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ORIGINAL ARTICLE

Changes in physico-chemical conditions and macrophyte abundance in a shallow soft-water lake mediated by a Great Cormorant roosting colony

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ABSTRACT

*This study examined the effects of the Great Cormorant (*Phalacrocorax carbo sinensis *L.) roosting colony on the physico-chemical conditions and macrophyte abundance in a shallow soft-water lobelia lake. We compared data collected in 1998 and 2009, before and after 9 years the birds colony was estabilished (2000) along the shoreline of the Lake Dołgie Wielkie (Poland, Europe). Additionally, soils and groundwater beneath the roosting colony were analyzed to evaluate the potential loads of nutrients conveyed to the lake through bird feces. Significant changes in the water quality of the lake were observed in terms of decreased water transparency, and increased conductivity, nitrogen, phosphorus and chlorophyll-a content. Abundance of the more sensitive macrophytes (*Littorella uniflora *and* Myriophyllum alterniflorum*) also decreased. At the same time, the occurrence of new, typically meso- and eutrophic macrophytes such as* Myriophyllum spicatum *and* C. demersum *was recorded. Soils beneath the bird roosting area were characterized by over 100 fold higher concentrations of nitrogen and phosphorus comparing to not impacted littoral area. Increased nutrient content was also found in the groundwater below the bird colony. The present study suggests that the establishment of the Cormorants colony increases the trophic state of a soft-water lake and affects its macrophyte assemblages.*

Key words: Great Cormorant, Lobelia Lake, eutrophication, nitrogen, phosphorus, macrophytes shift.

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INTRODUCTION

During the past 40 years a significant increases in the population of numerous species of Cormorants have been observed worldwide (van Eerden *et al*., 2012). However, the main causes of this phenomenon have not been fully elucidated. Along with many postulated explanations, the increased fish biomass resulting from the eutrophication of lakes and the decision to protect Cormorants in many countries are among the most plausible (Skov, 2011). Moreover, the global climate change (*e.g*., increases in the temperature of inland and coastal marine waters) was also suggested as an additional factor promoting the observed rise in the Cormorant populations (White *et al*., 2011).

In Northwestern Europe, the legal protection of Great Cormorants (*Phalacrocorax carbo sinensis* L.) has led to a dramatic increase in their number that is estimated of about 16% *per* year (van Eerden and Gregersen, 1995). In Poland, since the beginning of the 20th century the number of these birds has increased from 30 individuals to over 25,000 breeding pairs (Bzoma *et al*., 2003). The growing populations of Great Cormorants, re-colonization and the establishment of colonies in new areas have raised concerns as to the consequences of their presence in the environment. These birds have a very high metabolism and therefore can heavily influence the turnover of matter in colonized environments. Waterfowls such as Cormorant are very important intermediate links in some food webs facilitating the dislocation of matter between aquatic and terrestrial domains (Marion *et al*., 1994; Skov *et al*., 2014). They may also modulate the trophic state of water reservoirs. If they forage in water but excrete on land far from the water ecosystems, the process of eutrophication can be delayed (Mukherjee and Borad, 2001; Ligęza and Smal, 2003). On the other hand, despite possibility to prey on different aquatic ecosystems at the same time, Cormorants deposit feces over a relatively small area under the colony and near the lake shore (Przybysz, 1997; Kameda *et al*., 2006). Consequently, relevant amounts of nitrogen (N) and phosphorus (P), and other chemical compounds excreted by birds within the colony area may be then conveyed through groundwater or surface runoff to the nearby lakes, influencing their chemistry (Kameda *et al*., 2000; Nakamura *et al*., 2010; Klimaszyk, 2012; Klimaszyk and Rzymski, 2013a). Moreover, microbial pollution of littoral zones can be observed within the area of bird colonies (Klimaszyk and Rzymski, 2013b).

This is especially true for soft-water lakes that demonstrate particular susceptibility to influxes of additional quantities of nutrients and other chemical elements (Roelofs, 2002). Changes in the water chemistry of such ecosystems can lead to simultaneous alterations of macrophyte community composition including the disappearance of isoetids such as *Isoetes lacustris* L., *Littorella uniflora* (L.) Asch. and *Lobelia dortmanna* L. (Arts, 2002; Pulido *et al*., 2012).

