Arch. Pol. Fish.	Archives of Polish Fisheries	Vol. 13	Fasc. 1	91-98	2005

CLIMATE WARMING AND THE GROWTH OF WARM WATER FISH IN PONDS IN THE TEMPERATE ZONE

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ABSTRACT. In the temperate zone, climate warming improves the environmental conditions of warm water fish in many ways thus stimulating their growth and yield. Warming was observed in fishponds in the mid 1980s when seasonal sums of water temperature above 14°C, *i.e.* the temperature effective for carp, *Cyprinus carpio* growth, frequently exceeded the long-term average sum. There was considerable variability in the annual sums of temperature effective for carp growth with a decreasing tendency in the 1958-1980 period and an increasing tendency in the 1980-2003 period. The long-term distribution of the yield of three-year-old carp follows the sums of the effective temperature except in very warm seasons when the empirical yields were below those computed from the model. This implies that it is necessary to introduce into computations the upper temperature of the thermal limit effective for carp growth, which seems to be an average diel temperature of about 25°C. This paper presents the quantitative differentiation in thermal conditions of carp growth between Poland, France, and Bohemia.

Key words: CLIMATE WARMING, EFFECTIVE TEMPERATURE, COMMON CARP (*CYPRINUS CARPIO*)

INTRODUCTION

Many attempts have been made to determine and forecast the impact of climate warming on different domains of life. In the temperate climate, the importance of considering the warming effect on fish culture stems from the limitation of the growth and yield of warm water fish by thermal conditions during a considerable part of the year. An increase in the water temperature in ponds improves environmental conditions in many ways and stimulates growth in these fish species. At the same time, the increasing frequency of extreme meteorological events results in the great differentiation in thermal conditions in shallow ponds, which then display an increase of diel amplitude and vertical stratification (Szumiec 1984, 1986) as well as diel and seasonal water temperature fluctuations (Szumiec 1979, Augustyn 2004). This causes variations in fish growth and yield.

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The effect of climate warming on warm water fish culture is presented using the example of carp, *Cyprinus carpio* L. It is assumed that thermal demands are representative for the warm water fish species cultivated in polyculture with carp, such as grass carp, *Ctenopharyngodon idella* (Val.), silver carp, *Hypophthalmichthys moltrix* (Val.), and bighead carp, *Aristichthys nobilis* (Rich.) (Antalfi and Tölg 1975, Brylińska 1991). The warming effect is presented by data derived from results of long-term monitoring of water temperature in ponds and of the empirical and theoretical yield of three-year-old carp. The latter was computed from the stochastic-deterministic model based on, among other factors, the cumulative sum of the water temperature effective for carp growth, *i.e.*, above 14°C. The temperature-related growth of carp biomass in ponds was determined empirically (Szumiec and Szumiec 1979) and verified repeatedly (Szumiec 1990, 1997, Szumiec and Maliczak 1995). The energy of food ingested by carp at temperatures below 14°C is utilized in processes to maintain fish metabolism (Brett 1970, Smith 1989).

The impact of local European climates on the thermal conditions of carp culture was surveyed by comparing the results obtained in southern Poland, southern France, and southern Bohemia.

METHOD

Water temperature was monitored in ponds of the Gołysz Institute of Ichthyobiology and Aquaculture of the Polish Academy of Sciences (ΦN = 49°52‘, λE = 18°48’) from 1958 to 2003. The area of the ponds was a few hectares each, and their average depth was about 1.2 m. The water temperature has been measured at 07:00, 13:00, and 19:00 daily since 1958 and has been recorded since 1996. The effective water temperature in ponds was computed from the diurnal average temperature. The yield of the three-year-old carp ($C_{2\text{-}3}$) was obtained in the Gołysz ponds in 1980-2003, the simulated yield Y ($C_{2\text{-}3}$, kg ha^{-1}) was computed from the deterministic model set up on the product of the sums of the effective water temperature $\Sigma\tau_e$ (°C), on the percent of protein in feeds v, (assumed as the dimensionless indicator) and on the initial unit body weight G_0 (g fish^{-1}, Szumiec 1995, 1997, 1998):

$$Y(C_{2\text{-}3}) = G_0 + 0.018258 \times (\Sigma\tau_e^{\,1.6864} \times q^{15} \times G_0^{\,1.67437}) \times d$$

Fish fed wheat were taken into consideration. Exponents of $\Sigma\tau_e$ and of G_0 are valid within the limits of 600 – 1000°C and 200 – 450 g fish^{-1}, and stocking density between 2000-2500 fish ha^{-1} corresponding to the limits of the empirical yields.

