Studia Quaternaria, vol. 40, no. 2 (2023): 57–66 DOI: 10.24425/sq.2023.148032

THE GRAVEL PIT LAKES' WATER QUALITY, THEIR AQUATIC ECOSYSTEM FUNCTION, AND THE EFFECTS OF ENVIRONMENTAL CHANGES IN NORTHERN POLAND

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Abstract:
Water quality is an important factor to determine a development of living organisms, including the presence of amphibians. It this article we compared the water quality of both, natural infield reservoirs in areas with intensive cultivation of cereals and the recently created reservoirs in the gravel pits in Central Pomerania, northern Poland. We tested all the physico-chemical properties that may impact species richness and reproductive success of amphibians. We observed that gravel ponds were better oxygenated, with higher pH and conductivity, and were less fertile in nutrients. In Pomerania, the water reservoirs in gravel pits had better breeding conditions than in-field ponds with higher total nitrogen and total phosphorus concentrations. There are many scientific papers identifying a negative role of sand and gravel mines, including a release of heavy metals from sediments, a high non-metalic minerals concentration, a destruction of native species of vegetation and occurrence of alien species. Therefore, we should be careful in assessing the role of newly emerging reservoirs in sand and gravel mines. The purpose of our research is to show that sand/gravel mines can be used to protect nature and that they can have also a positive impact. Few previous studies indicate that they may be a favorable place for creating new breeding sites for amphibians, which may ultimately help to preserve species in the face of environmental pollution and climate change.

Key words: small water body, amphibians, anthropogenic pression, sand/gravel pit.

Manuscript received 4 February 2023, accepted 4 August 2023

INTRODUCTION

Many of small water bodies in the countries of the European Union are significantly under pressure from agricultural pollution, mainly nitrogen and phosphorus present in chemical and organic fertilizers (WWAP, 2015). In a crop production, water pollution from nutrients occurs when fertilizers are applied at a greater rate than they are fixed by soil particles or exported from the soil profile. Excess nitrogen and phosphate can move to ground and surface waters (e.g. mid-field ponds). Another threat to in-field reservoirs is their disappearance due to droughts. The frequency of droughts and their severity increased in recent years, and it is very likely that this phenomenon will increase in near future due to predicted climate changes.

The landscape of the Pomeranian region in northern Poland is characterized by a very large number of mid-field ponds and intensive cultivation of cereals, therefore many of these reservoirs are eutrophic with increased nutrients levels (Jarosiewicz *et al.*, 2018) . At the same time, this region, due to accumulation of natural aggregates (gravel and sand), is used to extract these minerals for the construction industry.

In Poland, natural aggregates are the basic group of extracted minerals. Poland is a leading producer of mineral aggregates, both in Europe (fourth largest producer) and worldwide. In 1989–2018, the extraction of aggregates (gravels, sands and broken stones) increased about 4 times, from 63 to 300 million Mg, which resulted in the increase of a number of sand and gravel mines (Kozioł and Baic, 2019). The importance of this natural aggregate is underscored by the fact that sand is now considered globally to be by volume the second (after freshwater) most exploited natural material. The extraction of sand and gravel in the world reaches up to 53 billion tons per year (Chilamkurthy *et al.*, 2016), and due to the wide application of aggregates (i.e. linear infrastructure, concrete production, prefabricated elements, civil and hydro engineering projects) the demand for them gradually increase.

In the Pomeranian region, the balance resources of gravel and sand amount to about 1.1 billion Mg, which is about 5.8% of the national resources. These deposits are mainly derived from glacial and glaciofluvial accumulation (Kozioł and Baic, 2020). In 2018, about 170 deposits were exploited, with the total annual production of 19 million Mg. In this area small and very small deposits predominate (about 60%), with production below 50 000 Mg. Only in two deposits (Gliśno and Mirowo) the production exceeded one million Mg a year.

Unfortunately, the construction of new and the exploitation of existing gravel pits have many negative environmental effects. Site preparation for mine expansion is a destructive process that changes abiotic and biotic environmental conditions (Sonter *et al.*, 2018). This involves landscape degradation (Willis and Garrod, 1999), loss of agricultural land (Dissanayake and Rupasinghe, 1996), soil erosion (Asabonga *et al.*, 2017), river degradation (Dissanayake and Rupasinghe, 1996; Meador and Layher, 1998; Syah and Hartuti, 2018) and other ecosystems (Sonter *et al.*, 2017) and biodiversity reduction (Asabonga et al. 2017; Sonter *et al.*, 2018). Gravel/sand aggregates production generates also other negative effects such as noise, dust, truck traffic and, pollution.

The exploitation of gravel deposits often results in development of new anthropogenic water reservoirs (sand and gravel mining ponds). Sand and gravel pit ponds are formed when open gravel pit cut mining has ceased and the mine void fills with water *via* groundwater inflow and/or surface runoff to create a water reservoir. The reservoirs are rapidly colonized by a variety of organisms, significantly enhance freshwater biodiversity (Williams *et al.*, 2008; Klimaszewski *et al.*, 2016). Sand and gravel mining ponds increase a density of water reservoirs in the landscape and can be an important factor to determine a presence of metapopulations of rare species (Williams *et al.*, 2008, Céréghino *et al.*, 2008).

