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The importance of avian-contributed nitrogen (N) and phosphorus (P) to Lake Grand-Lieu, France

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Key words: eutrophication, birds, lake, nitrogen, phosphorus

Abstract

The largest natural lake in France, Grand-Lieu, has suffered eutrophication. The objective of the study was to estimate the annual input of nutrients (N, P) resulting from avian excrement, deposited by birds feeding out of the lake and returning to its waters for breeding or roosting, as compared to the input by the rivers that enter in the lake. Two years are compared: 1981–82 and 1990–91. About 1600–2000 breeding herons and cormorants, 20000–33000 wintering ducks, gulls and cormorants and 1–2.4 million starlings deposited about 5800 kg total N in 1981–82 and 7640 kg in 1990–91. Respectively, 2000 and 2530 kg total P were deposited over the same time periods.These represent 0.7% and 0.4% of the total N input of the lake and 2.4 and 6.6% of the total P input in 1981–82 and 1990–91. Starlings account for 74% of the N and mallards most of the rest. P input by starlings (36% in 1981–82, 41% in 1990–91), and by mallards and herons (35% and 27% in 1981–82 and 22% and 24% in 1990–91 respectively) plays an appreciable role among birds. During the plant growing period (April–September), the contribution by birds can increase to 37% of total P input of the lake. Piscivorous bird colonies concentrate Phosphorus 42 times more within the colony than outside the colony. Overall, the role birds play in total N and P input is relatively small due to very high inputs from human sewage and agriculture run off. The monthly mean concentration of the water of the two rivers reaches currently 10 mg l^{-1} of N (to 23 mg during peak floods) and 394 mg m^{-3} of P (to 468 mg during peak floods). Earlier, for example in the 1960's, water in Brittany only contained 0.1 to 1.1 mg l^{-1} of N and 1 to 5 mg m^{-3} of P during the maximum flow period. At this time, birds could probably have represented annually up to 37% of the N input and up to 95% of the P input to the lake.

Résumé

Le plus grand lac de plaine français, Grand-Lieu, est actuellement largement eutrophisé. Le but de cette étude est d'estimer l'importation annuelle de N et P par les fientes des oiseaux qui s'alimentent à l'extérieur du lac, et de la comparer avec les apports des rivières alimentant le lac. Deux années sont comparées: 1981–82 et 1990–91. Les populations nicheuses (jusqu'à 956 couples de hérons cendrés et 136 couples de grands cormorans et 30000 canards) et hivernantes (jusqu'à 17000 canards, 1100 grands cormorans, 15000 goélands et 2,4 millions d'étourneaux) ont respectivement importé 5800 kg de N total en 1981–82 et 7640 en 1990–91, soit 0,7% et 0,4% des entrées totales du système, et 2000 à 2530 kg de P total soit 2,4 et 6,6% des entrées. Les étourneaux sont responsables des trois quarts des apports d'azote par les oiseaux, et les canards de l'essentiel du reste, tandis que la part dcs étourneaux baisse pour le phosphore (36% en 1981–82 et 41% en 1990–91), au profit des Canards et des Hérons (respectivement 35% et 27% en 1981–82, 22% et 24% en 1990–91). Mais pendant la phase de croissance végétale (avril–septembre), la part des oiseaux monte jusqu'à 37% des entrées totales de phosphore. L'action localisée des colonies d'oiseaux piscivores est significative, avec une teneur de phosphore 42 fois plus grande dans l'eau sous la colonie qu'à l'extérieur des colonies. A l'échelle du lac, l'action actuelle globalement mineure des oiseaux sur les apports totaux d'azote et de phosphore est largement due à l'augmentation catastrophique des apports d'origine humaine (agriculture intensive et stations d'épuration). La teneur moyenne des rivières atteint désormais 10 mg l^{-1} de N (jusqu'à 23 mg en crue) et 394 mg m^{-3} de P (jusqu'à 468 mg en crue). Avant cette pollution généralisée, l'eau des rivières bretonnes ne contenait dans les années 1960 que 0,1 à 1,1 mg l^{-1} de N et 1 à 5 mg m^{-3} de P lors des périodes de débits maximum. A cette époque, les oiseaux représentaient probablement jusqu'à 36% des apports de N et 95% des apports de P dans les entrées du système lacustre.

Mots clés: eutrophisation, oiseaux, lac, azote, phosphore

Introduction

The role of bird on the hydrology has rarely been studied (Dobrowolski, 1973; Dobrowolski *et al.*, 1976; Yesou, 1983). Kalbe (1969) showed that 8000 ducks on a lake imported an organic input equal to the sewage of a town with 1100 inhabitants. Manny *et al.* (1975) documented that 3000 Canada goose on a 15 ha pond were sufficient to make it hypereutrophic. Also, Brandvold *et al.* (1976) showed that bird droppings modified the organic and mineral quality of water in ponds. No such studies have been made, however, on large lakes. The purpose was to analyze the role of birds in the input of N and P in the largest plain lake in France, Grand-Lieu (6300 ha in winter). An important bird reserve, Grand-Lieu has become increasingly eutrophic in the last 30 years. As well the lake is filling rapidly with sediment (Marion & Marion, 1975; Marion *et al.*, 1992).

N and P were studied because they are the major elements of eutrophication, and the importation of organic matter by birds is quite small compared to the amount present in the lake. Also, only the feces imported in the system was considered, and not the nutrients merely recycled by birds feeding on the lake. This import was compared to that of the two rivers flowing into the lake. The change during the last decade is shown by comparing two annual cycles, 1981–82 and 1990-91.

This study is a part of a wider research project, studying the ecology of Grand-Lieu. Since 1970, the project has included ecological description of the area, general inventories of plants and vertebrates emphasizing changes over the last century (Marion & Marion, 1975; Marion *et al.*, 1989), eutrophication, with a survey of water quality and plant productivity (Marion *et al.*, 1987; Marion *et al.*, 1992), as well as the ecology of several bird species (Marion, 1988, 1989, 1991; Marion & Lanchon, 1989). A first study on nutrients imported by birds was made in 1987 (Clergeau & Brient, 1987).

