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Long term changes in the quality and water trophy of Lake Ińsko – the effect of the re-oligotrophication?

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Abstract: In 1970–2010, during the period of spring circulation and summer stagnation, hydrochemical studies were conducted in Lake Ińsko (Western Pomeranian Lake Region, Poland) with determination of the lake susceptibility to degradation and trophic changes. Also, the effect of the catchment area on the water quality in this waterbody was assessed. The waters of the study lake were characterised by low static index, which is an additional indicator of low dynamics of water masses, and low susceptibility to degradation. In spite of this, significant changes in the lake quality and trophy were observed. The hydrochemical parameters defining water quality of the study lake continued to improve. In the 70's, the water quality was at the border of class II and III, while in 2006 and 2010 it reached the level characteristic for class I waters. Moreover, in the 70's and 80's of the previous century, Lake Ińsko Duże was a mesotrophic lake. Then, an increase in the lake trophy was observed, resulting in signs of eutrophy. At the end of the 90's and in the first decade of the 21st century, the study lake returned to the state of mesotrophy. No restoration works were undertaken in Lake Ińsko in the study period. The improvement in water quality, called oligotrophication, resulted most probably from the lake reaction to changes in the soil use in the catchment area, since fewer phosphorus and nitrogen compounds flow into the lake, and also from the regulation of the wastewater management in the town of Ińsko.

Keywords: Lake Ińsko, oligotrophication, susceptibility to degradation, trophy, water quality

INTRODUCTION

Purity of lakes results primarily from progressive eutrophication [ZDANOWSKI 1999]. Its causes and consequences are well known and widely reported in the literature related to limnology [GÓRNIAK *et al.* 2016; JAROSIEWICZ *et al.* 2011; KAJAK 1979; 1995; 1998; KALFF 2002; LOSSOW 1996; OHLE 1955; OLSZEWSKI 1971; WETZEL 2001]. Hypereutrophy of surface waters is a major problem in the process of water protection [KALFF 2002; VOLLENWEIDER 1971; WESOŁOWSKI, BRYSIEWICZ 2015; WETZEL 2001]. Urbanisation, industrialisation, intensive agricultural production in the catchment area, as well as rapid development of tourism, combined with insufficient protection of lakes, result in the lakes being overloaded with biogenic substances, especially phosphorus and nitrogen [LOSSOW 1996]. An increase in water trophy and its consequences make it necessary to look for ways of slowing down, inhibiting, or even reversing this unfavourable process, or eliminating its negative consequences [LOSSOW 1998]. It is currently believed that eutrophication is the biggest threat to biodiversity of fresh water habitats [HILLBRICHT-ILKOWSKA 1998; KUBIAK, TÓRZ 2005]. Lake waters are especially sensitive to pollution, and it often happens that lakes do not return to their previous state, even after the sources of pollution are eliminated. Protection and restoration of lakes, especially of degraded ones, is extremely difficult, since it requires removal of degradation causes, and knowledge of the much complex ecosystem of the lake. It also requires selection of appropriate restoration methods, and then consistent, often long-lasting study of their efficacy. The costs of such works must be borne in order not to allow lake degradation [LOSSOW 1995].

Increased lake trophy results in lower value in use: lower natural values, reduced attractiveness regarding recreation, as well as reduced fishing potential [KALFF 2002; KUBIAK *et al.* 2009; LOSSOW 1998; VOLLENWEIDER 1971]. As a result, measurable economic harms are observed, and the necessity of lake protection becomes evident. Poland, similarly to other parts of Europe, has also experienced excessive flow of nutrients and organic matter to surface waters for many years [KUBIAK 2003]. In recent years, information of lake oligotrophication has also appeared [BERNAT *et al.* 2020; HATVANI *et al.* 2020]. This process, which is very rarely observed, is the opposite of eutrophication and is considered positive due to its effect on improved water quality and reduced trophy [BERNAT *et al.* 2020].

The aim of the study was to assess trophic changes in Lake Ińsko, the cleanest waterbody of Western Pomerania, occurring in the period of 1970–2010, with regard to changes in the lake use and activities organising the water and sewage management on the catchment area.