In our research, we wanted to estimate the importance of two types of water reservoirs for amphibians, i.e. natural mid-field small ponds that are strongly influenced by farming, and new ones created as a result of sand and gravel exploitation in Pomeranian region. Amphibians are regarded as good ecological indicators (for example, to indicate habitat fragmentation, ecosystem stress and impact of pesticides). The ecological importance of amphibians includes their association with both aquatic and terrestrial environments where matter and energy are circulated between aquatic and terrestrial habitats. Amphibians form a central part of many food webs being both predators and prey, and being poikilotherms, they turn a greater portion of their calories into biomass compared to homeotherms (West, 2018). They are useful regulators of biomass in water ecosystems, because they may contribute to reduction of trophy (Hocking and Babbitt, 2014). Additionally, they are biological control agents pests such as mosquitos or crop-damaging arthropods.

Therefore, we performed the physicochemical properties of water in agricultural mid-field ponds and new sand gravel mine ponds. The ones in the mines are younger and better protected from pollution, because they are located on large mine surfaces, so they have less contact with farming area. Finally, we examined a degree of use of both types of reservoirs by amphibians that reproduce.

STUDY AREA

The research concerned the catchments of 8 mid-field ponds and 6 sand mine ponds located in Central Pomerania in the districts of Słupsk and Lębork (Fig. 1). It is a region dominated by arable land (over 50% of the total area). A soil quality allows for cultivation and high yields of many cereal crops, rape and potatoes. Cattle breeding is also carried out in this area. Central Pomerania does not have major mineral resources, with the exception of common sands, gravels, clays, lake chalk and peat but they are exploited locally.

Table 1. Characteristics of studied water body.

Type of reservoir	Code	Latitude	Longitude	Surface area, ha	Catchment description
Sand and gravel ponds	SG1 !	N 54°36’14.3”	E 17°46’6.2”	6.40	G_A – 15.5 ha
	SG2 !	N 54°29’27.95”	E 17°29’46.9”	0.10	G_A – 5.6 ha
	SG3 ‟	N 54°30’1.6”	E 17°4’29.5”	0.40	G_A – 10.8 ha
	SG4 ‟	N 54°29’57.0”	E 17°4’35.0”	0.32	G_A – 11.8 ha
	SG5 ‟	N 54°26’4.8”	E 17°6’21.5”	0.95	G_A – 24.7 ha
	SG6 !	N 54°19’3”	E 16°56’17.2”	3.00	G_A – 15.2 ha
Midfield ponds	M1	N 54°27’4.7”	E 17°19’9.7”	0.13	A; B
	M2	N 54°25’0.8”	E 17°8’53.8”	0.06	A
	M3	N 54°26’28.6”	E 17°6’10.2”	0.30	V, F
	M4	N 54°28’16.2”	E 17°10’14.0”	0.15	A; B
	M5	N 54°28’22.1”	E 17°9’34.6”	0.37	A; B
	M6	N 54°27’3.2”	E 17°15’12.9”	0.15	A; B
	M7	N 54°27’8.0”	E 17°15’11.8”	0.25	A; B
	M8	N 54°27’54.7”	E 17°10’25.5”	0.08	A; B

! – active gravel pit; ‟ – derelict gravel pit; G_A – gravel pit area; A – arable lands; B – buffer zone; V- village; F – fallow lands

