## 2. STUDY LAKE AND RESULTS OF EXPERIMENTAL LIMING IN 70-TIES. AIM AND SCOPE OF PRESENT STUDIES
(Anna Hillbricht-Ilkowska)

Lake Flosek is located in Masurian Lakeland (NE Poland 53° 44' N, 21° 25' E). It is a mid-forest humic lake, typical of post-glacial landscape of Baltic belt of lakelands (Phot.1). In order to protect this landscape, Masurian Landscape Park was created in 1997. Lake Flosek is located in this park. Surface area of the lake is 4 ha, mean depth – 3 m, maximal depth – 7 m (Fig. 1), and its drainage basin of 46 ha area is covered in 90% by pine-spruce forest (*Pineto-Vaccinietum*). The lake has practically no outflow except during snow melt period when small outflow is functioning in the western part. The lake does not have typical littoral and is almost entirely surrounded by forest. Eastern part of the lake adjoins a peatbog formed by *Sphagnum* and covered by e.g. *Ledum palustris*, *Drosera rotundifolia* and other plants characteristic of peatlands. *Sphagnum* mat also occurs in the southern part of the lake (Phot. 1). Bottom sediments of Dy type with semi-liquid consistency and thickness up to 24.5 m (Więckowski, personal information after Hillbricht-Ilkowska *et al.* 1977) indicates that the lake originated from melted ice block. Weakly decomposed tree branches and leaves (mainly birch and pine) are abundant along the shoreline. The water is slightly brown-coloured.

In preliming period, Lake Flosek waters were weakly acid (ca. 6.0 pH), with temporary pH drops to ca. 5.5 at the bottom, and had average calcium concentration of several mg $l^{-1}$ (Hillbricht-

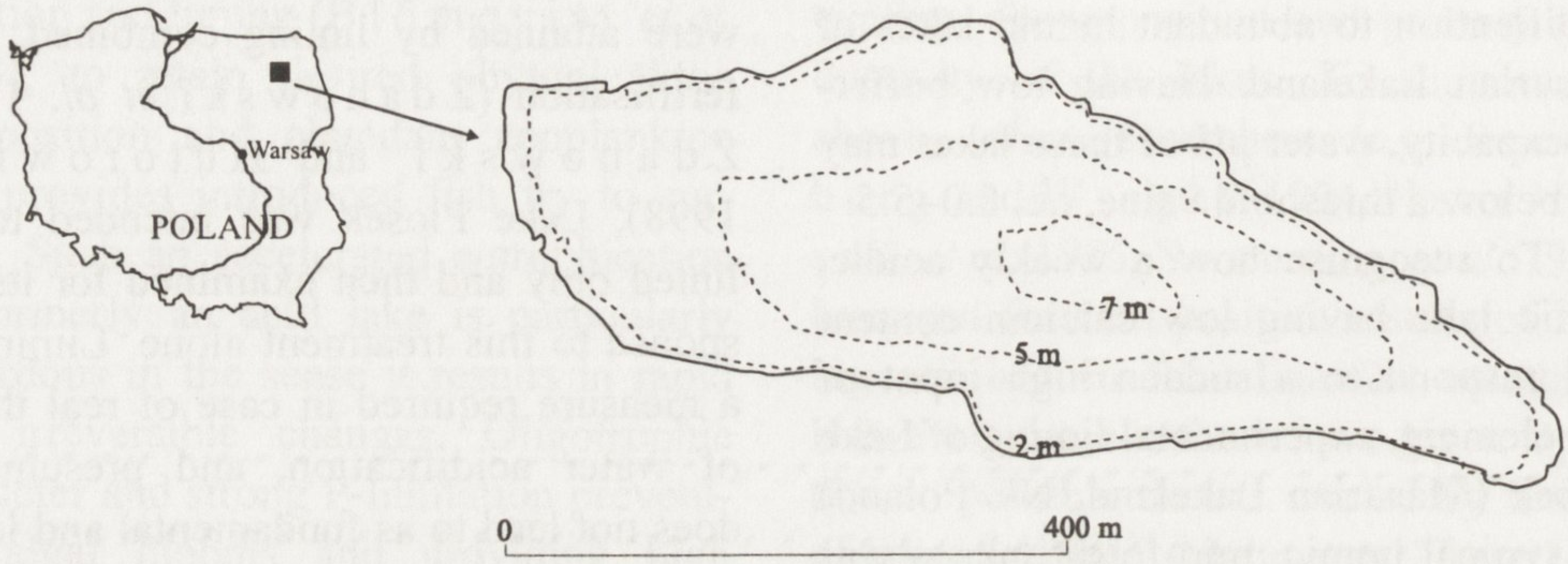


Fig. 1. Bathymetric map of Lake Flosek

-Ilkowska *et al.* 1977). According to Swedish standards (Nyberg and Thörnelöf 1988) such a lake needs to be limed, because Swedish lakes of pH values permanently or periodically below 6.0 should be limed in order to prevent their further acidification. Applying Dickson's equation (1988) to assess concentration of toxic Al (g $l^{-1}$) dependent on pH