The following study was undertaken to evaluate the potential effect of the Great Cormorant colony on the physico-chemical conditions and macrophyte abundance of a Polish soft-water, shallow lobelia lake characterized by the occurrence of *L. uniflora*. Since 1998, the number of the Great Cormorants living on the lakeshore has increased to at least 1000 individuals and continues to rise. The following hypothesis have been put forward: the chemical compounds deposited within the area of Great Cormorant colony may be transferred together with groundwater or periodic surface runoff to the lake, affecting its chemistry and trophic state; with consequent changes in macrophyte abundance, emerging species characteristic for higher trophic state and diminishing species sensitive to eutrophication (*e.g*., *L. uniflora*). To verify this hypothesis, we compared water physico-chemical conditions and macrophytes abundance in 1998 (before the establishment of the Great Cormorants roosting colony) and 2009 (9 years after the roosting colony was established). To evaluate the local effect of Great Cormorants, the concentrations of nutrients in soils and groundwater beneath the bird colony were also analyzed.

METHODS

Study site

Our investigations were carried out on the coastal Lake Dołgie Wielkie (South Poland, Europe) which is directly adjacent to the Baltic Sea (Fig. 1). The basin of the lake stretches longitudinally and is separated from the sea by a strip of sand dunes. The lake is shallow with a mean depth during the sampling period of 1.4 m and a maximum depth of 2.9 m. It is a polymictic lake with a surface of 139.5 ha. Strong winds can form waves which raise mineral and organic particles and decrease the water transparency. The catchment area (515 ha) is only 3.7 times greater than the surface of the lake and is covered with forests for a 87%, with the predominance of coniferous trees, particularly the Scots Pine (*Pinus sylvestris* L.). Low-lying peatlands account for a 10% of the catchment area whereas extensively used pastures comprise only the 3%. The lake does not have any tributaries and is being supplied primarily with rainwater and, to a lesser extent, with groundwater. The local human pressure is negligible, since the lake is placed within the strict protection zone of the Słowinski National Park, far from the main tourist trails.

Great Cormorants have been observed at the Lake Dołgie Wielkie since the middle of the 20th century. Initially, only individual specimens were counted, but since 2000 a group of Great Cormorants was established along the lakeshores giving rise to a stable colony. Annual counting of roosting Great Cormorants were performed by the same observers in the first week of October between 1998 and 2009 (Bregnballe *et al*., 2012). Additionally, in 2009 to estimate the accurate number of Great Cormorants in the roost and the time spent on the lake, counting of birds was performed 4 times between June and August every 4 h in dawn-dusk period. These numbers were then used in order to calculate the potential load of nitrogen carried by birds to the lake. For the first few years, the number of

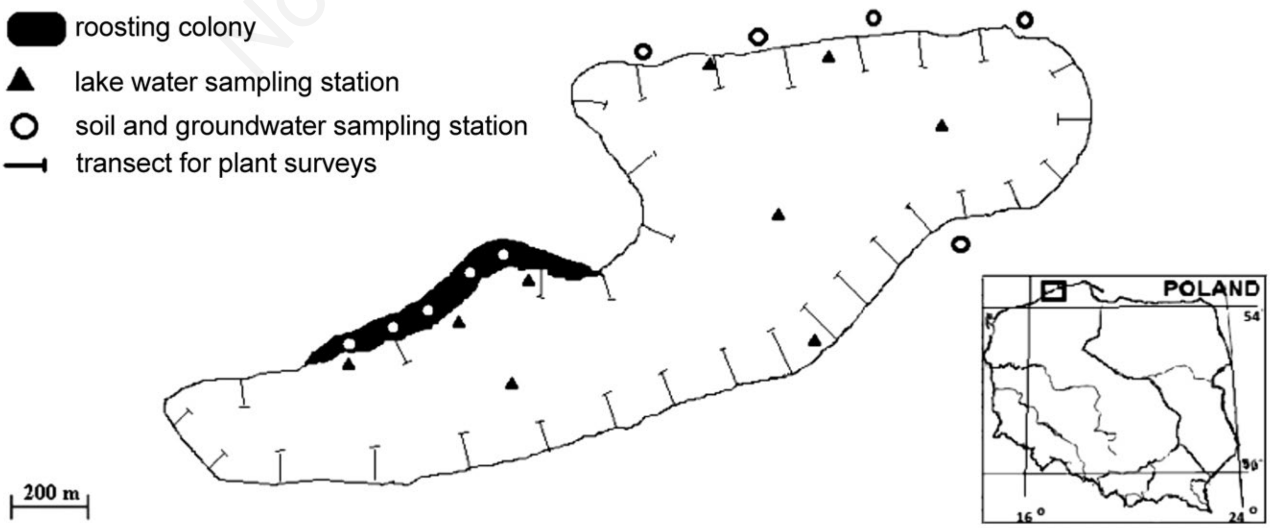

Fig. 1. Study site (Lake Dołgie Wielkie); we reported the location of the sampling stations (circles correspond to the soil and groundwater sampling stations; triangles correspond to the water sampling stations), of the Great Cormorant colony (black area).

