Acta Zoologica Academiae Scientiarum Hungaricae 54 (Suppl. 1), pp. 207–224, 2008

THE EFFECT OF AQUATIC BIRDS ON THE NUTRIENT LOAD AND WATER QUALITY OF SODA PANS IN HUNGARY

BOROS, E.[1], NAGY, T.[2], PIGNICZKI, CS.[2], KOTYMÁN, L.[3], BALOGH, K. V.[4] and VÖRÖS, L.[4]

[1]*Naturglob Ltd. H-1196 Budapest, Kossuth L. u. 76. E-mail: drborose@gmail.com*
[2]*Kiskunság National Park Directorate, Kecskemét, H-6000 Kecskemét, Liszt F. u. 19.*
[3]*Körös-Maros National Park Directorate, H-5541 Szarvas, Anna-liget. P.O.Box 72*
[4]*Balaton Limnological Research Institute, H-8237 Tihany, P.O.Box 35*

This study implemented the following guild model concept to demonstrate the role of aquatic birds in the nutrient load of lakes: net importer guild, importer-exporter guild, and net exporter guild. The net C, N, and P load by aquatic bird guilds were estimated by the counted numbers of the aquatic birds. C-, N-, and P-contents and volumes of bird excrement based on our own and literature data of the six most important soda pans and a control site (without birds) in the southern part of Hungary. The following selected water quality parameters were also measured: salinity, pH, and the concentration of nitrate-nitrogen (NO_3-N), orthophosphate-phosphorus (PO_4-P), total phosphorus (TP), total organic carbon (TOC), and dissolved organic carbon (DOC).

It was demonstrated that investigated soda alkaline waters had high TOC and DOC concentrations and hypertrophic levels of TP, but the nitrogen-phosphorus ratio was unusually below 1. It was concluded that the low N/P ratio was caused by high pH (pH > 9).

The aquatic bird contribution to the total external nutrient load was estimated to be approximately C: 50%, N: 35%, P: 70%. Significant linear regression was indicated between the yearly total carbon load (mg m^{-2} $year^{-1}$) by aquatic birds and the yearly average TOC concentration (mg L^{-1}), as well as between the yearly total phosphorus load (mg m^{-2} $year^{-1}$) by aquatic birds and the yearly average TP concentration (mg m^{-3}).

Key words: aquatic bird guilds, soda pans, nutrient load, hypertrophic status, buttom up function

INTRODUCTION

The shallow intermittent alkaline soda pans are very characteristic examples of wetlands on the lowland territory of the Carpathian Basin, and these constitute special types of inland saline waters. Their high pH and turbidity level are caused by a high amount of dissolved natrium-hydrogen-carbonate ions (BOROS 1999). However, there was a dramatic decrease in number of these wetlands during the last few decades in the Carpathian Basin (BOROS *et al*. 2006*c*).

There is evidence that Hungarian soda pans (wetlands) are very important cross-continental migrating and breeding sites for aquatic birds in Hungary, and this is why they are designated as Ramsar-sites. BOROS (2003) reported a significant and notable increasing trend in some wildfowl species in the soda pans of the Kiskunság National Park, which are included in this study. Most of the Hungarian studies have dealt with special food items and food resources of aquatic birds on soda pans in Hungary (STERBETZ 1968*a*, *b*, 1972*a*, *b*, 1988, 1991, BOROS *et al.* 2006*a*, *b*, FORRÓ & BOROS 1997).

Many studies can be found about the role of aquatic birds on nutrient loads at different levels of importance and in many types of aquatic environment all over the world, but only a few studies were done about continental aquatic systems. For example, MANNY *et al.* (1994) found that the contribution of aquatic birds to the total nutrient load was: carbon 69%, nitrogen 27%, and phosphorus 70% in Wintergreen Lake (USA). Similarly important contributions were estimated by POST *et al.* (1998): 40% of nitrogen and 75% of phosphorus were added by birds in New Mexico. PORTNOY *et al.* (1990) indicated gulls contribution to be 42% of the total phosphorus load of Cape Code kettle ponds. HOYER *et al.* (1994) found a close correlation between the density of aquatic birds and the ortophosphate-phosphorus concentration in the water. These examples indicated the high level of importance of aquatic birds in external nutrient addition within certain ecosystems, while other experiments found birds to be less important in the nutrient cycling of the aquatic ecosystems (e.g. MARION *et al.* 1994).

There are only a few studies on the role of aquatic birds on water quality and nutrient cycling in Hungary. Most studies were concentrated on Lake Balaton (STERBETZ 1992) and on the "Kis-Balaton" wetland system (GERE & ANDRIKOVICS 1994, ANDRIKOVICS *et al.* 1997, BÁLDI 2001), where the bird contribution to the total external nutrient load was very low. Two studies were published about the Cormorant (*Phalacrocorax carbo*) that estimated contribution of Cormorants was 2.2% in total phosphorus cycling on Kis Balaton area (GERE & ANDRIKOVICS 1992*a*, *b*). OLÁH (2003) ordered the aquatic bird species into 3 main different nutrient cycling guilds and he carried out nutrient load estimations with the number of aquatic birds on "Lake Fehér" soda pan at Kardoskút in South-East part of Hungary.

SCHMIDT (2003) analysed the water quality in soda pans of Kiskunság National Park and his data call to attention very high concentrations of dissolved phosphorus, as well as mentioning the question between the water quality nutrient load by birds. In contrast with the ornithological importance of Hungarian soda pans, the role of aquatic birds on nutrient load corresponding with their impact on trophic levels and function on soda pans in Hungary has not yet been investigated.

Based on previous studies and lack of knowledge about the role of aquatic birds on the nutrient load and effect on water quality of soda pans in Hungary, our first main goal was to estimate the carbon (C), nitrogen (N), and phosphorus (P) load of aquatic birds on the open water bodies of the most important migrating and breeding natural soda pans (Ramsar-sites). Corresponding with nutrient cycling functions, the second goal was to order the aquatic bird species into nutrient transporting guilds (importer, exporter, etc.). The third goal was to estimate the relative contribution of aquatic birds within the whole nutrient pool of soda pans, as well as to indicate the relationships between aquatic bird nutrient load and water quality.