MATERIAL AND METHODS

Lake Ińsko is located in north-western Poland (53°26'36" N; 15° 32'33" E) in the Lake Ińsko mesoregion with an area 750 km^2, which is part of Pomeranian Lake Region being a subprovince of South-Baltic Lake Region [KONDRACKI 2000]. Lake Ińsko, under the Polish Plain conditions, is a large lake with an area of 486.6 ha and significant depth (maximum and mean depth of 41.3 m and 12.9, respectively). This waterbody is characterised by mean shoreline development (shoreline development index $K1$ = 4.02) and poor effect of external factors on its waters (exposure index 37.82). The lake shoreline is 31 450 m long, and its total and direct catchment area is 40.6 and 15.9 km^2, respectively. Annual water turnover: 13.4% [CZERNIEJEWSKI *et al.* 2008].

Water samples for studies were collected from Lake Ińsko in 1970–2010. The studies were performed in 1970, 1971, 1978, 1982, 1987, 1992, 1996–1999, 2002, 2006 and 2010. Water samples were vertically collected usually from three study sites located at the deepest points of the lake (Fig. 1). While the samples were being collected, field measurements of temperature, water pH and Secchi disk visibility were taken. Laboratory chemical analysis was performed using widely accepted methods for this kind of studies [APHA 1995; 2005]. Annual sampling frequency was 6–8. The analysis of lake trophy was performed with generally used models of CARLSON [1977] and VOLLENWEIDER [1989] used in lake monitoring and described by BAJKIEWICZ-GRABOWSKA [2002]. The studies of lake water quality were based on the criteria used for lake monitoring in Poland [KUDELSKA *et al.* 1994]. The criteria included: mean depth, ratio of the lake volume and shoreline length, ratio of the active bottom area to epilimnion volume, intensity of water exchange, Schindler's index and management of the direct catchment area [KUDELSKA *et al.* 1994; BAJKIEWICZ-GRABOWSKA 2002].

The intensity of the catchment effect on the lake was assessed according to the principles used in Poland [BAJKIEWICZ-GRABOWSKA 2002]. The indices adopted for this assessment were:

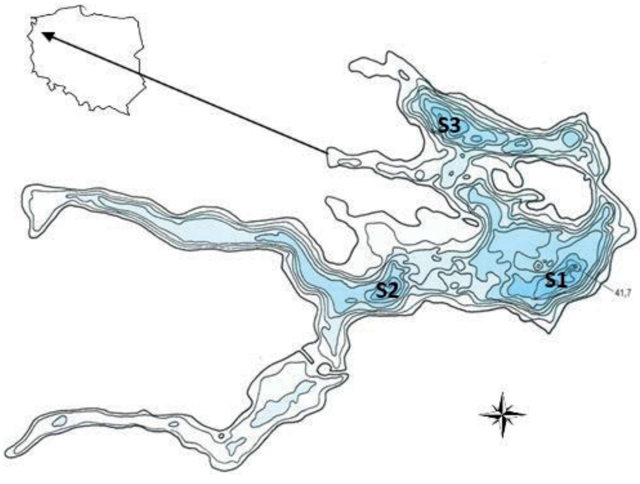

Fig. 1. Location of study sites – Lake Ińsko (53°26'36" N; 15°32'33" E); source: JAŃCZAK [1996], modified by authors

lake density of total catchment, and balance type of the lake. Moreover, the assessment included features of the direct catchment, i.e. density of river network, mean slope, geological structure and its management, and also percentage of closed drainage areas in the catchment area.

The comparison of the lake resistance and the intensity of the catchment effect on the waterbody allowed to determine the rate of its eutrophication [BAJKIEWICZ-GRABOWSKA 2002].

RESULTS AND DISCUSSION

WATER QUALITY

In the period of 1970–2010, the hydrochemical conditions of Lake Ińsko underwent significant changes (Tab. 1). In the whole study period, bottom water was characterised by good oxygenation during the summer stagnation. With regard to oxygen content in bottom waters during the long-term studies, 3 periods of different oxygen content were differentiated: the beginning of the 70's of the 20th century with the most preferable oxygen conditions (7.5 mg $O_2 \cdot dm^{-3}$ – in the summer of 1971); in the period of 1978–1987, the conditions were the least preferable (3.2–4.9 mg $O_2 \cdot dm^{-3}$); and a period of significant improvement in the lake oxygen condition, i.e. in 2006 and 2010 (6.6 and 6.9 mg $O_2 \cdot dm^{-3}$, respectively). This tendency is confirmed by another index defining oxygen conditions of the lake, i.e. mean oxygenation of hypolimnion (Tab. 1). Moreover, in the period of 2006–2010, the summer vertical oxygen distribution in the study lake was defined by a positive heterograde curve, while in the 80's of the 20th century, during the least favourable oxygen conditions, the heterograde curve was negative, with bottom water oxygenation below 20%.