Description of site studied

Grand-Lieu is a natural lake formed by several subsidence events between the Tertiary and the Pliocene periods, and oceanic influences until early Quaternary times. The lake covers 4000 ha during summer. In winter, flooding of adjacent marsh grasslands along the edge, that have progressively appeared in the last 7000 years (Fig. 1), the lake expends to 6300 ha. Two thousands hectares of the permanent water area are covered by a floating peat bog with *Phragmites*, *Salix* and *Alnus*, running near the shore for 20 km. Floating macrophytes (*Nymphea alba, Nuphar lutea, Nymphoides peltata, Trapa natans*) or emerging macrophytes (*Scirpus lacustris*, *Typha angustifolia*) are

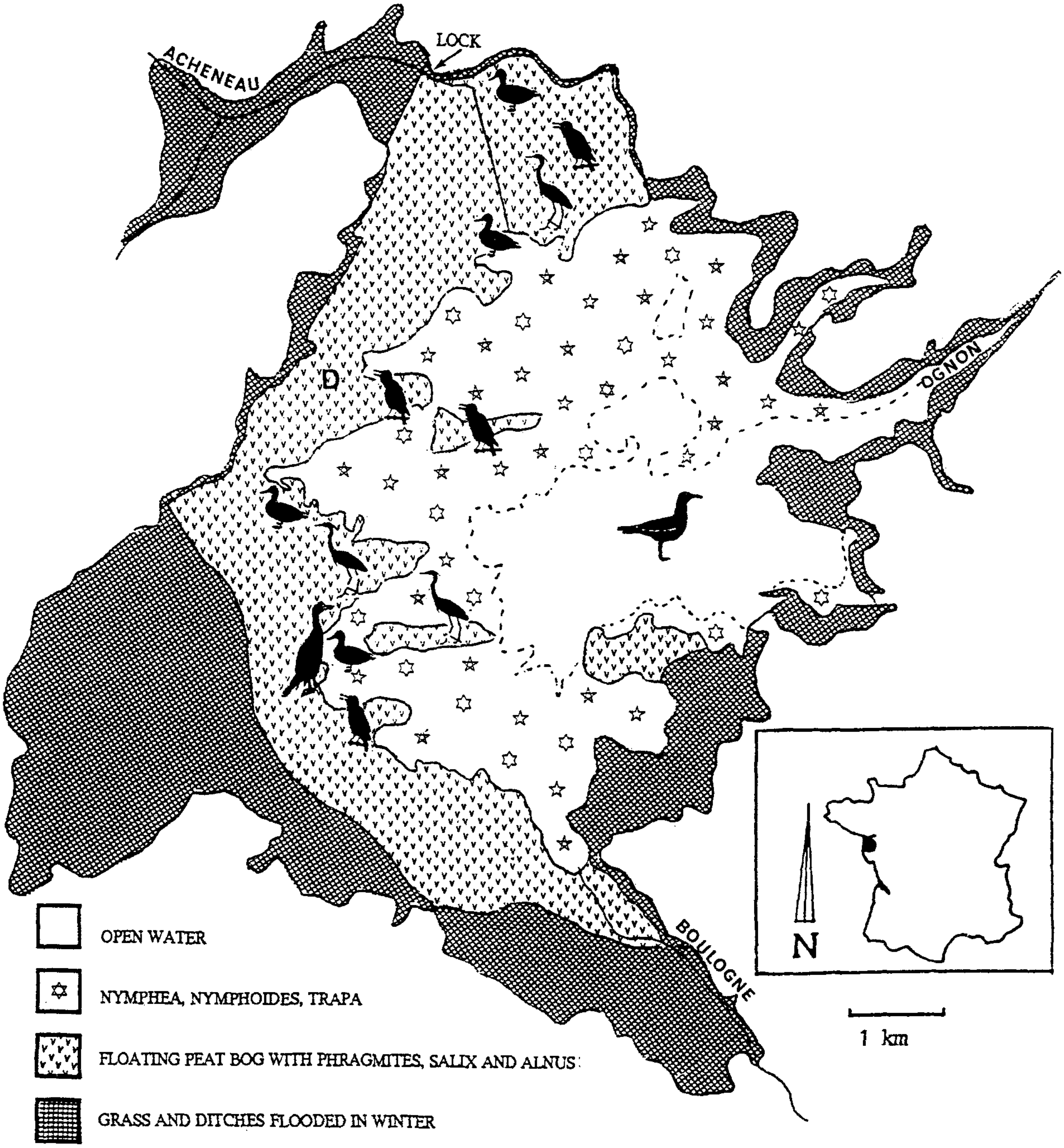

Fig. 1. Map of Lake Grand-Lieu, with the different vegetation areas and the localisation of the main bird species. D represent the point of sample of water in peat bog.

covering 1400 ha. The central openwater region (600 ha with no floating or emerging plants) extends to the eastern shore, which is either rocky or sandy. The western coast is muddy, and although it was originally the deepest area (20 m), the summer depth is now reduced to 0.7 m in the floating macrophytes zone and to 1.2 m to 1.7 m in the central region. Siltation causes the lake to lose about 2 cm of depth per year (Marion *et al.*, 1992). In winter, the water level increases up to 1.5 m above the summer level, by receiving water from two rivers. A drainage channel is flowing from the lake to the Loire estuary 25 km away. For more details see Marion & Marion (1975).

Materials and methods

The input of N and P from the drainage basin

The catchment area of the Boulogne and the Ognon covers 670 km^2. Each river is equipped with a gauge that continuously measures the flow. A floodgate built in 1964 on the drainage channel controls the level of the lake. It is opened from the first peak flood (between October to January depending upon the year), until a legally prescribed level is reached. At this point the peripheric marsh grasslands are then uncovered (generally in March or April). On average the lake receives 86% of its annual inflow between October and March (20 year average 1967–86, Marion unpublished data). During the rest of the year the daily flow is weaker and the floodgate is closed. The maximum volume of the lake is 115 million m^3 (winter), and 31 million m^3 in summer (exceptionally 25 million in September 1989 and 1990, due to the drought).

Two periods were compared: an 'estival period' (April–September), characterized by a minimal flow of water and the floodgate closed, the growing period plant (macrophytes and phytoplankton) and the breeding of birds; and a 'winter period' characterized by the inflow of water, the floodgate opened, the dormant plant and the presence of wintering birds.

Analyses were carried on each month in the two study years (1981–82 and 1990–91). Samples were collected from each river at its mouth (0.5 m below the surface in the middle of the river), at the outlet of the lake and from 6 points within the lake itself. Samples were stored at 4 °C for transport to the laboratory. Fluxes in N and P were obtained by multiplying the concentration of water of each river by their total monthly flow. This method gives similar results (+5.8%, Marion *et al.*, 1987) to those estimated from daily flow rates and the regression equation between concentration and flow, calculated from 15 monthly samplings.