MATERIAL AND METHODS

Study sites

The investigated six residences of the most important soda alkaline pans having white coloured water can be found in the southern part of the Great Hungarian Plain (Fig. 1). The “Fehér-tó” pan lies within the Körös–Maros National Park, the “Büdös-szék 2” pan belongs to the Pusztaszer Landscape Protection Area, and the three others are in the Kiskunság National Park (“Büdös-szék 1, Kelemen-szék, Zab-szék” pans), while the “Böddi-szék” pan is a nature conservation site that is located close to the Kiskunság National Park. All of them are designated on the List of Wetlands of In-

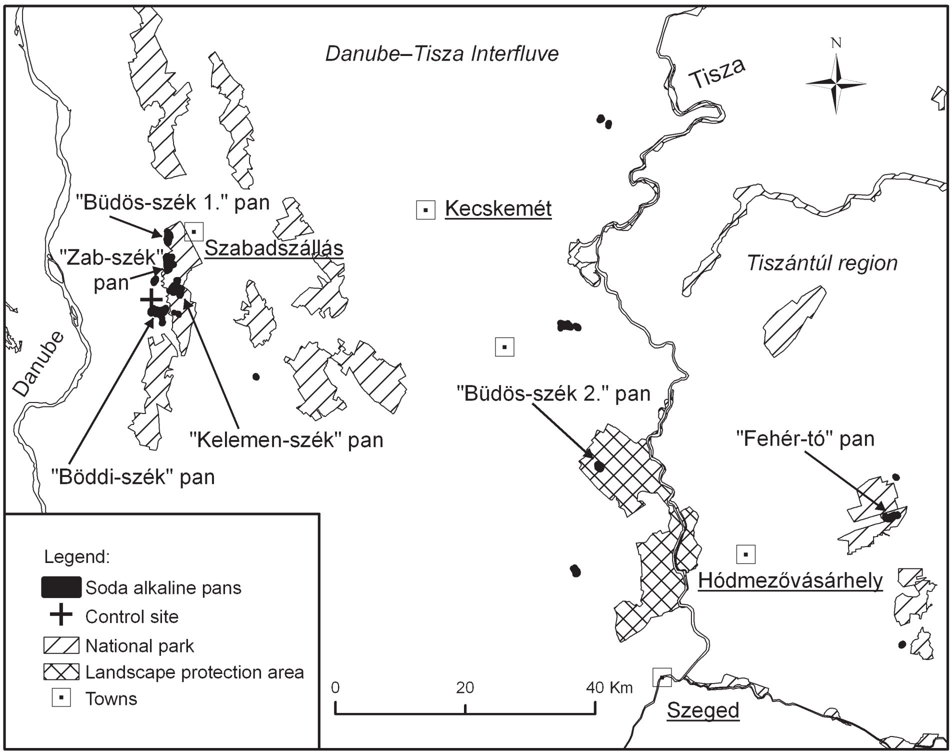

Fig. 1. The geographical location of the investigated soda pans and the control site in south part of the Great Hungarian Plain

ternational Importance of Ramsar Convention on Wetlands and as Special Protection Area of birds (Natura 2000 network), due to internationally important migration of aquatic bird populations, as well as on the Site of Community Interest in Natura 2000 network by unique habitats criteria. The implemented control site was a small soda alkaline pan (0.8 ha) supplied by groundwater where there were no observed aquatic birds at all by human disturbance during this experiment.

The soda pans are intermittent shallow alkaline waters (max. depth = 0.4–0.5 m) that frequently dry out entirely by the end of summer. Their salinity varies between hypo- (3–20 g L^{-1}) and mesosaline (> 20 g L^{-1}) ranges depending on seasonal water level fluctuation. These water bodies are characterized by the dominance of Na^+-, HCO_3^--, CO_3^{2-}-, and Cl^--ions which cause hypo- mesosalinity and pH values range between 9 and 10 (SCHMIDT 2003). The large amounts of suspended inorganic (clay) particles generally cause the very high turbidity and the light grey colour of the water. In spite of the shallowness of the lakes, high turbidity usually inhibits the development of benthic algae on the bottom (VÖRÖS *et al*. 2006). The characteristic endemic alkaline marshland *Bolboschoeno-Phragmitetum* and wet meadow *Lepidio crassifolii – Puccinellietum limosae* vegetation can be found along the shoreline, but there is no vegetation in the major part of the pan-beds during the wet periods (BOROS 1999).

Measurement of chemical parameters

The water quality samples were taken monthly from February to October in 2004 (6th February, 15th March, 25th April, 27th May, 4th July, 4th August, 3th September, 17th October). Each sample was taken from the same marked points, which were selected randomly at the beginning of the experiment. Conductivity was measured on the spot with a "WTW MultiLine P4" field instrument with a TetraCon 325 electrode, and salinity was calculated via conductivity based on FREEZE and CHERRY (1979) method. The pH level was also measured on the spot by "WTW MultiLine P4" field instrument with a SenTix 41 electrode.

All the other parameters were analysed in a laboratory from the original water samples. The nitrate concentration was measured by the Hungarian standard method (MSZ 448–12:1982). The orthophosphate-phosphorus concentration was measured by the method of MURPHY and RILEY (1962), and the total phosphorus (TP) concentration was determined from unfiltered water samples by kalium-persulphate destruction based on the method of MENZEL and CORWIN (1965).

The total organic carbon (TOC) (unfiltered water) and dissolved organic carbon (DOC) concentration (water was filtered through 0.45 combusted GF–5 glass fibre filter) was measured using an Elementar High TOC analyser.

Estimation of nutrient load of soda pans by aquatic birds

Our nutrient cycling guild conception was drawn based on our more than 20 year old experiment and on literary data (habitat selection, feeding, assembling, and roosting behaviour) on the ecology of aquatic birds, which is a simplified adaptation of OLÁH's (2003) nutrient transporting guild category of the soda pans. The implemented nutrient cycling guild categories were the following:

A) Net-importer guild: includes those species which feed exclusively outside of the open soda water bodies, but they use these waters as assembling and roosting sites (e.g. *Anser*-species).

B) Importer-exporter guild: includes those species which feed both outside and inside soda waters (e.g. most *Anas* species and certain Charadriiformes species.).

C) Net-exporter guild: includes those species which feed exclusively inside soda waters. (e.g. most Charadriformes species).

We assumed that the bird excrement is a very important external nutrient resource, because the main water volume comes from nutrient-poor groundwater into the intermittent soda pans. The external nutrient load by aquatic birds was directly estimated via bird density, and all other external resources were estimated by a control site. The birds were counted by means of binoculars (8×42) and field scopes (30×75) on a weekly basis on the open water bodies of the pans in 2004. The daily numbers of the birds were considered by average of weekly or biweekly counting data per each month.

The net C, N, and P load by aquatic bird guilds were estimated by literary data of daily net C, N, and P excretion for all species. The implemented daily net C, N, and P excrements data of the aquatic bird species and their residence time factors are listed in Table 1.

The estimated daily nutrient load by aquatic bird populations was calculated by the average monthly number of the birds and net daily C, N, and P excretion. The daily load data (g day $^{-1}$ ind.$^{-1}$)

Table 1. The implemented daily net C, N, and P excrements data [g day^{-1} ind.$^{-1}$] and residence time factors (RTF) of the aquatic bird species.