The seasonal cumulative sums of the water temperature effective for carp growth in ponds of the Plateau de La Dombes (France) in 1988-1990 (Martin-Goubier 1991) and in ponds of Hluboka (South Bohemia) in 1984-1985 (Bednarova et al. 1986) were compared with thermal conditions in Polish ponds. All pond centers are situated in sub-mountainous regions.

RESULTS AND DISCUSSION

In the climate of southern Poland, the water temperature in ponds increases to 14°C in the first decade of May and decreases below this temperature in the last decade of September, which limits the season of carp growth to about five months (Szumiec 1984). The average number of days with optimal diel temperature in ponds, *i.e.*, above 19°C (Spet 1967), in the 1958-1980 period was 71, while in the 1981-2003 period it increased to 90. Standard deviations of the decade sums of effective temperature in ponds indicated with about 67% probability the variation in the period of carp growth from thirteen decades, with an average water temperature constantly below 19°C, to seventeen decades with 116 thermally optimal days (Fig. 1).

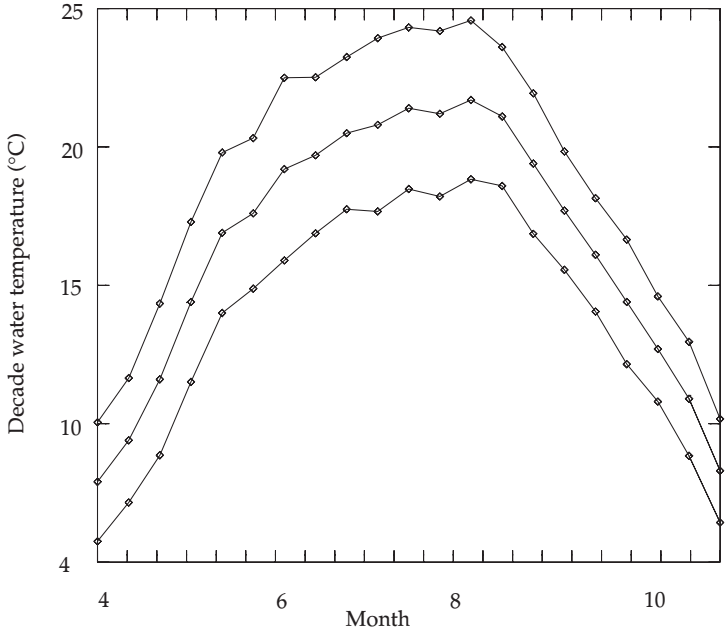

Fig. 1. Average 10-day water temperature in ponds, and temperature increased and lowered by standard deviations.

