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A MANAGEMENT MODEL OF CARP GROWTH IN PONDS

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A B S T R A C T. The model aims at facilitating the management of the semi-intensive and intensive carp culture in ponds situated in the temperate climate. It quantifies the cumulated effect of basic elements of carp culture techniques, like the fish density, the initial body mass, the protein content in feeds and the effective water temperature in ponds (higher than 14^{o}C) on individual growth and yield of one-, two- and three-year-old carp (C_{0-1}, C_{1-2}, C_{2-3}). The model enables adaptation of carp culture technology to the actual market demands and helps in optimising the production, predicting the final results and determining the density of C_{0-1} and C_{1-2} during the season. It is not applicable in the extensive culture.

Key words: CARP, PONDS, MODELLING, TEMPERATURE, AQUACULTURE TECHNIQUES

INTRODUCTION

Models of fish growth are helpful instruments in fish culture management and should be widely applied. A great number of pond aquaculture models was reviewed by Van Dam (1990). The majority of them consider the mechanisms of fish growth and development, and the energy flux through the trophic chain in the ecosystem (inter alia Jērgensen 1994, Klekowski & Menshutkin 1996). High flexibility is the advantage of mechanistic models in the wide range of pond ecosystem changes. Consequently, these models possess high predictive ability. Their disadvantage is difficult application in the practice.

In the managed fish ponds, the impact of the introduced culturing technique makes the system even more complex (e. g. Přikryl 1993, Tai et al. 1994), however, the role of the semi-intensive and intensive methods in the process of fish growth enables to consider them to be the basic forcing functions. In the temperate climate, thermal conditions limit the growth of warm water fish during the greater part of the year, and they should be considered as well. Such a combination of temperature, fish density and feed was presented as early as 1964 by Backiel.

Quantification of the effects of particular carp culture systems and of thermal conditions on the fish growth makes it possible to predict, in certain limits, the production results. The only unpredictable forcing function is the water temperature, but the long-time data on water temperature in Gołysz ponds enabled determination of the average, cool and warm seasons, covering about 70% of the whole limit of the temperature variation in Polish ponds. It can be assumed that in most parts of Central Europe, temperature in ponds varies within these limits. An attempt to foresee, at the beginning of May, thermal conditions in ponds in the forthcoming season was worked out by Szumiec (1996).

METHODS

The model is presented in form of equations and graphs. It has been worked out based on long-time results of experiments on carp production intensification, carried out in the experimental ponds of the Institute of Ichthyobiology and Aquaculture of the Polish Academy of Sc. at Gołysz (Szumiec 1985a, 1985b, Szumiec 1988, Szumiec 1993). The growth of the individual body mass, and the yield of one-, two- and three-year old carp (C_{0-1}, C_{1-2}, and C_{2-3}), was computed as the function of the cumulated decade or fortnight sums of water temperature in ponds, effective for carp growth (higher than 14^{o}C), final carp density in ponds, ie. stated during pond harvesting in autumn, the feed nourishing value, determined by the protein content, and the initial fish body mass in case of C_{1-2}, and C_{2-3}. Simulated values were computed for the limits of densities and initial body masses most usual in Polish carp culture.

Carp body mass was measured as a rule every ten days or every fortnight during the farming season (April – October). The number of measured fish was equal to about 50 – 100 C_{0-1}, 50 C_{1-2}, and 30 C_{2-3}. Fingerlings and one-year old carp were fed mostly pellets of different protein content, supplied by automatic and demand feeders, C_{2-3} was fed mostly wheat. Optimal feed portion, depending on fish age, water temperature, oxygenation, and water quality, were calculated. The food resources in ponds were stimulated by mineral-organic fertilization. Water temperature was measured and/or recorded since 1958, the average diel values were taken into account (Szumiec 1990). The growth of the individual carp body mass and the production were calculated in the season, with the average sum of the effective temperature (799) in warm and cool seasons, determined by adding or substracting the standard deviation (±118) from the average value.