Species, and groups	RTF	C	N	P	Source
Golden Plover (*Pluvialis apricaria*), Lapwing (*Vanellus vanellus*), Ruff (*Philomachus pugnax*)	0.6	2.52	0.65	0.12	OLÁH (2003)
Diving ducks (*Aythya* & *Mergus* spp.), Grebes (*Podiceps* spp.)	1	9.69	0.61	0.19	MANNY *et al.* (1994), OLÁH (2003)
Black-headed Gull (*Larus ridibundus*)	0.6	3.48	0.36	0.23	GOULD & FLETCHER (1978)
Crane (*Grus grus*)	0.6	8.40	3.48	0.58	OLÁH (2003)
Avocet (*Recurvirostra avosetta*), Black-winged Stilt (*Himantopus himantopus*), Black-tailed Godwit (*Limosa limosa*)	1	5.00	2.16	0.36	OLÁH (2003)
Cormorant (*Phalacrocorax carbo*)	1	19.60	1.04	4.58	MARION *et al*. (1994)
Great White Egret (*Egretta alba*), Grey Heron (*Ardea cinerea*), White Stork (*Ciconia ciconia*)	1	14.50	1.38	3.78	MARION *et al*. (1994)
White-fronted Goose (*Anser albifrons*)	0.6	8.60	0.69	0.08	KEAR(1963)
Greylag Goose (*Anser anser*), Bean Goose (*Anser fabalis*)	0.6	9.76	0.49	0.11	OLÁH (2003)
Sandpipers (*Calidris* spp.), small Plovers (*Charadrius* spp.)	1	3.00	0.93	0.11	OLÁH (2003)
Curlews (*Numenius* spp.)	0.6	3.00	1.30	0.22	OLÁH (2003)
Yellow-legged Gull (*Larus cachinnans*)	0.6	7.68	0.66	0.62	GOULD & FLETCHER (1978)
Snipe (*Gallinago gallinago*), bigger Sandpipers (*Tringa* spp.)	1	4.20	1.08	0.20	OLÁH (2003)
Terns (*Chlidonias* spp. and *Sterna* spp.)	1	4.50	0.60	0.38	estimated
Dabbling ducks (*Anas* spp.)	0.8	9.12	0.58	0.18	MANNY *et al.* (1994), OLÁH (2003)
Common Gull (*Larus canus*)	0.6	4.32	0.48	0.3	GOULD & FLETCHER (1978)

was modified by a species residence time correction factor (residence time hours/24) based on the local behaviour of birds.

Monthly total load = monthly average number of each aquatic bird species × day number of month × daily net C, N, P content of excrement × daily residence time (calculated separately for each aquatic bird species).

The annual summarised net C, N, and P loads were pooled up by 365 daily load data to the annual total load data, and calculated to surface related by the size of open water bodies of the pans. The open water bodies of the pans were measured by remote sensing control databases (aerial photographs). The control pan was the basis of the estimation of the relative contribution by aquatic birds in the total nutrient load (C, N, and P resource) of pans.

Statistical analysis

We investigated the different parameters and relationships via multiple linear and non-linear regressions by means of Statistica for Windows 7. Pearson correlations were also calculated and the implicated significant level was $p < 0.05$. The species compositions of aquatic bird community were also tested by principal component analyses (PCA).

RESULTS

Composition of aquatic bird population

78 aquatic bird species were observed on the shallow open water bodies of 6 soda pans in 2004. The species and guild characterisation of observed aquatic birds are listed in Table 2. According to the implemented guild concept, 22 species belong to the net importer guild, 19 to the exporter-importer, and 37 species to the net exporter guilds. This means that most species occurred in the net exporter guild, while the two others had similar species numbers. Outstanding species richness were found in Wildfowl (Anatidae) 21 sp. and Sandpipers (Scolopacidae) 20 sp. Families, all other groups were represented only by 1–6 species.

Based on population size, the PCA was divided into three main groups of aquatic bird species. The 78.43% of variances caused by factor 1 and 15.41% by factor 2, which were both comprised 93% of variances. This result means that the most abundant species were the White-fronted Goose, the Greylag-Goose, and the Black-headed Gull *(Larus ridibundus*), and all other species belonged to the third quantitative group (Fig. 2) on the 6 investigated soda pans in 2004.

Nutrient load of soda pans by aquatic birds

The estimated annual absolute and surfaced related nutrient load of the pans produced by aquatic birds is summarised in Table 3. The annual total absolute nu-

Table 2. The species list and guild characterisation of observed aquatic birds in 2004 in the investigated soda pans. A = Net importer guild, B = Importer-exporter guild, C = Net exporter guild

English name	Scientific name	Guild
Grebes	**Podicipedidae**	
Little Grebe	*Tachybaptus ruficollis* (PALLAS, 1764)	C
Great Crested Grebe	*Podiceps cristatus* (LINNAEUS, 1758)	C
Black-necked Grebe	*Podiceps nigricollis* C. L. BREHM, 1831	C
Cormorants	**Phalacrocoracidae**	
Cormorant	*Phalacrocorax carbo* (LINNAEUS, 1758)	A
Herons and Egrets	**Ardeidae**	
Night Heron	*Nycticorax nycticorax* (LINNAEUS, 1758)	A
Squacco Heron	*Ardeola ralloides* (SCOPOLI, 1769)	A
Great White Egret	*Egretta alba* (LINNAEUS, 1758)	A
Little Egret	*Egretta garzetta* (LINNAEUS, 1766)	A
Grey Heron	*Ardea cinerea* LINNAEUS, 1758	A
Purple Heron	*Ardea purpurea* LINNAEUS, 1766	A
Storks	**Ciconiidae**	
White Stork	*Ciconia ciconia* (LINNAEUS, 1758)	A
Black Stork	*Ciconia nigra* (LINNAEUS, 1758)	A
Ibises and Spoonbils	**Threskiornithidae**	
Spoonbill	*Platalea leucorodia* LINNAEUS, 1758	C
Glossy Ibis	*Plegadis falcinellus* (LINNAEUS, 1766)	B
Wildfowl	**Anatidae**	
Mute Swan	*Cygnus olor* (Gmelin, 1789)	C
White-fronted Goose	*Anser albifrons* (SCOPOLI, 1769)	A
Lesser White-fronted Goose	*Anser erythropus* (LINNAEUS, 1758)	A
Greylag Goose	*Anser anser* (LINNAEUS, 1758)	A
Bean Goose	*Anser fabalis* (LATHAM, 1787)	A
Barnacle Goose	*Branta leucopsis* (BECHSTEIN, 1803)	A
Red-breasted Goose	*Branta ruficollis* (PALLAS, 1769)	A
Ruddy Shelduck	*Tadorna ferruginea* (PALLAS, 1764)	C
Shelduck	*Tadorna tadorna* (LINNAEUS, 1758)	C
Pintail	*Anas acuta* LINNAEUS, 1758	B
Shoveler	*Anas clypeata* LINNAEUS, 1758	B
Teal	*Anas crecca* LINNAEUS, 1758	B
Wigeon	*Anas penelope* LINNAEUS, 1758	B
Mallard	*Anas platyrhynchos* LINNAEUS, 1758	A
Garganey	*Anas querquedula* LINNAEUS, 1758	B
Gadwall	*Anas strepera* LINNAEUS, 1758	B
Pochard	*Aythya ferina* (LINNAEUS, 1758)	C
Tufted Duck	*Aythya fuligula* (LINNAEUS, 1758)	C
Ferruginous Duck	*Aythya nyroca* (GÜLDENSTÄDT, 1770)	C
Goldeneye	*Bucephala clangula* (LINNAEUS, 1758)	C
Smew	*Mergus albellus* LINNAEUS, 1758	C
Rails and Crakes	**Rallidae**	
Coot	*Fulica atra* LINNAEUS, 1758	C
Cranes	**Gruidae**	
Crane	*Grus grus* (LINNAEUS, 1758)	A

