periodicity of the production. In the period from January to November 28, 1997, the production cycle changes monthly form approximately, since there are frequencies in the periodogram with significant coefficients that correspond to periods of 30, 38 and 51 days (long periods are dominant). After the introduction of the Law 54/1997, the periodicity of production is weekly form approximately, since frequencies that correspond to periods of 7 days are detected (short periods are dominant) (*Fig. 4*).

An analysis of the variance (ANOVA) carried out each day of the week has shown the presence of significant differences in the production level after the introduction of the Law 54/1997 (*Fig. 5*). A Tukey's test showed later that the 2 days on which the levels of production significantly decreased were Saturday and Sunday (Tukey: in all the cases, significance level from Monday–Tuesday–Wednesday–Thursday-Friday to Saturday and Sunday, respectively: $P_{\alpha Saturday} < 0{\cdot}05$; $P_{\alpha Sunday} < 0{\cdot}001$). Significant differences were not found between both days (Tukey: $P_{\alpha Saturday\text{–}Sunday} = 0{\cdot}052$). These differences were not detected before the introduction of the Law 54/1997 (*Fig. 5*). The comparison of the mean production values for weekdays before and after the Law 54/1997 showed significant differences in all cases (Table 1). This indicates that the electrical market liberalisation has not only affected the way and distribution moment of the energy but has also been responsible for the decrease of the energy generated by the Puente Nuevo thermal plant.

### 4.2. *Analysis of the water temperature inside the fishfarm and growth capacity index*

The temporal evolution of the water temperature in the rearing tanks is shown in *Fig. 6*. During 1997, 1998 and 1999 the water temperature fluctuates following a

