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RESEARCH ARTICLE

Long-term changes in commercial fish catches in Lake Mamry Północne (northeastern Poland) on the background of physical, chemical, and biological data

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Abstract. Lake Mamry Północne, a part of the Great Masurian Lake System in northeastern Poland, is a valuable body of water from environmental, recreational, and economic points of view. The paper evaluates long-term physical, chemical, and biological parameters as well as commercial fisheries data. Nitrogen and phosphorus influx data as well as physical and chemical data indicate that the trophic state of Lake Mamry Północne can be described as moderate from 1967 to 2006, making the lake borderline β-mesotrophic and eutrophic. The lake's trophic state increased with time, manifesting itself in an increasing concentration of biogenic substances, decreasing water transparency, and worsening oxygen conditions in the hypolimnion. Changes in physical, chemical, and biological parameters generally corresponded with changes in the commercial fish catches of selected species and groups of species indicative of the process of eutrophication.

Keywords: eutrophication, commercial fisheries, physical, chemical and biological data

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Introduction

The eutrophication of lakes is caused by increasing amounts of allochthonous matter transported in from their direct as well as total basins. The element fundamentally responsible for eutrophication is phosphorus, which regulates biological production, limits the development of algae, and determines the degree of eutrophication (Vollenweider 1968, Schindler 1977, Kajak 1979). Phosphorus generally stimulates the eutrophication of lakes with the results ranging from oligotrophy to eutrophy (Vollenweider 1968, 1976, Carlson 1977, Hickman 1980).

Eutrophication is a process that causes far reaching qualitative and quantitative changes at all levels of the trophic state (Kajak 1979). As fish represent one of the higher trophic levels, changes in their number and type are not short lived or accidental but are signs of clearly emerging patterns. This fact can be used to assess the degree of eutrophication in lakes and identify the impact of other factors associated with human pressure. The theoretical framework for this type of an assessment can be found in Colby et al. (1972), Hartmann (1977, 1979), Leach et al. (1977), Persson (1991), Zdanowski (1995), and Bnińska (1996). The principles that govern the succession of particular species and groups of species of fish from Salmonidae to Cyprynidae were used to help assess the degree of eutrophication in lakes in Poland. The assessment was performed based on commercial fisheries data for selected lakes (Bnińska 1991, Wołos and Falkowski 2007), selected fish farms (Bnińska 1985, Mickiewicz et al. 2003), and all lakes used for commercial fishing purposes with a total area of 280,000 hectares (Leopold et al. 1986).

The aim of the paper is to present long-term changes in commercial fish catches in Lake Mamry Północne with special attention being paid to species and groups of species indicative of eutrophication. The hypothesis that eutrophication impacts the size of fish populations in lakes was tested by comparing changes in fish catches with long-term variability in the physical, chemical, and biological parameters of water.

Materials and methods

Study area

Lake Mamry Północne is located in the Great Masurian Lake District. It is a western mesoregion of the Eastern Baltic Lake District located across the Eastern Baltic-Belarussian Lowland (Kondracki 2000). The Great Masurian Lakes are the largest lake district in Poland – interconnected either naturally or via a system of manmade canals. The lakes' water level is normally at about 116 m above sea level and is maintained via a system of dams on the Węgorapa River and Jegliński Canal. The Great Masurian Lakes occupy an area of about 307 km^2 and constitute about 10% of Poland's total lake surface area (Mikulski 1966, Choiński 1991).

The Great Masurian Lakes are located in a drainage divide zone between the drainage basins of the Wisła and the Pregoła rivers. The main tributaries are: the Krutynia, the Jorka, the Orzysza, and the Sapina. Water exits the lake system to the north via the Węgorapa River and to the south via the Pisa and Narew rivers that flow into the much larger Vistula River. The drainage divide in the Great Masurian Lake District runs along the southern edge of Lake Kisajno at the mouth of the Giżycki Canal (Mikulski 1966). The location of the divide can change from Lake Dargin in the north to Lake Mikołajskie in the south, while during periods of drought, from Przystań to Lake Śniardwy (Bajkiewicz-Grabowska 2008). Pollutants in the waters of the central part of the Lake District are usually carried south but in some cases, they can be carried north to Lake Mamry Północne.

Lake Mamry Północne is the northernmost of the Great Masurian Lakes (Table 1). It occupies an area of 2,504 hectares with a mean depth of 11.7 m and a maximum depth of 43.8 m. The lake formed inside a basal moraine. Today, it is supplied with water by Lake Dargin via Lake Kirsajty as well as by Lake Święcajty whose main tributary is the Sapina River. Water exits the lake via the Węgorapa River. Lake Mamry Północne possesses two basins: Przystań and Bodma. A slightly separate portion of the lake is called Lake Mamry Małe. The bottom of Lake Mamry Północne features a diverse topography with numerous depressions and shallows.

Table 1
Limnological characteristics of Lake Mamry Północne (unpublished Inland Fisheries Institute (IFI) data)

Parameters	
Surface area (ha)	2,504.0
Maximum depth (m)	43.8
Mean depth (m)	11.7
Meane depth x maximum depth^{-1}	0.27
Volume (thousands m^3)	298,300.0
Maximum length (km)	7.6
Maximum width (km)	5.2
Area of direct basin (km^2)	32.0
Area of total basin (km^2)	562.3
Mean annual runoff rate (mln m^3 year^{-1})	90.2
Water exchange percentage per year (%)	30
Retention time (years)	3.3
Hydraulic load (m year^{-1})	3.6

The lake is surrounded by agricultural land and some forests. Numerous wetlands and thickets line its fringes. The small town of Przystań and a part of the town of Trygort are located next to the lake with the city of Węgorzewo also nearby. There are two recreational centers, a number of summer homes, and five camp sites in close proximity to the lake (Różański 2001). According to the GUS Almanac (2001), the average population density in the lake's direct basin is 15 persons km^{-2}. The Almanac also reports 911 tourists day^{-1} based on hotel beds. The lake does not have any point sources of pollution while wastewater from the recreational centers is shipped to the municipal treatment plant in Węgorzewo. An inland waterway runs across the lake connecting the port of Węgorzewo in the north to ports located in the southern part of the lake district.

Data collection and treatment

The lake's biogenic substance load was calculated using the Giercuszkiewicz-Bajtlik (1990) estimation method. Data on phosphorus and nitrogen sources were obtained from the following institutions: the Regional Inspectorate for Environmental Protection in Olsztyn and its branch in Giżycko, the county governments of Giżycko and Węgorzewo, the National Highway Authority, as well as the County Road Authority in Giżycko. Population and tourist data for the basin were obtained from the 2001 GUS Almanac. Calculations were performed using biogenic compound runoff coefficients produced by Giercuszkiewicz-Bajtlik (1990). The calculated load data was compared to results produced by a static model and a hydraulic model (Vollenweider 1968, 1976).