In the period of 1970–2010, the study lake waters also changed their organic matter contents. The highest values of COD_{Cr} (over 30 mg $O_2 \cdot dm^{-3}$) were observed at the turn of the 70s and 80s, and at the end of the 90s, while the lowest values were observed during the last years of the study (Tab. 1).

The phosphorus content in Lake Ińsko was decreasing in the whole study period. In the spring, the phosphate phosphorus content in surface water changed from 0.056 (1976) to 0.009 and 0.010 mg PO_4-P $\cdot dm^{-3}$ (2006 and 2010). In the summer, the

Table 1. Changes in the water quality of Lake Ińsko in 1970–2010

Index	**Season**	**Layer**		**Years**												
				1976	**1971**	**1978**	**1982**	**1987**	**1993**	**1996**	**1997**	**1998**	**1999**	**2002**	**2006**	**2010**
Mean oxygenation of hypolimnion	Su	bottom	value	54.6	67.5	37.9	40.6	43.4	46.3	49.1	50.8	52.8	46.3	59.3	59.6	62.0
			point	1	1	2	1	1	1	1	1	1	1	1	1	1
DO	Su	bottom	value	6.0	7.5	3.2	4.0	4.0	4.2	5.2	5.0	6.1	4.9	5.5	6.6	6.9
			point	1	1	2	1	1	1	1	1	1	1	1	1	1
COD_{Cr}	Su	surface	value	28.0	26.4	32.0	30.4	28.8	28.8	27.2	28.4	30.4	30.4	22.4	21.9	19.8
			point	2	2	3	3	2	2	2	2	3	3	2	2	2
BOD_5	Su	surface	value	2.8	1.7	4.1	4.2	3.4	3.2	4.2	3.2	4.2	4.0	2.6	1.6	2.0
			point	2	1	3	3	2	2	3	2	3	2	2	1	1
	Su	bottom	value	2.0	1.7	1.9	2.6	4.2	2.4	4.2	2.4	2.8	3.0	2.8	1.4	1.5
			point	1	1	1	2	2	2	2	2	2	2	2	1	1
PO_4-P	Sp	surface	value	0.056	0.050	0.056	0.060	0.035	0.040	0.038	0.018	0.018	0.020	0.012	0.009	0.010
			point	3	3	3	3	2	2	2	1	1	1	1	1	1
	Su	bottom	value	0.090	0.093	0.084	0.079	0.065	0.065	0.036	0.036	0.034	0.030	0.025	0.028	0.025
			point	4	4	4	3	3	3	2	2	2	2	2	2	2
Total phosphorus	Su	bottom	value			0.144	0.098	0.095	0.090	0.091	0.080	0.075	0.062	0.057	0.039	0.035
			point			2	2	2	2	2	2	2	2	1	1	1
	mean (Sp+Su)	surface	value			0.052	0.050	0.041	0.031	0.034	0.042	0.030	0.034	0.024	0.038	0.030
			point			2	1	1	1	1	1	1	1	1	1	1
Mineral nitrogen	Sp	surface	value	0.36	0.27	0.23	0.37	0.23	0.37	0.29	0.13	0.13	0.16	0.19	0.21	0.20
			point	2	2	2	2	2	2	2	1	1	1	1	2	2
NH_4-N	Su	bottom	value	0.90	0.70	0.22	0.17	0.40	0.32	0.12	0.27	0.16	0.22	0.10	0.06	0.06
			point	2	2	2	1	2	2	1	2	1	2	1	1	1
Total nitrogen	mean (Sp+Su)	surface	value			1.72	1.64	1.21	1.30	1.24	1.08	1.37	1.21	0.83	0.68	0.72
			point			3	3	2	2	2	2	2	2	1	1	1
Conductance	mean (Sp+Su)	surface	value	189	182	172	180	182	196	182	176	178	168	181	188	182
			point	1	1	1	1	1	1	1	1	1	1	1	1	1
Chlorophyll	mean (Sp+Su)	surface	value			17.0	14.3	16.5	15.0	11.5	12.3	15.0	14.3	9.5	14.5	10.0
			point			3	2	3	2	2	2	2	2	2	2	1
Seston dry matter	mean (Sp+Su)	surface	value	12.0	13.2	9.5	11.5	14.0	12.5	13.0	12.0	15.0	11.5	8.5	11.5	9.5
			point	3	4	3	3	4	4	4	3	4	3	3	3	3
Visibility	mean (Sp+Su)	surface	value	4.2	4.5	3.2	3.8	4.1	4.0	4.3	4.5	4.7	4.9	5.5	5.3	5.5
			point	1	1	2	2	1	1	1	1	1	1	1	1	1
Mean				**1.92**	**1.92**	**2.38**	**2.06**	**1.94**	**1.88**	**1.81**	**1.63**	**1.75**	**1.69**	**1.44**	**1.38**	**1.31**
Class				**II**	**II**	**II**	**II**	**II**	**II**	**II**	**II**	**II**	**II**	**I**	**I**	**I**