Droppings import

The size of populations was determined for the 220 bird species in the lake in 1974 (Marion & Marion, 1975), and the number of species and the size of populations of herons, ducks, cormorants and starling have been made annually from this overall inventory. In 1990–91, Grand-Lieu had 236 species of birds, including 136 breeding species. If the densities of passerines (except starling) have not significantly changed since 1974, the estimated bird population in 1990–91 would be 98 500 individuals in estival period and 1 064 000 in the winter period. But only the birds feeding outside the lake and returning to rest, brood or feed their young effectively import nutrients through excrement. They represent 56% of the individuals in the estival period and 96% in the winter period. There is no export of nutrients out of the lake by the birds, if the small gain of body mass of migrating birds that feed in the lake is ignored. Except for small numbers of few passerines and ardeids species, the major species importing nutrients are mallards (*Anas platyrhinchos*), grey herons (*Ardea cinerea*), cormorants (*Phalacrocorax carbo*), gulls (*Larus argentatus, L. cachinnans, L. fuscus*) and starlings (*Sturnus vulgaris*). In 1990–91 these species represented 99% of birds importing nutrients during the estival period (N = 56 500), and 95% during the winter period (N = 1 035 000).

Table 1 shows the total number of birds for these species, which was determined at least monthly, by aerial census or by boat with binoculars for mallards, gulls, starlings and cormorants, or by census of occupied nests for breeding herons and cormorants. For starlings and gulls, all the individuals resting in the lake imported excrement. For the other species it was necessary to consider biological rhythms and behavior

Table 1. Monthly bird number (in thousand) in the lake. In brackets: % of birds importing nutrients in the lake by droppings (i.e. birds feeding out of the lake). +: bird number < 100 ind.

1981–82	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Mallard	4	4	20	30	20	10	15	12	11	11	4	4
	(0)	(0)	(10)	(50)	(10)	(10)	(10)	550)	(100)	(100)	(100)	(10)
Starling	+	+	+	50	50	100	200	1000	1000	800	500	500
Gull	0.1	0.1	0.1	1	1	2	2	4	4	5	5	1
	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Heron	1.6	1.6	1.2	0.4	+	+	+	+	+	+	0.2	0.8
	(95)	(95)	(90)	(90)							(95)	(95)
Cormorant	+	+	+	+	+	+	+	+	+	+	+	+
1990–91												
Mallard	4	4	20	30	20	25	17	12	8	6	4	4
	(0)	(0)	(10)	(50)	(10)	(10)	(10)	(50)	(100)	(100)	(100)	(10)
Starling	+	+	+	50	50	100	100	500	500	2400	2000	500
				(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Gull	0.1	0.1	0.1	1	1	5	5	10	10	15	15	2
	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Heron	1.8	1.8	1.3	0.50	+	+	+	+	+	+	0.2	1
	(95)	(95)	(90)	(90)							(95)	(95)
Cormorant	0.4	0.4	0.4	0.5	0.5	0.7	1.1	0.5	0.5	0.3	0.4	0.4
	(0)	(0)	(10)	(15)	(20)	(25)	(50)	(50)	(50)	(40)	520)	(0)

(Marion, 1988 for herons, Lanchon unpublished data for mallards, Marion unpublished data for cormorants), in order to estimate the precise proportion of birds that imported nutrients (% in brackets, Table 1). To obtain the total mass of droppings imported in the lake per species per month, the number of birds importing nutrients are multiplied by the daily mass of droppings and by the number of days of each month (Fig. 2).

The daily mass of droppings per bird depends upon species, individuals and diet. Since there is little data on this subject in the literature we have adopted different methods to calculate mass of droppings according to our knowledge of species:

Grey herons only use Grand-Lieu lake during the breeding season (February to July), with 800 breeding pairs in 1981-82 and 956 in 1990–91. Most feeding is outside of the lake, on the Bourgneuf marshes (see Feunteun & Marion, 1994). The imported nutrients were estimated from food consumption. Their diets have been studied during 10 years (1976–85) at Grand-Lieu, through observation of adults on the feeding areas and analysis of young's regurgitations in the nests (Marion, 1988). A standard brood (3 young) receives 45.32 kg (wet weight) of prey during the 9 weeks of rearing, equivalent to 5.87 kg (dry weight DW) for each adult. The DW of droppings represents 38% of the ingested food (Marion, 1988), *i.e.* 2.23 kg. The adults' food requirements (not including its brood's consumption) during the breeding season is 21.42 kg (5.55 kg DW and 2.10 kg DW of droppings). Unlike the young, adults spend 44.7% of their time (night and day) away from the lake during the incubation period (which represent 28% = 4 weeks of the breeding cycle), and 75.5% during the rearing period (Marion *loc. cit.*). Droppings are regularly excreted during 24 hours. The quantity of droppings on the lake per adult is then: 2.1 kg × 0.28 × 0.553 for incubation and 2.1 kg × 0.72 × 0.245 for rearing: all together 0.7 kg of droppings, plus droppings of half a brood (2.23 kg). Then each breeding adult corresponds to the input of 2.93 kg of droppings (DW) during the breeding season. Unlike the other species importing nutrients in the