Data acquired during the 2000 growing season (spring – autumn) at the deepest sampling sites on Lake Mamry Północne were used to test for changes in physical and chemical parameters. Two more sampling sites were added in 2001. Oxygen content was measured using an oxygen probe recording data every one meter from the bottom to the surface of the lake. A Secchi disk was used to measure the transparency of water. Chlorophyll and seston content was determined using water samples collected from the 0-10 m layer. Samples were filtered through glass filters (45 μm), dried in order to obtain a constant mass at 105°C, and then weighed. Information on chlorophyll content in the epilimnion was obtained from a paper by Napiórkowska-Krzebietke and Hutorowicz (2005). A Ruttner sampler was used to obtain water for physical and chemical testing purposes from the following three layers: subsurface (0.5 m), metalimnion (15 m), and bottom (0.5 m above the bottom). Standard analytical methods were then employed (Standard Methods 1992, Hermanowicz et al. 1999). The concentration of phosphate and total phosphorus as well as ammonia nitrogen was determined colorimetrically using a Schimadzu UV-1601 spectrophotometer. Total nitrogen and nitrite were determined using an Epoll ECO 20 spectrophotometer. Total nitrogen content, that is the sum of the concentrations of organic and inorganic compounds, was determined for summer periods from 1991 to 1994 and from 2000 to 2001. The trophic state of the lake was determined for summer seasons based on measurements of Secchi disk visibility (SD), total phosphorus concentration (P_{tot}), and chlorophyll content (Chl). Carlson's Formula (Carlson 1977) was used to transform the results into the trophic state index (TSI). The oligo-mesotrophic state was characterized by TSI_{SD}, TSI_{Ptot}, TSI_{Chl} values below 40, while values between 40 and 60 were considered moderately trophic (mesotrophic), and eutrophic exceeding 60. The paper includes archival materials from the Inland Fisheries Institute concerning research on Lake Mamry Północne from 1986-89 and 1990-99 (Zdanowski and Hutorowicz 1994, unpublished IFI data). Change patterns in the physical and chemical parameters of lake water were tested using the nonparametric statistical Mann-Whitney and Kruskal-Wallis tests. A significance level of $P < 0.05$ was used for each test.

Commercial fisheries data obtained from Lake Mamry Północne fisheries logs for the 1967-2006 time period were used to analyze changes in the fish population. The Lake Mamry Północne commercial fishing was supervised by the Giżycko State Fisheries Cooperative until 1993. In 1994, the lake's fishing came under the jurisdiction of the Polish Anglers' Association (PAA) in the provinces of Suwałki.

The paper identifies three groups of species that are considered to be indicative of eutrophication processes:

A. Species and their sizes indicative of poorly eutrophic lakes:
   - coregonids (vendace, *Coregonus albula* (L.) and common whitefish, *Coregonus lavaretus* (L.))

- littoral species (pike, *Esox lucius* (L.), tench, *Tinca tinca* (L.), and crucian carp, *Carassius carassius* (L.))
- perch, *Perca fluviatilis* (L.)
- "large" cyprinids (large and midsize stocks of bream, *Abramis brama* (L.) and large roach, *Rutilus rutilus* (L.))

B. Species and their sizes indicative of increasing eutrophication:

- "small" cyprinids (small varieties of bream – under 0.5 kg, roach – under 0.2 kg, and white bream, *Abramis bjoerkna* (L.))
- pikeperch, *Sander lucioperca* (L.)

C. Species that may be considered "indifferent" given their level of tolerance for environmental changes. On the other hand, eel, *Anguilla anguilla* (L.) comes exclusively from fish farms:

- eel
- Other (smelt, *Osmerus eperlanus* (L.), bleak, *Alburnus alburnus* (L.), as well as small trash fish)

Two methods were used in the analysis of commercial fisheries data. The first method was used to analyze the catches of selected species. In the case of bream and roach, stock size was also taken into consideration via the use of time series (trends) including polynomials up to the fourth degree and exponential curves with a threshold significance level of $P < 0.05$. Statistically significant polynomials were graphed. In the absence of such polynomials, raw data was graphed instead. Commercial fisheries data (in %) were also analyzed for four consecutive decades (1967-1976, 1977-1986, 1987-1996, 1997-2006) based on the following classification of species: coregonids, littoral species, perch, "large" cyprinids, "small" cyprinids, pikeperch, eel, and others.

Results

Basin influence on the lake

In 2000-2001, the direct basin of Lake Mamry Północne was capable of delivering a phosphorus load no larger than 0.13 g P m^{-2} $year^{-1}$ and a nitrogen load no larger than 1.61 g N m^{-2} $year^{-1}$, a load value close to the critical value (Table 2). Its total basin, on the other hand, was capable of delivering a phosphorus load of 0.62 g P m^{-2} $year^{-1}$ and a nitrogen load of 9.83 g N m^{-2} $year^{-1}$, values that are three times critical levels. Over 75% of the loads came from spatial

Table 2

Estimated potential phosphorus and nitrogen influx to Lake Mamry Północne from its direct basin and total basin in 2001-2002

Source	Annual phosphorus load (kg P $year^{-1}$) direct basin	Annual phosphorus load (kg P $year^{-1}$) total basin	Annual nitrogen load (kg N $year^{-1}$) direct basin	Annual nitrogen load (kg N $year^{-1}$) total basin
Point[1]				
Spatial	1,502	7,679	32,562	164,075
Dispersed (animal husbandry)	931	4,007	3,725	16,029
Atmospheric precipitation	887	3,905	3,860	65,620
Swimming areas	5	24	100	376
Linear	1	2	2	5
Lake's actual phosphorus and nitrogen loads (g m^{-2} $year^{-1}$)	0.133	0.624	1.607	9.832
Lake's critical nitrogen and phosphorus loads (g m^{-2} $year^{-1}$)	0.109-0.219[2] 0.111-0.222[3]		1.75-3.50[2]	

[1] Point sources of pollution were not identified

[2] Vollenweider (1968) based on average depth criteria

[3] Vollenweider (1976) based on hydraulic criteria

and dispersed sources such as arable land, animal husbandry, recreation, as well as the influx of more fertile waters from Lake Święcajty and the southern part of the Mamry Lake System.

Oxygen conditions

Lake Mamry Północne is a dimictic lake where waters mix twice during the year – in the spring and autumn. It is a third degree static-type lake, highly susceptible to the mixing of epilimnion waters during the summer stagnation period. Oxygen content ranged from 8.0 to 15 mg dm^{-3} in the surface layer and from 0 to 13.8 mg dm^{-3} in the bottom layer. Trace amounts of oxygen were detected near the bottom of the lake from 1995 to 2001. Significantly reduced oxygen content in the metalimnion of Lake Mamry Północne was observed in the thermocline layer. Oxygen content variability along the vertical cross section of the lake was described by a negative clinograde curve, typical for β-mesotrophic lakes (Fig. 1). Oxygen content in the metalimnion was as low as 1.2 mg dm^{-3}. Oxygen content in the hypolimnion fluctuated from 1.3 to 5.1 mg dm^{-3} (10.7% to 42.4% saturation).

Supply of biogenic substances

Average total phosphorus concentration in the epilimnion was 0.060 mg dm^{-3}. The concentration of phosphorus in the bottom layer of the lake was, on average, 0.090 mg dm^{-3} (Table 3). Only trace amounts of phosphate were normally detected in the epilimnion. Phosphate content did not exceed 20% of total phosphorus content during the summer season. In the bottom layer, phosphate made up about 70% of total phosphorus content. No significant change patterns in the phosphorus supply of surface waters of Lake Mamry Północne were detected.