Explanations: *DO* = dissolved oxygen, COD_{Cr} = chemical oxygen demand, BOD_5 = five-day biological oxygen demand, Su = summer, Sp = spring.
Source: own study.

content change in the bottom water was from 0.090 to 0.025 and 0.028 mg·dm^{-3}, respectively. In the study period, a decrease in the content of various nitrogen forms was observed (Tab. 1). For example, NH_4-N level in bottom waters was 0.90 mg NH_4-N · dm^{-3} in 1976, and 0.06 mg NH_4-N · dm^{-3} in 2006 and 2010.

A decreasing level of nutrients in the water of Lake Ińsko resulted in decreased primary production (reduced chlorophyll "a"), which in turn caused reduction in the seston content and increased visibility of Secchi disk (Tab. 1).

Defining the water quality of Lake Ińsko with the use of the criteria provided by Kudelska *et al.* [1994] it must be concluded, that it continued to improve. In 1978, the water quality was at the border of purity class II and III, while in 2006 and 2010 it reached the level characteristic for class I waters (Tab. 1).

ASSESSMENT OF LAKE SUSCEPTIBILITY TO DEGRADATION

Lake Ińsko is characterised by significant resistance to degradation, which results from its high depth, average intensity of water mass mixing and a favourable ratio of the catchment area to the lake volume (Tabs. 2, 3). The small bottom area in the epilimnion and significant participation of hypolimnion in the total lake volume resulted in reduced intensity of nutrient recirculation from bottom waters and sediments to the trophogenic layer. Circulation of matter and internal inflow of nutrients was limited. This was also promoted by the significant depth, as well as by eumictic, with a tendency to bradymictic, type of mixing of the lake water masses [Kubiak 2003]. Indeed, the rate of matter circulation in lakes, including the rate of nutrient recirculation

Table 2. Assessment of Lake Ińsko susceptibility to degradation using the method of Kudelska *et al.* [1994]

Indices of the assessment of lake susceptibility to degradation													Mean score	Assessment of lake susceptibility to degradation	
mean depth H_m		*V*/*L*		% stratification		*ABA*/*EV*		% water exchange		Schindler's index		catchment land use		susceptibility category	lake resistance
value	cat.	value	cat.	value	cat.	value	cat.	value	cat.	value	cat.	cat.			
12.9	1	2.2	2	42.0	1	0.1	1	13.0	1	0.7	1	2	1.3	I	highly resistant

Explanations: cat. = category; *V* = lake volume, *L*{ts/}= shoreline length, *ABA* = active bottom area, *EV* = epilimnion volume; % stratification acc. to Bajkiewicz-Grabowska [2002]; category of: catchment land use: I{ts/}≥ 60% of forests, II < 60% of forests; 60% of arable land, III ≥ 60% of arable land, IV = catchment with urban development.
Source: own study.