Great Cormorants did not exceed 100 individuals. Since 2000, their number has increased greatly, resulting in the development of the colony. In 2010, more than 1000 individuals were observed. To date, however, the birds do not nest at the reservoir. Usually, they appear in April and remain until October-November but the highest numbers are observed between June and September.

Physico-chemical analyses

Water samples were collected from the littoral zone (near the colony and from a control site) and central part of the lake in two years, 1998 and 2009. The location of the sampling points is reported on Fig. 1. Additionally, conductivity and pH of the littoral waters in the lake sector near the Great Cormorants colony were measured in the field each year in August between 1994-2010 using YSI 556 Multiparameter Instrument. Water transparency was measured using a Secchi disc. Analyses were conducted in the field or immediately after transportation to the laboratory; if not, samples were frozen at -20ºC. Following parameters were analyzed: ammonia (N-NH_4^+, using Nessler method), nitrites (N-NO_2^-, using sulfonic acid method), nitrates (N-NO_3^-, using sodium salicylate method), organic nitrogen (N_{org}, using Kjeldahl method), calcium (Ca, using EDTA titration), total phosphorus (TP, using molybdate method after mineralization), orthophosphates (TRP, using molybdate method) chlorides (Cl, detected with ion chromatography), potassium ions (detected with ICP-MS) and alkalinity (using titration with sulfuric acid) (APHA, 2005). Water color was determined using the platinum-cobalt color scale. Chlorophyll-*a* was determined after extraction in the 90% aqueous acetone solution (ESS Method 150.1, EPA, USA). Chemical oxygen demand (COD) was analyzed using the potassium permanganate method. To determine the dominant phytoplankton species in littoral zone in 2009, microscopic counting in Bűrker chamber was conducted.

In August 2009, 10 samples of groundwater were taken from a series of piezometers installed beneath the roosting colony of Great Cormorant. For comparison, samples from a control site (n=10), unaffected by the direct impact of bird colony were also taken. Location of sampling points is presented on Fig. 1. Collected water samples were filtered through a cellulose filter GF/C to remove soil particles. Physico-chemical analyses were performed using the aforementioned methods. Simultaneously, at the same sites (Great Cormorants colony, n=10; control site, n=10) soils were collected at 3 genetic horizons: organic - the ectohumic soil horizon at depth of 0-5 cm, the eluvial horizon at depth of 2-20 cm, and the mineral horizon at a depth of >20 cm. Collected soil samples were air-dried and sieved using a 1 mm sieve to separate gravel (particle size >1 mm) and non-soil components. The total amount of nitrogen (N_{tK}) was determined using the Kjeldahl method (van Reeuwijk, 1995), constituting the sum of organic and ammonium nitrogen. Content of N-NO_3^- and N-NH_4^+ were determined after extraction in CH_3COOH (0.03 mol L^{-1}) using Nessler's method, whereas N-NO_2^- was analysed using method with phenoldisulfonic acid (Prince, 1955). Plant available potassium (K_{av}) was extracted with Ca-lactate (0.04 mol) and HCl (0.02 mol L^{-1}) at pH=3.6, and analysed with ICP-MS. TP content in soils was determined at 850 nm using a Shimadzu UV-1610 spectrophotometer (molybdate method) after burning the samples at 550°C and mineralization in suprapure HNO_3 (14 mol L^{-1}) and H_2SO_4 (18 mol L^{-1}) (Sobczyński and Joniak, 2009).

Macrophytes analysis

Macrophyte abundance was analyzed in August 1998 and 2009. The investigations were conducted by applying the phytosociological approach along 32 evenly spaced transects placed perpendicular to the shoreline (Fig. 1) (Braun-Blanquet, 1964; Jensen, 1997). In the both years of study, the transects were positioned at the same points (located with GPS and field markers), whereas the areas investigated were found to be different depending on the transect structure. In other words, along each transect the width of the sampling plots was set at 10 m whereas their length was found to be determined by the spatial arrangement of the plant communities along the depth gradient. The mean sampling area was estimated to be approximately 100 m^2, with a range of variability from 25 to 320 m^2. The species abundance was calculated considering the percentage of the sampling plots colonized by each taxon. Exclusively for *L. uniflora*, a comparison of the coverage values recorded in the two different years of monitoring was performed. For each record the corresponding water depth was noted.