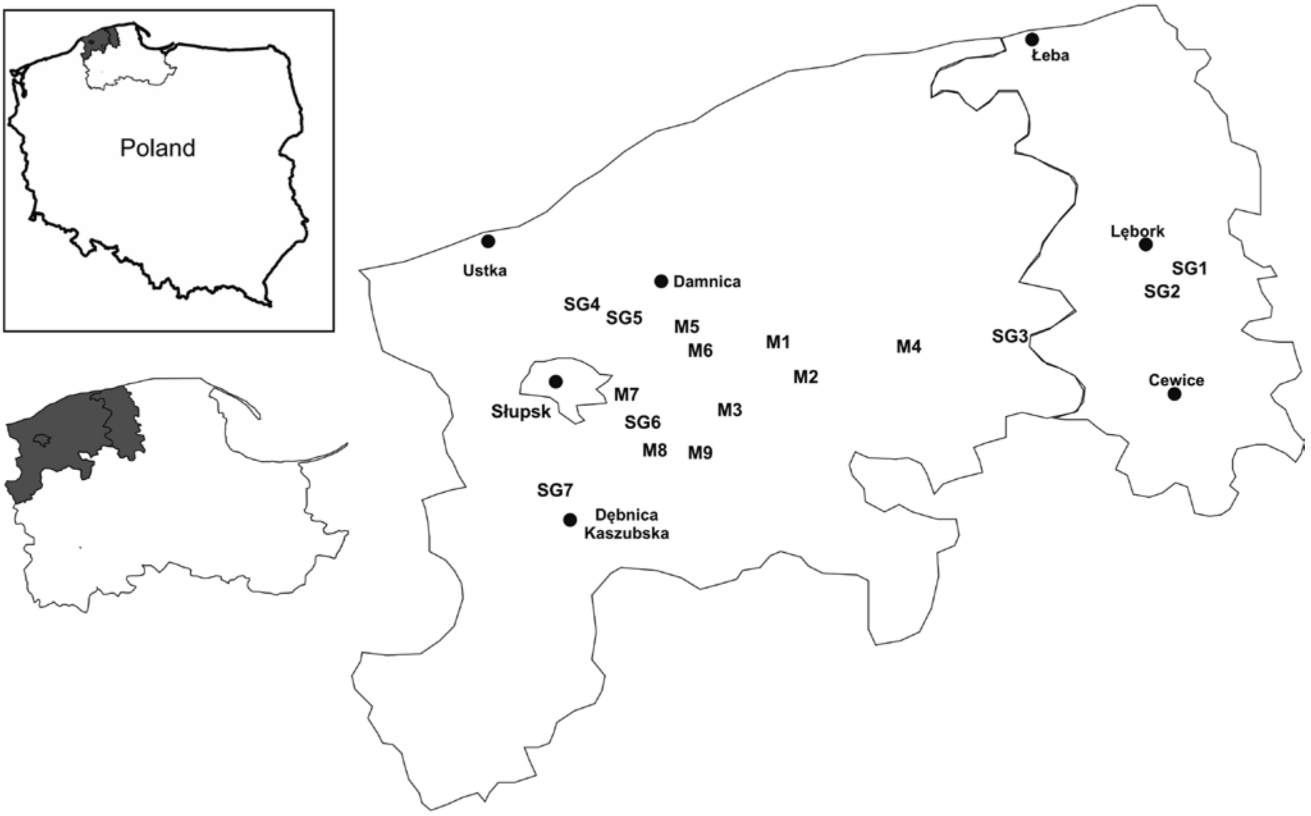

Fig. 1. Location of measurement points. M – midfield ponds; SG – sand/gravel mine ponds

The examined water reservoirs were close to one another. The SG1 and SG6 ponds were the most distant (about 60 km) from each other. Only SG3, SG4 and SG5 had a developed rushes zone, and the others are very stingy. An exact location, area and description of the catchment area of the water reservoirs under study are presented (Table 1). The mid-field ponds were from 0.06 ha to 0.37 ha in area. The surveyed mid-field ponds were located in areas intensively used for agriculture and they were most often surrounded by wheat, rapeseed and potato crops. Most of them were surrounded by a buffer zone consisting of shrubs, thickets and trees. Reservoirs in sand/gravel mines had an area from 0.1 to 6.4 ha (Table 1). They were located in the mines, the area of which was from 5.6 ha to 24.7 ha. We tested both actively mined and derelict sand mine ponds.

MATERIAL AND METHODS

Physico-chemical measurements

The study was conducted in 2019 in two types of reservoirs: sand/gravel mine ponds (n = 6) and mid-field ponds (n = 8). From each type of ponds, two samples were collected: first in March and second in May (n = 28). Water samples were collected in open waters, at a distance of approx. 1 m from the shore at 0.5 m depth. The field measurements included pH (CX-315, Elmetron), water conductivity (CC-401, Elmetron), and dissolved oxygen concentration (HI 9146 Microprocessor Dissolved Oxygen Meter, Hanna). Other laboratory parameters, i.e. the concentrations of chlorophyll a, nitrogen concentration i.e. total nitrogen (N-tot), nitrates ($N\text{-}NO_3$) and ammonium nitrogen ($N\text{-}NH_4$), and phosphorus concentration i.e. total phosphorus (P-tot) and mineral phosphorus ($P\text{-}PO_4$), were determined in a laboratory setting using the standard analytical procedures. Concentration of chlorophyll a (CLA) was determined spectrophotometricially according to the standard method in cold water with 90% acetone (Jeffrey and Humphrey, 1975). Concentrations of total phosphorus and total nitrogen were determined after their oxidation to nitrates and phosphates by autoclaving and digestion in perichloric acid according to respective colorimetric methods (Grashoff, 1976). Phosphate concentration was measured spectrophotometrically (SP-830 plus Metertech) using the ascorbic acid method (890 nm) according to EN ISO 6878:2006. Nitrate concentration was determined at 410 nm, after reaction with sodium salicylate according to PN-C-04576-08:1982. Ammonium concentration was measured at 690 nm, using the ammonium test spectroquant (Merck – method compatible with EPA 350.1 i ISO 7150/1). The concentration of organic nitrogen (N-org) and organic phosphorus (P-org) were estimated as the difference between total nitrogen (phosphorus) and the sum of inorganic nitrogen ($N\text{-}min = N\text{-}NO_3 + N\text{-}NH_4$) (phosphates), respectively.

Trophic condition

To describe and compare the trophic condition of the examined small water bodies, we used the trophic state indices proposed by Carlson (1977) and Kratzer & Brezonik (1981). The indices were computed for each pond based on each of the three parameters N-total, P-total and phytoplankton chlorophyll a content. Trophic condition of the studied ponds (TSI – trophic State Index) was calculated as a mean value of the three indices (TSI_{Ntot}, TSI_{Ptot}, and TSI_{CLA}).