Table 2 (continued)

English name	Scientific name	Guild
Oystercatchers	**Haematopodidae**	
Oystercatcher	*Haematopus ostralegus* LINNAEUS, 1758	C
Avocets and Stilts	**Recurvirostridae**	
Black-winged Stilt	*Himantopus himantopus* (LINNAEUS, 1758)	C
Avocet	*Recurvirostra avosetta* LINNAEUS, 1758	C
Lapwing and Plovers	**Charadriidae**	
Kentish Plover	*Charadrius alexandrinus* LINNAEUS, 1758	C
Little Ringed Plover	*Charadrius dubius* SCOPOLI, 1786	C
Ringed Plover	*Charadrius hiaticula* LINNAEUS, 1758	C
Golden Plover	*Pluvialis apricaria* (LINNAEUS, 1758)	B
Grey Plover	*Pluvialis squatarola* (LINNAEUS, 1758)	C
Lapwing	*Vanellus vanellus* (LINNAEUS, 1758)	B
Sandpipers	**Scolopacidae**	
Sanderling	*Calidris alba* (PALLAS, 1764)	C
Dunlin	*Calidris alpina* (LINNAEUS, 1758)	C
Curlew Sandpiper	*Calidris ferruginea* (PONTOPPIDAN, 1763)	C
Little Stint	*Calidris minuta* (LEISLER, 1812)	C
Temminck's Stint	*Calidris temminckii* (LEISLER, 1812)	C
Broad-billed Sandpiper	*Limicola falcinellus* (PONTOPPIDAN, 1763)	C
Ruff	*Philomachus pugnax* (LINNAEUS, 1758)	B
Snipe	*Gallinago gallinago* (LINNAEUS, 1758)	C
Bar-tailed Godwit	*Limosa lapponica* (LINNAEUS, 1758)	C
Black-tailed Godwit	*Limosa limosa* (LINNAEUS, 1758)	C
Curlew	*Numenius arquata* (LINNAEUS, 1758)	A
Whimbrel	*Numenius phaeopus* (LINNAEUS, 1758)	A
Spotted Redshank	*Tringa erythropus* (PALLAS, 1764)	C
Wood Sandpiper	*Tringa glareola* LINNAEUS, 1758	C
Greenshank	*Tringa nebularia* (GUNNERUS, 1767)	C
Green Sandpiper	*Tringa ochropus* LINNAEUS, 1758	C
Marsh Sandpiper	*Tringa stagnatilis* (BECHSTEIN, 1803)	C
Redshank	*Tringa totanus* (LINNAEUS, 1758)	C
Common Sandpiper	*Actitis hypoleucos* (LINNAEUS, 1758)	C
Turnstone	*Arenaria interpres* (LINNAEUS, 1758)	C
Gulls	**Laridae**	
Yellow-legged Gull	*Larus cachinnans* PALLAS, 1811	A
Common Gull	*Larus canus* LINNAEUS, 1758	A
Lesser Black-backed Gull	*Larus fuscus* LINNAEUS, 1758	A
Mediterranean Gull	*Larus melanocephalus* TEMMINCK, 1820	B
Little Gull	*Larus minutus* PALLAS, 1776	B
Black-headed Gull	*Larus ridibundus* LINNAEUS, 1766	B
Terns	**Sternidae**	
Caspian Tern	*Sterna caspia* PALLAS, 1770	B
Common Tern	*Sterna hirundo* LINNAEUS, 1758	B
Gull-billed Tern	*Gelochelidon nilotica* (GMELIN, 1789)	B
Whiskered Tern	*Chlidonias hybridus* (PALLAS, 1811)	B
White-winged Black Tern	*Chlidonias leucopterus* (TEMMINCK, 1815)	B
Black Tern	*Chlidonias niger* (LINNAEUS, 1758)	B

trient load was very variable because of different sizes of bird populations, while the relative nutrient load (g m^{-2}) was more uniform among the pans. The relative importance of different nutrients was also varied among the sites because of different compositions of aquatic bird populations. The carbon load ranged between 4.9–13.9 tonnes, and the nitrogen ranged 0.9–1.3 tonnes, while the phosphorus ranged only 0.008–0.4 tonnes per year among the pans. The estimated average proportion of nutrients was C: 88%, N: 9%, P: 3% in the excrements of all species in the 6 investigated pans.

The contribution of the different guilds to the total nutrient load by birds was also different. The net importer guild was the most important, because it provided 77% of C, 71% of N, and 61% of P. The second most important was the importer-exporter guild with 21% of C, 24% of N, and 31% of P, while the third was the net exporter guild with 2% of C, 5% of N, and 5% of P contribution. The relatively higher proportions of nitrogen and phosphorus were detected at the importer-exporter and net exporter guilds, where the mixed feeder and carnivore species dominated, while in region where herbivores dominated, the net importer guild imported relatively more carbon into the pans. The seasonal changes of nutrient load by birds followed the migrating seasons especially in regard to the dominant wildfowl net importer and exporter importer species. According to the migrating seasons there were two peaks of nutrient load by birds, one of in early spring (February) and another in late autumn (November).