Table 3. Assessment of Lake Ińsko susceptibility to degradation using the method of Bajkiewicz-Grabowska [2002]

Indices of the assessment of lake susceptibility to degradation												Mean score	Assessment of lake susceptibility to degradation	
mean depth H_m		*V*/*L*		% stratification		*ABA*/*EV*		water exchange/year		Schindler's index			susceptibility category	lake resistance
value	cat.	value	cat.	value	cat.	value	cat.	value	cat.	value	cat.			
12.9	0	2.2	2	42.0	0	0.1	0	0.1	3	0.7	0	0.83	II	moderately resistant

Explanations as in Tab. 2.
Source: own study.

from the bottom layers, and the trophy itself, depends on the water mass dynamics [Choiński 2007; Kalff 2002; Patalas 1960; Wetzel 2001]. It is believed that lakes with lower water dynamics show a slower process of eutrophication, and such lakes are more resistant [Kubiak *et al.* 2009]. Eumictic type of water mixing, with a tendency to bradymictic type, resulted in slow circulation of the matter in Lake Ińsko. The waters of the study lake were characterised by low static index, which is an additional indicator of low dynamics of water masses, and thus a low susceptibility to degradation.

ASSESSMENT OF THE CATCHMENT EFFECT ON THE LAKE

The catchment area of Lake Ińsko is characterised by moderate capacity to mobilise load. Its positive features which reduce nutrient inflow include low lake density, low density of river network and small slopes of direct catchment, its loamy geological structure and positive ratio of the catchment area to the lake volume [Bajkiewicz-Grabowska 2002]. Negative features include the flow-through type of the lake and no closed drainage areas in the direct catchment (Tab. 4). However, the catchment area partially covered by forests and also used by agriculture showed an average activity regarding mobilisation of the load of deposited matter and moderate capacity to deliver matter to the lakes.

LEVEL OF TROPHY

Changes in the hydrochemical conditions of Lake Ińsko in the period of 1970–2010 made it possible to determine changes in the trophy level. In the first years of the study (1970–1987), trophy was much higher than in the final years (2006–2010). In the summer, the chlorophyll "a" content was always at the level

Table 4. Catchment characteristics – suppliers of nutrient matter of Lake Ińsko acc. to model of Bajkiewicz-Grabowska [2002]

Index	Characteristics of Ińsko catchment	
Lake density (%)	value	8.3
	score	0
Lake balance type[1), 2)]	type	outflow
	score	1
Density of river network[1)] ($km \cdot km^{-2}$)	value	0.10
	score	0
Mean catchment slope (%)	value	9.1
	score	1
Closed drainage areas[3), 4)] (% of catchment area)	value	0
	score	3
Catchment geological structure[5), 6)]	type	loamy
	score	1
Catchment land use	type	forest-agricultural with development
	score	3
Mean score	**score**	**1.29**
Group of susceptibility		**II**
Catchment features	**low susceptibility to load mobilisation and low capacity of load supply to the reservoir**	

[1)]Jańczak [1988]. [2)]Filipiak and Raczyński [2000]. [3)]Friedrich *et al.* [1989]. [4)]Czarnecka *et al.* [1989]. [5)]Duda and Duklas [1968]. [6)]Jańczak [1983]
Source: own study.

Table 5. Trophic changes in Lake Ińsko in the period of 1970–

2006

Year	Acc. to Carlson [1977]						Acc. to OECD [Vollenweider 1989]					
	TSI-SD		TSI-chlorophyll "a"		TSI-TP		TP - mean	Ch a - max. (summer)	Ch a - mean (spring–summer)	SD – max. (summer)	SD - mean (spring–summer)	$\%O_2$ – bottom
	value	trophic state	value	trophic state	value	trophic state						
1970	41	MS	56	MS	61	EU	EU	MS	EU	OL	MS	MS
1971	40	MS	58	MS	62	EU	EU	MS	EU	OL	MS	EU
1978	45	MS	60	MS	62	EU	EU	MS	EU	MS	MS	EU
1982	42	MS	59	MS	65	EU	EU	MS	EU	OL	MS	EU
1987	42	MS	59	MS	65	EU	EU	MS	EU	OL	MS	EU
1992	42	MS	59	MS	53	MS	MS	MS	EU	OL	MS	EU
1996	41	MS	56	MS	59	MS	MS	MS	EU	OL	MS	MS
1997	40	OL	58	MS	57	MS	EU	MS	EU	OL	MS	MS
1998	39	OL	59	MS	56	MS	MS	MS	EU	OL	MS	EU
1999	39	OL	59	MS	58	MS	MS	MS	EU	OL	MS	EU
2002	37	OL	57	MS	52	MS	MS	MS	EU	OL	MS	MS
2006	38	OL	59	MS	56	MS	MS	MS	EU	OL	MS	MS
2010	38	OL	53	MS	53	MS	MS	MS	EU	OL	MS	MS
Mean	40	OL	58	MS	58	MS	MS	MS	EU	OL	MS	EU/MS