The concentration of nitrogen in the lake increased in 2000-2001. Organic compounds made up the major portion of total nitrogen in the epilimnion. Inorganic nitrogen (nitrate, nitrite, ammonia) accounted for about 5% during the summer. Ammonia nitrogen was the key determinant of the quantity of total nitrogen in the bottom layer (about 80%). Its

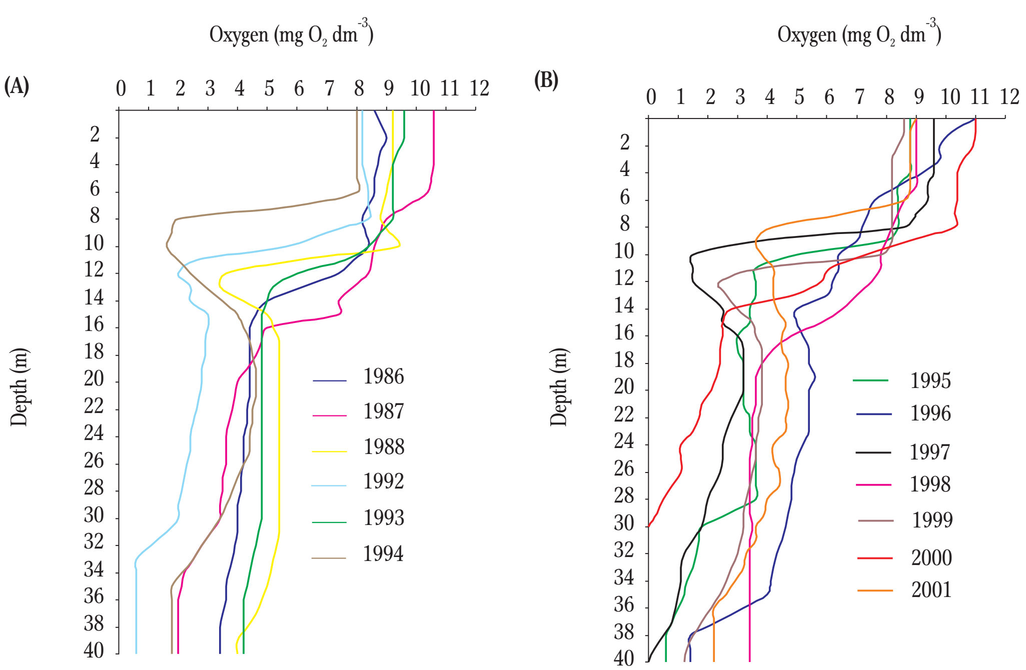

Figure 1. Oxygen conditions during the summer stagnation period from 1986 to 1994 (A) and from 1995 to 2001 (B).

Table 3
Changes in the trophic parameters of water in the surface layer (a) and the bottom layer (b) of Lake Mamry Północne (sampling site #1)

Parameter		Time Period			
		1986-1989[1] (n=22)	1991-1994[2] (n=12)	1995-1999[2] (n=13)	2000-2001 (n=13)
Tot-P ($mg\ dm^{-3}$)	a	0.032-0.104	0.034-0.039	0.009-0.096	0.032-0.072
	b	0.044-0.152	0.072-0.110	0.076-0.200	0.055-0.188
PO_4-P ($mg\ dm^{-3}$)	a	0.001-0.052	0.0-0.006	0.0-0.023	0.007-0.055
	b	0.001-0.100	0.010-0.082	0.042-0.095	0.006-0.147
Tot-N ($mg\ dm^{-3}$)	a	-	0.63-1.75	-	1.12-2.02
	b	-	0.86-2.31	-	0.89-2.56
NO_3-N ($mg\ dm^{-3}$)	a	0.03-0.17	0.05-0.06	0.0-0.06	0.0-1.42
	b	0.02-0.25	0.14-0.50	0.0-0.09	0.0-0.29
NO_2-N ($mg\ dm^{-3}$)	a	0.0-0.010	0.0-0.004	0.0-0.008	0.0-0.015
	b	0.0-0.019	0.0-0.005	0.0-0.020	0.003-0.035
NH_4-N ($mg\ dm^{-3}$)	a	0.02-0.15	0.03-0.15	0.06-0.21	0.04-0.09
	b	0.010-0.460	0.100-0.180	0.060-0.390	0.038-0.405
Secchi disk visibility (m)		2.5-9.5	2.4-4.6	2.0-4.5	2.5-6.5
Seston content (mg d.m. dm^{-3})		0.3-2.5	-	0.4-3.8	0.4-2.1
Chlorophyll content ($mg\ m^{-3}$)[3]		0.7-8.9	5.8-5.8	1.7-5.6	2.7-14.9
COD_{Mn} ($mg\ O_2\ dm^{-3}$)		8.7-20.5	8.3-14.4	3.2-13.8	5.4-12.8

[1] Zdanowski and Hutorowicz (1994)
[2] archival material from the IFI Department of Hydrobiology in Olsztyn
[3] Napiórkowska-Krzebietke (2004)

concentration did not exceed 0.46 mg dm^{-3} during the summer (Table 3).

No appreciable differences in the supply of nitrogen and phosphorus were detected in the open waters of the lake. Higher concentrations of total phosphorus (up to 0.250 mg dm^{-3}), mainly phosphate and ammonia nitrogen (under 1.2 mg dm^{-3}), were detected in 2000-2001 only at an isolated sampling site on Upałty Island. Here, a total lack of oxygen was recorded in the bottom layer.

Water transparency

Decreased water transparency was noted in the summer period with an average of about 4.0 m. In most cases, suspended material (about 2.0 mg d.m. dm^{-3}) and chemical oxygen demand (COD_{Mn}) were the reasons for this. Long-term data indicates that water transparency decreased temporarily (as low as 2.0 m) during the last year analyzed. The decrease can be attributed to extensive phytoplankton development in Lake Mamry Północne as measured by increased chlorophyll content (14.9 mg m^{-3}). Changes in water transparency in the lake tended to be more related to seston content than chlorophyll content. Changes in seston content in Lake Mamry Północne explained 47% of the changes in Secchi disk visibility (r^2 = 0.4735, P = 0.007) while changes in chlorophyll content explained only 28% of changes in visibility (r^2 = 0.277, P=0.036). Only changes in chlorophyll content could have been connected with changes in nitrogen content (r^2= 0.580, P = 0.028).

Trophic state

The epilimnion of Lake Mamry Północne was classified, in most cases, as mesoeutrophic based on its water transparency index (TSI_{SD} – 37-50) and chlorophyll content (TSI_{Chl} – 45-59). The phosphorus concentration index (TSI_{TP} – 36-70) varied within a range characteristic of waters experiencing elevated eutrophication. A rise in the lake's fertility was noted for the latter part of the research period.