The model was calibrated using regression equations and verified by the Kolmogorov-Smirnov test (Szumiec 1990, 1993, 1995b, 1997). Correlation coefficients between empirical and theoretical values oscilated around 0.95, significance level around 0.96.

The model was set up for monoculture of carp hybrids of the third Gołysz line with the Hungarian W and T lines (Szumiec 1988), then it was tested for some other carp hybrids and lines, for polyculture of carp with thew silver carp and the grass carp or the big head, and for a wide range of fish densities (Szumiec 1993). It was also tested in a very high temperature in 1994, and in ponds supplied with water of different chemical composition (Augustyn et al. 1994). Testing pointed to high agreement between theoretical and empirical values (c. coeff. > 0.9).

RESULTS

ONE – YEAR – OLD CARP C_{0-1}

Growth of the individual body mass G_{0-1} is defined by

$$G_{0-1} = 5.03622 \cdot 10^{-5} (\Sigma \vartheta_e)^{2.09744} \cdot 0.999988^{d} \cdot ln\ (v)^{0.56656} \qquad (1)$$

where $\Sigma\vartheta_\varepsilon$ is the sum of water temperature effective for carp growth (> 14°C) in the considered period, d is the fish density (fish/ha) at the end of the farming season, v is the percentage of protein content in feed (Szumiec 1993).

In the temperate climate, ponds are usually stocked with fry in the third decade of May or first decade of June, when the water temperature reaches about 18°C. The results obtained from equation (1) show that at the end of the season of average thermal conditions, the individual body mass of C_{0-1} fed 10% protein feed varies from about 35 to about 65 g/fish, when the final fish density varies from 25000 to 75000 fish/ha respectively (Fig. 1). To obtain body mass of C_1 higher than 65 g/fish, lower stock densities are required, or feeds of higher protein values; 20 and/or 30% protein pellets enable to maintain the final individual body mass raising respectively the initial stock d_0 by about 40000 and 80000 fry/ha (Fig. 1). Densities d_0 are calculated taking into account the average mortality rates of C_{0-1} and C_{1-2} equal to circa 50 and 20%.

Increase of the stock density elevates the yield only to a certain limit, because the equation (1) multiplied by d has its maximum by about 80000 fish/ha. It means that at higher final fry densities, the yield does not increase; it slightly decreases even when higher protein feeds are applied (Fig. 2). In the average temperature and in the considered limits of d and v, the yield of C_1 varies from about 1600 to 3300 kg/ha.

Warm and cool seasons elevate or lower the individual growth of C_{0-1} and the yield by about ±30% from the normal. In the extreme cold seasons 1978 and 1980, when