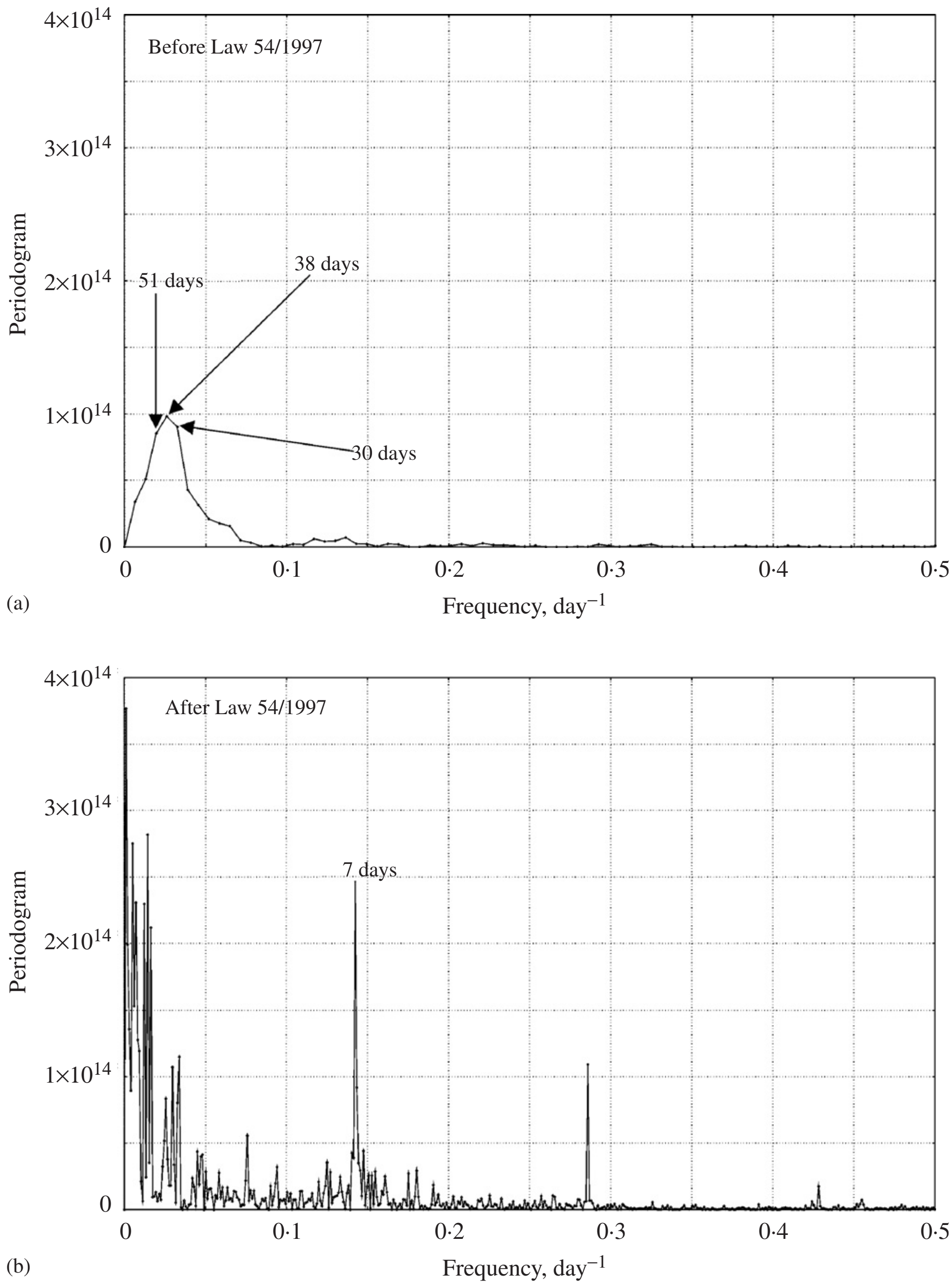


*Fig. 4. Energy-generated periodograms before (a) and after (b) of Law 54/1997*

general pattern with low values in the autumn–winter months and high values in the spring–summer months (this pattern is not visible in the year 2000), although in 1998 and 1999 winter temperatures are lower than in 1997. In the study period, the highest level of stability is recorded in pre-Law period (standard deviation pre-law = 1·698; standard deviation post-law = 2·481; Levene statistic = 84·847; $P_\alpha < 0{\cdot}001$).

The comparison of the mean temperatures for each day of the week before the introduction of the Law 54/1997 has indicated the total absence of any significant differences. The same occurred after the introduction of the Law 54/1997 although in the weekend a decrease of mean temperature could be expected as a consequence of the decrease of energy production and the significant statistic correlation among water temperatures in rearing tanks and generating energy (correlation coefficient $R = 0{\cdot}32$; $P_\alpha < 0{\cdot}05$). It shows no variation of pattern for this parameter throughout the 7 days of the week (*Fig. 7*). The Fourier transforms

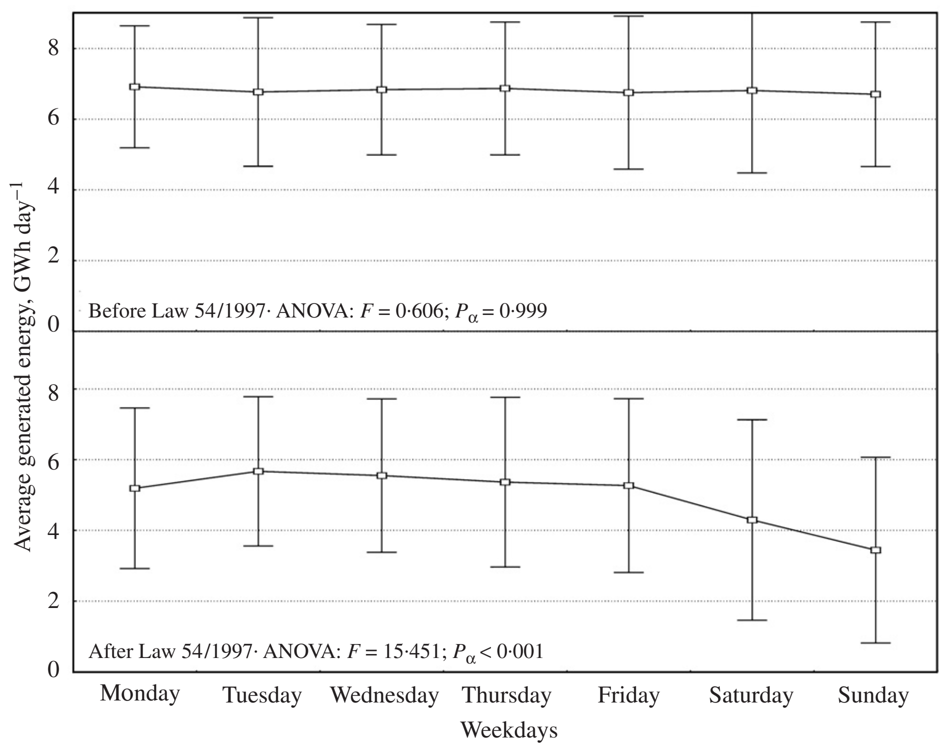


*Fig. 5. Average generated energy (GWh day$^{-1}$) for weekdays before and after the electric non-regulated market; results of the variance analysis (ANOVA) are shown; F, ratio of variance; $P_\alpha$, probability*