Statistical analyses and calculations

The empirical watershed model (Ryding and Rast, 1989), detailed by Szyper and Gołdyn (2002) was used to calculate the loading of the lake with N and P. This allowed estimation of the mean annual mass loading with nutrients that flows directly into the lake from diffuse sources of pollution. To estimate mean monthly loading of the lake and roost with N and P of Great Cormorant origin, the model based on Marion *et al*. (1994) was applied. According to it, the mean daily input of droppings is 27 g of dry weight per bird per day, assuming that Great Cormorants spend four hours daily on foraging outside the roost area and the lake (Marion *et al*., 1994). According to Gwiazda *et al*. (2010) we assumed that 10.2% of dry mass of droppings was constituted of N whereas 7.9% of P. Therefore, mean daily input of N and P used in our calculations was 2.75 g and 2.10 g per one bird per day, respectively.

The results of physicochemical parameters and coverage area of *L. uniflora* were analyzed with Statistica 10.0 software (StatSoft, USA). Gaussian distribution was tested with Shapiro-Wilk's test. Data that did not met this assumption were analyzed using non-parametric Mann Whitney U test (water samples) and Wilcoxon test (soil samples from different horizons). Normally distributed data were compared using Student's *t*-test; a P value of <0.05 was considered as statistically significant.

RESULTS

Lake chemistry

Significant differences in the water physico-chemical parameters were found between 1998 to 2009 data (Tab. 1). Both, N and P concentrations were considerably increased in 2009. TP content was nearly threefold higher in 2009, whereas TRP increased nearly twofold. Moreover, N$_{org}$, N-NH$_4^+$ and N-NO$_3^-$ concentrations in 2009 compared to values measured in 1998 were over twofold, fivefold and fourfold higher, respectively (Tab. 1). Alkalinity of water was increased fourfold; while conductivity was increased twofold. Higher concentrations of K were also found. Notably, very high concentration of chlorophyll-*a* (nearly 300 µg L^{-1}) was also observed in 2009; this represented an almost fivefold rise when compared to that of 1998 (Tab. 1). The chlorophyll-*a* concentrations observed in 2009 were associated with cyanobacteria blooms (mainly represented by *Microcystis aeruginosa* Kützing). Significant reduction of water transparency (from 0.70 to 0.15 m) was also observed (Tab. 1). Annual measurements of conductivity have found a rise in its value since the first mass appearance of Great Cormorants along the shoreline of the lake (Fig. 2).

Significant differences in the physico-chemical conditions of water were also observed between the littoral zone adjacent to the bird colony and the littoral zones unaffected by birds as well as the lake pelagic zone (Tab. 1). Littoral zone adjacent to the Great Cormorants colony was characterized by over twofold higher concentrations of N-NH$_4^+$, N$_{org}$, TP compared to control littoral and pelagic sites. Similarly, the water TRP content in the proximity of the bird colony was fivefold higher than in the pelagic zone and threefold higher than in the unaffected littoral areas. Moreover, the littoral zone near the Great Cormorants colony was characterized by higher concentration of chlorophyll-*a* (Tab. 1).

Soil and groundwater chemistry

Beneath the bird colony, concentrations of N, P and K were significantly higher compared to the control sites (Tab. 2). The highest values of these elements were determined in the surface layer of soils. N pool was dominated by N$_{org}$ (over 8000 mg kg^{-1}), while the mean detected level of N-NH$_4^+$ and N-NO$_3^-$ amounted to 750 mg kg^{-1} and 145 mg kg^{-1}, respectively. Deeper-lying soil layers were found to be poorer in nutrients although their content from colony area was always higher than this from the control sites (Tab. 1).

Tab. 1. Mean values ±SE of the selected water physico-chemical parameters of Lake Dołgie Wielkie in 1998 and 2009; we report data on the central part of the lake and the littoral zone separately.