$Al = 10^{(5.0 - 0.64 pH)}$ for heavily stained lakes

$Al = 10^{(7.05 pH)}$ for weakly stained lakes

it turned out that in preliming period Al as free cation could reach concentrations of about 30–40 µg $l^{-1}$ (at pH about 5.5), which is close to the assumed threshold toxicity value, i.e. 50 µg $l^{-1}$. Higher and dangerous Al concentrations occur below 5.5 pH (Motowicka-Terlak 1993), especially when Ca concentration is lower than 3.5 mg $l^{-1}$ (according to Svedrup and Warfringe 1988). Thus, temporary Al-toxicity of Lake Flosek waters in preliming period cannot be excluded, though it might be low and undetectable due to relatively high humus content. According to Lee (1985), organically bound Al predominates at pH > 6.0. No studies were conducted on ichtyofauna prior to Lake Flosek liming. Nevertheless, the lake was not completely fishless, this having been confirmed by frequent observations of perch and roach fry feeding near shore, and single pike individuals (Table 1).

In the period July–October 1970, 12 tonnes of powdered $CaCO_3$ were applied, the amount theoretically sufficient to raise calcium concentration in the lake from 3–4 mg $l^{-1}$ to about 40 mg $l^{-1}$. From May to October 1963 and 1966 (control years), 1970 (treatment year) and 1971–1974 (years following treatment), studies on water and sediment chemistry, phytoplankton production and decomposition *in situ* (oxygen uptake in water), composition and abundance of phytoplankton, bacterioplankton, zooplankton and zoobenthos were carried out with different frequency. The synthesis of results were published in Węgleńska *et al.* (1975) and Hillbricht-Ilkowska *et al.* (1977).

The most important consequences of Lake Flosek liming in the 4-year-period following the treatment included:

– an increase in calcium level in the water to 14–17 mg $l^{-1}$ (5–6 times higher than before liming) and sediments to 0.4–1.6% of dry weight (i.e. doubled); increases in pH (from 6.0–6.5 to 7.0–8.0)

Table 1. Approximate status of ichthyofauna in Lake Flosek in 1989–1993 period

| Year | Fish introduction (spring) | Fishing (autumn) | Supposed fish pressure[1)] of: non-predators | predators |
|---|---|---|---|---|
| 1989 | crucian carp<br>tench | | low | low |
| 1990 | | pike[2)] | low | low |
| 1991 | bleak | pike[2)] | low | low |
| 1992 | – | perch [3)]<br>common bream<br>tench<br>pike | low | high |
| 1993 | roach | wels<br>bleak<br>roach<br>white bream<br>perch [4)]<br>sunbleak<br>eel | high | low |

[1)] on zooplankton (non-predators) or fish (predators)
[2)] pike has constantly been occurring in Lake Flosek but in unknown numbers
[3)] very poor condition of predatory fish indicating starvation
[4)] good condition of predatory fish

and conductivity (from ~20 to ~100 μS $cm^{-1}$). At pH 7–8 and elevated Ca, Al concentration should not be higher than 1–3 μg $l^{-1}$ (according to Dickson's equation, 1988).

– a slight increase in phosphate phosphorus concentration and significant increase in concentration of mineral nitrogen (the sum of ammonium and nitrate nitrogen) in the year of lime application. In the subsequent years, both forms dropped substantially resulting in low concentrations of those nutrients four years after the treatment.

– a drop in gross phytoplankton production in the treatment year followed by a steady increase in the subsequent years. This was accompanied by an opposite tendency in organic matter decomposition (daily oxygen uptake in pelagial measured *in situ*), i.e. a considerable increase in the treatment year followed by a decrease, which led finally to a balance between decomposition and production of organic matter in plankton.

– no apparent tendencies in abundance nor biomass of planktonic algae community, despite altered species composition: replacement of dinoflagellates (*Pyrrophyta*) by certain species of diatoms and flagellates common to eutrophic lakes and predomination of nanoplankton, i.e. small-sized (up to 20 μm) phytoplankton component.

