Relationships between phytoplankton and fish yields in Lake Balaton

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Abstract

Coefficients of determination between fish yields in Lake Balaton (kg/ha) and different measurements of phytoplankton abundance were: phytoplankton biomass (0.48), chlorophyll a (0.45). The same indices for catch per unit of effort (CUE) proved to be 0.82 and 0.88, respectively. The correlation between fish yields and phytoplankton density has been described in second-degree polynomials.

Introduction

According to Melack (1976), Almazan & Boyd (1978), Tsiskarishvili (1979) and others, measurements of primary production may be used to improve the assessment of fish yield from tropical and temperate lakes and reservoirs. Melack (1976) and Liang *et al.* (1981) have concluded that primary production is a better predictor of fish yield in lakes than other suggested relationships between yield and environmental variables. Melack offers linear regression equations relating fish yield and primary production, while Liang *et al.* found arithmetic, semilog, and log-log regression equations appropriate for the Chinese ponds and lakes. They examined the range of regression equations applied to PG–FY (gross photosynthetic rates and annual fish yield) correlation and proposed that a logistic curve describes the full range of PG–FY relations. They showed that each of the previously published regression equations describes a portion of most of the logistic curve. However, the dynamics of fish populations are usually masked by such overall mathematical functions.

During the development of the 'Balaton Eutrophication Model' there were no attempts to correlate fish yields with limnological factors (Herodek & Csáki 1980), though primary productivity approached its theoretical maximum in certain areas of Lake Balaton (Herodek & Tamás 1976).

The aim of this paper was accordingly to establish the type of regression equation describing the relation between fish yield and phytoplankton in the shallow Lake Balaton.

Material and methods

Data on annual fish yields (1964–79) were obtained from the Balaton Fishing Company. Fisheries statistics also contained the annual fishing efforts for the five fishing areas of the lake (Fig. 1). Fish yields in weight were converted to catch per unit of effort (CUE = kg/ha 100 h active seining/yr).

Samples of algae were counted by Utermöhl's technique and phytoplankton biomass (wet weight) was estimated from the cell volume by Tamás (1974, 1975), Herodek & Tamás (1976) and Vörös (1980a, b). Chlorophyll a content of the water was determined biweekly from water samples filtered with Whatman GF/C glass-fibre filters and extracted with methanol (Tóth, F. 1979; Tóth, L. 1981, pers. comm.). After cleaning, the extinction

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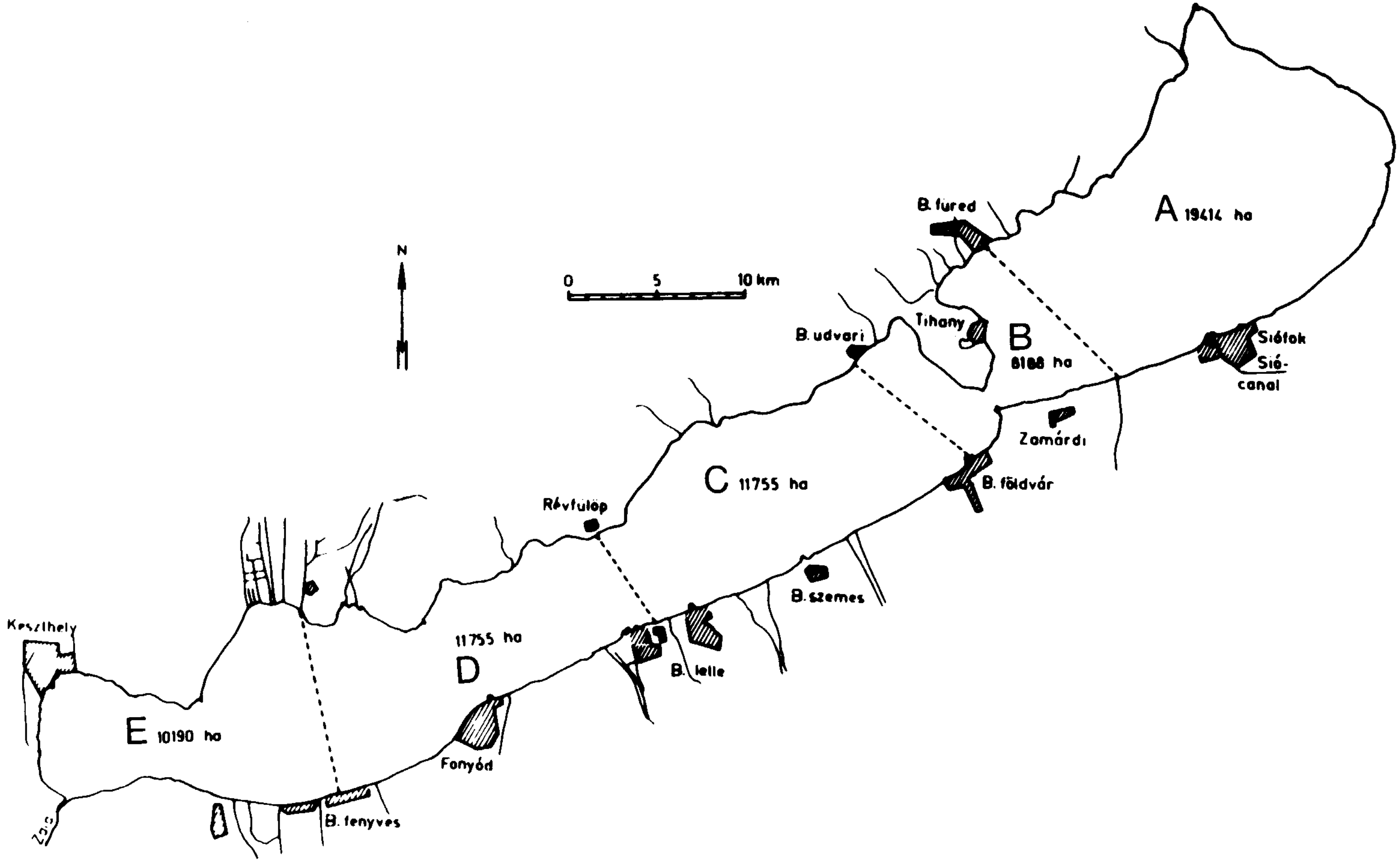