		CPL		LZ				
				Ubc	Uz	Mann Whitney U test		
		1998	2009	2009	2009			
		A	B	C	D	A *vs* B	B *vs* C	C *vs* D
Transparency	(m)	0.70	0.15	0.1	0.1	-	-	-
pH	(range)	6.676.96	8.67-8.92	8.6-8.9	7.2-8.1	*	ns	ns
Colour	(mg Pt L^{-1})	29±1.9	42 ±3.7	42±4.3	40±2.8	*	ns	ns
Cod	(mg O L^{-1})	24.2±2.27	42.7±1.2	53.8±2.03	44.8±2.1	*	**	**
N-NH$_4^+$	(mg N L^{-1})	0.1±0.05	1.2±0.31	2.5±0.8	1.3±0.41	*	*	*
N- NO$_{3-}$	(mg N L^{-1})	0.03±0.01	0.8±0.31	1.8±0.7	1.1±0.3	*	**	*
N$_{org}$	(mg N L^{-1})	1.43±0.25	3.4±0.62	7.1±0.86	3.7±1.2	ns	***	***
TP	(mg N L^{-1})	0.57±0.06	1.38±0.29	2.22±0.17	1.29±0.5	**	**	**
TRP	(mg P L^{-1})	0.03±0.02	0.06±0.02	0.35±0.22	0.12±0.06	ns	*	*
Chlorides	(mg Cl L^{-1})	12±2.6	12±3.3	12.7±1.5	13.8±6.5	ns	ns	ns
Potassium	(mg K L^{-1})	1.5±0.25	2.8±0.17	3.2±0.26	2.3±0.23	*	ns	*
Calcium	(mg Ca L^{-1})	12.2±0.37	14.2±1.5	13.6±1.5	11.9±3.5	ns	ns	ns
Conductivity	(µS cm^{-1})	73±3.1	141.7±8.8	198.7±9.2	148±10.2	**	***	**
Alkalinity	(mval L^{-1})	0.25±0.04	1.1±0.3	1.6±0.6	0.9±0.09	**	ns	*
Chlorophyll-*a*	(µg L^{-1})	57.3±11.1	293±57.3	431.3±43.3	288±66.2	***	***	***

*CPL, central part of the lake; LZ, littoral zone; Ubc, data collected under the bird colony; Uz, data collected in unaffected zones by birds.*P<0.05; **P<0.01; ***P< 0.001; ns, not significant.*

Increased concentrations of nutrients and other chemical compounds were also found in the groundwater beneath the roosting colony of Great Cormorants (Tab. 3). It contained significantly higher amount of diluted mineral salts as demonstrated by conductivity which was nearly tenfold higher than in groundwater from the control sites. Similarly, in the groundwater beneath the colony, the N-NH_4^+ and N-NO_3^- reached concentrations over tenfold and fourfold higher, respectively. Also TP and TRP content was increased by over 100-fold in both cases (Tab. 3).

Macrophytes diversity and abundance

Overall, 31 different macrophytes were recognized in the period 1998-2009, including submerged, floating leaved and emergent species (Tab. 4). The emergent species (*i.e.*, helophytes) (17 taxa, accounting for 54.8% of the total local diversity) were most abundant, with the dominance of *Eleocharis palustris* (L.) Roem. et Sch., *Glyceria maxima* (Hartm.) Holb., and *Schoenoplectus lacustris* (L.) Palla. Submerged macrophytes were represented both by elodeids, with the dominance of *Myriophyllum alterniflorum* DC., and by the isoetid *L. uniflora.* Among the floating leaved macrophytes (*i.e.*, nymphaeids), *Polygonum amphibium* L.*,* *Nuphar lutea* (L.) Sibth. et Sm. and *Potamogeton natans* L. were the dominant taxa.

During the investigated period *L. uniflora* exhibited a rapid decline, both in terms of abundance (passing from 43 to 27%), and mean percentage coverage values (pass-

Tab. 2. Nutrients content in soils (mean±SE) beneath the Cormorant colony and at control site (n=10).