– a marked increase in abundance and biomass of planktonic rotifers and changes in species composition of both rotifers and crustaceans; Likewise, biomass and abundance of zoobenthos increased. Seasonal dynamics of each community was altered exhibiting clear-cut spring-summer and autumn peaks in abundance, similar to those observed in eutrophic lakes.

It was hypothesised that the four-year-lasting effects of Lake Flosek liming resulted from enhanced decomposition of organic matter accumulated in the water and sediments. This, in turn, was an effect of acidity neutralisation. Under such circumstances organic matter resources were mobilised which, being in a form of easily assimilable detritus in water and sediments and bacterial biomass, became more available to heterotrophs. This is testified by decomposition rate estimates and increased biomass of rotifers (among which detrivores predominate) and macrobenthos. The same is indicated by composition of heterotrophic bacteria; participation of rod-shaped forms, usually dominant in waters rich in slowly decomposed organic matter, has decreased. Moreover, increased activity of bacteria was observed after liming (Hillbricht-Ilkowska *et al.* 1977).

Generally, the structural and functional changes observed correspond fairly well with those reported for limed humic lakes (e.g. in Scandinavia) in the sense that components involved directly in enhancing decomposition and bacterial transformations, for instance zoobenthos (including shredders) and detrivore zooplankton, show the highest increases in diversity and abundance (Raddum *et al.* 1986) when compare to relatively least responding components (e.g. phytoplankton) dependent on nutrient regeneration. Among bacterial processes intensified by lime application nitrification should be mentioned, the process responsible for nitrogen cycling (Blömqvist *et al.* 1993).

A question however arises, how stable are the changes observed immediately after liming of the humic lake ecosystem, when several decades, not several years are considered? Will the effects recorded four years after liming, i.e. in 1974, remain unchanged after some 20 years?

A fundamental question is whether the raised calcium concentration (comparing with the pre-liming period) is maintained or – as it should be expected – it tends to be lower due to dilution, leaching, sedimentation, capturing by moss surroundings? The latter case would suggest that re-liming should be performed, as is commonly practised in Scandinavia in order to maintain increased buffering capacity of the limed lakes.

To answer the above questions, additional investigations of Lake Flosek were performed in 1990–1993, using comparable methods. Measurements and assessment of water chemistry (I. Kufel), sediment chemistry (M. Rzepecki), primary production and chlorophyll concentration (J. I. Rybak), species composition and abundance of phytoplankton (I. Spodniewska), including its finest fraction (0.2–0.3 μm) – pikoplankton (I. Jasser), planktonic crustaceans (T. Węgleńska), planktonic rotifers (J. Ejsmont-Karabin) and zoobenthos (K. Dusoge) were made several times in 1990 and 1991, and every month in 1992 and 1993. Certain subjects were examined by the same authors as 20 years ago. Additionally, some new investigations were included having no equivalents in the former studies but essential for assessment the present state of the lake, like these comprised assessment of species composition and biomass of aquatic plants and filamentous algae (T. Ozimek) as well as laboratory studies on nature of chemical compounds and turnover rates of mineral phosphorus in bottom sediments under aerobic and anaerobic conditions (M. Rzepecki). The lattest studies aimed to find whether the phosphorus contained in matter deposited in the sediments may re-enter the cycle and affect productivity of the lake.

Because the lake was leased for angling purposes, small quantities of roach and bleak were introduced in 1990–1993 in order to feed perch and pike (Table 1). This was sufficient to stimulate typical cascade effects in zooplankton (Węgleńska *et al.* 1996). Thus, possible effects of fish introduction should be taken into account along with liming effects when one is to consider the changes 20 years after the treatment. Changing fish pressure on invertebrates, particularly on planktonic crustaceans, occurred in those years might have overlapped with the long term effects of raised calcium concentration. Such a coincidence makes Lake Flosek resemble Scandinavian lakes, e.g. Lake Gardsjön, where similar measures were applied (Stenson and Svenson 1994, 1995).

Including control studies in 1963 and 1966, investigations of Lake Flosek comprised nearly 30-year-period (from 60-ties to 90-ties). This has provided a long term data series for one lake. Many-year series are particularly valuable when one is to analyse transformations of aquatic ecosystems (Likens 1989). In Poland, few such series exist. An example may be Great Masurian Lakes (Gliwicz and Kowalczewski 1981, Hillbricht-Ilkowska 1989), heated lakes near Konin (Hillbricht-Ilkowska and Zdanowski 1983), some lakes in Wigierski National Park (Zdanowski 1992), and already mentioned humic Lake Smolak (Zdanowski and Hutorowicz 1998) which was limed and fertilised.