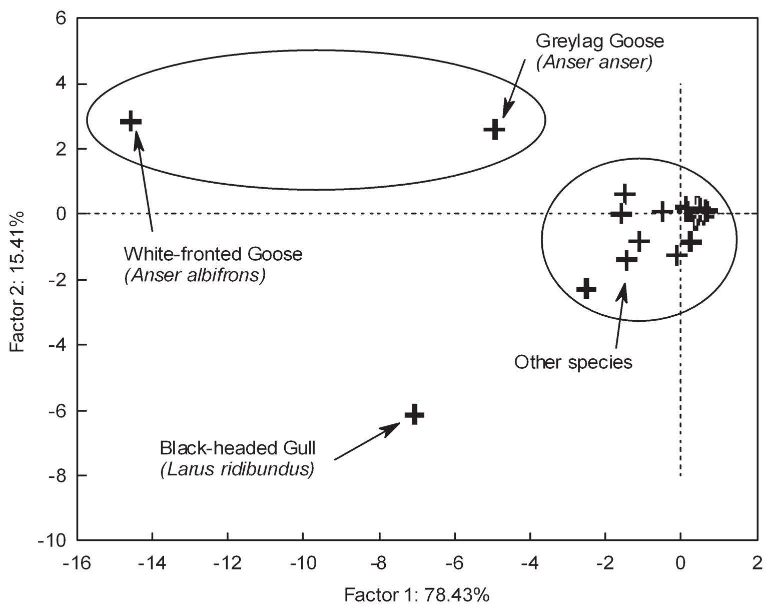

Fig. 2. The PCA result of the density of the aquatic bird species on the investigated soda pans in 2004

Table 3. The estimated annual absolute and surface related nutrient load of the pans produced by aquatic birds

Sites	Carbon		Nitrogen		Phosphorus	
	Kilogram	g m^{-2}	Kilogram	g m^{-2}	Kilogram	g m^{-2}
"Böddi-szék" pan	11025	31.521	927	2.636	212	0.578
"Büdös-szék 1" pan	4931	31.964	387	3.582	84	0.748
"Büdös-szék 2" pan	8415	16.830	1028	2.056	330	0.600
"Fehér-tó" pan	7703	32.251	1130	4.639	419	2.500
"Kelemen-szék" pan	13902	17.922	1293	1.569	363	0.424
"Zab-szék" pan	13330	24.376	1168	2.134	329	0.615

The water quality of the pans

The mean water quality data of the investigated soda pans in 2004 is summarised in Table 4. The annual average of salinity varied between 2.07–6.37 g L^{-1} in the hyposaline range. The lowest value was found in "Fehér-tó" pan and the highest in "Böddi-szék". The annual average of pH varied between 9.04–9.28 in alkaline range, the lowest value was in "Büdös-szék 1 and 2" pans, and the highest one was in the "Böddi-szék" as well. The salinity and pH were regulated by notable water level fluctuations, which means that the minimum data were measured at the highest water level in spring, while the maximum data occurred at the lowest water level, but neither pans dried out entirely during this experiment. Moreover, a significant positive correlation was indicated between the salinity (x) and the pH (y).

$$y = 8.847 + 0.094 \times \log_{10}(x);\ r = 0{,}951,\ p < 0.00001;\ n = 42$$

Table 4. The average and standard errors of the measured water quality data on the investigated soda pans in 2004

Sites	n	Salinity average (g L^{-1})	pH average	TOC average (mg L^{-1})	DOC average (mg L^{-1})	NO_3-N average (µg L^{-1})	PO_4-P average (µg L^{-1})	TP average (µg L^{-1})
"Böddi-szék" pan	8	6.37±4.27	9.28±0.30	72±37	58±32	253±153	599±362	2619±1408
"Büdös-szék 1" pan	8	2.46±1.48	9.04±0.35	76±25	60±25	381±277	1263±431	6412±203
"Büdös-szék 2" pan	8	2.07±1.09	9.04±0.29	51±19	39±14	339±64	792±526	3647±208
"Fehér-tó" pan	7	2.35±1.06	9.14±0.30	98±65	45±42	544±414	1758±522	14156±993
"Kelemen-szék" pan	8	3.41±1.98	9.17±0.33	55±15	47±16	633±370	669±279	3203±118
"Zab-szék" pan	8	2.55±1.46	9.14±0.26	66±7	45±13	1053±606	1029±416	5706±119
Control site	9	3.93±0.76	9.20±0.32	34±14	28±8	226±10	21±22	181±157

The TOC and DOC concentrations were relatively high in the waters compared with other Hungarian waters which accounted for salinity, because significant positive correlation was indicated between salinity (x) and DOC (y).

$$y = 24.823 + 6.464 \times x;\ r = 0.876;\ p < 0.00001;\ n = 44$$

The highest average TOC concentrations were measured in "Fehér-tó" pan, while the lowest one was found in the control site. In contrast with it, the highest average DOC concentration was measured on "Büdös-szék 1" pan, but the highest maximum occurred in also "Fehér-tó" pan.

The average concentration of NO_3-N was the lowest at the control site, while the highest average concentration occurred in "Zab-szék" pan. Nevertheless, moderately close but significant correlation was found between salinity (x) and NO_3-N (y) concentration.

$$y = 821.615 - 633.123 \times \log_{10}(x);\ r = -0.460\ p = 0.00003;\ n = 29$$

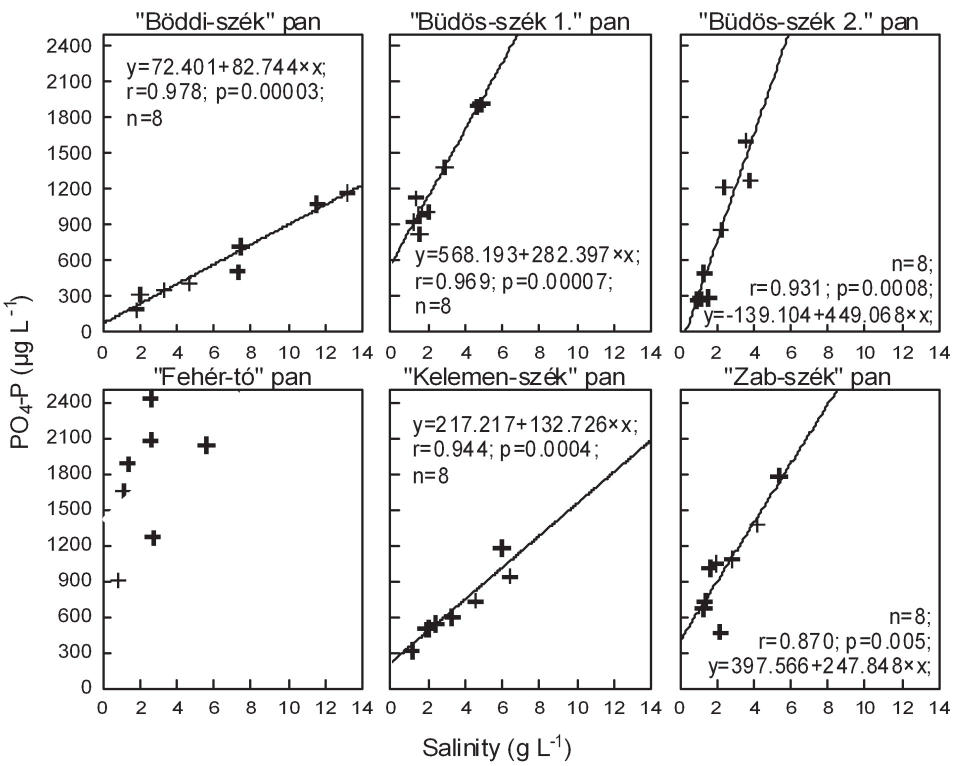

Fig. 3. Relationship between salinity and PO4-P concentration in the investigated soda pans in 2004

The average of PO_4-P concentration was an order of magnitude lower on the control site than in the exposed pans to the birds. The PO_4-P concentration of the exposed pans was very high (> 1.000 µg L^{-1}). The average concentration of PO_4-P was the lowest in "Böddi-szék" pan, while the highest was in "Fehér-tó" pan. The contribution of PO_4-P concentration to TP varied between 12–22%. At the same time the average of TP concentration was also an order of magnitude lower in the control pan than in the exposed pans. This result means that the annual average of TP exceeded with an order of magnitude the OECD (1982) hypertrophic limit in the soda pans, except in the "Fehér-tó" pan, where the average was higher with two orders of magnitude then the hypertrophic limit. Comparing the investigated pans the average of TP were the highest in "Fehér-tó" pan, and lowest in "Böddi-szék" pan.