		Soil layer			
		Organic (0-5 cm)	Mineral-organic (5-20 cm)	Mineral (>20cm)	Wilcoxon test
NH_4^+ (mg kg^{-1})	Control	60.5±10.8	39.4±9.5	26.7±14.4	Z=3.05
	Colony	755.7±268.5	339.7±49.6	185±59.1	P<0.001
NO_3^- (mg kg^{-1})	Control	12.0±2.9	6.4±3.12	4.5±1.8	Z=3.52
	Colony	145±119.4	72.5±12.2	70.5±12.5	P<0.001
N_{org} (mg kg^{-1})	Control	66.5±6.2	32.5±4.4	33.3±11.4	Z=2.95
	Colony	11,345±4002.5	457.7±210.2	70±31.7	P<0.001
TP (mg kg^{-1})	Control	58.75±11.5	15.5±3.7	14.0±2.9	Z=3.205
	Colony	1449.75±194.4	177.7±25.5	119.2±24.4	P<0.001
Potassium (mg kg^{-1})	Control	34.5±12.8	16.2±8.3	11.2±2.5	Z=3.06
	Colony	930.0±332.0	328.0±50.7	78.3±11.9	P<0.001

Tab. 3. Mean±SE values of selected physical and chemical properties of the groundwater of the catchment area of the Lake Dołgie Wielkie (n=10).

		Under the colony	Control site	Mann Whitney U test
pH	(range)	6.2-6.5	5.7-6.0	-
Colour	(mg Pt L^{-1})	258±8.5	226.3±18	ns
COD	(mg O L^{-1})	773±120.1	83±6.7	***
NH_4^+	(mg N L^{-1})	14.9±2.16	1.2±0.2	***
NO_2^-	(mg N L^{-1})	0.1±0.10	nd	-
NO_3^-	(mg N L^{-1})	5.5±1.14	0.6±0.59	***
N_{org}	(mg N L^{-1})	22.4±2.90	1.6±0.55	***
TP	(mg P L^{-1})	16.4±2.10	0.1±0.04	***
TRP	(mg P L^{-1})	12.7±1.85	0.06±0.01	***
Chlorides	(mg Cl L^{-1})	62.7±8.02	63.3±7.23	ns
Potassium	(mg K L^{-1})	9.3±1.73	4.8±1.57	**
Calcium	(mg Ca L^{-1})	72.7±9.24	12.3±2.08	**
El. conductivity	(µSm cm^{-1})	1563±376.1	163±32.5	***
Alkalinity	(mval L^{-1})	1.5±0.31	0.18±0.08	***

**P<0.05; **P< 0.01; ***P< 0.001; nd, not detected; ns not significant.*

ing from 21 to 8%; Fig. 3). In 1998, the stands of *L. uniflora* grew to a depth of approximately 110 cm; after 11 years, the depth of plant appearance did not exceed 60 cm. A similar tendency was observed for *M. alterniflorum*. Between 1998 and 2009 abundance of *M. alterniflorum* decreased from 18 to 2%. In 1998 this species occurred at depths varying between 20 and 80 cm with maximum cover values up to 40% (and a mean value of 12%); on the contrary during the 2009 survey, *M. alterniflorum* was found in a single plot and occurred at the depth of 25 cm and with a percentage cover value of about 10%. At the same time, new species, not present in 1998, were found: *Myriophyllum spicatum* L., *Ceratophyllum submersum* L. and *C. demersum* L.*C. submersum* and *C. demersum* were present only at littoral zone adjacent to the Cormorants colony. The frequency of other macrophytes was similar in 1998 and 2009 (Tab. 4).

DISCUSSION

Numerous studies have already demonstrated that Cormorants can largely affect the concentrations of nutrients in soils (Hobara *et al*., 2001; Ligęza and Smal, 2003; Hobara *et al*., 2005; Osono *et al*., 2006; Breuning-Madsen *et al*., 2010), and trigger the alterations in terrestrial vegetation (Hebert *et al*., 2005) and communities of soil invertebrates (Kolb *et al*. 2010) under roosting colonies. Our study partially corroborates these findings and demonstrates that Cormorants may be responsible for profound changes in colonized freshwater ecosystems.

Over the three decades preceding our study, the physicochemical properties of the water of the Lake Dołgie Wielkie were stable and underwent insignificant fluctuations (Bur-

Tab. 4. Comparison of frequency (in %) of hydromacrophyte taxa in Lake Dołgie Wielkie in 1998 and 2009.