Trends of commercial fish catches

Total commercial fish catches clearly decreased from 1967 to 2006 (Fig. 2). Maximum catches – over 80 tons – were recorded from 1967 to 1977. The smallest catches – about 20 tons – were recorded in 1981-1982 and 1991. Fish catches consisted of twelve species of fish – some were labeled as "other" in commercial fishing statistics. Vendace catches fluctuated significantly (Fig. 3) but did not tend to decrease. Common whitefish (Fig. 4) catches have been on the decline since 1976. Pike catches have been rather constant over the last 20 years (Fig. 5), however, they were much lower than in the 1960s and 1970s. Commercial perch catch (Fig. 6) resembles that of pike catch. Despite some small fluctuations, pike and perch catch has stabilized at about 4,000 kg (each) in recent years. Maximum tench catch was recorded from 1968 to 1976, however, beginning in 1977, catch began to drop rapidly with minimum catch being recorded in the 1990s (Fig. 7). Tench catch has seen a small rebound in the last few years. Bream catch was characterized by substantial fluctuations, which made it impossible to construct a statistically significant trend line (Fig. 8). Lake Mamry Północne is

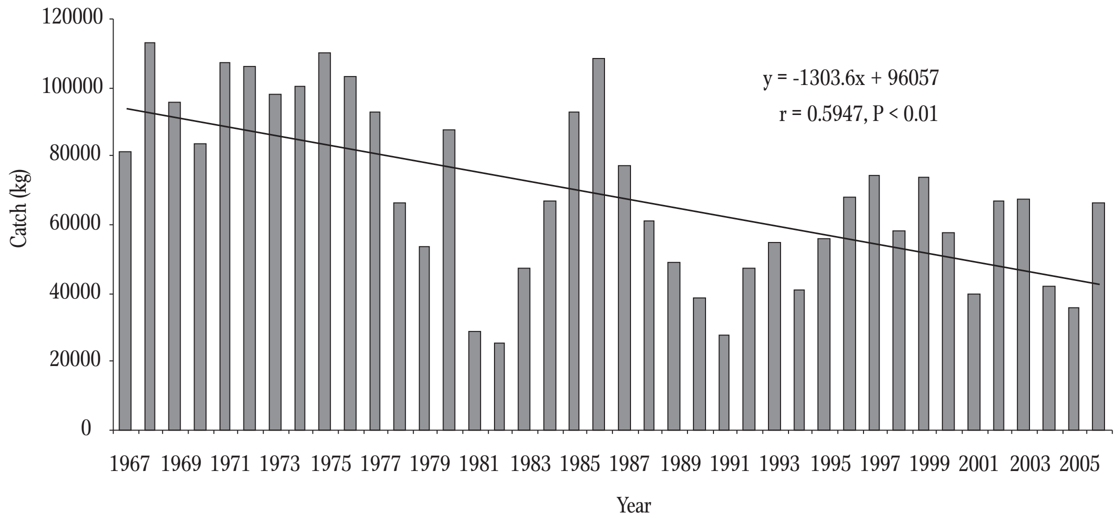

Figure 2. Total commercial fish catches from 1967 to 2006 in Lake Mamry Północne.

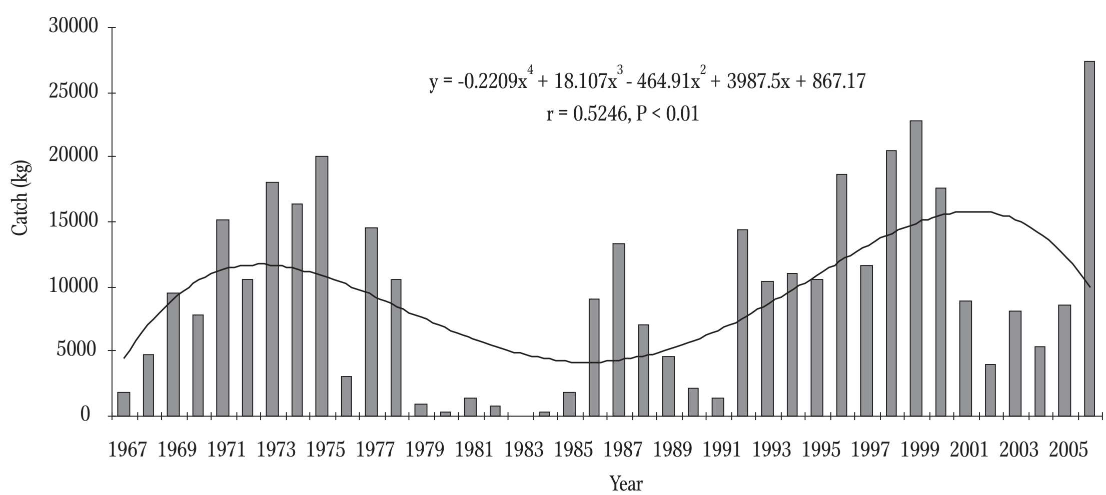

Figure 3. Commercial vendace catches from 1967 to 2006.

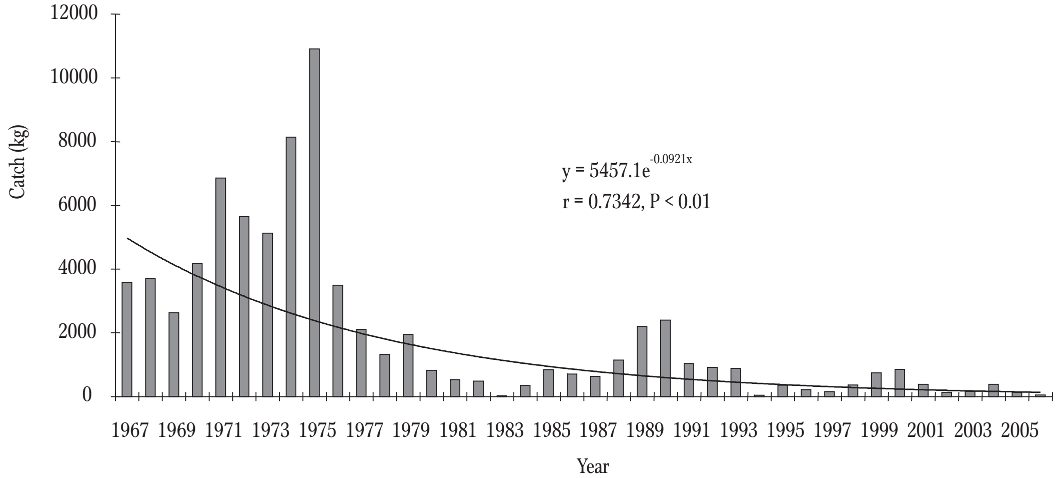

Figure 4. Commercial common whitefish catches from 1967 to 2006.

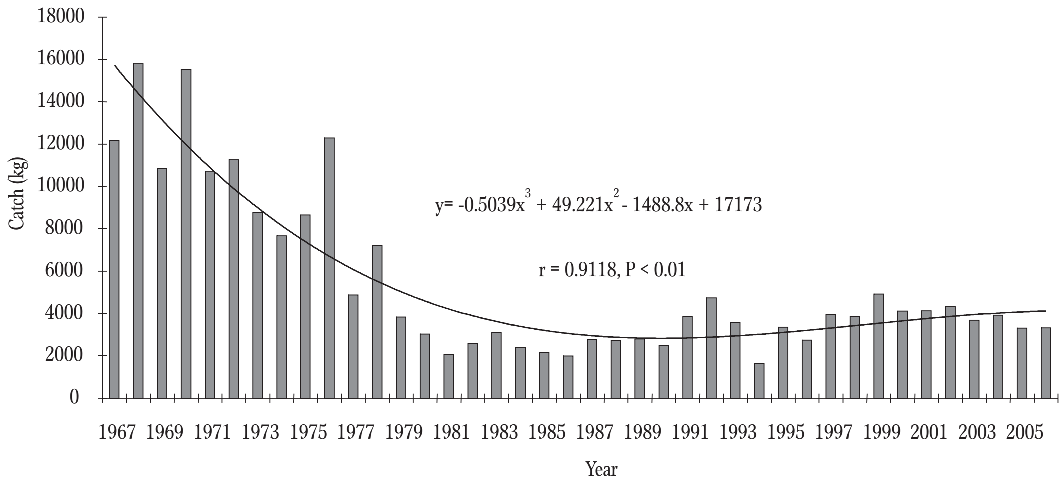

Figure 5. Commercial pike catches from 1967 to 2006.