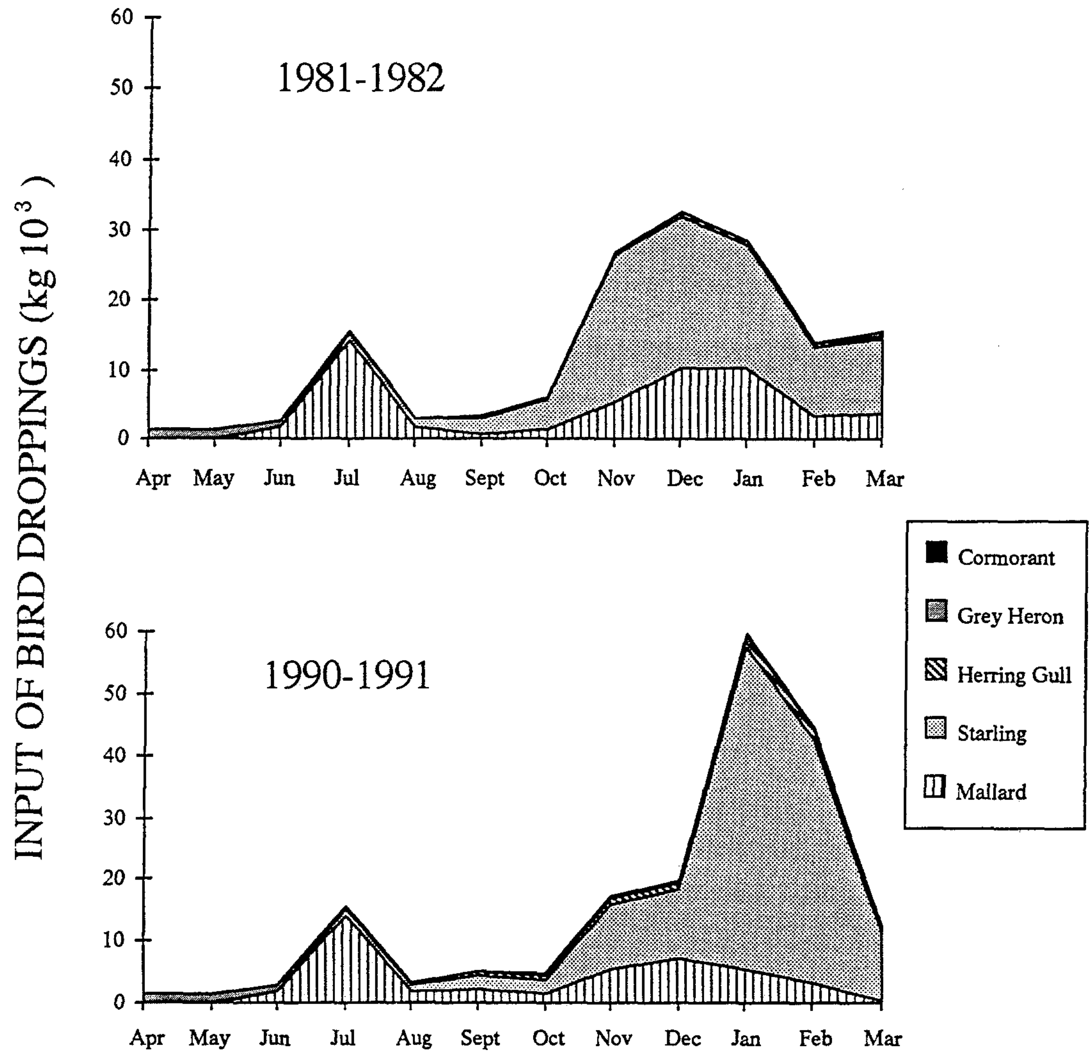

Fig. 2. Change in bird excreta input to the lake between 1981–82 and 1990–91. Cumulative dry weight for the different bird species input in tonnes.

lake, the daily mass of droppings varies during the breeding season (according to the growth of brood) and it would be misleading to give here a mean. For the Fig. 2, precise mass of droppings was calculated for each month without using an average of daily mass.

Only a small proportion of cormorant population feeds outside the lake and only does so outside of the breeding season. A cormorant eats an average of 0.33 kg of food per day (Voslander, 1988), *i.e.* 85 g of DW. As the droppings appear to be similar to those of herons (aspect, N and P content and from similar diet), they were assumed to represent the same proportion of ingested food (38%, *i.e.* 32 g per day). The time spent on the lake is more important because cormorants catch their prey very quickly (approximately 4 hours of feeding per day). Although cormorants are only diurnal and because digestion is slow, droppings are probably produced regularly throughout the night. The input of droppings was estimated to be 27 g DW per cormorant per day (32 g x 20/24 h).

Gulls only use the lake as a night dormitory. Spanns (1971) gives a daily consumption of 150 g (= 39 g DW) for *Larus argentatus*. Without data in literature, we used the same assimilation rate as the other piscivorous birds, and we assumed they excrete 15 g DW per day. The quantity of droppings in the lake has been approximately estimated to 4 g per Gull.

Only a small proportion of mallards left the lake for feeding (none in April and May, and about 10% during the rest of the year), but this population is partially (40% in July) or totally (from November to February) fed with wheat given at the lake. This corresponds to an input to the system (see Marion & Lanchon, 1989), and at this time it is assumed that all the droppings of the fed mallards occurred in the lake (Table 1). The observed daily excretion in two mallards captured at Grand-Lieu, and placed in an aviary for a week with natural food and wheat, were 16.7 g per day per bird (12.2 ± 1.07 feces, Lanchon unpublished data). The number of droppings is similar to those observed by Clark *et al.* (1986: 10.8 per day), but the daily mass is less than the estimates from daily food consumption given by Street (1978) and Sugden (1979) of 50 to 170 g per day. These figures are equivalent to 20 to 68 g of droppings if an assimilation of 60% is assumed. We have taken a middle value (30 g DW per day) between these estimates (44 g) and the data of Lanchon (16.7 g).

For starlings, we used the estimate of production of excreta at roosting of 1 g DW per night given by Gramet (1978).

Analysis Methods to determine the concentration of N and P in droppings and water

Total N and total P were analyzed on droppings sampled in natura from various individuals, after air drying at 60 °C. These droppings and the samples of water of rivers and lake were analyzed by the method of Koroleff (1972) and D'Elia *et al.* (1978, see Golterman *et al.* 1978 and Smart & Reid 1981): the nitrogen compounds were oxidized to nitrates by an alkaline solution of persulfate in a pressure sealed container at 120 °C, at 1 bar for 45 min. The nitrates were reduced to nitrites and measured photometrically. Total P was converted into soluble inorganic phosphate with an acid persulfate digestion by the method as described by Murphy & Riley (1962).

Results

Import of N and P by birds

Starlings are the most numerous with a roost of 50000 (summer) to 2400000 birds (winter, Table 1). The starling roosts only had 1000000 birds in 1981–82, but on average it had 1.5 to 2 million birds since 1971, and exceptionally 6 million in 1975 (Marion & Marion, 1975). Mallards were second in abundance with 4000 to 30000 individuals in the two study years and, contrary to the starlings, had a variable proportion of individuals that import nutrients (0 to 100%). The winter roost of gulls had increased by 2 to 3 times in 10 years, and reached 15000 birds at the maximum, all of which importing nutrients. Colony size of grey herons have little changed between the years (800 and 956 breeding pairs), but the monthly number of breeders varies from 200 to 1800 according to the asynchronous breeders. The great majority of herons import nutrients to the lake. The number of cormorants has increased tremendously during the decade, from 7 to 136 breeding pairs, and from 50 to 1100 wintering birds, among which a low proportion bring nutrients into the lake.