**Table 1**
**Comparison of the mean energy production of Puente Nuevo thermal power plant for weekdays before and after the electric non-regulated market; the *t*-Student statistic and the significance level $P_\alpha$ for each day are shown**

| | *Weekdays* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Monday* | *Tuesday* | *Wednesday* | *Thursday* | *Friday* | *Saturday* | *Sunday* |
| Mean energy generated before Law 54/1997, GW h | 7·067 | 6·770 | 6·836 | 6·870 | 6·752 | 6·793 | 6·698 |
| Mean energy generated after Law 54/1997, GW h | 5·154 | 5·671 | 5·550 | 5·366 | 5·268 | 4·319 | 3·468 |
| *t*-Statistic | 4·122 | 2·729 | 2·906 | 2·777 | 3·178 | 4·807 | 6·457 |
| $P_\alpha$ | 0[a] | 0·002[a] | 0[a] | 0[a] | 0[a] | 0[a] | 0[a] |

[a]Significant differences.

of the water temperature data showed the presence of coefficients with absolute values, which are significantly far from the value zero. However, these coefficients were associated with very small frequency and high periods. On the other hand, the comparison of the global mean temperature before and after market liberalisation showed significant differences (Mann–Whitney's test: mean temperature before the Law 54/1997 = 25·5 °C; mean temperature after the Law 54/1997 = 24·3 °C; Mann–Whitney statistic $U = 49\,999{\cdot}0$; $P_\alpha < 0{\cdot}001$).

In *Fig. 7* the maximum and minimum variation ranges are shown together with the temperature standard deviations on every day of the week. It is possible to observe how before the Law 54/1997 the temperature variation was between 29 and 22·3 °C. Nevertheless, after the introduction of the Law 54/1997 the temperature ranged between 29·7 and 17·2 °C. The comparison of the mean temperatures for each day of the week before and after the Law showed significant differences for Monday, Tuesday, Wednesday, Saturday and Sunday and marginally significant differences for Thursday

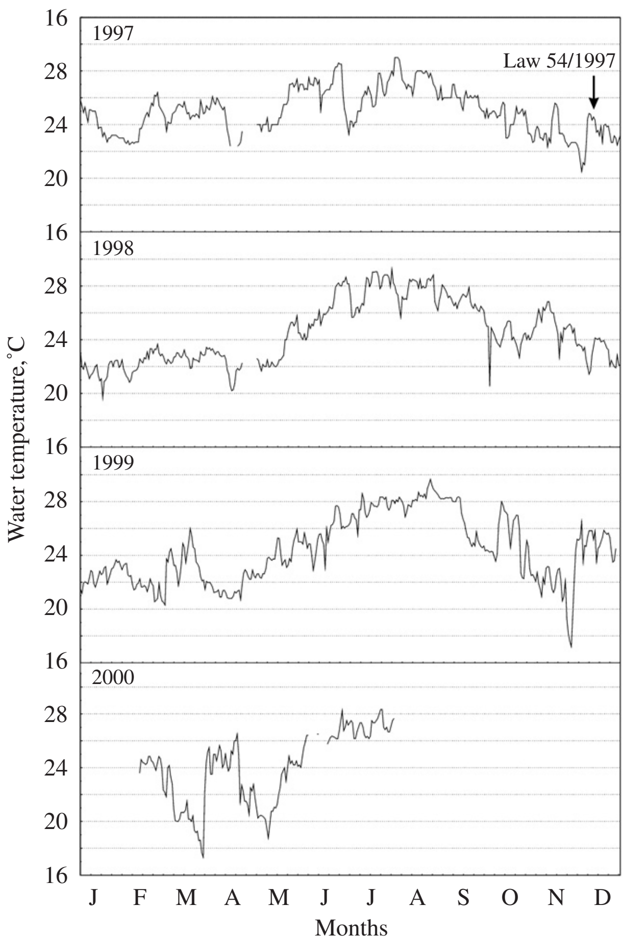


*Fig. 6. Water temperature variation in the rearing tanks between January of 1997 and July of 2000*

and Friday (Table 2). The comparison of the variance by a Levene's test every day of the week before and after the market liberalisation, indicated that the level of the temperature variation after the Law was significantly higher than it was in the year 1997 for all the cases (Table 3).