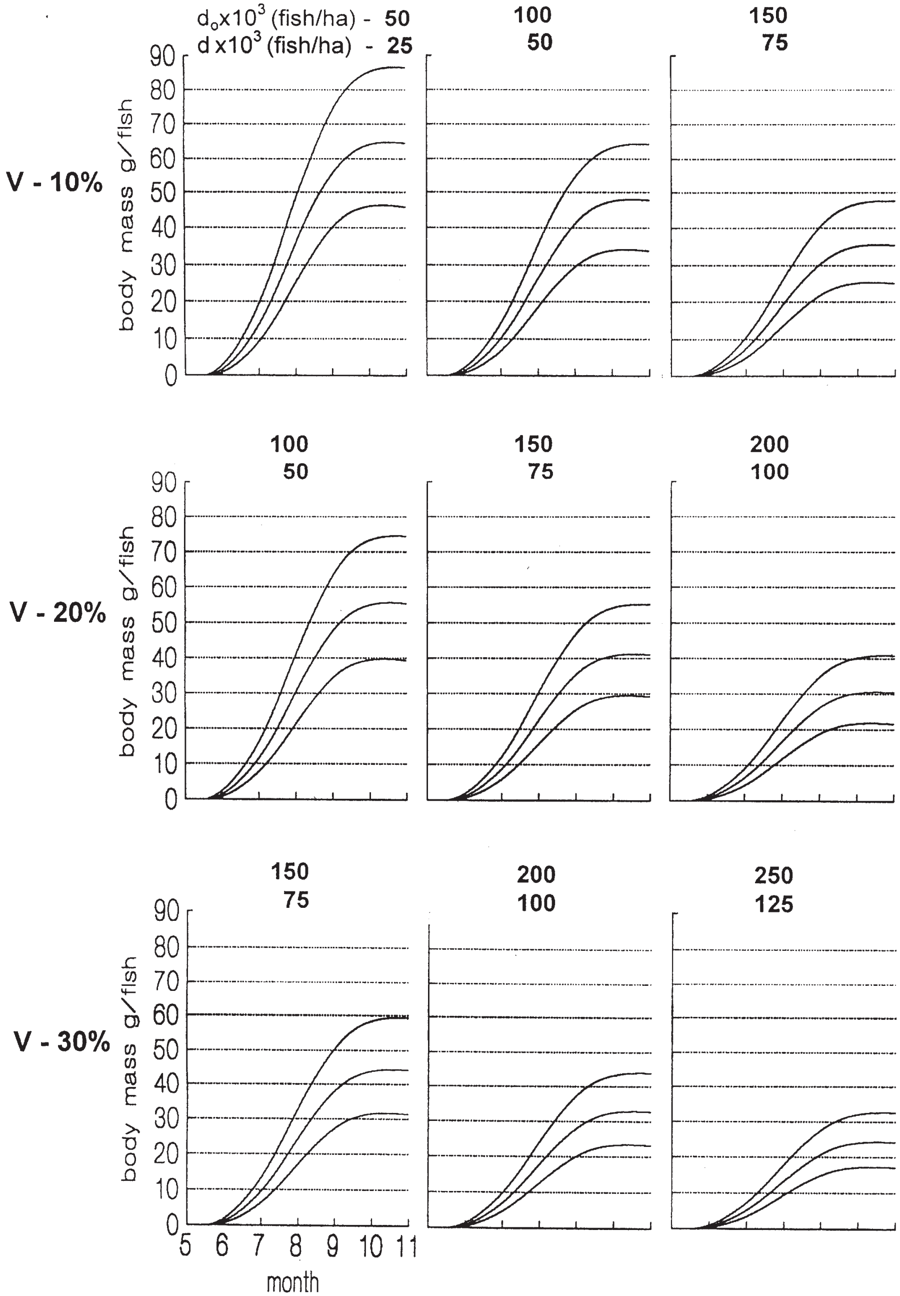

Fig. 1. Simulated growth of individual body mass of carp fingerling C_{0-1} cultured in different densities d, fed different protein v feed, in cool, average and warm seasons (lower, middle, upper curves).