Figure 2 shows the monthly changes of imported droppings for each species for the two years. The total input is largely dominated by starlings (89000 kg in 1981–82, 130000 kg in 1990–91), then by mallards (53000 kg and 44000 kg), herons (4800 kg and 5400 kg), gulls

Table 2. N and P bird droppings values.

	n	% N total	% P total
Mallard	12	2.62 ± 0.08	1.32 ± 0.13
Starling	11	4.62 ± 0.39	0.79 ± 0.08
~~Gull~~	~~14~~	~~2.96 ± 0.37~~	~~1.62 ± 0.29~~
Heron	11	4.21 ± 0.67	11.47 ± 1.21
Cormorant	2	3.28 ± 0.02	14.32 ± 0.35

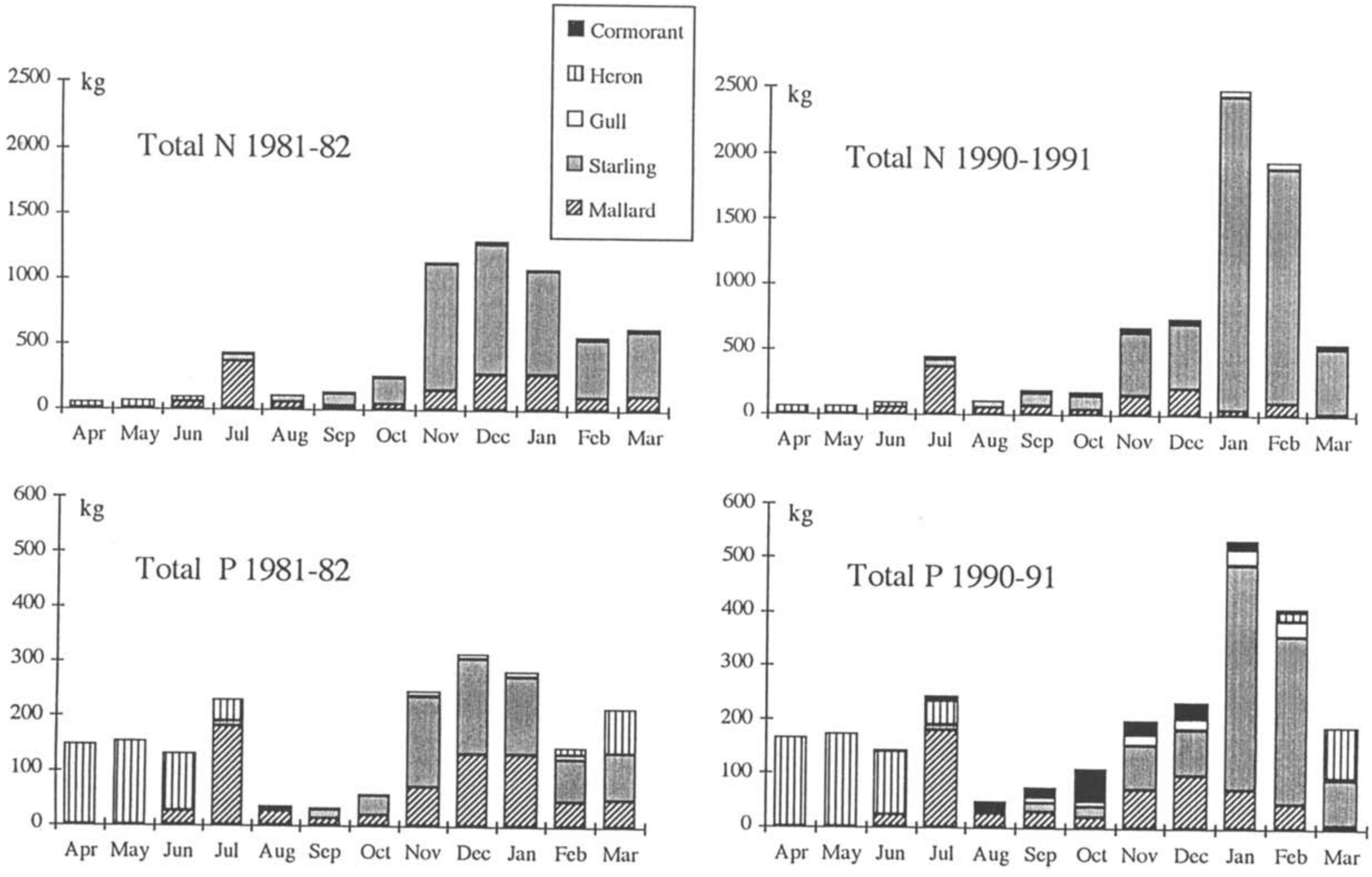

Fig. 3. Change in N and P input by birds to the lake between 1981–82 and 1990–91. Cumulative values for the different bird species.

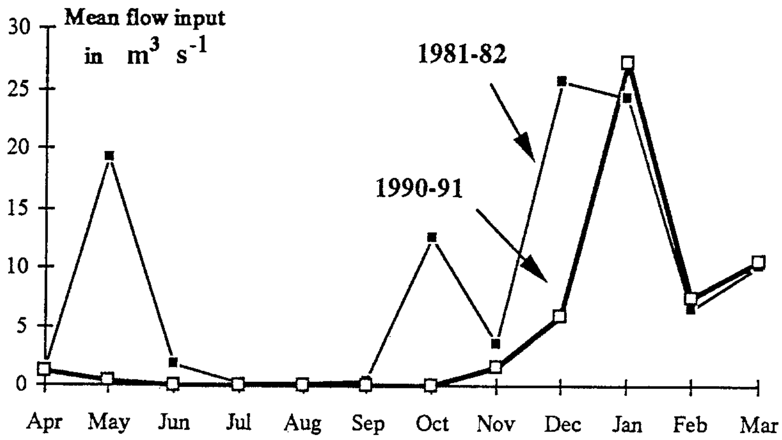

Fig. 4. Mean flow input of the two rivers of the lake during both study years.

(3000 kg and 7700 kg) and finally cormorants (1300 kg in 1990–91 only). Most of the input occurred during the winter months.

The richest droppings in nitrogen are those of starlings and herons (>4.2% of N-DW, Table 2). Gulls and mallards only exhibit <3% N-DW. Differences in P are more significant, cormorants and herons having a concentration ten times higher (>11.5%) than those of other species, depending upon their fish diet.

The total input of N by birds was 5800 kg in 1981–82 and 7640 kg in 1990–91. Input of P was 2000 kg in 1981–82 and 2530 kg in 1990–91. Starlings brought three quarters of the nitrogen and mallards most of the rest (Fig. 3). The starlings' part of the total P was 36% in 1981–82 and 41% in 1990–91. Mallards and herons also played an appreciable role (35% and 27% in 1981–82 and 22% and 24% in 1990–91, respectively).