Likewise the maximum difference between the temperatures of 2 consecutive days before and after the Law, during the year 1997 was at all times about 2 °C whereas in the years 1998–2000 the maximum difference was approximately 5 °C (which can be reached in 2 or 3 h). The analysis of mean and deviation of water temperature differences between two consecutives by water temperature ranges showed that in the 16–18 and 18–20 °C ranges only water temperature differences were observed after Law 54/1997. Additionally for rest of ranges, the deviation of water temperature differences were higher in post-Law period except in the 28–30 °C range (*Fig. 8*).

The temporal variation of the $I_{GC}$ is shown in *Fig. 9*. Significant differences were observed between the mean value of pre-Law period and the other years (*t*-test: mean $I_{GC}$ pre-Law: 0·915; mean GCI post-Law: 0·854; $t = 6{\cdot}385$; $P_\alpha < 0{\cdot}001$). Also, significant differences were found among standard deviations of the $I_{GC}$ of pre-Law and post-Law periods (standard deviation pre-Law-0·119; standard deviation post-Law = 0·157; Levene's statistic = 41·108; $P_\alpha < 0{\cdot}001$). These results show that the $I_{GC}$ in pre-Law period was 6·67% higher than the observed one in post-Law period, although the mean water temperature in post-Law period was very close to 24·5 °C (temperature of maximum growth capacity) (Table 2). This is a consequence of the convex (upwards) shape of the growth capacity function (*Fig. 2*) which results in reduced production when temperature fluctuations are higher, similar to that which as prevailed after 1997 (*Figs 6* and *9*).

## 5. Discussion

In the same way as in Spain, the electric power supply by means of non-regulated tariffs subject to market laws is also implemented in some European Union countries, such as Sweden and Great Britain (Banks, 1994, 1996). Independent of the market type, the profitability of the electric generation is strongly influenced by the raw materials from which it is obtained, the efficiency of the equipments, the installed power and the strategic location of the power plant. A coal thermal power plant with middle-low installed power will produce more expensive energy than a nuclear power station with high power. On the regulated market, the low profitability of some generating plants was compensated by the energy commercialisation of other plants belonging to the same supply company. However, the separation imposed by the liberalised market between generation and commercialisation, aiming to optimise the production costs, makes the functioning of generating plants depend almost exclusively on the kW h price produced.

These factors that determine the liberalised market, added to the characteristics of the energy generation from coal at middle-low installed power (such as, Puente Nuevo power plant), involve the adjustment of the generation to energy demand patterns, which have a typically weekly periodicity with a decrease of the demand happening during the weekend. The high probability of interruption or a significant decrease in energy supply results in a decrease of the warm water flow from the power plant, which consequently produces significant water temperature variations in a short time.

The impact of the electrical generating plants on the thermal regimes of both the aquatic natural and