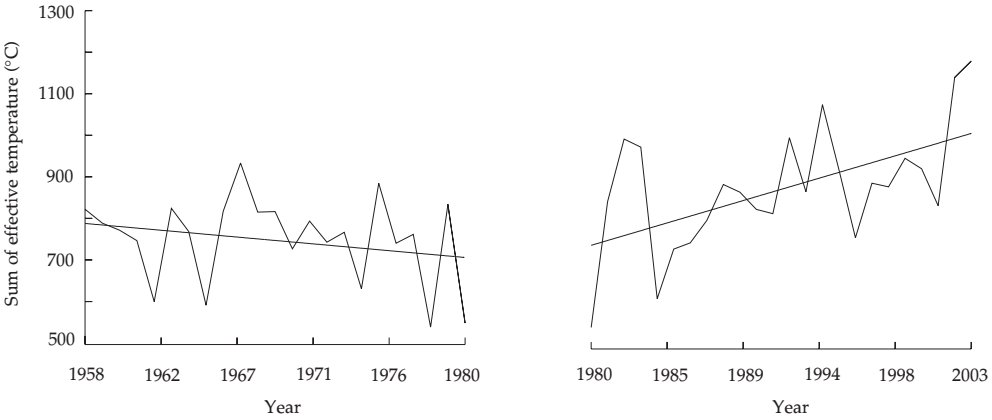

Fig. 2. Annual sums of water temperature effective for carp growth and tendencies in the 1958-1980 and 1980-2003 periods.

The annual sums of water temperature effective for carp growth show considerable inter-annual variability with a decreasing tendency in the 1958-1980 period and a distinctly increasing tendency from 1980 to 2003 (Fig. 2). Before the 1980s, very cold seasons with a sum of effective temperatures below 650°C occurred five times, and an absolute minimum seasonal sum of effective temperature of 537°C in the ponds was noted in 1978. The beginning of pond warming occurred in the mid 1980s when the seasonal sums of effective temperature exceeded the long-term average of 818°C. A great increase occurred in 2002-2003 with an absolute maximum seasonal effective sum of 1189°C in 2003 (Fig. 3). In the coldest season of 1978, the average diel water temperature exceeded 19°C only during a few days, while in the warmest season of 2003 it was maintained for four months (Szumiec 1979, Augustyn 2004). In the coldest season in 1978, the yield of the three-year-old carp was lower by over 50% than in the warmest season in 2003.

Good accordance between the empirical and theoretical yield of the three-year-old carp was found in the Gołysz ponds except in the very warm seasons when the empirical yield was evidently below the simulated yield (Fig. 4). In comparison with the Gołysz ponds, the annual cumulative sum of the effective temperature in the La Dombes ponds was higher by 200°C, and the period of carp growth was longer by about three weeks. In the Hluboka ponds, the sum was lower by about 100°C, and the period was shorter by about 10 days (Fig. 5).

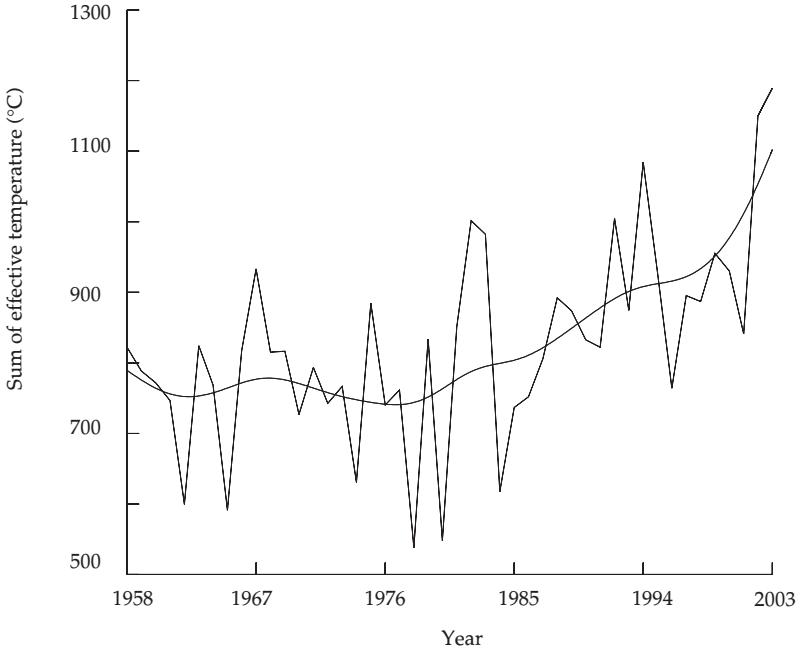

Fig. 3. Annual sums of water temperature effective for carp growth smoothed by distance weighted least squares.