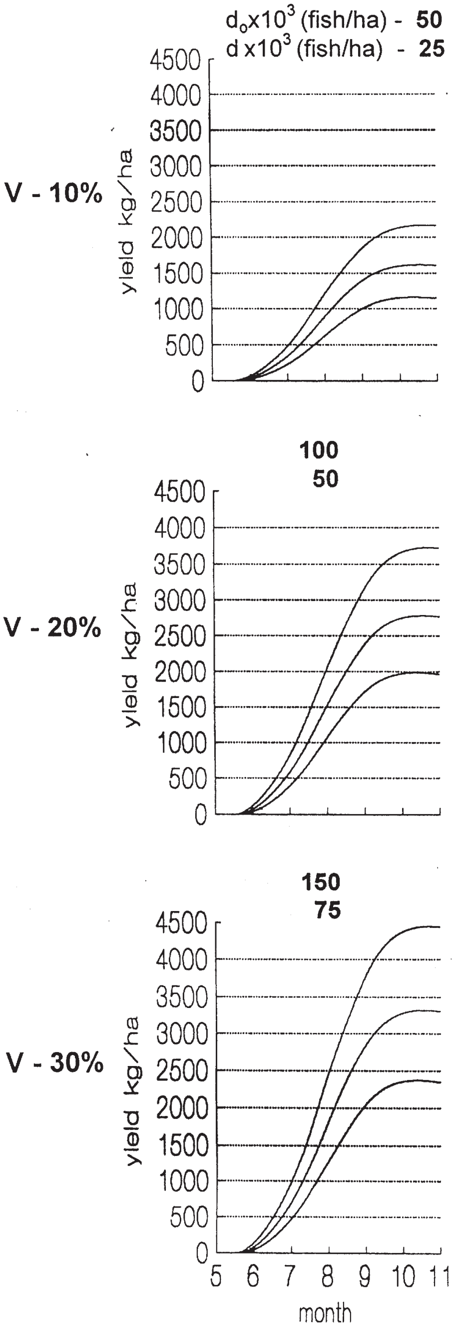

Fig. 2. Simulated yield of C_{0-1}.

$\Sigma\vartheta_\varepsilon$ were equal to about 500, yield amounted only to half of that obtained in the extremely warm season 1994, when $\Sigma\vartheta_e = 1100^oC$.

TWO – YEAR-OLD CARP C_{1-2}

Growth of body mass G_{1-2} is expresses by

$$G_{1-2} = G_0 + 1.5381 \cdot (\Sigma\vartheta_e)^{1.14239} \cdot d^{-0.55190} \cdot v^{0.27330} \cdot G_0^{0.51793} \quad (2)$$

where G_0 is the initial body mass (Szumiec 1995a). G_0 distinctly affects the growth of the individual body mass and the production. In the season of average thermal conditions, variation of G_0 from 20 to 50 g/fish caused G_2 to vary from above 180 to 300 g/fish when the fish were fed 10% protein pellets, stocked at the density of 15000 and harvested at the density of 12000 fish/ha (Fig. 3). The corresponding yield varied from circa 2100 to 3600 kg/ha (Fig. 4). Increasing both the protein content in pellets to 20 and the fish density to 20000 fish/ha changed G_2 to about 160 and to 280 g/fish, when G_0 was equal to 20 and to 50 g/fish respectively (Fig. 3). The corresponding yield varied from about 3300 to 5600 kg/ha (Fig. 4).

Cool and warm seasons deviate the individual growth and the yield from the usual by about ±15%.

THREE – YEAR – OLD CARP C_{2-3}

Growth of carp in the third year of its life is expressed by (Szumiec 1995b)

$$G_{2-3} = G_0 + 0.018258 \cdot (\Sigma\vartheta_e)^{1.16864} \cdot 1.00789^{v} \cdot ln(G_0)^{1.67437} \quad (3)$$

The equation (3) does not comprise the term of fish density because in the considered limit of 1500 – 2500 C_{2-3}/ha, the density did not affect the fish growth.

Three–year–old carp is mostly fed wheat or other cereals containing about 10% protein. Applying such feeds, after the season of normal thermal conditions, carp reaches above 1 kg only when G_0 is equal to about 250 g/fish; in favourable thermal conditions this is possible when G_0 is equal to 200 g/fish, in a cool season only when G_0 is not lower than 350 g/fish (Fig. 5). In a normal season, the increase of the protein content in feed to 20%, or the decrease of the fish density in ponds by some hundreds fish, elevate the individual carp mass by about 60 and 100 g/fish (Fig. 5), and the yield by