Contribution of N and P by rivers

Important differences of water inflows occurred during the two years, with an abnormal situation in 1981–82 due to an exceptional flooding in May, which brought 40 million m^3 in three days (Fig. 4). The annual inflow was 270 million m^3. On the contrary 1990–91 was characterized by an estival drought, with no flow during 4 months, and with an annual inflow of 135 million m^3. In average, the annual inflow of this lake was 168 ± S.E. 20 million m^3 (1946–90, $N = 45$), with a minimum of 46 million m^3 and a maximum of 306 million m^3. The 1990–91 situation is closer to normal than the first study year.

The concentrations in nutrients were generally very high in both rivers in both years, but with a large increase of N in 1990–91 (3.7 times higher for the Boulogne and 4.3 higher for the Ognon). The higher concentrations occurred in winter with up to 23 mg l^{-1} (Fig. 5). The increase of P was somewhat lower (×1.2 and 1.4 for the two rivers respectively), but the peak of concentration reached 760 mg m^{-3}.

The total flux of the lake from inputs from the catchment area was 780 000 kg and 82 000 kg for N and P in 1981–82, as compared with 2 184 000 kg and 36 000 kg in 1990–91.

The difference between the two years for N and P is believed to be due to the drought and the concentrations during the peak floods of the rivers. Nitrogen concentration was very high during the single peak flood in 1990–91 from December to February (from 12 to 23 mg l^{-1}, *i.e.* 2 111 000 kg for these months = 97% of the annual input of the rivers), although it was relatively low during the four peak floods in 1981–82 (mean for the two rivers = 2.2 mg l^{-1} in May, 4.1 in

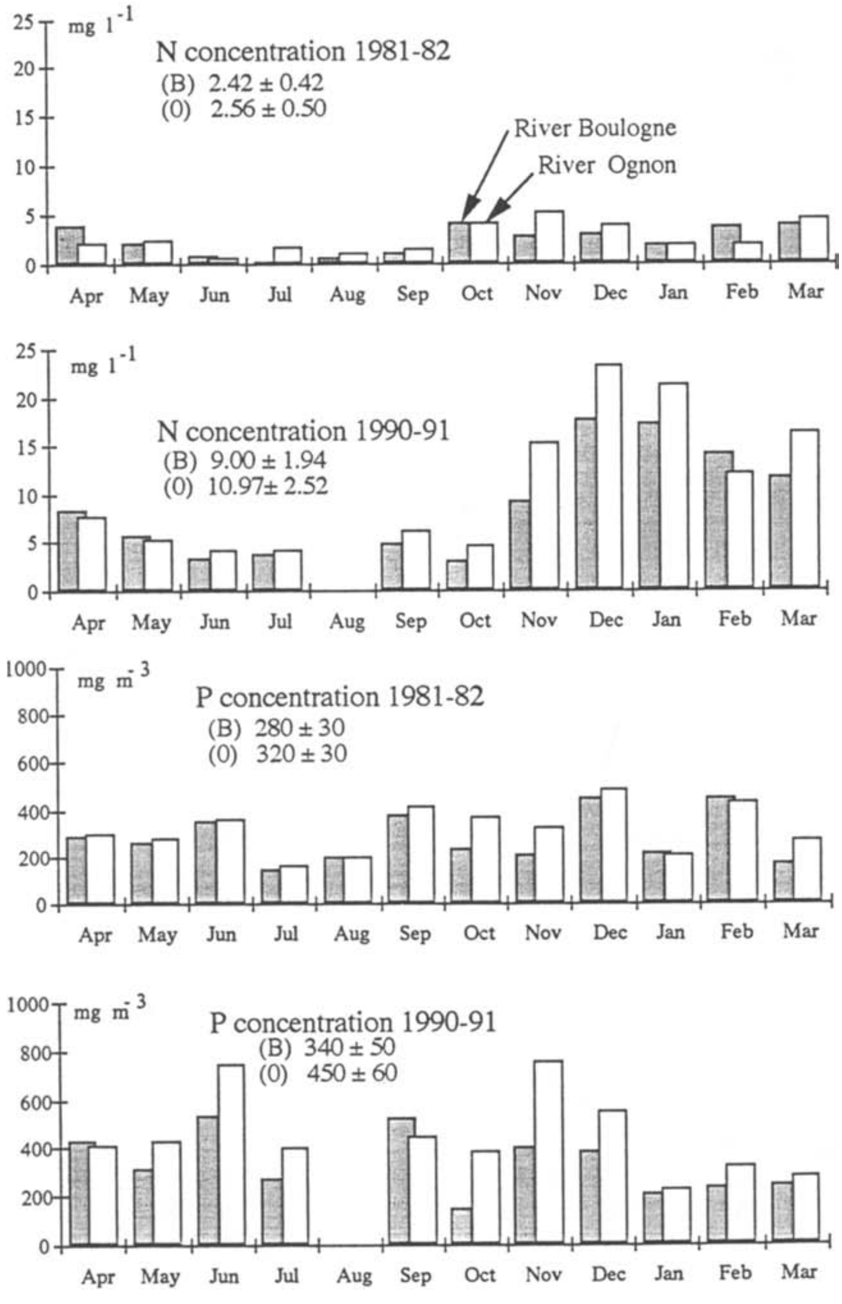

Fig. 5. N and P concentrations in mouth of Rivers Boulogne and Ognon.

October, 3.5 in December and 4.2 in March, *i.e.* only 565 000 kg of $N = 72\%$ of the annual input of the rivers).

It was not the case for P: the peak floods of the rivers from December to February in 1990–91 only brought respectively 468-218-280 mg m^{-3}, *i.e.* 25 000 kg (69% of the annual input of the rivers), and in 1981–82 the peak floods of May (270 mg m^{-3}), October (300), December (471) and February (220) brought 57 000 kg (69%).

The annual flow of phosphorus in 1981–82 corresponds to the estimates (C.E.T.E. Ouest

1982) of the sources of P in the catchment area (1 kg per year per inhabitant = 37000) and 0.5 kg per agricultural ha (67000), by estimating that 20% were retained in the rivers.