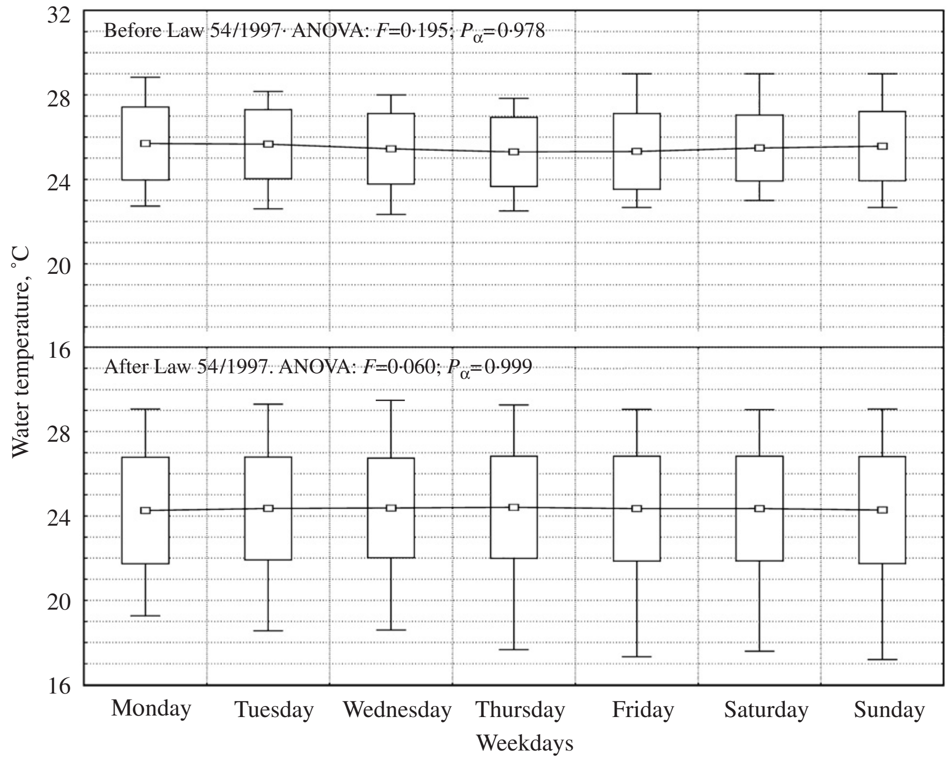


*Fig. 7. Water average temperatures ± standard deviations (boxes) for weekdays; the maximum and minimum temperatures are shown as bars; results of the variance analysis (ANOVA) are shown; F, ratio of variance; $P_\alpha$, probability*

**Table 2**
**Comparison of the mean water temperature in the rearing tanks for days before and after the electric non-regulated market; the *t*-Student statistic and the significance level $P_\alpha$ for each day are shown**

| | *Weekdays* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Monday* | *Tuesday* | *Wednesday* | *Thursday* | *Friday* | *Saturday* | *Sunday* |
| Mean water temperature before Law 54/1997, °C | 25·3 | 25·3 | 25·2 | 25·1 | 25·0 | 25·1 | 25·2 |
| Mean water temperature after Law 54/1997, °C | 24·3 | 24·4 | 24·4 | 24·4 | 24·3 | 24·3 | 24·3 |
| *t*-Statistic | 2·577 | 2·432 | 2·036 | 1·653 | 1·799 | 2·072 | 2·300 |
| $P_\alpha$ | 0·01[a] | 0·02[a] | 0·03[a] | 0·07 | 0·08 | 0·04[a] | 0·03[a] |

[a]Significant differences.

**Table 3**
**Comparison of the temperature variability in the fishfarm for weekdays before and after the electric non-regulated market; the Levene statistic and the significance level $P_\alpha$ for each day are shown**

| | *Weekdays* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Monday* | *Tuesday* | *Wednesday* | *Thursday* | *Friday* | *Saturday* | *Sunday* |
| Levene | 5·984 | 5·835 | 4·663 | 4·578 | 4·182 | 9·223 | 6·901 |
| $P_\alpha$ | 0·020[a] | 0·020[a] | 0·030[a] | 0·030[a] | 0·040[a] | 0·003[a] | 0·010[a] |

[a]Significant differences.

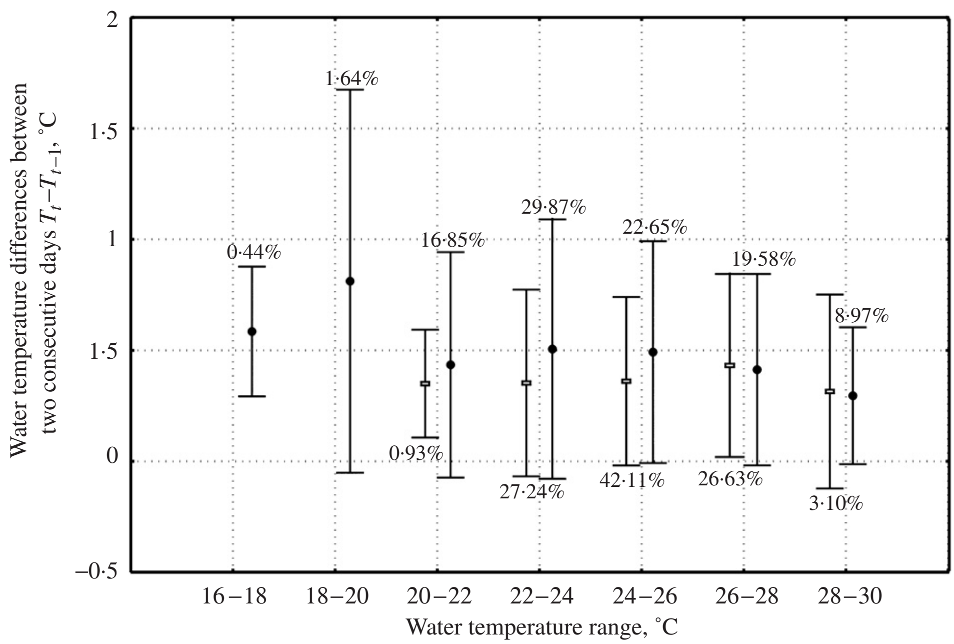


*Fig. 8. Means and standard deviations of water temperature differences of the day t minus day t−1 ($T_t - T_{t-1}$) for temperature ranges; white box is the mean temperature before Law 54/1997; black circle is the mean temperature after Law 54/1997; percentage of data number is shown for each temperature range and period*