Amphibians abundance

We measured the species composition and abundance of amphibians in the examined reservoirs. The prevalence of breeding amphibians was recorded between the end of March and the end of June 2019. The water bodies were monitored 5 times, and the number of individuals belonging to each species was recorded in the middle of the day. Additionally, one night control was conducted in May in order to determine the prevalence of night species (e.g. the natterjack toad, *Epidalea calamita*). All sites were surveyed using two methods: visual encounter surveys and auditory surveys. A typical survey period involved systematically walking of observer through a shoreline of the pond, identifying adults found opportunistically and identifying amphibians calls heard during the survey. The number of amphibians breeding in a given water body was defined as the highest value of multiple measurements. The number of the common frog (*Rana temporaria*, Linnaeus 1758) and the moor frog (*Rana arvalis*, Nilsson, 1842) were determined in a 5–10-m distance from the shore due to great skittishness of breeding individuals. The number of the common toad (*Bufo bufo*, Linnaeus, 1758) was determined directly at the shore as most of the representatives of this species are not frightened in the presence of humans. We counted natter jack toads based on the voices of males in the evening and at night. We did not count the smooth newt (*Lissotriton vulgaris*), only its occurrence in the given reservoirs. Determining the number of this species was often impossible due to the difficulties in moving along the muddy sandy shore of large gravel pits. The total number of the water frog complex (*Pelophylax esculentus* complex, Linnaeus, 1758) was analyzed without classification into separate species. The number of individuals was calculated, having regard to the sex ratios 1:1.

Statistical analyses

All the statistics were performed in R software (R Development Core Team, 2018) with the 'lme4' package (Bates, 2010).

We used Pearson's correlation to analyse the relationship between environmental variables. We used Principal Component Analysis (PCA) to reduce dimensionality and then we performed for the two first principal components biplot and then we added to the plot type of the reservoir.

To test the difference between mid-field and mine ponds we used generalised linear mixed model with normal error distribution. Because the samples were taken two times at each of surveyed pond, we took reservoir id as random effect. Also there were two sessions of sampling (March and May) and in order to control the effect of season, we added as random effect the month of sample collection. We performed separate model for each of environmental variable: temperature (temp), oxygen, pH, conductivity, total nitrogen (N-tot), nitrates ($N\text{-}NO_3$), ammonium nitrogen ($N\text{-}NH_4$), mineral nitrogen forms (N-min), organic nitrogen (N-org), total phosphorus (P-tot), mineral phosphorus (P-min), organic phosphorus (P-org), ratio of the total nitrogen and total phosphorus (N:P), chlorophyll (Cla).

We related the size of ponds to the environmental variables (reduced to first and second principal component) and type of reservoir. Next we performed generalised linear model with negative gamma error distribution. As dependent variables we took type, PC1 and PC2. We started testing the variable from the global model with all explanatory variable and then we dropped all non-significant effects ($P > 0.05$).

We related the abundance of amphibians (without newts) to the environmental variables (reduced to first and second principal component) and type of a reservoir. Because there were two environmental samplings per reservoir we averaged the principal components value. Next we performed generalised linear model with negative binomial error distribution. As dependent variables we took type, PC1, PC2 and area of a reservoir. We started testing the variable from the global model with all explanatory variable and then we dropped all non-significant effects ($P > 0.05$).

RESULTS

Physico-chemical properties and reservoirs types

The surface water of both types of water reservoirs had different physico-chemical properties (Table 2). Reservoirs in gravel pits were characterized by a higher pH and a much higher mineralization. The conductivity of sand/gravel mine ponds water amounted on average 414±175 μScm^{-1}, whereas it was on average 170±87.5 μScm^{-1}in mid-field ponds.

The studied water bodies were generally rich in nutrients, but their concentrations were different in each type of ponds (Tables 2, 3). Sand/gravel mine ponds contain significant amounts of nitrogen and phosphorus, however compared to midfield ponds, they are nutrients poorer.

Mean total nitrogen concentration in the sand/gravel mine ponds amounted 1.643 $mgNdm^{-3}$, of which about 35% was mineral nitrogen forms (mean concentration of $N\text{-}NO_3$ – 0.485 $mgNdm^{-3}$, and $N\text{-}NH_4$ – 0.083 $mgNdm^{-3}$).

Table 2. Physico-chemical properties of two type of small water bodies (sand/gravel mine ponds and midfield ponds) min/max/mean/SD.

		Sand/gravel mine ponds	Midfield ponds
T, °C	min	9.2	6.6
	max	17.5	15.6
	mean/SD	12.2/2.6	11.6/2.9
O_2, %	min	47	25
	max	121	92
	mean/SD	82/17	51/24
pH	min	7.78	6.88
	max	9.23	8.31
	mean/SD	8.30/0.433	7.62/0.467
Conductivity, μScm^{-1}	min	205	50
	max	695	400
	mean/SD	414/175	170/87.4
Ntot, mgNdm^{-3}	min	0.916	1.183
	max	3.172	4.258
	mean/SD	1.643/0.667	2.256/0.858
N-NO_3, mgNdm^{-3}	min	0.045	0.060
	max	2.479	4.02
	mean/SD	0.485/0.849	0.694/1.098
N-NH_4, mgNdm^{-3}	min	0.007	0.023
	max	0.543	0.866
	mean/SD	0.083/0.143	0.208/0.301
N-min, mgNdm^{-3}	min	0.075	0.180
	max	2.531	4.144
	mean/SD	0.568/0.842	0.903/1.087
N-org, mgNdm^{-3}	min	0.313	0.114
	max	1.687	2.008
	mean/SD	1.074/0.368	1.353/0.555
Ptot, mgPdm^{-3}	min	0.030	0.065
	max	0.064	0.603
	mean/SD	0.047/0.009	0.239/0.172
P-PO_4, mgPdm^{-3}	min	0.019	0.026
	max	0.047	0.435
	mean/SD	0.027/0.009	0.153/0.143
P-org, mgPdm^{-3}	min	0.008	0.02
	max	0.031	0.214
	mean/SD	0.019/0.008	0.085/0.057
Cla, mgm^{-3}	min	1.66	5.52
	max	33.61	95.43
	mean/SD	9.86/8.824	35.15/29.83