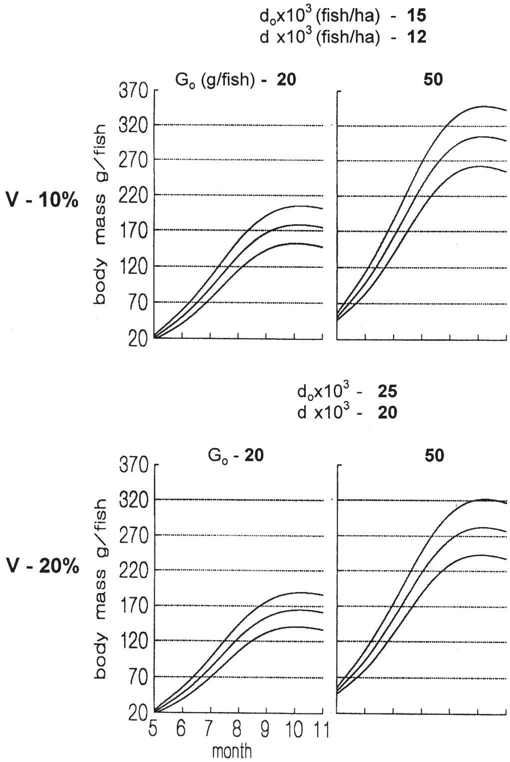

Fig. 3. Simulated growth of individual body mass of 2-year-old carp C_{1-2} cultured in 2 different densities d, 2 different initial masses G_0, and fed 2 different protein v feeds, in cool, average and warm seasons.

90 and 120 kg/ha for G_0 equal to 150 to 350 g/fish respectively (Fig. 6).

In warm and cool season, the body mass and the yield of C_3 deviate by about ±13% from the usual levels.

MODEL TESTING

Model has been tested many times in the wide limits of $\Sigma\vartheta_e$, d, v and G_0 (Szumiec 1993, 1995), and in most cases showed a good flexibility of the growth of C_{0-1}, C_{1-2} and C_{2-3} during the season (Fig. 7A, 8A, 9) Distinctly higher final theoretical masses pointed to mortality in the late season, when low temperature made the fish unable to grow according to their reduced density (Fig. 7B, 8B). Differences between theoretical and empirical values might have also been caused by some other limitations, like unfavourable environmental conditions and/or fish diseases, and/or invasion of some parasites. Higher empirical masses than the theoretical ones might have resulted

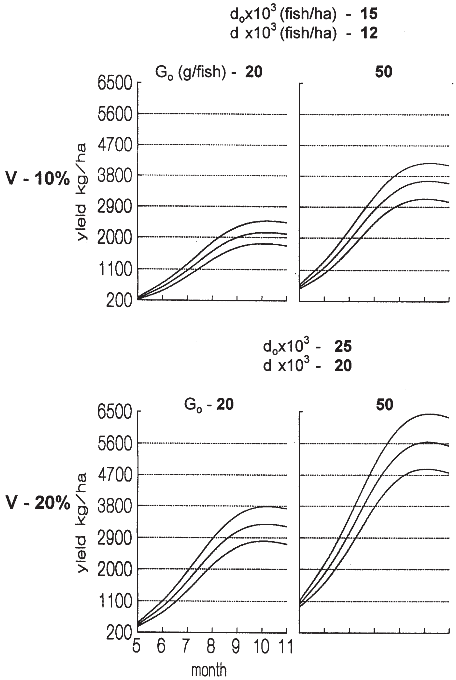

Fig. 4. Simulated yield of C_{1-2}

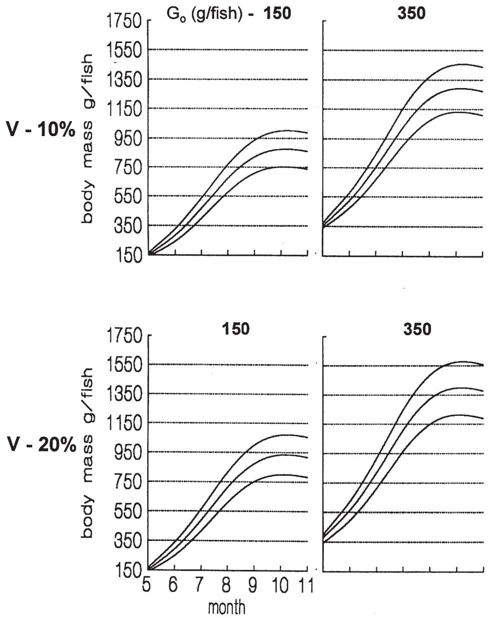

Fig. 5. Simulated growth of individual body mass of 3-year-old carp C_{2-3} cultured in densities from 1500 to 2500 fish/ha, of different initial masses