artificial ecosystems has been a concern during the last decade (Mariazzi *et al.*, 1992; Barnthouse, 2000; Richkus & McLean, 2000). This is due to the fact that the water temperature directly affects many physiological processes of fish: therefore it deeply influences aspects such as those related to reproduction and growth (Burns, 1976; Dosoretz & Degani, 1987; Luksiene & Sandström, 1994; Maule & Schreck, 1990; Soderberg, 1990; Israeli-Weinstein & Kimmel, 1998). In intensive aquacultural installations the appearance of stress is associated with a great variety of environmental conditions, such as high levels of nitrogenous products, the concentration of dissolved oxygen or water temperature variations (thermal stress) (Sylvester, 1972; Scott, 1984; Gutiérrez-Estrada, 2003).

In this paper, the results show that the change of the water temperature regime had a significant influence on the growth capacity of fish, consequent to the rapid and high variations of the water temperature around the optimal physiological temperature of eel in Hidrorecursos S.A. These temperature variations can induce thermal shock which generates a stress reaction with physiological and immunological consequences (Kinkelin *et al.*, 1991). The effects of stress thermal on the biological aspects of fish have been widely studied in natural environments (Luksiene & Sandström, 1994). Nevertheless, the studies that relate the thermal stress to the levels of growth and productivity in intensive production installations in aquatic environment are practically unknown at present (Engelsma *et al.*, 2003). At the laboratory level, the relationships among the water temperature oscillation, the acclimation processes, growth and thermal stress accumulation have been analysed although the results of these studies have not been totally conclusive (Otto, 1974; Hokanson *et al.*, 1977; Cox & Countant, 1981; Konstantinov & Zdanovich, 1987; Heath *et al.*, 1993; Bennett & Beitinger, 1997). This can be due to the fact that the water temperature where the stress begins also depends on the species level of tolerance, exposure or acclimation records. This way, a typical environment of acclimatisation allows the fish to be more tolerant to high water temperatures in summer than in winter. On the other hand, an unknown aspect relating to the stress recovery when the exposure to sublethal temperatures is eliminated is to be taken into account. In this respect, the temperature when it occurs, the recovery rate and the time necessary for the full recovery are unknown (Bevelhimer & Bennett, 2000).

Therefore, the thermal stress and its influence on the growth of fish are controlled by the rate and direction of water temperature variation. A rapid and high increase of water temperature above the optimal physiological temperature implies a strong decrease of the growth capacity as a consequence of the metabolism overload and an imbalance of the oxygen transport. A rapid and high decrease of water temperature below the optimal physiological temperature is not so traumatic but

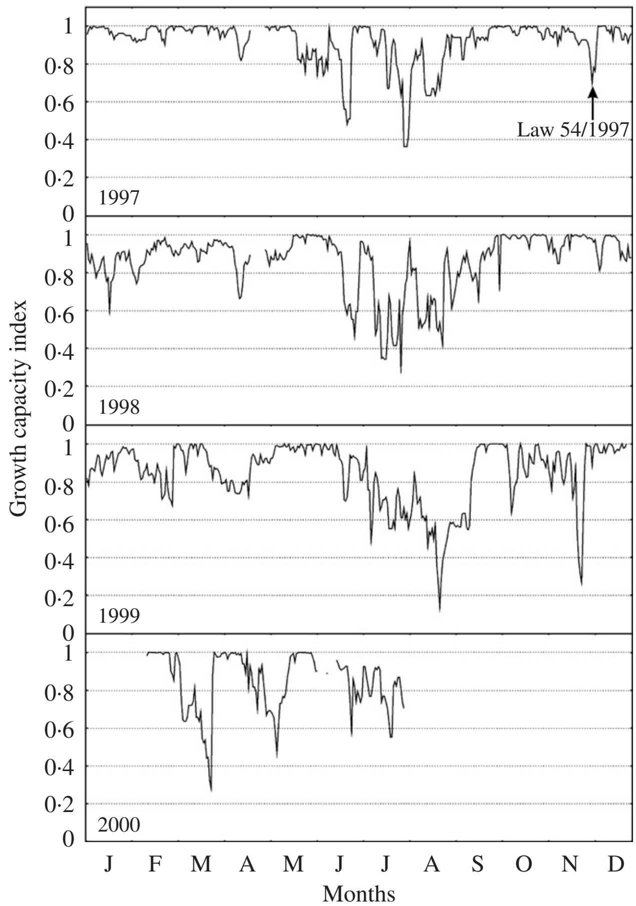


*Fig. 9. Growth capacity index variation in the rearing tanks between January of 1997 and July of 2000*

likewise implies a decrease of the growth capacity. These effects are implicit in the shape of the growth capacity function used and are reflected in the temporal variation of the $I_{GC}$.