The increasing tendency in the sums of the effective temperature in ponds observed in the mid 1980s confirmed that the warming effect was maintained. In the temperate zone it stimulates a significant increase in the yield of warm water fish. However, in the very warm seasons the empirical carp yield was below the simulated yield. This seems to suggest the necessity of considering the upper temperature in the thermal limit effective for carp growth. Since in warm seasons the frequency of days with an average diel temperature in ponds above 25°C increased significantly, this might suggest that this is the upper thermal limit of carp biomass growth. At an average temperature of 25°C, the diel maximum temperature in ponds usually exceeds 28°C, which might stimulate some undesirable effects in the pond environment and in the fish. In such warm periods, the dense suspensions in pond water limit the penetration of solar radiation into the deeper layers causing unfavorable oxygen conditions and decreasing temperature. Fish moving to the bottom water layer are stressed by the great difference between their body temperature and the ambient temperature; this might involve disturbances in oxygen exchange between fish gills and the water (Fry 1967).

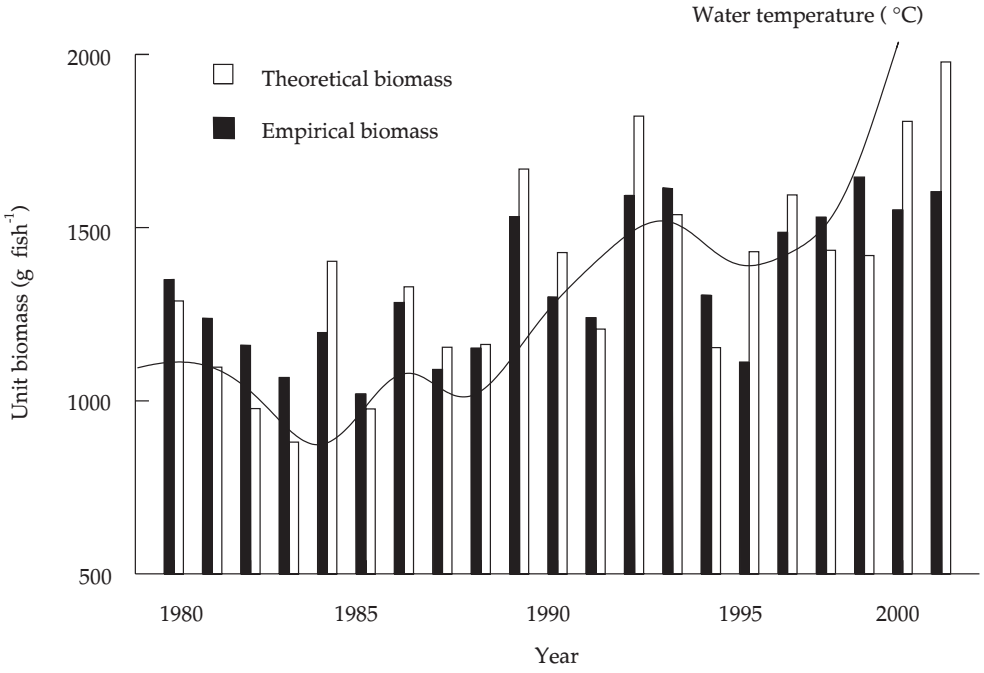

Fig. 4. Empirical and theoretical biomass of three-year-old carp and the smoothed annual sums of the effective water temperature in Gołysz ponds in the 1980-2003 period.