Discussion

The percentage of total lake N input imported by birds was low: 0.7% of total input in 1981–82 and 0.4% in 1990–91. If we take into account contributions from rainfall (0.5 mg l^{-1}, *i.e.* 120–180 kg y^{-1} for the lake with 800 mm) and also the fixation of atmospheric nitrogen by some plant species such as *Alnus glutinosa* (numerous in the adjacent peat bog), and by cyanobacteria, the role of birds in the total input of nitrogen to the lake is negligeable. But birds are more significant vectors for phosphorus input: 2.4% in 1981–82 and 6.6% in 1990–91. This reached 37% of total input of P during the growing vegetation period in 1990–91 (April–September), due to the low flow

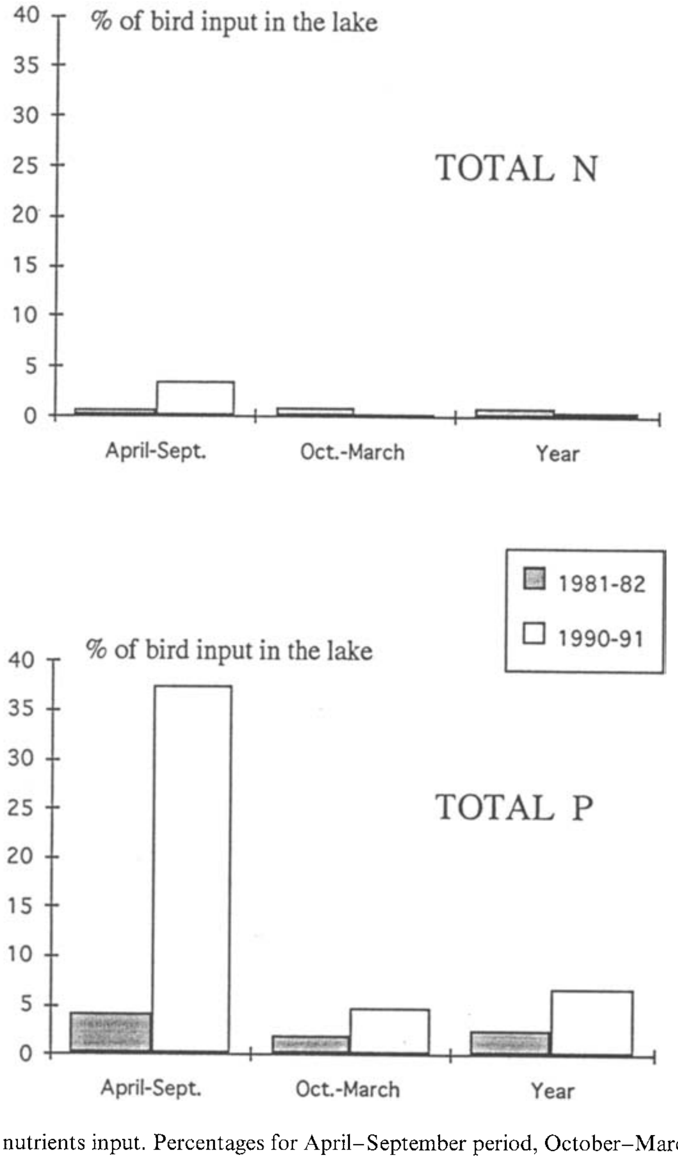

Fig. 6. Importance of birds in nutrients input. Percentages for April–September period, October–March period and for the whole year are indicated.

of water in the lake from the rivers (Fig. 6). With an average inflow (period 1945–90), birds would import about 30% of total P between April and September, and up to 38% of the annual total P in 1973, the minimum annual inflow observed during this 1945–90 period.

Despite their abundance, birds generally play small role in the eutrophication of the lake. Eutrophication of Grand-Lieu is largely due to the very high import of N and P resulting from recent human activities in the catchment area (intensive agriculture and town sewage). In France and particularly in Britanny, the 1960's nutrients concentrations in the rivers were much lower, with only 0.1 to 1.1 mg l^{-1} of N and 1 to 5 mg m^{-3} of P during the maximum flow period, that is to say from 20 to 120 times less for N and 100–200 times less for P (Bertru unpublished data). If we