On the other hand, the change of the water temperature regimen can be avoided by an refined adjustment of the water-mixing control, although this situation is very difficult when a manual management of the water-mixing is carried out (as in Hidrorecursos S.A.). This way, a change in the electrical Law implies that (for a same yield level) is necessary a change in the management scheme of the fishfarm which could imply additional operation costs (like a higher regulation of pumping groups) and inversion costs (like water heaters or telemetric systems) is necessary.

## 6. Conclusions

The influence of electric power market liberalisation (Law 54/1997) on fish growth capacity and water temperature regimen in a fishfarm associated with a thermal power plant has been analysed. The power plants in electrical market liberalisation generate electricity in a non-constant way. Therefore, these power plants are associated with a non-constant flow of warm water with many variations in its temperature regimes. In Hidrorecursos S.A., a decrease in the mean water temperature and an increase of the water temperature variation range were observed in the rearing tanks after introduction of the Law 54/1997. This work has shown that these temperature regimen changes implied a decrease of 6·67% in the fish growth capacity without modifying the management scheme of the production system.

In future works, the optimisation of the plant operation scheme should be analysed to avoid the decrease of the fishfarm yield. This optimisation model should include an automatic control of mixing-water that allows the operators to quickly adapt solutions to compensate water temperature changes in rearing tanks.

## Acknowledgements

This work has been possible thanks to the funding from the Spanish Ministry of Education and Culture through the Training Program for Researchers in I + D (Investigation & Development) private institutes. Likewise, we want to thank Juan Luis-Pina and Sixto-Rodríguez for the information about the generation of the Puente Nuevo thermal power plant.

## References

**Banks F E** (1994). Electricity pricing in Sweden in theory and practice. Energy Research, **16,** 519–530

**Banks F E** (1996). Economics of electricity deregulation and privatization: an introductory survey. Energy, **21,** 249–261

**Barnthouse L W** (2000). Impacts of power-plant cooling system on estuarine fish populations: the Hudson River after 25 years. Environmental Science and Policy, **3,** 341–348

**Bennett W A; Beitinger T L** (1997). Temperature tolerance of the sheppshead minnow, Cyprinodon variegatus. Copeia, **1997,** 77–87

**Bevelhimer M; Bennett W** (2000). Assessing cumulative thermal stress in fish during chronic intermittent exposure to high temperatures. Environmental Science and Policy, **3,** 211–216

**Bloomfield P** (1976). Fourier Analysis of Time Series: An Introduction. John Wiley & Sons, New York

**BOE** (1997). Ley 54/1997, de 27 de noviembre, del Sector Eléctrico, núm. 285: 35097–35126. [Law 54/1997 of the Electrical Sector.] Spanish Official Bulletin (BOE), Madrid

**Burns J R** (1976). The reproductive cycle and its environmental control in the pumpkinseed, Lepomis gibbosus (Pisces Centrarchidae). Copeia, **3,** 449–455

**Coll J** (1991). Acuicultura Marina Animal. [Animal Marine Aquiculture]. Mundi-Prensa, Madrid

**Cox D K; Countant C C** (1981). Growth dynamics of juvenile striped bass as a function of temperature and ration. Transactions of the American Fishery Society, **110,** 226–238

**Dosoretz C; Degani G** (1987). Effect of fat rich diet and temperature on growth and body composition of european eels (*Anguilla anguilla*). Comparative Biochemistry and Physiology, **87A,** 733–736

**Engelsma M Y; Hougee S; Nap D; Hofenk M; Rombout J H W M; van Muiswinkel W B; Lidy B M; Kemenade V V** (2003). Multiple acute temperature stress affects leucocyte populations and antibody responses in common carp, *Cyprinus carpio* L. Fish and Shellfish Immunology, **15,** 397–410

**Gutiérrez-Estrada J C** (2003). Desarrollo y evaluación de modelos para la toma de decisiones. Caracterización de la producción de anguilas (*Anguilla anguilla* L.) en sistemas intensivos. [Development and evaluation of management models. Characterisation of the eels (*Anguilla anguilla* L.) yield in intensive systems.] PhD Thesis, Escuela Técnica Superior de Ingenieros Agrónomos y de Montes, Universidad de Córdoba, Spain.