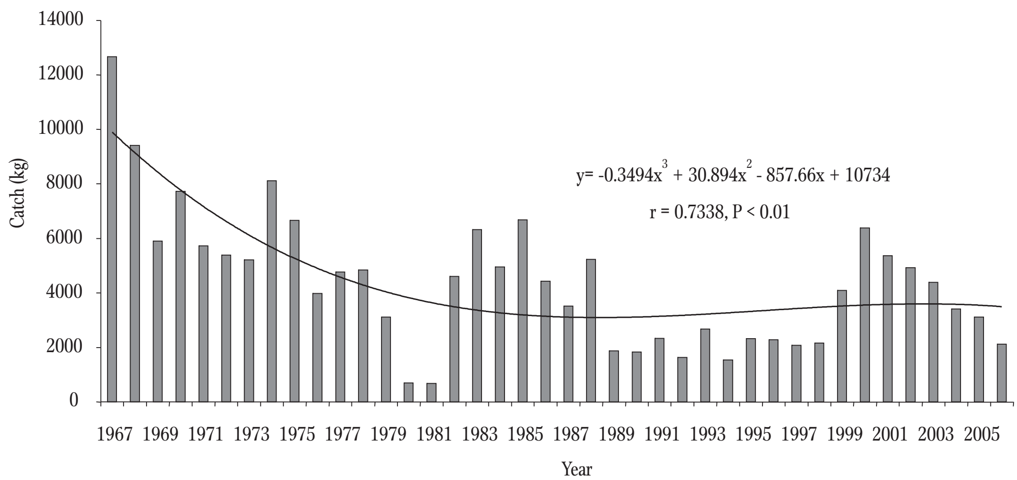

Figure 6. Commercial perch catches from 1967 to 2006.

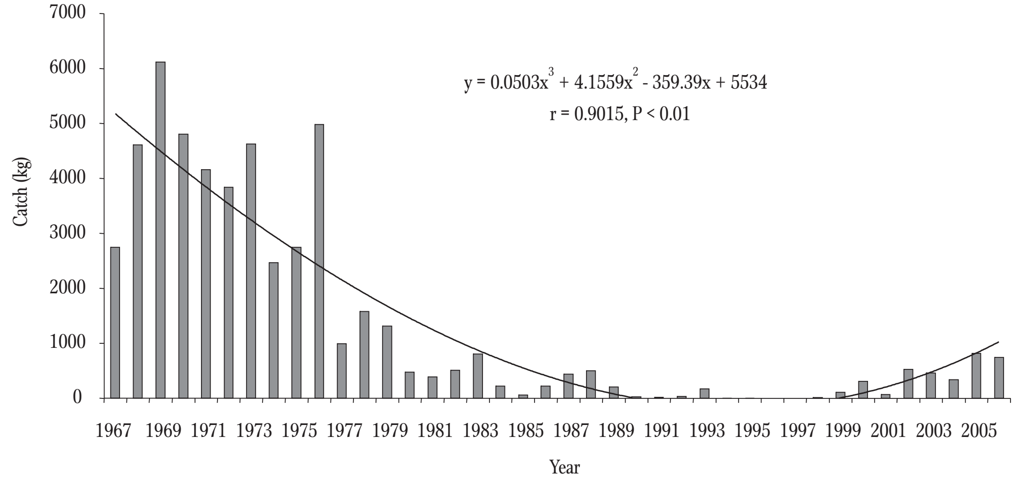

Figure 7. Commercial tench catches from 1967 to 2006.

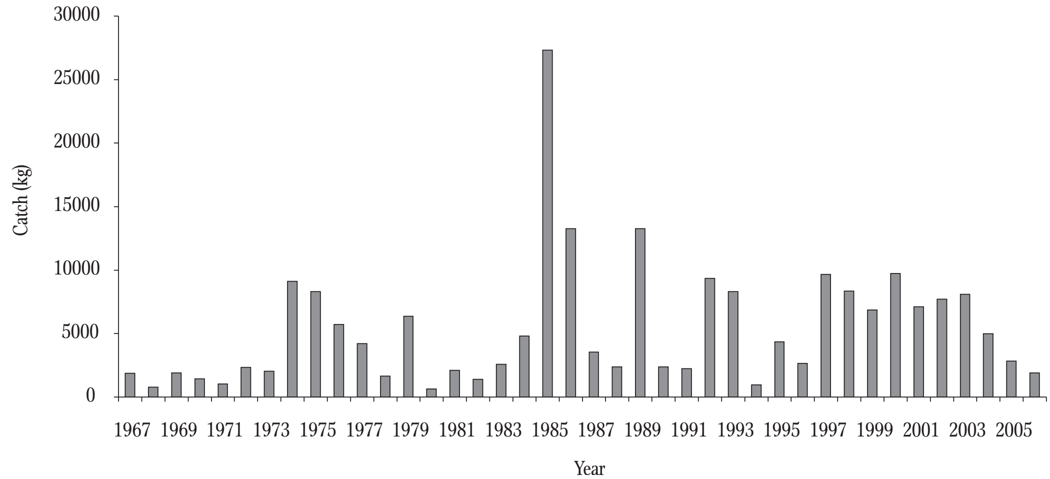

Figure 8. Commercial pikeperch catches from 1967 to 2006.

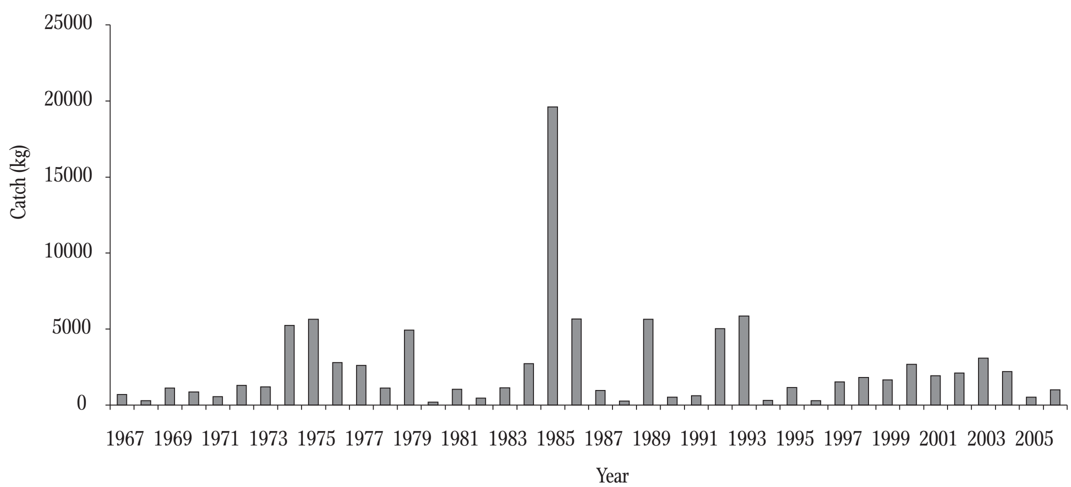

Figure 9. Commercial large bream catches from 1967 to 2006 (large bream – fish with body weight above 1.0 kg).