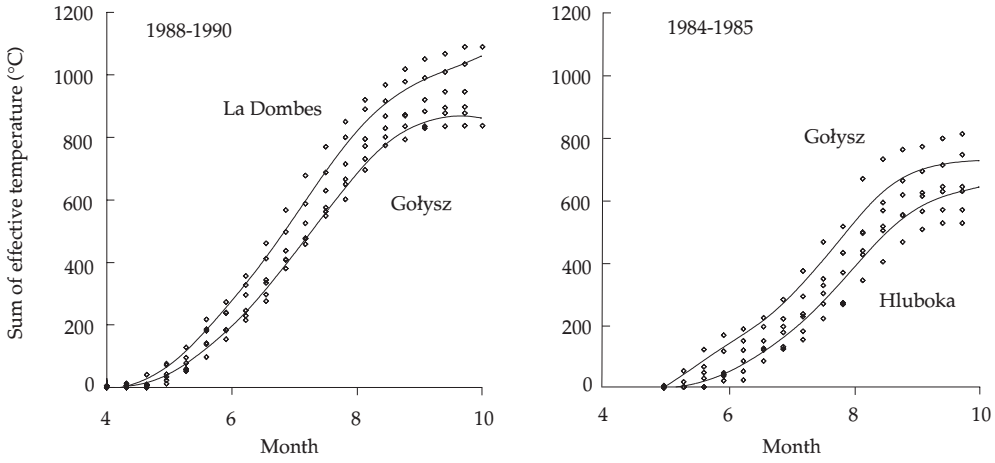

Fig. 5. Cumulative sums of the effective temperature in La Dombes and Gołysz ponds, and in Hluboka and Gołysz ponds smoothed by distance weighted least squares.

By increasing sum of the temperature effective for fish growth and lengthening the period of their growth, climate warming significantly stimulates the production of warm water fish in thermally less favorable parts of Europe.

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Received – 12 October 2004

Accepted – 11 February 2005

STRESZCZENIE

OCIEPLENIE KLIMATU I WZROST RYB CIEPŁOLUBNYCH W STAWACH STREFY UMIARKOWANEJ

Wpływ ocieplenia klimatu na wzrost ryb ciepłolubnych w stawach przedstawiono na przykładzie wieloletniego rozkładu sum temperatury wody efektywnej dla wzrostu karpia (wyższej od 14°C) oraz empirycznej i teoretycznej produkcji karpia konsumpcyjnego, obliczonej przy uwzględnieniu, m.in., sumy temperatury efektywnej. Odchylenie standardowe średniej dekadowej temperatury wody w stawach wykazało, że w warunkach klimatycznych południowej Polski okres z temperaturą efektywną może się wahać od 13 do 17 dekad (rys. 1). Roczne sumy temperatury efektywnej wykazały malejącą tendencję w latach 1958-1980 i wzrostową w latach 1981-2003, charakteryzowały się też znacznymi wahaniami między poszczególnymi latami (rys. 2). Największy wzrost sum temperatury efektywnej pojawił się w 2002 roku, z dalszym niewielkim wzrostem w 2003 (rys. 3). W najchłodniejszym sezonie 1978 średnia dobowa temperatura w stawach osiągnęła optymalny przedział dla wzrostu karpia (powyżej 19°C) tylko w czasie kilku dni, podczas gdy w najcieplejszym sezonie 2003 utrzymywała się przez około cztery miesiące. Wynikiem tego produkcja karpia w sezonie 1978 była niższa o ponad 50% w porównaniu z sezonem 2003. W większości lat końcowa biomasa trzyletniego karpia na ogół kształtowała się zgodnie z biomasą teoretyczną, wyjątkiem były bardzo ciepłe sezony, kiedy empiryczna biomasa ryb była wyraźnie niższa od biomasy teoretycznej (rys. 4). Zdaje się to wskazywać na potrzebę wprowadzenia do przedziału temperatury efektywnej górnego progu. Wyraźny wzrost częstotliwości dni ze średnią dobową temperaturą wody wyższą od 25°C w czasie ciepłych sezonów może wskazywać, iż jest ona górnym progiem przedziału temperatury efektywnej dla wzrostu karpia.

Ocenę przestrzennych zmian warunków cieplnych chowu karpia w Europie przeprowadzono dla stawów położonych w południowej Francji i w południowych Czechach. W porównaniu z południową Polską stawy francuskie charakteryzuje wyższa o około 200°C roczna suma i dłuższy o 3 tygodnie okres z temperaturą efektywną, podczas gdy stawy czeskie niższa o około 100°C suma temperatury efektywnej i krótszy o około 10 dni okres efektywny dla wzrostu karpia (rys. 5). Wyniki potwierdzają tendencję do ocieplania się klimatu, co w strefie umiarkowanej umożliwia wzrost produkcji ryb ciepłolubnych.