Fig. 1. Map of Lake Balaton showing the five fishing areas from NE (area A) to SW basin (area E).

of extracted pigments was measured photometrically at 653, 666 and 750 nm (Iwamura *et al.* 1970).

Data for limnological measurements were averaged and correlations determined between average annual values for each area of the lake and net fish yields.

Results

Phytoplankton biomass in Lake Balaton definitely increases from east to west along the longitudinal axis of the lake. This tendency was characteristic in the 1960s and is still observable now. The trophic stage of the lake varied significantly in both space and time. During the last 15 years the phytoplankton biomass has increased in all areas of the lake. In 1976 the measured maximum biomass of algae was 4 mg/l in the NE basin and 8.2 mg/l in the SW one, whereas during the late 1970s (e.g. 1977–79) the maximum biomass of algae ranged from 5 to 8 mg/l in the NE basin and from 40 to 57 mg/l in the SW basin.

Five fishing areas were compared with special attention to the NE and the SW ones (Fig. 1); they differed in limnological conditions, stage of eutrophication and annual fish harvest. Fish yield in the SW basin (area E) were 4 to 5 times higher than that in the NE one (area A). The other areas (B–D) occupy intermediate positions. However, the water area around Tihany Peninsula (B) proved to be the second most productive one (Fig. 2). Annual fishing efforts differed greatly, and varied between 227 and 505 h/yr in the NE basin (areas A–B) and between 324 and 600 h/yr in the SW one (area E). Fish yields ranged from 7.6 to 10.8 kg/ha in the NE and from 39 to 46.3 kg/ha in the SW basin, respectively (Fig. 2).

Preliminary arithmetic, semilogarithmic and log–log plots of fish yields versus phytoplankton biomass and chlorophyll a content of the water indicated that an equation of the form $Y = a + bX + cX^2$ provided the most satisfactory fit to the data. Results in Figs. 3 and 4 reveal a high degree of correlation between each of the two indices of phytoplankton density and fish yield. All regression lines were curvilinear, indicating that fish yield did not increase in direct proportion to plankton biomass or chlorophyll a content. The closest significant correlations between phytoplankton measurements and fish yields (CUE) were found in the SW basin of the lake ($R = 0.986$ and 0.982). Coefficients of determination ($R^2 = 0.82$ and 0.88) indicated that fish yields were clearly influenced by phytoplankton biomass and chlorophyll a content of the water, especially in the SW basin. These relationships were linear over considerable ranges of phytoplankton density. However, all sets of data could best be fitted with curvilinear regression, indicating that above a certain level of either phytoplankton biomass or chlorophyll a content of the water, each additional increment of phytoplankton resulted in progressively smaller amounts of fish yield. Only the regression for the highly eutrophic SW basin indicated that fish harvest in kg/ha does not depend heavily on phytoplankton biomass ($R^2 = 0.22$) (Fig. 3).