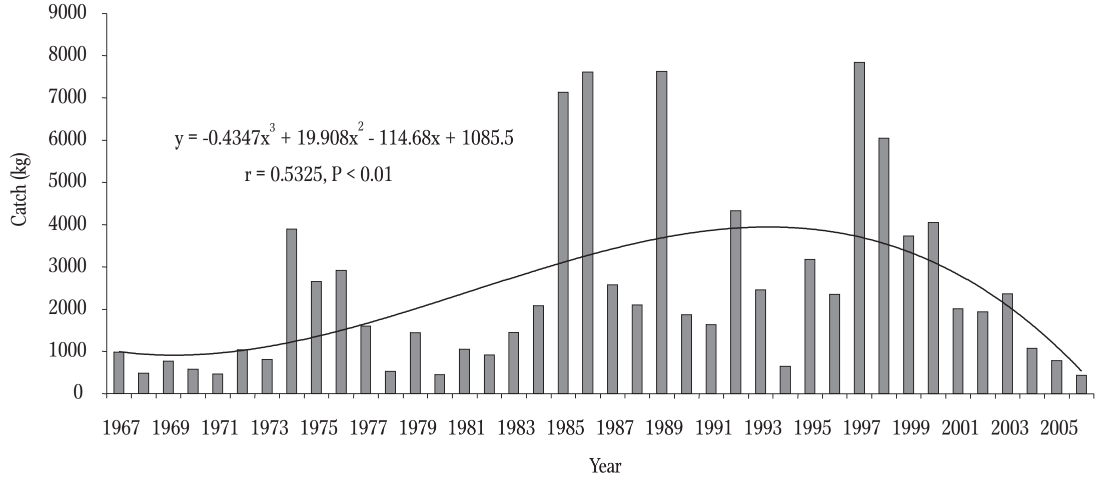

Figure 10. Commercial medium-size bream catches from 1967 to 2006 (medium-size bream – fish with body weight 0.5 -1.0 kg).

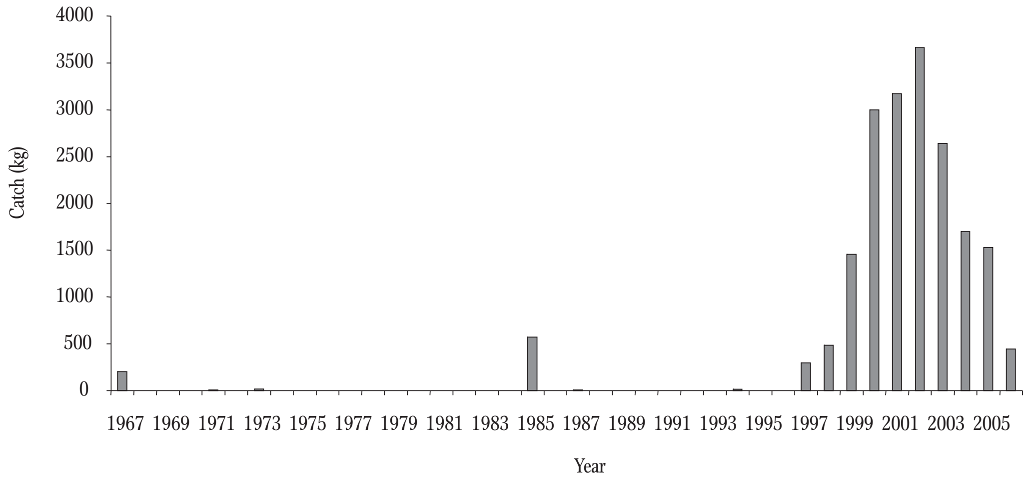

Figure 11. Commercial small bream catches from 1967 to 2006.

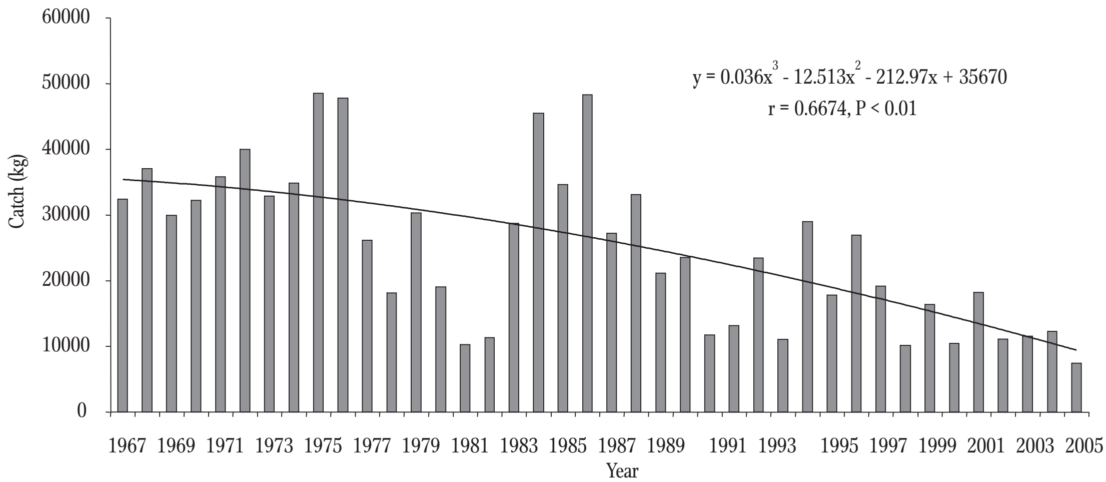

Figure 12. Total commercial roach catches from 1967 to 2006.

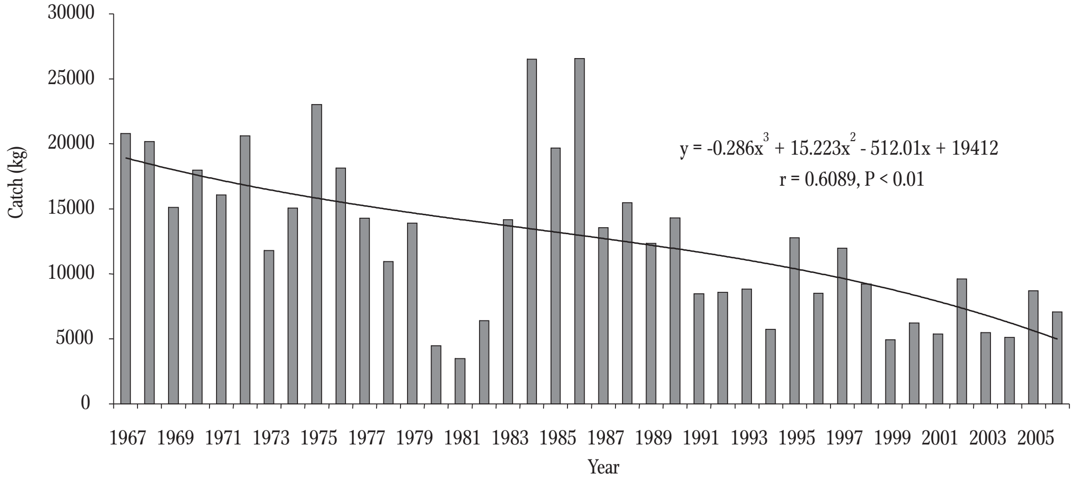

Figure 13. Commercial large roach catches from 1967 to 2006.