In contrast with the negative relationship between salinity (x) and NO_3-N (y) concentration, significant positive correlation and linear relationships were found between the salinity (x) and PO_4-P (y) concentration. However, we found a linear relationship with significant individual slopes at each investigated pan, except for at the upper limit of PO_4-P concentration on "Fehér-tó" pan (Fig. 3). Similar relationship was detected in the control pan, but there was no clear relationship between the salinity and PO_4-P. In contrast with PO_4-P concentrations, there was not a clear tendency between salinity and TP at all on the investigated sites. The nitrogen-phosphorus ratio was generally very low (< 1), because the nitrogen correlated negatively and phosphorus correlated positively with the salinity. According to this phenomenon there was also a significant negative relationship between the salinity and the nitrogen-phosphorus ratio (NO_3-N / PO_4-P) (Fig. 4).

Relationship between aquatic bird population and water quality

We also investigated the relationship between the nutrient load by aquatic bird populations and water quality. First of all, there was no direct relationship between nutrient load by aquatic birds and water quality parameters on a fine time scale, e.g. during daily, weekly, monthly periods, but direct relationships can be detected on a yearly scale. The annual sum of nutrient loads by aquatic birds were correlated with the annual average concentration of investigated C, N, and P nutrients in the six exposed soda pans plus in the control pan. Significant positive correlation was found between the annual sum of C load by aquatic birds and the annual average of TOC concentration (Fig. 5), as well as between the annual sum of P load by aquatic birds and the annual average of TP concentration (Fig. 6). However, we did not find any relationship between the annual sum of N load by aquatic birds and annual average of NO_3-N concentration.

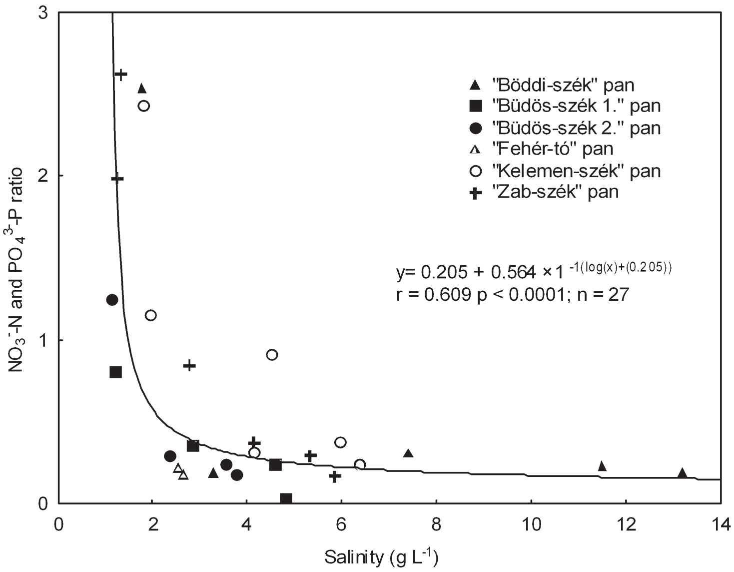

Fig. 4. Relationship between salinity and nitrogen-phosphorus ratio (NO3-N / PO4-P) in the investigated soda pans in 2004

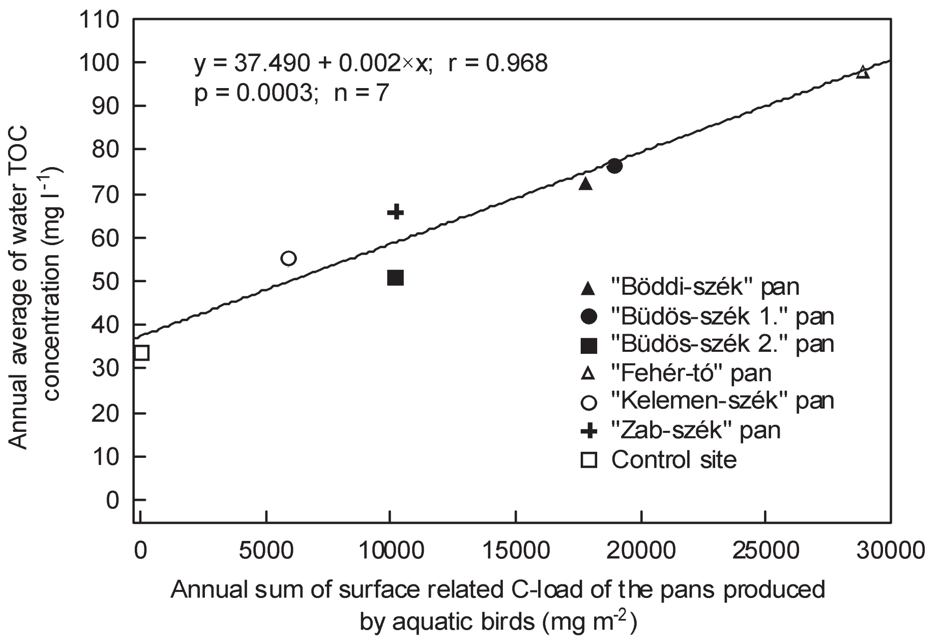

Fig. 5. Relationship between annual sum of surface related C-load produced by aquatic birds and TOC concentration of the pans in 2004

DISCUSSION

According to our estimations, the herbivore net-importer guild (C: 77%, N: 71%, P: 61%) had the most important contribution to the nutrient load of aquatic bird community in the six representative soda pans (Ramsar-sites). The second most important was the mixed feeder importer-exporter guild (C: 21%, N: 24%, P: 31%), while the contribution of the net-exporter guild (C: 2, N: 5, P: 5%) to external nutrient load was almost of negligible importance. The most numerous external nutrient importer aquatic bird species were the White-fronted and Greylag Geese and the Black-headed gull; the other species together had similar importance to the three most common species.