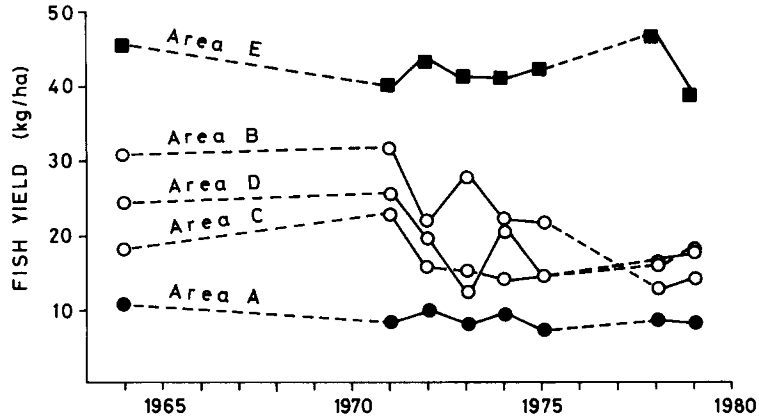

Fig. 2. Annual commercial fish yields from the five fishing areas (A–E) of Lake Balaton in 1964–79.

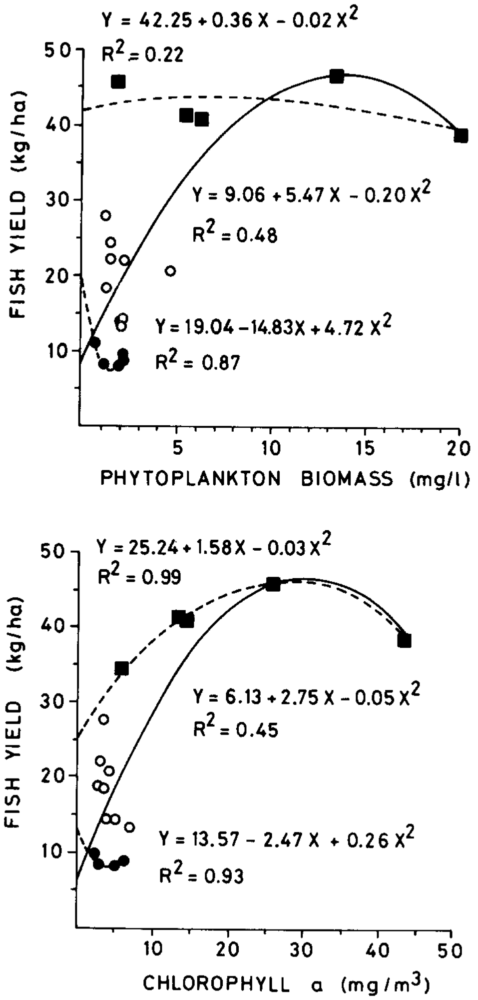

Fig. 3. The relationships of fish yield (kg/ ha) to different measurements of plankton density. All coefficients of determination were significant at the 0.01 level of probability. Black squares with dotted line refer to the SW basin (area E); black circles with dotted line refer to the NE basin (area A); solid line with all the data including open circles (central areas of the lake B–D) shows the overall regression for Lake Balaton.