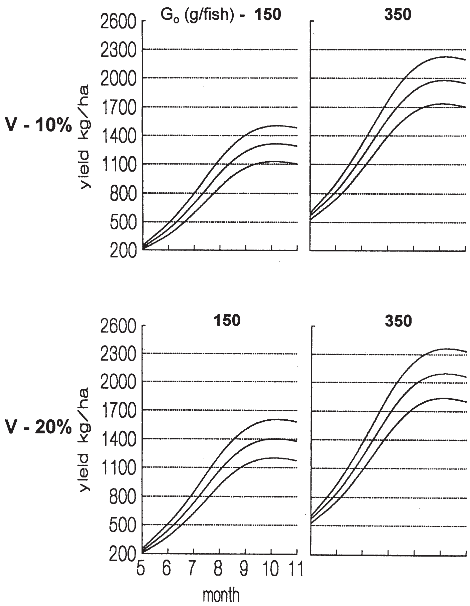

Fig. 6. Simulated yield of C_{2-3}.

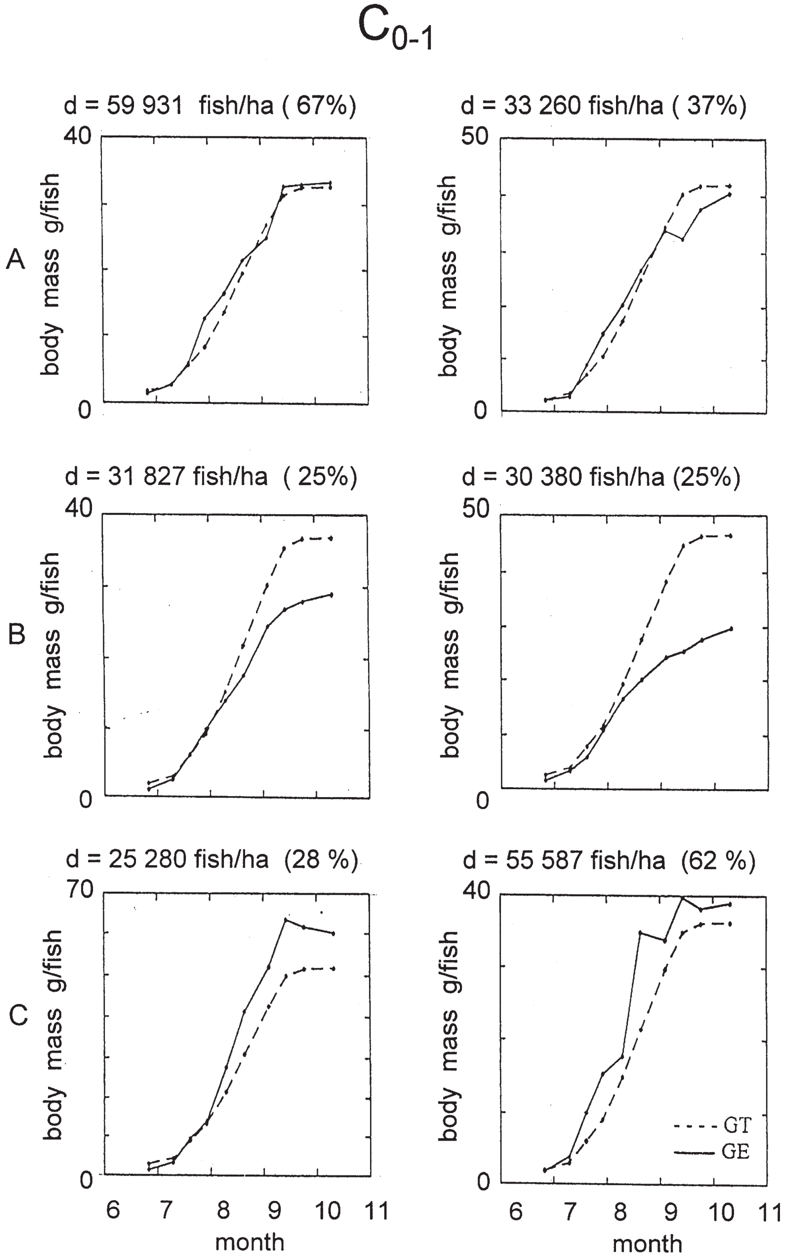

Fig. 7. Theoretical GT and empirical GE growth of body mass of C_{0-1} in ponds with different carp densities d and different survival rates (%). Examples of: A – high agreement between empirical and theoretical values, B – too low empirical masses caused by late fish mortality, C – too high empirical masses probably caused by erroneous fish counting.

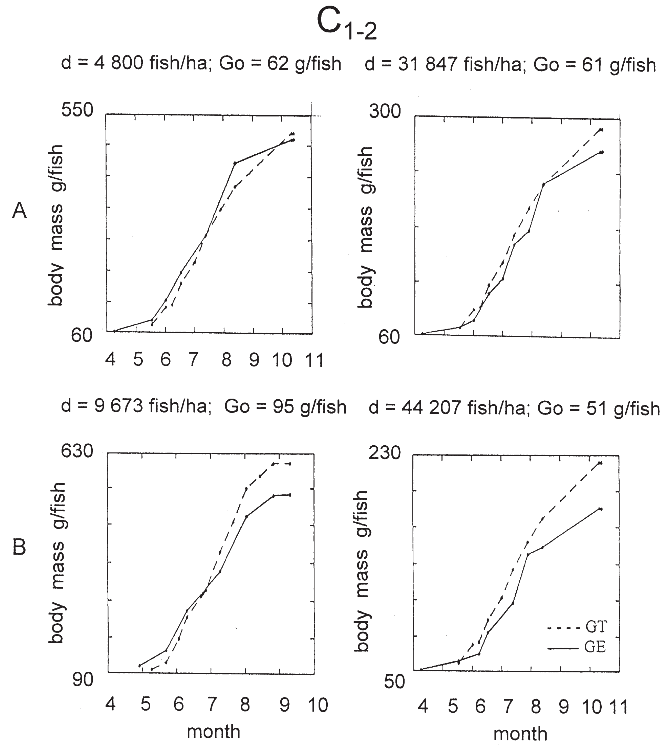

Fig. 8. Theoretical GT and empirical GE growth of C_{1-2}.

from erroneous fish counting during the pond stocking or harvesting (Fig. 7C).

The model of yield of C_{2-3} was tested only on the results obtained during autumnal harvest of productive ponds. Their water surface area was several times greater, and stock density lower (1100 – 1350 fish/ha) than the values considered in the model. This low density caused the v value in the equation (3) to raise up to 20% protein, despite the fact that the fish were fed wheat. In most of the 10 ponds, good coincidencee between simulated and measured carp masses was observed (Fig. 9). The average difference between the empirical and theoretical masses amounted to 28 g/fish, ie. to about 2% of the average fish mass.

DISCUSSION

The management model facilitates carp culture, quantifying the effect of semi–intensive or intensive techniques on the carp growth in ponds and their yield in the temperate climate and in different limits of fish density, protein content in feed, and initial body