	1998	2009
Submerged macrophytes		
Littorella uniflora (L.) Asch.	43	27
Myriophyllum alterniflorum DC.	18	2
Potamogeton perfoliatus L.	8	2
Elodea canadensis Michx.	2	4
Myriophyllum spicatum L.	-	2
Ceratophyllum demersum L.	-	2
Ceratophyllum submersum L.	-	2
Floating leaved macrophytes		
Polygonum amphibium f. natans L.	22	20
Nuphar lutea (L.) Sibth. et Sm.	20	28
Potamogeton natans L.	20	29
Nymphaceae sp.	18	20
Hydrocharis morsus-ranae L.	8	13
Emergent macrophytes		
Eleocharis palustris (L.) Roem et Sch.	39	42
Schoenoplectus lacustris (L.) Palla	33	40
Phragmites australis (Cav.) Trin. ex Steud.	29	33
Glyceria maxima (Hartm.) Holmb.	26	29
Equisetum fluviatile L.	24	22
Carex rostrata Stok.	13	18
Sagittaria sagittifolia L.	12	8
Carex acutiformis Ehrh.	10	11
Typha latifolia L.	10	9
Typha angustifolia L.	4	4
Sparganium emersum Rehm.	4	2
Lysimachia thyrsiflora L.	2	7
Juncus bulbosus L.	2	4
Eleocharis acicularis (L.) Roem et Sch.	2	2
Carex lasiocarpa Ehrh.	2	2
Sium latifolium L.	4	-
Rumex hydrolapathum Huds.	2	-
Alisma plantago-aquatica L.	-	2
Peucedanum palustre (L.) Moench.	-	2

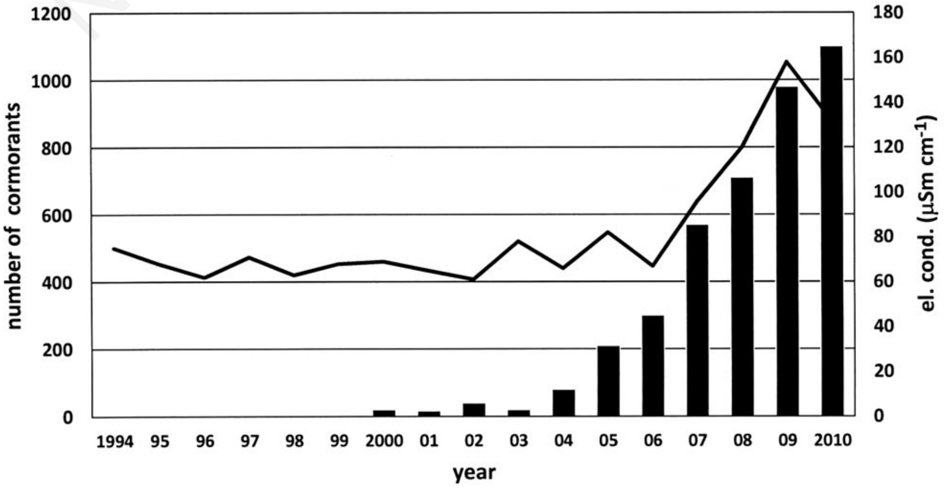

Fig. 2. Comparison of maximal number of roosting Cormorants (bars) and electrical conductivity of littoral water at the station near the colony (line) between 1994 and 2010.

chardt, 2004). Due to the small catchment area, flat relief and insignificant human impact, this lake receives a small load of nutrients from diffuse sources. The mean month N load from these accounted to 156 kg whereas for P it reached 3.1 kg. In turn, mean monthly load of nutrients (for the period June-August) supplied by Cormorants was estimated at 37.6 kg of N and 28.3 kg of P. McCann *et al.* (1997) calculated that Cormorants colony is responsible for 70% and 36% of total P and N content in the small and shallow Lake Aldair (USA). It should be, however, noted that bird feces are partially deposited in the ground beneath the colony, while the rest is deposited directly into the water. The N and P content found in surface layers of soil beneath the Cormorant colony in our study is comparable with this noted in soils from perennial colonies (Ligęza and Smal, 2003; Hobara *et al*., 2005). In deeper soil layers nutrients content was lower although studied roosting colony was functioning shortly. Despite it, the content of nutrients in soils was several-fold higher than this found in soils unaffected by birds. Moreover, it was found that Cormorants have a significant impact on chemistry of shallow groundwater. As demonstrated in other studies, nutrients concentration in groundwater beneath long-lasting perennial nesting colony of Cormorant can be even higher (Klimaszyk, 2012). Chemical compounds deposited within colony area can be consequently transferred to nearby aquatic environment (Marion *et al*., 1994; McCann *et al*., 2000; Klimaszyk, 2012); more rapidly through the surface runoff or slowly with the groundwater (Klimaszyk *et al*., 2008; Gwiazda *et al*., 2010). Velocity of movement of nutrients in the aquifer is slow (Canton *et al*., 2010), hence the colony can affect the lake chemistry even when the Cormorants are absent. Apart from the role of surface runoff and groundwater in transferring nutrients deposited in soils to the lake, Cormorants can deposit their feces directly to the water since some birds roost on tree branches directly above the water surface. If high concentration of nutrients is being delivered to the lake from the area of colony, eutrophication process can be promoted (Nakamura *et al.,* 2010). Our study clearly demonstrated that the establishment of a colony significantly affected the chemistry of the Lake Dołgie Wielkie by increasing concentrations of N, P and other chemical elements in littoral zone adjacent to the birds roosting site. Accordingly, it appears that the nutrients delivered by the birds to the littoral easily spread throughout the entire volume of the lake (Klimaszyk, 2012), promote primary production, increase the possibility of phytoplankton blooms and consequently affect macrophytes.