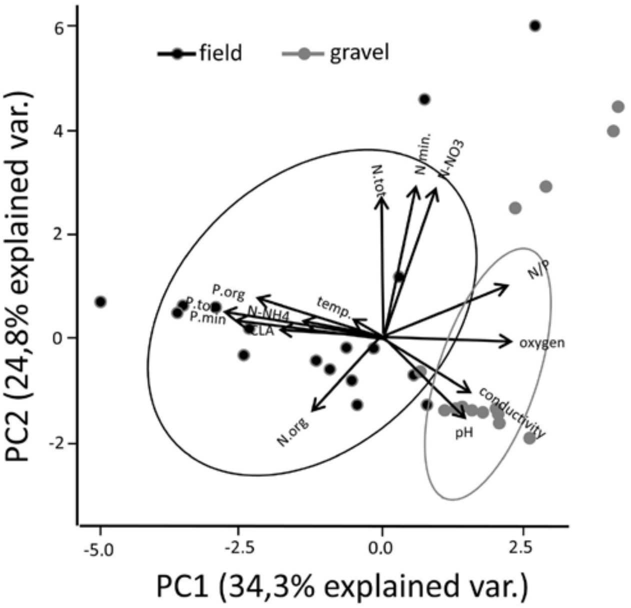

Fig. 2. Two principal components of environmental variables in relation to the two types of reservoirs.

Concentration of N-tot in mid-field ponds amounted on average about 2.3 mgNdm^{-3}, and mineral nitrogen forms was about 40% of N-tot (mean concentration of N-NO_3 – 0.694 mgNdm^{-3}, and N-NH_4 – 0.208 mgNdm^{-3}). Total phosphorus concentration varied in sand/gravel mine ponds from 0.03 to 0.064 mgPdm^{-3} (mean 0.047 mgPdm^{-3}). Inorganic phosphorus (P-min) was about 57% of P-tot, with a mean concentration of 0.027 mg P dm^{-3}. In the mid-field ponds mean P-tot value was about 5 times higher than in the mine ponds (0.239 mgPdm^{-3}). Mineral phosphorus concentration was about 0.153 mg dm^{-3}, and accounted about 65% of P-tot. Also concentration of P-min was about 5.5 higher in the mid-field ponds. Chlorophyll a concentration in water changed from about 2 to 33.6 mg m^{-3} in the sand/gravel pit reservoirs, and from 5.5 to about 95 mg m^{-3} in the mid-field ponds. On the average, mean values of the phytoplankton Cla in agricultural ponds were three times higher.

Analysis of two principal components of environmental variables in relation to the two types of reservoirs proved that the first principal component (PC1) explained 34% of variance and the second – 25% of variance (Fig. 2). According to this, PC1 is related to gradient from the reservoirs with high content of phosphates (mid-field type) to the reservoirs with high N:P, oxygen, conductivity and higher pH (sand/gravel type). The second gradient is related mostly to nitrates: from organic to non-organic and it distinguished highly field types of reservoirs.

Table 3. Difference between two types of reservoirs; each variable was tested as separate model.

	T	O_2	pH	Con.	N-tot	N-NO_3	N-NH_4	N-min	N-org	P-tot	P-min	P-org	Cla
F	0.77	11.7	7.434	11.7	2.713	0.192	1.698	0.509	1.824	9.631	4.877	17.24	7.61
p	0.396	**0.005**	**0.017**	**0.005**	0.124	0.669	0.215	0.488	0.200	**0.008**	**0.046**	**0.000**	**0.01**

Table 4. Carlson type trophic state indices for sand/gravel mine ponds and midfield ponds.

		Sand/gravel mine ponds	Midfield ponds
TSI_{Ptot}	min	53.2	61.7
	max	64.1	96.7
	mean	59.3	79,2
TSI_{Ntot}	min	53.1	56.7
	max	71.1	75.3
	mean	60.6	65.2
TSI_{Cla}	min	35.8	35.4
	max	65.3	75.6
	mean	50.1	61.3

TSIs values between 0 and 30 – an oligotrophic state; 30–40 oligo-mesotrophic state; 40–50 mesotrophic state; 50–60 meso-eutrophic state; 60–70 eutrophic state; and over 70 hypertrophic state.

Trophic conditions of both types of the water reservoirs are presented (Table 4). Generally, sand/gravel mine ponds were characterized by lower values of TSI-s, thus lower trophy level: meso-eutrophy to eutrophy. The trophy indices of mid-field ponds indicate an eutrophic or hypertrophic character of the reservoirs.