By comparing the nutrient resource of "birdless" control and the exposed soda pans it was estimated that the aquatic bird contribution was C: 50%, N: 35%, and P: 70% to the total external nutrient load. Our relatively high level of contribution by aquatic birds to the nutrient load corresponded to the similar results of MANNY *et al.* (1994), POST *et al.* (1998) and KITCHELL *et al.* (1999) on other important continental stopover wetland sites for birds. It is also similar to the level of nutrient load by birds to the OLÁH's (2003) former estimation on the "Fehér-tó" pan, although he did not investigate water quality parameters and its relationships with the birds in the same time. We clearly demonstrated a close relationship be-

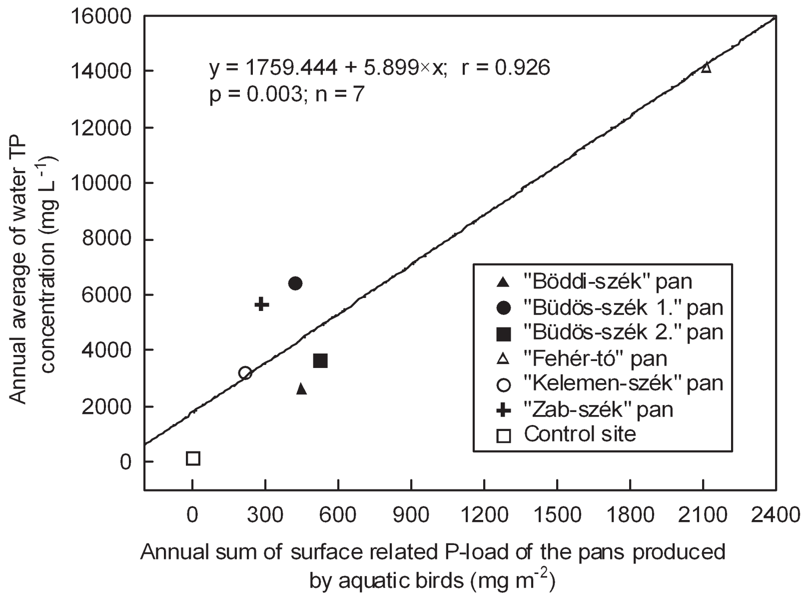

Fig. 6. Relationship between annual sum of surface related P-load produced by aquatic birds and TP concentration of the pans in 2004

tween water quality and the aquatic bird population density, especially regarding the carbon and phosphorus load. The indicated level of nutrient load by aquatic birds is an ecologically important determinant factor in the nutrient cycle in this ecosystem, in contrast with Lake Balaton (STREBETZ 1992) and the "Kis-Balaton" wetland system (GERE & ANDRIKOVICS 1994, Andrikovics *et al*. 1997, BÁLDI 2001, GERE & ANDRIKOVICS 1992*a*, 1992*b*), where the bird contribution to the total external nutrient load was almost negligible compared with other inlet nutrient sources.

We can conclude by the composition of aquatic bird nutrient guilds that the major part of the bird nutrient load is of external origin. The external nutrient load of aquatic birds into the shallow open waters of the soda pans are determined by those large bodied herbivore species that use these water tables only as roosting and overnight places. In this meaning these aquatic bird communities bring the nutrients into the soda pans from an extensive surrounded area around the relatively small (0,5–1 km^2) open water bodies, consequently the aquatic birds have a bottom up function in this ecosystem. The standing water bodies of soda pans have no inlets or outlets, and they have small watershed areas. Nevertheless aquatic birds provide the nutrient incomes. It is also presented here that the net-exporter guild is built up of rather smaller bodied species and has less importance in avian nutrient load than the net-importer and importer-exporter guilds, which are determined by aquatic bird species of larger body size and those that are most numerous.

On the basis of our measured data we determined that the investigated intermittent turbid soda pans have very large inorganic and organic nutrient pools, for example the yearly average of total phosphorus (TP) exceeded by one order of magnitude the internationally implemented lower limit of hypertrophic status by OECD (1982). This high level of TP which is caused by birds issues the determining role of birds in eutrophication process, because BOROS (2003) demonstrated a significant population increase (100% or more) of some net importer aquatic bird species populations during the last 25 years. At the same time, the rich inorganic plant nutrient pools coupled with unusual low nitrogen and phosphorus ratios (yearly average of N-P ratio < 1). We also proved that the nitrate-nitrogen and ortophosphate-phosphorus ratio had an inverse relationship with salinity. Based on these facts we conclude that one of the main causes of low nitrogen phosphorus ratio is the ammonia waste from the water column due to the characteristic high pH level, according to the next scheme:

$$NH_4^+ + OH \rightarrow NH_3 + H_2O \text{ (in pH 8–10 range)}$$

SCHEFFER (1999) mentioned that the inlet of HCO_3^- rich water may result in a pH rise in poorly buffered soft-water systems, leading to an increased phosphorus release from the sediment. According to this phenomenon, we prove here that the ortophospathe-phosphorus level depends on salinity, which is the other factor of the low nitrogen-phosphorus ratio of the alkaline soda waters compared with other natural Hungarian shallow waters. Based on the significant relationships between aquatic bird C, P load and TOC, and TP concentration of soda pan waters, our final conclusions are that the implemented aquatic bird nutrient cycling guild concept can give a proper model to describe the role of birds in the external nutrient load of the water bodies. Furthermore, we demonstrated that the hypertrophic level of soda pans caused by aquatic birds is in close interaction with characteristic chemical features (salinity and pH) of the waters in the important bird stopover Ramsar-sites. Finally, we suggest a more intensive limnological research on these special and extreme wetlands.

*

Acknowledgements – We wish to extend our gratitude to the Kiskunság National Park Directorate for its technical support, to ANTAL SCHMIDT and his colleagues at Alsó-Duna-völgyi Environment Protection Authority for their indispensable nitrogen analysis, as well as for the financial support of the Hungarian Scientific Research Fund (OTKA T-038033, and T-042977).

REFERENCES

ANDRIKOVICS, S., GERE, G. & FUTÓ, E. (1997) The nutrition of Greylag Goose and its effects on the eutrophication of Kisbalaton (Hungary). *Wetlands International Publication* **43**: 199–210.

BÁLDI, A. (2001) A vízimadarak tápanyagforgalmának jelentősége a Kis-Balaton II. üteme vízminőségére irodalmi adatok alapján. (The role of waterfowl mediated nutrients in the water quality of the Lake Fenéki at Kis-Balaton marshland: a literature review.) *Természetvédelmi Közlemények* **9**: 287–297. [in Hungarian with English summary]

BARRIE, A. & LEMLEY, M. (1989) Automated $^{15}N/^{13}C$ analysis of biological materials. *American Laboratory* **21**(8): 1–7.