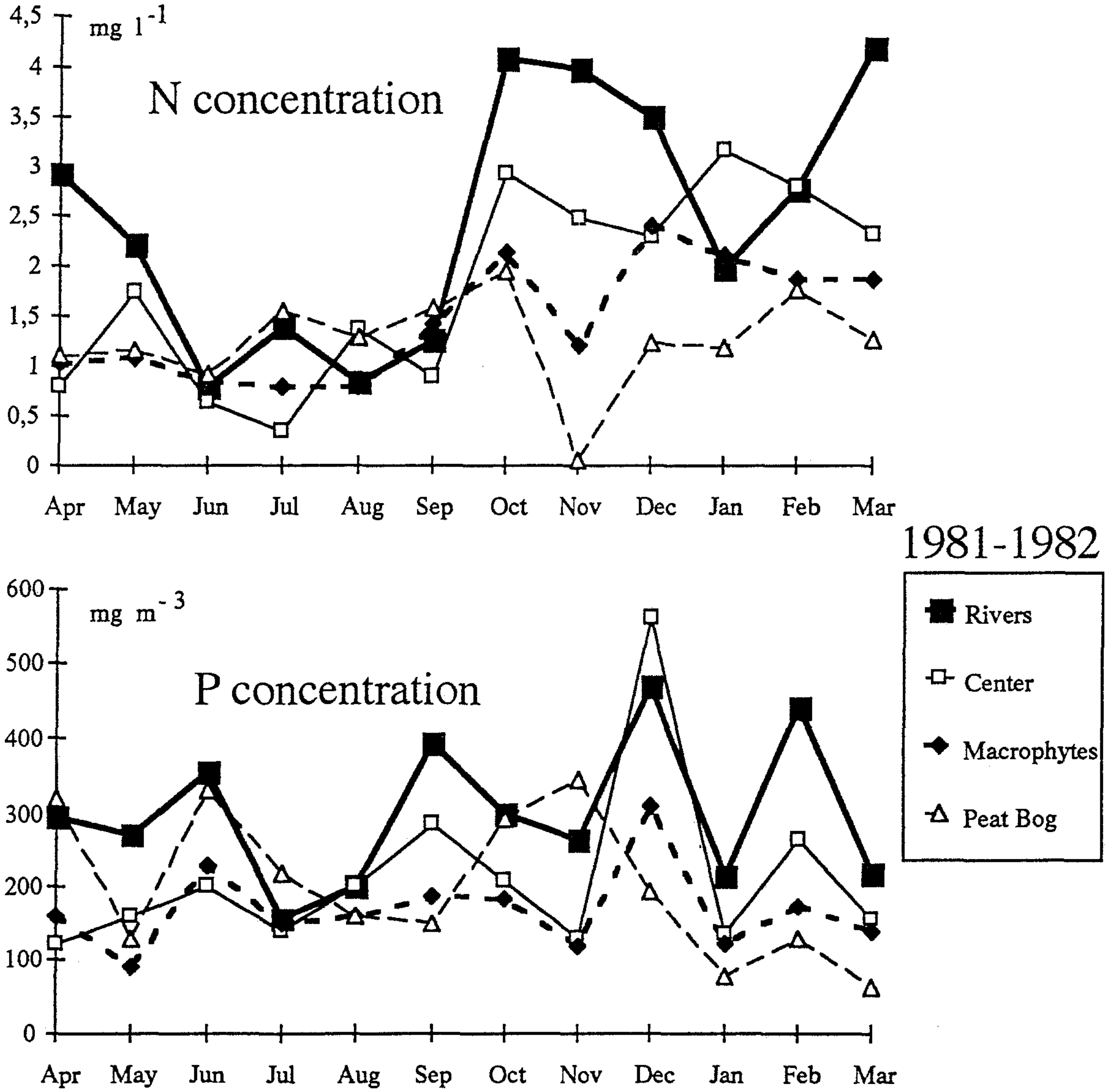

Fig. 7. Comparison of total N and total P values in four areas of the lake. Rivers: mean of the two rivers at their mouth; Center: open water; Macrophytes: mean of *Nymphea* and *Trapa* samples; Peat bog: a ditch (see Fig. 1, point D).

applied these values of N and P imported by rivers, present importation by birds would represent from 2 to 36% of the annual input of N and from 60 to 95% of P, in the case of inflows that were observed in the two study years; in the case of mean inflow (1945–90), the value would be about 76%.

Where birds are located in the lake determines the level of their impact on the lake. All species excepted gulls roosted and nested in the peat bog (Fig. 1) where the water concentrations of N and P are poorest in the lake (as compared to the two rivers, the central zone of the lake or the macrophytes zone, Fig. 7). For instance, nitrogen value within the colonies of herons can reach 8 times more than without herons nests and phosphorus value until 42 times more (Fig. 8). Dusi (1977) observed an increase of phosphates in the soil by 60 times through droppings of cattle egrets in a terrestrial colony in Alabama, USA. But it seems that concentrations of droppings are not high enough at Grand Lieu to damage the plants, as is often the case in trees in terrestrial habitats, particularly with starlings, cormorants and herons (Kortland, 1942; Dusi, 1977; Clergeau, 1981).

No previous comparisons between input of nutrients to a lake by birds and by rivers have been found in the literature. Brandvold *et al.* (1976) give an indirect approach by comparing the concentration of nutrients in above and downstream ponds and marshes which were used by flocks of aquatic birds, but this does not allow direct assessment on the role of the birds. Manny *et al.* (1975) give the annual input per m^2 of 3000 Canada goose (1290 mg of N and 390 mg of P), higher than those observed at Grand-Lieu (191 mg of N and 63 mg of P), but the water area is quite different (only 15 ha as compared with 6300). Closer to our results related to bird concentration, Dobrowolski *et al.* (1976) show that 4600 aquatic birds (coots, grebes, dabbling and diving ducks, gulls) on a 620 ha lake brought 9.67 mg m^{-2} of P per year. But in all these cases, all droppings are taken into account, and then it is more recycling of nutrients into the open water than real importation in the system. During the summer period of the Grand-Lieu study, 44% of the birds were not taken into account for this reason.

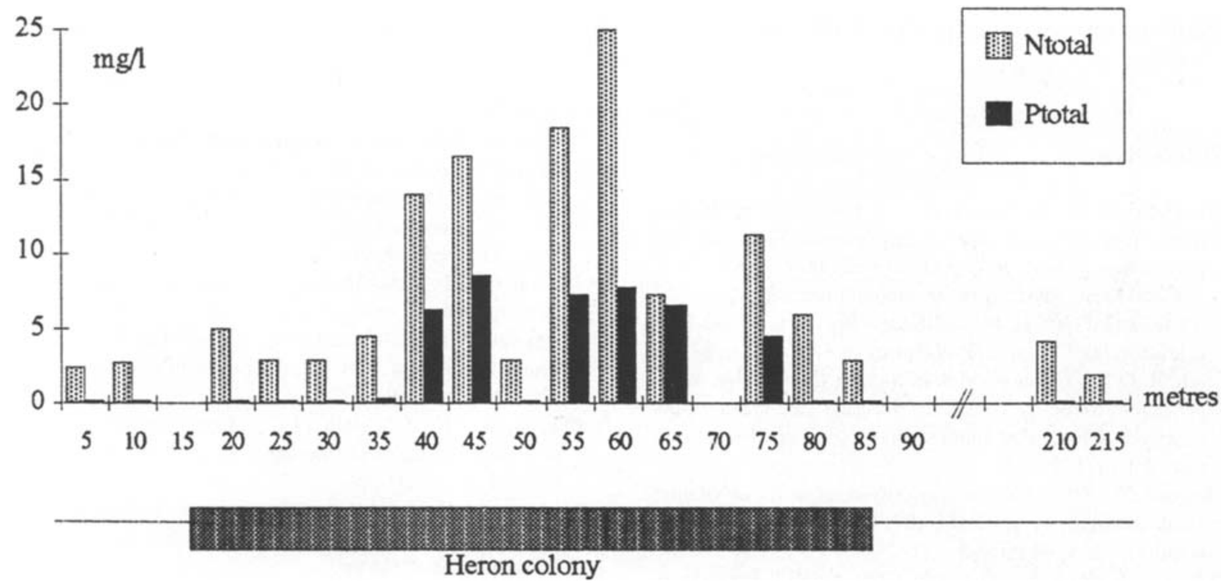

Fig. 8. Concentrations of total N and total P in water along a transect in the peat bog used by a heron colony (data concerning the end of nestling period).

Conclusion

The input of N and P by birds is relatively low in the hypereutrophic Lake Grand-Lieu (0.4 to 0.7% of N, 2.4 to 6.6% of P according to the study years). But during the plant growing period (April–September), the contribution of birds can increase to 37% of total P input of the lake. The local concentration on areas directly occupied by colonies of herons is important for P (42 times more than out of the colonies). Overall, the role of birds in total input of N and P is small due to human sewage and agriculture inputs. Earlier, for example in the 1960's when human inputs were much lower, the birds could probably have represented up to 36% of the annual N input and 95% of the annual P input to the lake.

Birds could be important in other systems, that are less polluted, smaller or with higher densities of birds (for example ponds), and above all with lower water flows. Our results show that birds have to be included in hydrobiological studies when important gathering of birds occurs.

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