Explanations: OL = oligotrophic, MS = mesotrophic, EU = eutrophic, TSI-SD = trophic state index – Secchi disk visibility, TSI – chlorophyll "a" = trophic state index – chlorophyll "a", TP = total phosphorus, Ch a = chlorophyll „a", SD = Secchi disk visibility.
Source: own study.

typical of mesotrophy (Tab. 5). On the other hand, the phosphorus content in Lake Ińsko classified its waters to the group of eutrophic (1978–1987), or mesotrophic (1992–2010) reservoirs [Kubiak 2003; Kubiak *et al.* 2009; Kubiak, Knasiak 1996; Kubiak, Tórz 2005; Nguyen 1972] – Table 1. In the lake bottom waters, complete deoxygenation was never found. With regard to oxygenation, the lake was more frequently eutrophic (10–40%) than mesotrophic (over 40%). In the final years, mean oxygenation of hypolimnion was over 60% (Tab. 5). In the summer period of 2006–2010, increased visibility of the Secchi disk (over 5.5 m) was observed, reaching the values considered by Vollenweider [1989] typical of oligotrophic water, which indicates further improvement in the water quality of the study lake.

The studies performed in Lake Ińsko showed mesotrophic features of the water in the 70's, followed by increased trophy in the 80's and first half of the 90's, and return to the state of mesotrophy at the end of the 90's. In the latter period, Lake Ińsko was characterised by slight hyperoxygenation, in the summer, of the surface layers and good oxygenation of the bottom water – never below 25%. The summer vertical oxygen distribution in Lake Ińsko was similar to the one defined by a negative heterograde curve, typical of -mesotrophic lakes [Hutchinson 1957; Wetzel 2001]. Due to good light conditions, defined by the Secchi disk visibility, resulting from low water load with organic compounds, the compensation plan was located deep and vertical oxygen gradients were small [Kubiak 2009]. Yet, the result of the final years of studies (2006, 2010) show that the water quality was further improved: class II waters, previously even purity class II/III acquired features typical of class I. Some of the indices (e.g. visibility) had in the final period the values typical of oligotrophic waters (Tab. 5). Moreover, in the final years of studies, bottom waters of the lake revealed small changes in oxygenation during the year. The hypolimnion water showed low rated of oxygen use during the formation of summer stratification, which is confirmed by low level of trophy [Hutchinson 1957; Kalff 2002; Kubiak *et al.* 2009; Wetzel 2001] – Table 6.

The changes in trophy and water quality of the lake over the study years were probably caused by intensification of animal and

Table 6. Rate of hypolimnion oxygen use between spring homothermia and summer heterothermia in Lake Ińsko in the period of 1970–2010

Years	Areal hypolimnion oxygen deficit ($mg\ O_2 \cdot cm^{-2} \cdot day^{-1}$)
1970	0.048
1971	0.042
1978	0.053
1982	0.042
1987	0.035
1993	0.034
1996	0.037
1997	0.038
1998	0.038
1999	0.039
2002	0.036
2006	0.031
2010	0.031

Source: own study.

plant production in the catchment area (mainly in the 70s and 80s), including industrial grow-out fattening of steelhead trout (1977–1982). At that time, about 27 Mg of industrial fish were produced, and the load of organic pollution was estimated at 10–15 thous. of equivalent inhabitants. Moreover, the trophic state of water was undoubtedly affected by the introduction of raw (untreated) municipal waste from the city of Ińsko to the lake [Kubiak 2003; Kubiak *et al.* 2009].