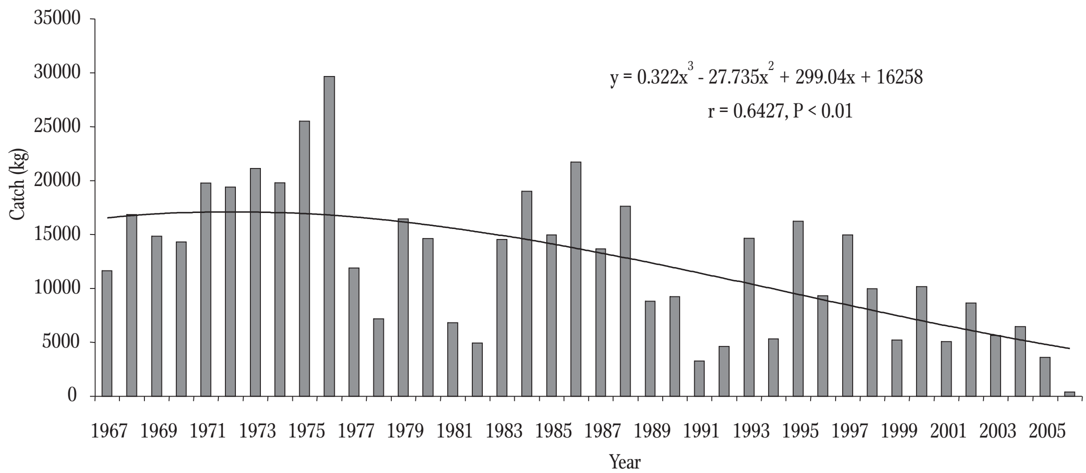

Figure 14. Commercial small roach catches from 1967 to 2006.

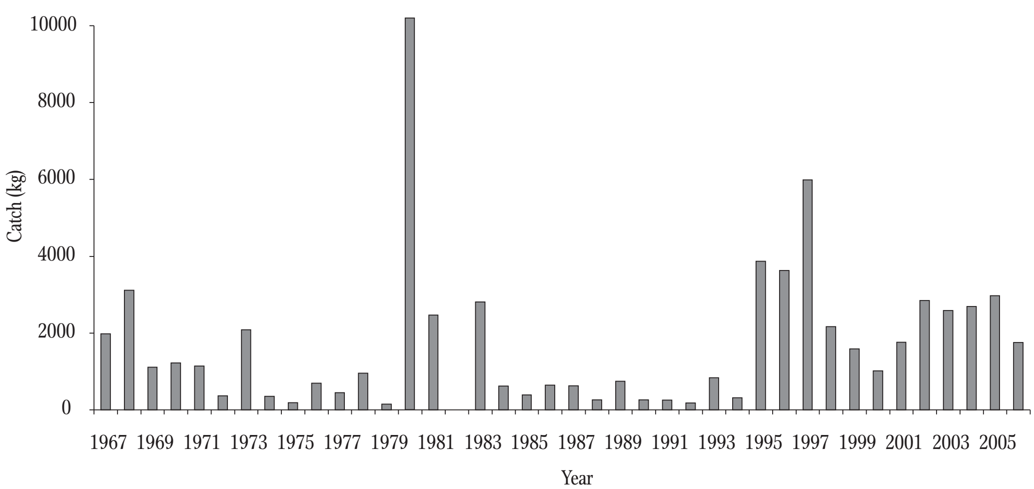

Figure 15. Commercial white bream catches from 1967 to 2006.

dominated by larger bream, however, it is worth noting that the catches of smaller bream have been clearly on the rise since 1997 (Figs. 9, 10, 11). Roach catch is characterized by a clearly decreasing trend (Fig. 12). The size of the different sizes of roach in the lake are quite similar and the calculated trends point to a clear decrease towards the end of the period of interest (Figs. 13, 14). White bream catch in Lake Mamry Północne has been rising since the middle 1990s compared with earlier periods. Given the huge differences in white bream catch during the period of interest, the calculated trend line was statistically insignificant (Fig. 15).

Changes in composition of commercial fish catches

Commercial fish catches were dominated by large sizes of cyprinids from 1967 to 1976. Cyprinids made up 21.3% of total catch (Table 4). The second most common type of fish caught were "small" cyprinids at 20.6%. Large cyprinids continued to dominate commercial fish catches over smaller sizes in the years that followed. Cyprinids made up most of the lake's commercial fish catches during the time period of interest, however, coregonid catches (as a percentage of total catch) continued to rise from year to year, with the exception of the period from 1977 to 1986. Coregonids became the dominant group of fish (23.8% of total catch) during the last decade studied (1997-2006). Perch catches remained steady as a percentage of total catches during all four analyzed decades, ranging from 4.9% in 1987-1996 to 7.1% in 1967-1976. The highest percentage of littoral species noted in commercial fishing records was 15.5% during the first of the four analyzed decades. The catches of littoral species continued to decline in the years that followed, with the lowest years of catch (5.9%) on record from 1977 to 1986.

Discussion

In light of its environmental and economic value, Lake Mamry Północne has been the subject of numerous hydrobiological research studies. Zdanowski (1983) as well as Zdanowski and Hutorowicz (1994) studied the lake's thermal and oxygen conditions, its water chemistry, water transparency (Secchi disk), and chlorophyll content. Research on the relationship between chlorophyll, nutrient concentration, and visibility of Secchi's disk was performed by Kufel (1998). The lake's biogenic substance loads were estimated by Giercuszkiewicz-Bajtlik and Głąbski (1981) as well as Giercuszkiewicz-Bajtlik (1990). Changes in the types of species present as well as changes in phytoplankton, chlorophyll, and phaeophyta content were also studied (Napiórkowska-Krzebietke and Hutorowicz 2005).

The data used in the paper indicate that the load of biogenic substances from the lake's drainage basin

Table 4
Catch composition (%) of selected fish species and groups of species from 1967 to 2006 in Lake Mamry Północne

Species/groups of species	1967-1976 (%)	1977-1986 (%)	1987-1996 (%)	1997-2006 (%)	1967-2006 (%)
Coregonids	16.2	7.3	19.8	23.8	16.3
Littoral species	15.5	5.9	6.2	7.5	9.7
Perch	7.1	6.1	4.9	6.5	6.3
"Large" cyprinids	21.3	30.4	30.4	21.0	25.2
"Small"cyprinids	20.6	25.6	21.9	19.5	21.8
Eel	3.6	9.1	7.4	3.1	5.6
Other	15.7	15.6	9.4	18.6	15.1

was largely responsible for the trophic conditions in Lake Mamry Północne. Potential phosphorus and nitrogen loads coming from the lake's total basin were three times greater than critical levels in 2000-2001 and ten times greater than load values forecasted by Giercuszkiewicz-Bajtlik and Głąbski (1981). The direct basin of the lake supplied only 20% of its biogenic substance load and did not exceed critical levels. Elevated concentrations of phosphorus in the epilimnion indicate a growing degree of eutrophication in Lake Mamry Północne in 2000-2001 (< 0.100 mg dm^{-3}). Other signs of encroaching eutrophication include reduced water transparency (as low as 2.0 m) and larger losses of oxygen content from the hypolimnion during summer periods with saturation at 11% (Gieysztor and Odechowska 1958, Zachwieja 1975, Gliwicz et al. 1980, Soszka et al. 1979, Zdanowski et al. 1984, Zdanowski and Hutorowicz 1994, Wróblewska 2002). Oxygen content losses taking place in 2000-2001 and increasing concentrations of phosphate and ammonia nitrogen near the bottom may have been signs of the release of biogenic substances from lake bottom deposits, which would make internal ion delivery more significant as means of lake eutrophication. Physical and chemical parameters were used to classify the lake in 2001 as Class II Water Purity (Wróblewska 2002) while Carlson's trophic index (1977) was used to classify the lake as mesoeutrophic for the purpose of this paper.