Amphibians abundance

Amphibians were present in every examined reservoir. The following species reproduced in both types of the reservoirs: *Bufo bufo*, *Epidalea calamita*, *Rana temporaria*, *Pelophylax esculentus* complex and *Lissotriton vulgaris*. Only in some mid-field reservoirs, a moor frog was additionally found. In sand/gravel mine ponds an average of 3.2 species (min. 2; max. 4) were recorded, and in mid-field ponds 3.1 (min. 2; max. 4). In the former, a total of 5, and in the latter, 6 species of amphibians were found (Table 5). The species that did not occur in the relatively large reservoirs in the sand and gravel mine area was the moor frog *Rana arvalis*. The frog *Rana temporaria* and the green frog *Pelophylax esculentus* complex were most common in both types of reservoirs, but they were more numerous in the sand/gravel mine reservoirs. The common toad *Bufo bufo* and natterjack toad *Epidalea calamita* were also more frequent and numerous. Only the smooth newt *Lissotriton vulgaris* was found more often in midfield reservoirs.

DISCUSSION

We compared water quality of natural mid-field reservoirs in areas with intensive cereal cultivation and of recently created reservoirs in the gravel pits in northern Poland. The latter were characterized by lower nutrients concentration, higher oxygenation, higher pH and conductivity. Although there was no correlation between concentration of total nitrogen and total phosphorus in the two groups (Fig. 3), and the concentration of chlorophyll a was not statistically significantly correlated with any form of nutrients (except for the positive correlation with P-min in gravel ponds), ponds in gravel pits seem to develop in a more balanced way. This is confirmed by a comparison of trophic indicators (Fig. 4). In theory, all Carlson's indicators should be the same, which would indicate a harmonious water ecosystems evolution. The greater the differences between the indicators, the greater the probability of the occurrence of external factors (especially anthropogenic ones) affecting the disturbance of the development of

Table 5. Distribution and abundance of amphibians species in the analyzed ponds.

Type of reservoirs	Code	Species and number of individuals					
		Rana temporaria	*Rana arvalis*	*Bufo bufo*	*Epidalea calamita*	*Pelophylax esculentus* complex	*Lissotriton vulgaris*
Sand and gravel mine ponds	SG1	7	–	–	–	10	
	SG2	100	–	30	–	35	+
	SG3	20	–	15	–	45	
	SG4	500	–	70	30	100	
	SG5		–	80	15	55	
	SG6	–	–	40	25	30	
	Sum	**627**	**0**	**235**	**70**	**275**	**+**
Midfield ponds	M1	20	30	–	–	30	+
	M2	15	–	–	–	15	+
	M3	35	–	30	15	35	
	M4	20	–	–	–	10	+
	M5	50	–	40	–	50	
	M6	20	–	–	–	10	
	M7	15	–	–	–	25	+
	M8	30	50	–	–	15	
	Sum	**205**	**80**	**70**	**15**	**190**	**+**

(+) the prevalence of *Lissotriton vulgaris* (the number is unknown).

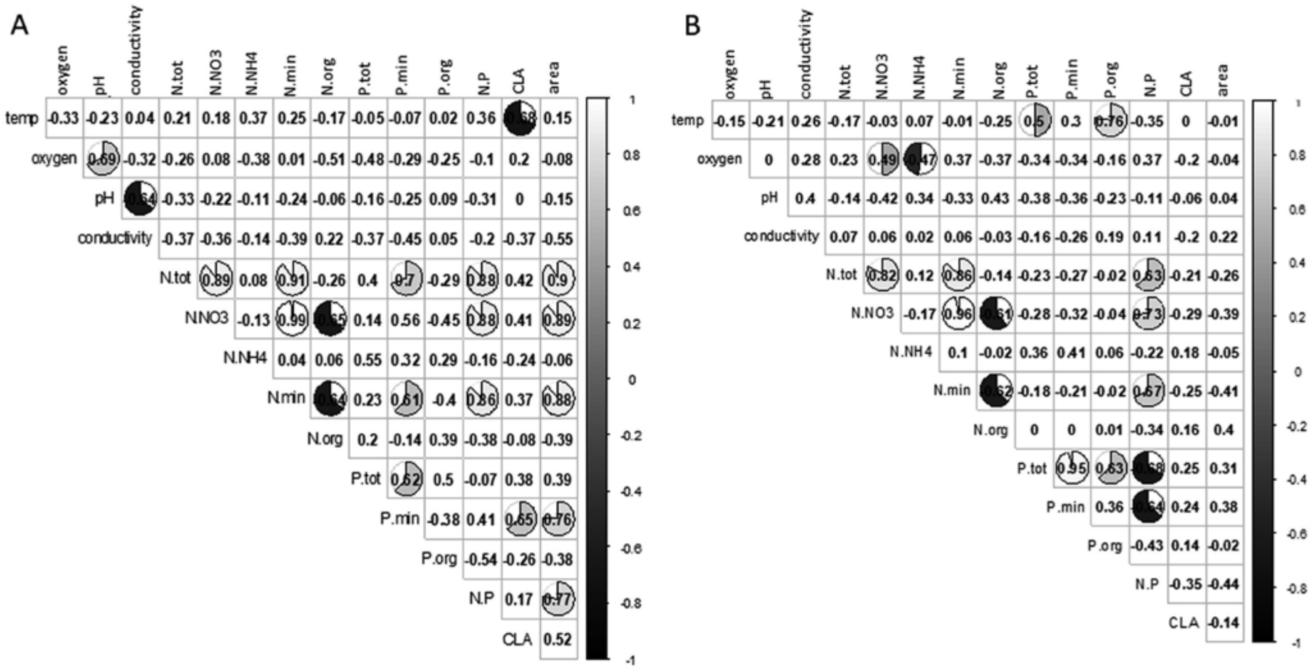

Fig. 3. Pearson correlation coefficients. Pie charts show only significant values: A) Only sand/gravel mine ponds, B) only midfield ponds