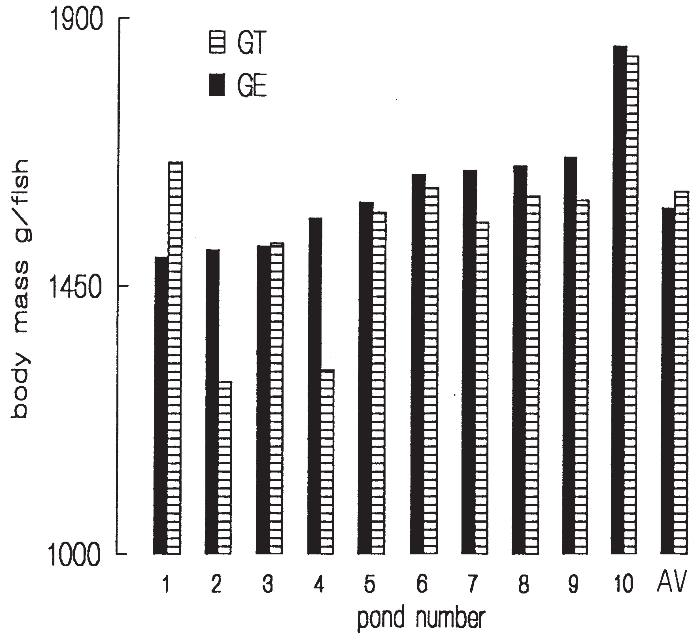

Fig. 9. Theoretical GT and empirical GE final body masses of $C_{2\text{-}3}$ obtained in 10 productive ponds. AV – average mass, d varied from 1000 to 1500 fish/ha, G_0 from 230 to 500 g/fish.

mass. Its objective is to optimise carp culture adapting the fish culture technology to the present market demands. The model equations allow to determine the density of $C_{0\text{-}1}$ and $C_{1\text{-}2}$ in ponds during particular periods of the season, resulting in a adequate determination of feed portions, when $G_{0\text{-}1}$ and $G_{1\text{-}2}$ are known from fish sampling.

The model is not applicable in the extensive carp culture; in this case the model equations take different form. It cannot be applied in ponds of throphic level distinctly different from Gołysz ponds.

Distinct differences betweeen the empirical and the simulated masses of $C_{0\text{-}1}$ and $C_{1\text{-}2}$ point out that either the assumed survival rates differ from the reality, or the carp growth is limited by fish diseases, and/or by unfavourable environmental conditions (e.g. lack of oxygen).

Although the model was widely tested in Gołysz ponds, applying different aquaculture techniques, including mono- and polyculture, different genetic lines and hybrids, and in differentiated thermal conditions, it requires further validation, especially in the object where it is to be applied.

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STRESZCZENIE

MODEL WZROSTU KARPIA W STAWACH

Zadaniem modelu jest umożliwienie optymalizacji chowu karpi w stawach w warunkach klimatycznych Polski poprzez ukazanie ilościowej zależności jednostkowego wzrostu i produkcji tych ryb od poszczególnych elementów semi-intensywnych i intensywnych metod chowu oraz temperatury wody. Model opracowano na podstawie statystycznej analizy wyników badań biometrycznych trzech roczników karpi K_{0-1}, K_{1-2}, K_{2-3} prowadzonych w ramach badań nad intensyfikacją chowu karpi w stawach doświadczalnych ZIGR PAN w Gołyszu. Model przedstawia, w postaci równań matematycznych i w formie graficznej, zależność wzrostu jednostkowego i produkcji karpi od sumy temperatury efektywnej $\Sigma\vartheta_e$ (wyższej od 14°C) dla ich wzrostu, od końcowego zagęszczenia d ryb w stawach, zawartości białka v w paszy i początkowej masy ciała ryb G_0 (dla K_{1-2} i K_{2-3}). Przydatność modelu w praktyce rybackiej polega na możliwości planowania wyników przed sezonem hodowlanym zgodnie z wymaganiami rynku i uwarunkowaniami ekonomicznymi. Brak możności uzyskania prognozy warunków cieplnych w nadchodzącym sezonie hodowlanym skłonił do obliczenia wzrostu jednostkowego i produkcji karpi w sezonie ze średnią temperaturą efektywną, w sezonie chłodnym i ciepłym, określone odchyleniem standardowym sumy temperatury efektywnej, obejmującym około 70% zakresu zmienności. Walidacja modelu wykazała wysoką zgodność wyników teoretycznych z uzyskanymi w stawach produkcyjnych. Model nie może być stosowany do obliczeń wyników uzyskanych w ekstensywnym chowie karpi.

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