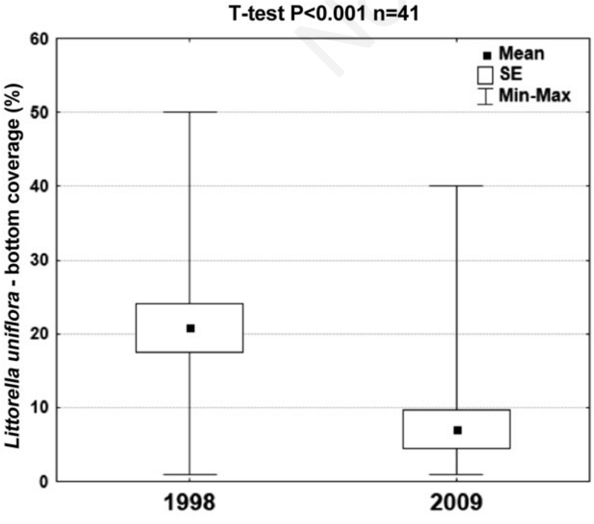

Fig. 3. Differences in bottom coverage values of *Littorella uniflora* in Lake Dołgie Wielkie in 1998 and in 2009.

Changes of water chemistry observed between 1998 and 2009 were accompanied by alterations in the abundance of macrophytes. As relatively high decrease of water transparency and increase in chlorophyll-a concentration were found between studied periods, further changes of macrophyte structure can be expected in near future. The most profound changes concerned the *L. uniflora*. This species is typically found in uncontaminated soft-water lakes characterized by low carbon concentrations (Boston and Adams, 1987; Pedersen *et al*., 2006). Trophic changes can lead to its partial or complete disappearance. *L. uniflora*, similarly to other isoetids, draw carbon from the environment only in the form of free CO_2. Increase in alkaline reaction as observed in Lake Dołgie Wielkie between 1998 and 2009 can lead to domination of carbonates and bicarbonates (Andersen, 2002) and limit the ecological success of *L. uniflora*. However this species represents C_4 cycle and Crassulacean Acid Metabolism (Keeley, 1998; Madsen *et al*., 2002), these mechanism are insufficient under conditions of limited light availability (Robe and Griffiths, 1990). The alkalinity of water in the littoral zone of Lake Dołgie Wielkie in 2009 reached the boundary values for *L. uniflora* (Robe and Griffiths, 1994; Vestergaard and Sand-Jensen, 2000). Finally, *L. uniflora* can be outcompeted by algae and elodeids which grow faster and are promoted at higher nutrient concentrations (Murphy, 2002). Changes in chemistry of Lake Dołgie Wielkie led to the occurrence of macrophyte species previously not reported in the lake such as *M. spicatum*, *C. submersum* and *C. demersum*. The appearance of these species, indicated as typical of eutrophic waters, is probably due to the increases of the water trophic state triggered by the Great Cormorant colony (Arts, 2002; Szoszkiewicz *et al*., 2006).

CONCLUSIONS

Our results support the key role played by Great Cormorants in modulating nutrients availability in waters and soils with dramatic effects on the biological components of the lacustrine environments. In this context, soft-water lakes with a low buffer capacity such as lobelia lakes are particularly susceptible to changes induced by the occurrence and the establishment of Cormorants colonies. At Lake Dołgie Wielkie, we have observed a rapid disappearance of *L. uniflora* and *M. alterniflorum* resulting from a significant reduction in water transparency and water CO_2 availability, and relevant increase in water alkalinity and pH. These significant changes occurred within time as short as 9 years. The gradual spread of Great Cormorants along the shorelines of lobelia lakes can lead to a degradation of their trophic status over a relatively short period of time.

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