The study waterbody is located on land which was previously used for intense industrial animal production and large-scale plant production characterised by high doses of artificial fertilisers – the catchment area of Lake Ińsko was intensely utilised by agriculture. This largely contributed to transport of high nutrient loads to these waterbodies [Gotkiewicz *et al.* 1990; Kubiak *et al.* 2009; Lossow 1995; Lossow, Więcławski 1991], because agricultural use of land is the basic source of nitrogen and phosphorus for waters. At that time, annual phosphorus loss from soils in the ground moraine landscape of Western Pomerania was 23.9 kg $P_2 \cdot O_5 \cdot km^{-2}$ [Chudecki, Duda 1971]. Durkowski [1998] estimated it at 4% of the input fertiliser dose and claimed that the annual loss from heavily fertilised agricultural areas is maximum 5.5 kg $N \cdot ha^{-1}$ and 0.6 kg $P \cdot ha^{-1}$. According to Lossow [1995], 1–5% phosphorus and 10–20% nitrogen introduced to soil with mineral fertilisers are leached into local waters. In the Vistula basin, 52% nitrogen and 45% phosphorus come from land sources (mainly agricultural land), and in the Oder basin – 43% and 30%, respectively [Niemrycz *et al.* 1993].

In vast majority, the catchment area of Lake Ińsko belonged in the 70's and 80's to state agricultural farms, which applied fertilisation reaching 750 kg $NPK \cdot ha^{-1}$ [Borowiec *et al.* 1978]. In the period between 1979/1980 and 1992/1993, a decrease in mineral fertilisation was observed in Poland (on average to 66 kg $NPK \cdot ha^{-1}$, and on individual farms even to 61 kg $\cdot ha^{-1}$ of agricultural land) [Rajda *et al.* 1995]. A similar tendency was observed in the Western Pomerania. In 1992–1993, there was a sudden decline in fertilisation to 63.1 kg $\cdot ha^{-1}$ [WUS Szczecin 1974; 1980; 1995]. Given the above, it may be stated that lake eutrophication of Western Pomerania lakes in the 90's could have been inhibited by significant reduction in fertilisation [Zdanowski 1999].

It should be noticed, however, that sizeable point sources, including those of municipal waste, can outweigh the agricultural effect on a given waterbody [Kajak 1979; 1995; 1998]. Inadequate water and sewage management on rural areas is an important cause of water eutrophication. In parallel to development of water supply networks, waste must be adequately controlled and treated. Otherwise, not only rapid lake degradation will occur but also worsening of groundwater quality [Lossow 1995; 1998]. In the town of Ińsko, the wastewater management was organised only at the end of the 90's, and the discharge of treated wastewater was directed outside the lake. The regulation of wastewater management and changes in the soil use in the lake catchment area resulted in significant improvement in the water quality of Lake Ińsko, and reduced level of trophy. The reduced trophic level caused changes in the ichthyofauna structure of Lake Ińsko. In the final years of study, a significant increase in the proportion of vendace (*Coregonus albula* Linnaeus) in commercial catches was observed. In 2003–2004, this species constituted only 6–7% of total weight of commercial catches on Lake Ińsko. Steadily improving abiotic conditions and rational fishery management, as well as regular intense stocking in consecutive years resulted in increased presence of this species. The highest increase was observed in 2010 (53% of total weight of catches) and in 2011 (75% of total weight of catches) [Biernaczyk *et al.* 2012].

CONCLUSIONS

In the study period of 1970–2010, Lake Ińsko was always characterised by good oxygen conditions, and the bottom waters revealed good oxygenation during summer stagnation. A decreasing phosphorus and nitrogen content in the waters, lower primary production manifested as small amounts of chlorophyll "a" in the surface water, increasing water transparency, increasing nitrogen-to-phosphorus ratio and slower reduction of oxygen content in hypolimnion during formation of summer oxygen distribution confirm a decreasing trophic level of Lake Ińsko. At the same time, the above factors confirm a mesotrophic nature of this waterbody. Moderate susceptibility of the catchment to nutrient load mobilisation and high resistance of the waterbody were the factors deciding about the eutrophication rate of Lake Ińsko, which was considered moderate. The presented characteristics of Lake Ińsko and its catchment area, together with changes in the soil use and wastewater management of the town of Ińsko, resulted, in the last 10 years, in significant improvement of the water quality in the study lake and return to the state of mesotrophy. Taking into account the changes in the water quality of Lake Ińsko, and the assessment of trophy level using the presented models, it may be concluded that the study waterbody has undergone the process of natural oligotrophication.

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