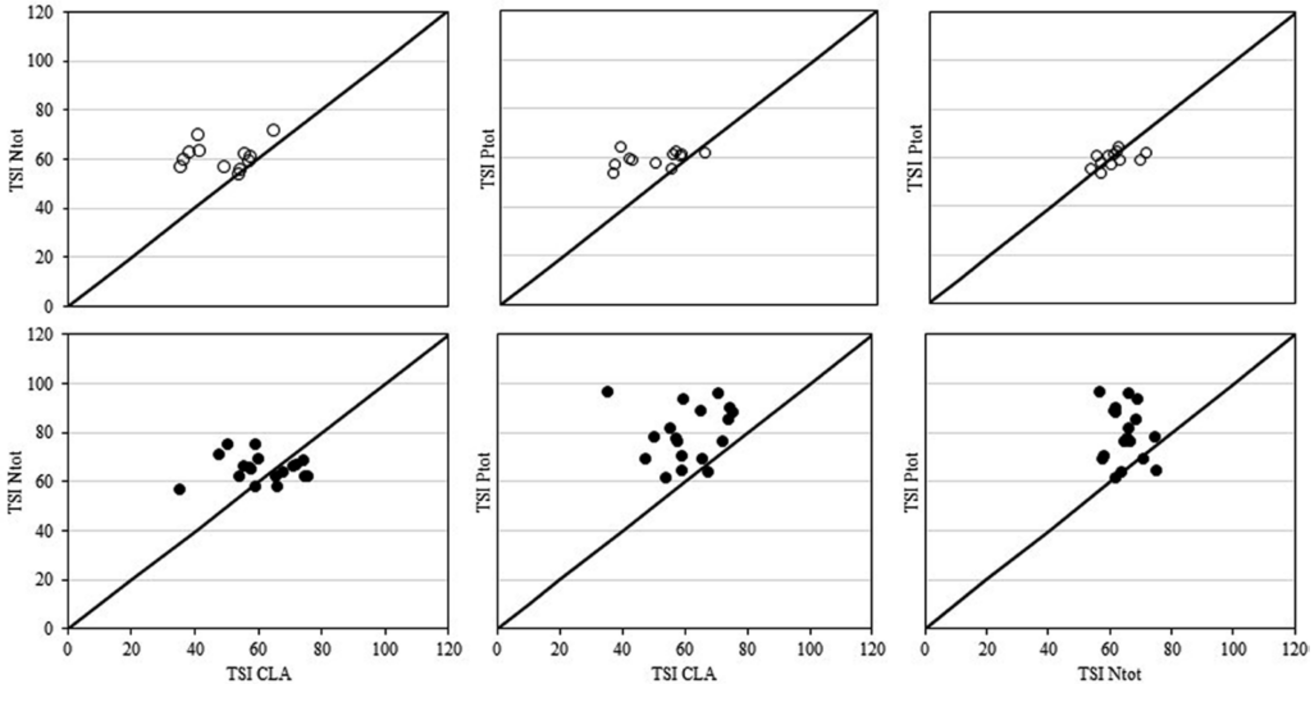

Fig. 4. Relationships between Carlson's tropic state indices; sand/gravel mine ponds (top); midfield ponds (bottom)

aquatic ecosystems (Carlson, 1977; Jarosiewicz *et al*., 2014; Markowski, 2017; Saluja and Garg, 2017; Jarosiewicz *et al*., 2018). The values of TSI indices of sand/gravel mine ponds were more similar to each other than in the case of mid-field ponds (Table 4). In addition, such an arrangement of indicators suggests that in mine reservoirs, a limitation of primary production is "normal" (Cigagna *et al*., 2016), i.e. P is the factor that restricts a production of phytoplankton. Although the indicators based on the concentration of P-tot are higher than those calculated based on the concentration of chlorophyll a, the differences are not large. In addition, the calculated mean N/P ratio was 35 (varying from 21 to 57 depending on the reservoir). In mid-field ponds, limitation of primary production is "high" and there is some other limiting factor that reduces the phytoplankton productivity, and it is probably nitrogen (in the case of mid-field ponds, N/P is less than 10:1 – M5; M6; M7 and M8) or another factor (toxic substances, sediment resuspension) (Jarosiewicz *et al.*, 2018). Interestingly, in agricultural water bodies the surface area of ponds was not significantly correlated with other trophic state variables (Fig. 3). In models describing reservoirs size, the environmental variables represented by the first and the second principal analyses were not significant (for two of them $p > 0.05$). Only effect of reservoir size was significant in gravel reservoirs (scaled deviance = 20.286, $p < 0.001$; for field: median = 0.15, lower quartile = 0.08, upper quartile = 0.25; for gravel: median = 0.675, lower quartile = 0.32, upper quartile = 3).