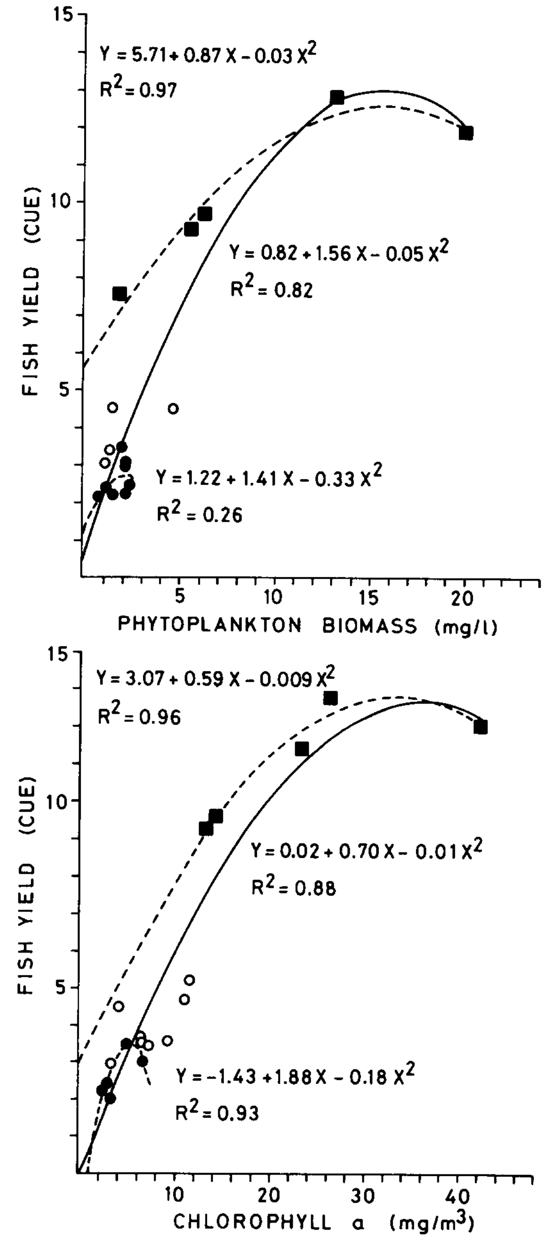

Fig. 4. The relationships of fish yield converted to catch per unit of efforts (CUE) versus phytoplankton biomass and chlorophyll a content of the water. For explanation see Fig. 3.

Discussion

One way to predict potential or optimum fish harvest may be to quantify the available and utilizable organic base in the exploited ecosystem (e.g. Melack 1976; Biró 1978). Two general problems apply to such functions. First, when estimates of biomass of primary producers made for a few stations several times in one year are converted to overall averages, errors are exaggerated (Ganf 1975; Melack 1976). Second, commercial catch records may indicate fishing efforts, not potential yield (Balon & Coche 1974; Henderson & Welcomme 1974), and may apply to only one region of the lake. The Ryder's morphoedaphic index (Ryder *et al.* 1974) for Lake Balaton, calculated by dividing measured total dissolved solids (400 mg/ l) by mean depth (3 m), is 133; it predicts 11.16 kg/ha annual yield for Lake Balaton.

The coefficient of determination (R^2) between fish yield and phytoplankton number (ind./ml) was 0.78, and between fish yield and chlorophyll a was 0.89 in *Tilapia* ponds in Alabama (Almazan & Boyd 1978). In ecologically diverse African and Indian lakes, commercial fish yields increase logarithmically as primary productivity increases arithmetically ($R^2 = 0.57$) (Melack 1976). This implies that percent conversion increases as primary productivity increases. For Lake Balaton this is inversely valid. In the NE basin the primary productivity was about 96 g C/m^2/yr and the fish yield was about 0.91 g/m^2/yr. The percent conversion (from calorific values) was maximum here: 0.095%. The same values for the SW basin were 830 g C/m^2/yr and 4.1 g fish/m^2/yr, and the percent conversion proved to be minimum (0.049%). This finding supports the observation of Hrbáček (1969), who compared plankton primary productivity with carp *(Cyprinus carpio)* yield from fish ponds and found that the percent conversion of primary to fish production decreases as primary productivity increases, even at a high proportion of phytophagous fish (Wolny & Grygierek 1962). During the accelerated cultural eutrophication processes of Lake Balaton, the fish yield did not increase parallel with increasing density of primary producers (Biró 1978), but we could not correlate fish yields with sporadic data on primary production. Another problem is that ^{14}C-measurements in Lake Balaton mean gross photosynthesis (Vörös *et al.* 1982), and net production may be significantly less than gross production (Melack 1976).

The relation between phytoplankton density and fish yield was very close in the SW basin (area E) and significantly differed from that of the central areas (B–D) of the lake. The shape of our curves generally supports the findings of Liang *et al.* (1981). When using these curves for predictive purposes, some time lag may alter the relationships obtained for Lake Balaton, i.e. the phytoplankton density in year 'n' may determine the fish yield in year 'n + 1', 'n + 2' or even 'n + 3'.

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