Phytoplankton research studies also identified an increase in the fertility of the waters of Lake Mamry Północne (Napiórkowska-Krzebietke and Hutorowicz 2005). Common cyanophytes such as *Microcystis aeruginosa* and *Leptolingbya thermalis* were determined to be responsible for the elevated concentration of chlorophyll and greater abundance of plankton. The two types of cyanophytes are characteristic of eutrophic waters (Eloranta 1998, Bucka and Wilk-Woźniak 2002).

In addition to purely environmental considerations, Lake Mamry Północne and all of the Great Masurian Lakes are also quite important in terms of their recreational and fishing value (Nowicki and Glińska 2000). The lakes' fishing, in conjunction with increasing level of lake eutrophication, has been the subject of many research papers (Zachwieja 1966, Wołos 1988, Grabowska and Wołos 1989, Pyka et al. 1989, Zakęś and Pyka 1990, Krzywosz 1999, Czerwiński and Wołos 2001, 2004).

The 40-year commercial fisheries data set for Lake Mamry Północne presented in the paper illustrates the changes that have taken place in its fish populations. It is important to note that the lake has been classified as a vendace-type lake. According to Szczerbowski (1981), lakes of this type are generally over 20 m deep, feature a hard bottom, sandy shores, little lake bottom vegetation, where the main "indicator" species are vendace, smelt, bleak, common whitefish, and burbot (*Lota lota*). Other species in the lake include common predators and cyprinids. Mehner et al. (2005) identified two types of fish populations in German lakes: 1) cold water-type with vendace and perch in deeper lakes, and 2) warm water-type with cyprinids in shallower lakes. At the same time, the researchers argued that population types are determined primarily by maximum depth, average depth, chlorophyll, and lake volume. In Poland, other factors affecting fish populations include commercial fishing and fish farming.

Analysis of commercial fisheries data has shown unequivocally that changes taking place in Lake Mamry Północne are generally consistent with the model based on the influence of eutrophication developed by the pioneers in the field: Colby et al. (1972) and Hartmann (1977, 1979). However, some departures have been identified, which may be the result of changes in the intensity of fishing efforts.

Clear cut differences in the types of species caught by commercial fishermen are obvious from the 40-year data set (1967-2006). This is especially true of selected species and groups of species indicative of the process of eutrophication. "Large" and "small" cyprinids made up almost 50% of total commercial fish catches. Coregonids, on average, were at 16.3%. Littoral species made up 10% and perch 6.3% of total catch. It is important to note that species labeled "other" made up as much as 15% of total commercial fish catch. Such "other" species include smelt and bleak – species found along with vendace in lakes with low or moderate trophic states (Szczerbowski 1981). These results unequivocally show that the trophic state of the lake as well as the rate of change of the trophic state were moderate from 1967 to 2006. One only needs to note that the percentage of coregonids remained quite high, reaching as much as 24% during the last years of the study period. The percentage of littoral species stood at 7.5% during the same period of time, while perch was at 6.5%, and species labeled "other" made up as much as 19% of total catch.

All species exhibited a declining catch trend, which is consistent with national catch trends (Wołos et al. 2007). Vendace catch fluctuated significantly with no clear trend in sight. Vendace catch reached a 40-year maximum of over 27 tons in 2006. Strong fluctuations in vendace catch are characteristic of this species. In the case of pike, catch fell abruptly towards the end of the 1970s and then stabilized at a rather low level. Pike catch experienced a small rebound after 2000, which may have been associated with increased lake-based fish stocking efforts throughout Poland (Mickiewicz 2008). The trend in the case of the catch of the other common predator, perch, is almost identical to that of pike. Tench catch declines rapidly down to zero in the 1990s and rebounds somewhat after 2000. Total bream catch fluctuates a lot and a statistically significant tendency cannot be established. Large bream dominates commercial fish catch throughout the time period of interest, however, small bream catch increases rapidly starting in 1997, which may be a sign of a moderate increase in the trophic state of the lake. Roach catch continues to decline. This is true of both large and small sizes.

In summary, it can be argued that commercial fishing trends for most species were in agreement with the eutrophication-based fish population model. However, some of the trends presented herein are substantially different from those produced by the model. Examples include the decrease in roach catch and the absence of an increase in the case of bream. These exceptions are associated with reduced fishing efforts caused by low market prices as well as increased cormorant activity (Krzywosz 2003). Such factors are used by Wołos et al. (2007) to explain the decrease in the yield of less valuable cyprinid species throughout Poland.

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Streszczenie

Wieloletnie zmiany w odłowach gospodarczych ryb z jeziora Mamry Północne na tle wskaźników fizyko-chemicznych i biologicznych

Jezioro Mamry Północne usytuowane w kompleksie Wielkich Jezior Mazurskich należy do zbiorników szczególnie cennych z przyrodniczego, rekreacyjnego i gospodarczego punktu widzenia, a jednocześnie przez wielolecia charakteryzowało się bardzo niskim poziomem troficznym i korzystnymi warunkami środowiskowymi. W pracy założono, że zmiany troficzne wód w jeziorze implikują zmiany odłowów gospodarczych ryb. Jej zasadniczym celem było zatem zweryfikowanie tezy, że zmiany trofii mogły wpłynąć w znaczącym stopniu na wielkość i strukturę gatunków odłowów ryb wskaźnikowych dla różnych poziomów troficznych. Weryfikację tej hipotezy oparto na podstawie oceny wieloletnich parametrów fizyko-chemicznych i biologicznych oraz statystyk połowów gospodarczych ryb. Przeprowadzone analizy dopływu azotu i fosforu do jezior oraz zmian parametrów fizyko-chemicznych (tlen, przezroczystość wody, chlorofil, seston, utlenialność ($ChZT_{Mn}$), fosforany i fosfor całkowity, azot amonowy, azot całkowity i azotyny) wykazały, że w całym badanym okresie trofia jeziora Mamry Północne była stosunkowo niska, kwalifikując jezioro na pograniczu beta-mezotrofii i eutrofii. Wykazano jednak, że w miarę upływu czasu w jeziorze Mamry Północne następował stały umiarkowany wzrost trofii, przejawiający się m.in. wzrostem koncentracji biogenów, spadkiem przezroczystości i pogorszeniem warunków tlenowych w hipolimnionie. Zmiany parametrów fizyko-chemicznych i biologicznych na ogół korespondowały ze zmianami w odłowach gospodarczych gatunków, a także wyodrębnionych grup gatunków wskaźnikowych dla procesu eutrofizacji. Symptomatyczne były zmiany odłowów koregonidów, które przy pewnych fluktuacjach utrzymują się stale na wysokim poziomie. Modelowy przebieg miały tendencje odłowów gatunków litoralowych i okonia, natomiast odbiegały od modelu trendy odłowów mniej cennych gatunków karpiowatych (płoci i leszcza), co można m.in. tłumaczyć zmniejszoną intensywnością eksploatacji rybackiej, oraz zwiększoną presją kormoranów.