We suppose that observed differences in physical and chemical properties of two groups of ponds were caused by two factors. Firstly, the reservoirs in the gravel pits were younger than the mid-field reservoirs and secondly, the reservoirs in the gravel pits were surrounded by large mine areas (from 5.6 ha to 25 ha), thanks to which they had no direct contact with the soils of the agricultural land (and potential agricultural pollutions). On the other hands, many researchers pointed out, that agriculture catchments (especially arable lands) promote higher nutrients concentration in mid-field surface waters (Declerck *et al.*, 2006; Davies *et al.*, 2008; Gałczyńska *et al.*, 2011; Jarosiewicz *et al.*, 2018). Mid-field reservoirs are mainly exposed to surface and subsurface runoff on fertilizers, especially in situations where fertilizer use exceeds the nutrient requirements of the crop.

We studied the reproduction of amphibians in reservoirs in sand and gravel mines, which had a larger area and were younger than the studied second group of natural mid-field reservoirs. Amphibians were present in every researched ponds and the number of species was similar in both types of reservoirs. We found that in models describing amphibians', abundance of environmental variables represented by first and second principal analyses were not significant (for two of them $p > 0.05$). Models revealed also that the reservoir area was not significant ($p > 0.05$). Only effect of a type of the reservoir was significant and total number of amphibians was higher in gravel reservoirs (likelihood-ratio test = 7.132, $p = 0.007$; for field: median = 60, lower quartile = 30, upper quartile = 90; for gravel: median = 117.5, lower quartile = 85, upper quartile = 170). We found that in models describing newts occurrence, none of the independent variables were significant (for four of them $p > 0.05$). However, it turned out that species such as common frog, common toad, natterjack toad and green frog reproduced in greater numbers in the reservoirs at the mine sites. On the other hand, the common newt was less frequent there, and the fire-bellied toad did not occur at all. New reservoirs in agricultural areas are readily occupied by common toads, but reluctantly by smooth newts (Baker and Halliday, 1999). The absence of fire-bellied toad in large reservoirs in mines was probably due to its preferences, as the species is more likely to breed in small reservoirs.

Currently, we observe in northern Poland a deterioration in the quality of mid-field reservoir water in agricultural areas as a result of agricultural pollution. The main source of contamination of the mid-field surface water is the agricultural runoff from arable land, which transports fertilizers and plant protection products (Declerck *et al.*, 2006). Another threat to mid-field reservoirs is their disappearance as a result of droughts. The frequency and severity of droughts increased in recent years and it is very likely that they will intensify in the near future due to the predicted climate change (Lehner *et al.*, 2006, Łabędzki, 2009, 2016). Periodic disappearance of water reservoirs is also observed in Pomerania in northern Poland. This means that new reservoirs can play a positive role in providing breeding sites for the amphibians.

Water quality is important for amphibians, and all the physico-chemical parameters can affect the species richness and reproductive success of amphibians, especially survival rate and growth of tadpoles. Jarosiewicz *et al.* (2014) observed inverse relationship between the concentration of biogenic substances and the prevalence of amphibians in urban ponds. Higher concentrations of phosphorus, found in our studied mid-field reservoirs, may reduce amphibian reproductive success (Knutson *et al.*, 2004). Also, the increased level of nitrogen has a negative impact (Rouse *et al.*, 1999; Marco *et al.*, 1999; Rannap *et al.*, 2020). Bishop *et al.* (1999) studied intensively farmed lands in Canada and concluded that nitrate levels in wetlands was more important than a pesticide use in affecting amphibian survival and species diversity. Laboratory studies have established that lethal and sublethal effects in amphibians are detected at nitrate concentrations between 2.5 and 100 mg dm^{-3} (Rouse *et al.*, 1999). In our studies, the average concentration of total nitrogen in mid-field ponds was lower than in sand/gravel ponds, but in some of them exceeded 2.5 mgNdm^{-3} (ponds: M2 – 3.41 mgNdm^{-3} and M8 – 4.02 mgNdm^{-3}). Also, the water pH can affect development of amphibians. Low water pH may influence reproduction of amphibian, resulting in direct mortality of embryos and larvae (Freda, 1986). The concentration of dissolved oxygen in water has also significant effect on the embryonic and larval development of amphibians, because at low oxygen concentrations the mortality of frog and tadpoles increases (Smith, 1997; Dmitrieva, 2015). Thus, in our studies the sand/gravel mine ponds created more convenient and more attractive conditions for reproduction of amphibians.

There are many scientific papers defining the negative role of sand and gravel mines for environment. Sand and gravel mining can release heavy metals from sediments (Ogbuagu and Samuel, 2014; Koki *et al.*, 2019). High concentration of non-metallic minerals such as boron, magnesium or fluorine was observed in a mine water (Atanacković *et al.*, 2013). Mines exploitation can destroy native vegetation species, and alien species may appear in their area. Therefore, one should be careful in assessing the role of new water reservoirs in the areas of sand and gravel mines. The aim of this article is to show that sand/gravel mines can be used to protect nature , that they can also have a positive meaning. Few previous studies indicate that they may be great for creating new breeding sites for amphibians, which in turn may help to preserve species in face of environmental pollution and climate change. This is confirmed by the few earlier studies on the colonization the reservoirs in gravel pits by amphibians.

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