BOROS, E. (1999) Ecological state of sodic water bodies in Hungary. *Acta Biologica Debrecina Supplementum oecologica hungarica* **9**: 13–80. [in Hungarian with English summary]

BOROS, E. (2003) Vízimadár populációváltozások és környezeti okai a Kiskunsági Nemzeti Park szikes tavain és mocsarain (KNP II. sz. területének térségében). (Waterbird population changes and their environmental reasons on the sodic lakes of the Kiskunság National Park.) *Természetvédelmi Közlemények* **10**: 289–312. [in Hungarian with English summary]

BOROS, E., ANDRIKOVICS, S., KISS, B. & FORRÓ, L. (2006*a*) Feeding ecology of migrating waders (Charadrii) at soda-alkaline pans in the Carpathian Basin. *Bird Study* **53**: 86–91.

BOROS, E., BÁNFI, Sz. & FORRÓ, L. (2006*b*) Anostracans and microcrustaceans as potential food sources of waterbirds on soda pans of the Hungarian plain. *Hydrobiologia* **567**: 341–349.

BOROS, E., MOLNÁR, A., OLAJOS, P., TAKÁCS, A., JAKAB, G. & DÉVAI, GY. (2006*c*) Geographical distribution, GIS database and nature conservation status of opened sodic (alkaline) water bodies in Pannonic Biogeographical Region. *Journal of the Hungarian Hydrological Society* **86**(6): 146–147. [in Hungarian with English summary]

FORRÓ, L. & BOROS, E. (1997) Microcrustacean zooplankton as potential food of Recurvirostra avosetta in soda waters of the Hungarian Plain. *Wetlands International Publication* **43**: 239–250.

FREEZE, R. A. & CHERRY, J. A. (1979) *Groundwater*. Prentice Hall, Engwood Cliffs, New Jersey. pp. 15–29.

GERE G. & ANDRIKOVICS S. (1992*a*) The role of Cormorants (Phalacrocorax carbo) in the organic matter cycle of the Kis-Balaton. *Aquila* **99**: 27–32. [in Hungarian with English summary]

GERE, G. & ANDRIKOVICS, S. (1992*b*) Effects of waterfowl on water quality. *Hydrobiologia* **243–244**: 445–448.

GERE, G. & ANDRIKOVICS, S. (1994) Feeding of ducks and their effects on water quality. *Hydrobiologia* **279–280**: 157–161.

GOULD, D. J. & FLETCHER, M. R. (1978) Gull droppings and their effects on water quality. *Water Research* **12**: 665–762.

HOYER, M. V. & CANDFIELD, D. E. (1994): Bird abundance and species richness on Florida lakes: influence of trophic status, lake morphology, and aquatic macrophytes. *Hydrobiologia* **279–280**: 107–119.

KEAR, J. (1963) The agricultural importance of wild goose droppings. *The wildfowl Trust, 14 Annual Report* **1961–1962**: 72–77.

KITCHELL, J. F., SCHINDLER, D. E., HERWIG, B. R., POST, D. M. & OLSON, M. H. (1999) Nutrient cycling at the landscape scale: The role of diel foraging migrations by geese at the Bosque del Apache National Wildlife Refuge, New Mexico. *Limnology and Oceanography* **44**(3, part 2): 828–836.

MANNY, B. A., JOHNSON, W. C. & WETZEL, R. G. (1994) Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. *Hydrobiologia* **279–280**: 121–132.

MARION, L., CLERGEAU, P., BRIENT, L. & BERTRU, G. (1994) The importance of avian-contributed nitrogen (N) and phosphorus (P) to Lake Grand-Lieu, France. *Hydrobiologia* **279–280**: 133–147.

MENZEL, D. H. & CORWIN, N. (1965) The measurement of total phosphorus in seawater based on the liberation of organically bound fractions by persulfate oxidation. *Limnology and Oceanography* **10**: 280–282.

MURPHY, J. & RILEY, J. P. (1962) A modified single solution method for the determination of phosphate in natural waters. *Anal. Chem. Acta* **27**: 31–36.

OECD [Organization for Economic Cooperation and Development] (1982) *Eutrophication of waters. Monitoring, Assessment and Control.* Final Report OECD Cooperative Programme on Monitoring of Inland Waters (Eutrophication Control), Environment Directorate, OECD, Paris, 154 pp.

OLÁH, J. (2003) Waterbird trophic guilds. *Hungarian Waterfowl Publication* **10**: 381–423. [in Hungarian with English summary]

PORTNOY, J. W. (1990) Gull contributions of phosphorus and nitrogen to a Cape Cod kettle pond. *Hydrobiologia* **202**: 61–69.

POST, D. M., TAYLOR, J. P., KITCHELL, J. F., OLSON, M. H. & SCHINDLER, D. E. (1998) The role of migratory waterfowl as nutrient vectors in a managed wetland. *Conservation Biology* **12**(4): 910–920.

PRESTON, T. & BARRIE, A. (1991) Recent progress in continuous flow isotope ratio mass spectrometry. *American Laboratory* **23**(11): 1–4.

SCHEFFER, M. (1998) *Ecology of Shallow Lakes.* Chapman & Hall London, 343 pp.

SCHMIDT, A. (2003) Kiskunsági szikes tavak (KNP II) összehasonlító vízkémiai vizsgálata. (Comparing water chemical investigation of sodic ponds in the Kiskunság National Park (KNP II).) *Természetvédelmi Közlemények* **10**: 153–162. [in Hungarian with English summary]

STERBETZ, I. (1968*a*) The investigation on the environment of wild ducks in the Kardoskút nature reserve. *Aquila* **75**: 45–77. [in Hungarian]

STERBETZ, I. (1968*b*) The comparative feed-examination of Gargeney and Teal (Anas querquedula L. and Anas crecca L.). *Acta Zoologica Academiae Scientiarium Hungaricae* **55**(1–4.): 119–122. [in Hungarian with English summary]

STERBETZ, I. (1972*a*) The food resource of Hungarian Waterfowl. *Acta Zoologica Academiae Scientiarium Hungaricae* **59**(1–4): 119–125. [in Hungarian with English summary]

STERBETZ, I. (1972*b*) *Waterfowl.* Mezőgazdasági Kiadó, Budapest, 204 pp. [in Hungarian]

STERBETZ, I. (1988) Observation on the feeding of Waders at Kardoskút–Fehértó, SE Hungary. *Aquila* **95**: 142–161. [in Hungarian]

STERBETZ, I. (1991) On the feeding patterns of Anas species protected in Hungary. *Aquila* **98**: 37–45. [in Hungarian with English summary]

STERBETZ, I. (1992) The excretum production of Northern wild goose masses wintering on the lake Balaton. *Aquila* **99**: 33–40. [in Hungarian with English summary]

VÖRÖS, L., BOROS, E., SCHMIDT, A., V. BALOGH, K., NÉMETH, B., SOMOGYI, B. & MÓZES, A. (2006) Physical and chemical environment of phytoplankton in soda pans having white coloured water. *Journal of the Hungarian Hydrological Society* **86**(6): 139–141. [in Hungarian with English summary]

Revised version received April 21, 2007, accepted May 30, 2007, published December 30, 2008