**Gutiérrez-Estrada J C; De-Pedro E; López-Luque R; Pulido-Calvo I** (2004). Influencia del mercado liberalizado de la energía eléctrica sobre instalaciones de acuicultura intensive asociadas a efluentes de refrigeración. [Effect of the liberalised electric market on intensive aquiculture plants associated with cooling effluents]. Información Técnica Económica Agraria (ITEA), **100A,** 89–106

**Heath A G; Turner B J; Davis W P** (1993). Temperature preferences and tolerances of three fish species inhabiting hyperthermal ponds on mangrove islands. Hydrobiologia, **259,** 47–53

**Hokanson K E F; Kleiner C F; Thorslund T W** (1977). Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout, Salmo gairdneri. Journal of the Fisheries Research Board of Canada, **34,** 639–648

**Israeli-Weinstein D; Kimmel E** (1998). Behavioral response of carp (Cyprinus carpio) to ammonia stress. Aquaculture, **165,** 81–93

**Kinkelin P; Michel C; Ghittino P** (1991). Tratado de las enfermedades de los peces. [Handbook of the fish diseases]. Acribia S.A., Zaragoza (Spain)

**Konstantivov A S; Zdanovich V V** (1987). Peculiarities of fish growth in relation to temperature fluctuation. Journal of Ichthyologia, **26,** 65–74

**Lo K M; Chen C S; Clayton J T; Adrian D D** (1975). Simulation of temperature and moisture changes in wheat storage due to weather variability. Journal of Agricultural Engineering Research, **20**(1), 47–53

**Luksiene D; Sandström O** (1994). Reproductive disturbance in a roach (Rutilus rutilus) population affected by cooling water discharge. Journal of Fish Biology, **45,** 613–625

**Lund J W** (1986). Agriculture and aquaculture applications of geothermal energy. Geothermics, **15,** 415–420

**Lund J W; Freeston D H; Boyd T L** (2005). Direct application of geothermal energy: 2005 Worldwide review. Geothermics, **34,** 691–727

**Mariazzi A A; Donadelli J L; Arenas P; DiSiervi M A; Bonetto C** (1992). Impact of a nuclear power plant on water quality of Embalse del Río Tercero reservoir (Córdoba, Argentina). Hydrobiologia, **246,** 129–140

**Maule A G; Schreck C B** (1990). Changes in numbers of leukocytes in immune organs of juvenile Coho salmon after acute stress or cortisol treatment. Journal of Aquatic Animal Health, **2,** 298–304

**Nash C E; Paulsen C L** (1981). Water quality changes relevant to heated effluents and intensive aquaculture. Proceedings of the World Symposium on Aquaculture 'Heated Effluents and Recirculation System', Berlin.

**Otnes R K; Enochson L** (1978). Applied Time Series Analysis. Wiley Interscience, New York

**Otto R G** (1974). The effects of acclimation to cyclic thermal regimes on heat tolerance of the western mosquitofish. Transactions of the American Fisheries Society, **103,** 331–335

**Palackova J; Gajdusek S; Jirasek J; Fasaic K** (1990). Effect of sublethal concentration of ammonia in water on changes in and correlations of some biochemical indices in carp fry (*Cyprinus carpio* L.). Ichthyologia, **22,** 57–67

**Park H H** (1998). Analysis and prediction of walleye pollock (*Theragra chalcogramma*) landings in Korea by time series analysis. Fisheries Research, **38,** 1–7

**Richkus W A; McLean R** (2000). Historical overview of the efficacy of two decades of power plant fisheries impact assessment activities in Chesapeake Bay. Environmental Science and Policy, **3,** 283–293

**Scott N R** (1984). Livestock buildings and equipment: A review. Journal of Agricultural Engineering Research, **29**(2), 93–114

**Soderberg R W** (1990). Temperature effects on the growth of blue tilapia in intensive aquaculture. Progressive Fish-Culturist, **52,** 155–157

**Sylvester J R** (1972). Possible effects of thermal effluents on fish: a review. Environmental Pollution, **3,** 205–215

**Veil A J** (1998). The potential for effluent trading in the energy industries. Environmental Science and Policy, **1,** 39–49