Aquatic bird populations as possible indicators of seasonal nutrient flow at Ichkeul Lake, Tunisia

Alain Tamisier & Charles Boudouresque
1 Centre d’Ecologie Fonctionnelle et Evolutive, Centre National de la Recherche Scientifique, B.P. 5051, F-34033 Montpellier, France; 2 Laboratoire de Biologie Marine et d’Ecologie du Benthos, Faculté des Sciences de Luminy, F-13288 Marseille Cedex 9, France

Key words: Ichkeul, Mediterranean lagoon, waterbirds, bio-indicator, nutrient flow

Abstract

Lake Ichkeul is fed in autumn and winter by 7 main freshwater oueds (rivers) which create an overflow towards the mediterranean sea. Conversely, seawater enters the lake after the end of the rainy season. Thus, strong inverse variations occur twice a year both in water depth and salinity level, with a major hydraulic flow to the sea between October and January.

Waterbirds exploit the lake (ca 50 species belonging to 13 families) with a marked seasonal variation in specific richness and diversity; in winter, population size (200000 ducks, coots and geese) and biomass are much higher: 92.2% of the trophic impact occurs between October and March, because of both numbers and size of the wintering birds. The bird community is phytophagous for 96.2% of its annual biomass.

The data, related to the hydraulic regime of the lake, support the hypothesis of an energetic input (N and P) which is mostly linked to the freshwater flow and an export brought about by migrating birds and the harvesting of fish. Nutrients would be a limiting factor for both plant and animal communities, Ichkeul being an atypic (rather oligotrophic) mediterranean lake. New dams around the lake (for drinking and irrigation water) are changing drastically this energetic balance and will lead to an important loss of the main characteristics of the lake, making Ichkeul an ordinary man-managed wetland.

Introduction

Ornithological data collected on Ichkeul Lake (Tunisia) over the last 9 years revealed a strong seasonal variation in bird populations through the year. Peak populations of migrant waterbirds occur in winter whereas in summer the avian community is quite limited in numbers and species. There is no indication of accumulation of organic matter (unconsumed plants) or summer eutrophication as occurs on most Mediterranean lagoons (Belkhir, 1984; Frisoni, 1990). What happens with the trophic resources which support the huge waterfowl community in winter? Is the excessive organic matter exported outside Ichkeul Lake, and if so, how? The objectives of our study is to use ornithological and hydrobiological data in the context of the hydraulic functioning of the ecosystem in order to provide some hypotheses addressing these questions.

Site description and recent changes

Ichkeul Lake (37°10’ N 9°33’ E), Tunisia, in the northeastern portion of the African continent
along the Mediterranean Sea, is a permanent wetland of 80 km² surrounded by 30–40 km² of temporary marshes. It collects fresh water directly from rains (annual mean: 60 million m³) and from a drainage basin of 8000 km² bringing 340 million m³ by 7 oueds (temporary rivers). It is linked by a small channel (Tindja) to the Lake of Bizerte (37° 18' N 09° 35' E) which in turn opens to the Mediterranean sea.

The annual rainfall varies between 234 and 1330 mm (mean = 640–670 mm) with a maximum in autumn and winter. Mean monthly temperatures are 11–12 °C from October to March, and 23–26 °C from July to September. Autumn and winter rainfalls fill up the oueds and the lake with freshwater that overflows into the Lake of Bizerte through channel Tindja. In summer, high evaporation favoured by hot easterly winds lowers the water level and allows seawater to enter Ichkeul Lake (Zaouali, 1975; Hollis, 1977; Lemoalle, 1983; Ben Rejeb-Jenhani, 1989; Ennabli, 1990).

A primary characteristic of Ichkeul lake is an annual alternation of high water levels and low salinity in winter (mean salinity 3 g l⁻¹, mean depth 2–3 m with all marshes inundated) and low water level but high salinity in summer (mean salinity 30–50 g l⁻¹, mean depth 1 m, marshes dried up) (Fig. 1). A high annual variability adds to this alternation in depth (Fig. 2) (Bredin et al., 1986; Tamisier, 1987, 1990). The freshwater output through the Channel Tindja is 47 to 955 million m³ per year (mean 305), the mean saltwater input is ca 60 million m³ per year. The wide disequilibrium in the input-output water balance appears as the second characteristic of the lake (Boudouresque, 1990; Floret, 1990).

Because high annual climatic variations are characteristic of the Mediterranean basin, the means have usually a lower significance than the extreme values.

The lake is usually close to being saturated with dissolved Oxygen (5–11 mg l⁻¹). Phosphate varies from 0.01 to 2.94 μg l⁻¹ with higher values either in summer or winter times according to the 2 annual sets of available data (Ben Rejeb-Jenhani, 1989). Concentrations of nitrate vary from 0 to 35 μg l⁻¹ with strong annual differences and highest values in February (stream from Ichkeul to Bizerte). Nitrite concentrations remain lower than 1 μg l⁻¹. Fluctuations in the N/P ratio lead to an alternation between N and P as the limiting factor in the phytoplankton production (Ben Rejeb, 1986; Ben Rejeb-Jenhani, 1989).

The aquatic vegetation community is very simple with large monospecific beds of Potamogeton pectinatus in the eastern and western parts of the lake, small patches of Zostera noltii and Ruppia sp. mostly close to the Oued Tindja and scattered patches of Scirpus maritimus and Sc. lacustris in the marshes. The lake and marshes are separated by a thin strip of reeds (Phragmites australis). For the past 15 years, large seasonal and annual fluctuations of the extent (0.5 to 4.5 km²) and the biomass of submerged macrophyte beds

---

**Fig. 1.** Schematic annual alternation of water level and water salinity, drawn after Hollis et al. (1986).

**Fig. 2.** Inter-annual variability of water level for the winter seasons 1982–83 to 1988–89.
were observed (Hollis et al., 1986). During the winter 1991–1992, the phytomass of the lake reached 9000 t (dry weight, Niéri et al., 1992).

Breeding bird community is rather low in numbers and species while waterfowl populations winter there in large numbers (180000 to 230000 birds, Tamisier, 1990).

Because of the high identified value of this wetland unique among numerous sebkhas and salt lakes, several national and international designations have been applied for protection purposes since the early 1980’s: National Park, Ramsar Convention List, MAB Biosphere Reserve, UNESCO World Heritage List. Nevertheless, a project was proposed in 1982 to build 6 dams on the main oueds in order to catch water for drinking and irrigation. Today, 2 dams are operating which retain ca 25% of the freshwater volume of the lake, 1 is to be completed in 1993 and the other 3 are still under discussion. When operating, the first 3 dams together can retain ca 70% of the water volume, and the 6 dams 100% (Hollis et al., 1986).

A scientific program was set up in 1982 to summarize the existing data and to (1) evaluate the richness of the waterbird populations, (2) examine and model the functioning of the whole ecosystem, (3) predict changes likely to occur in the near future after the completion of the dam projects and (4) develop management proposals aimed at preventing a full loss of the aquatic ecosystem due to a lack of water.

Material and methods

Ornithological data were derived from 2 main sources.

(1) Many occasional observations were made by various ornithologists, providing basic information on the breeding, migrating and wintering aquatic avifauna (Gautier, 1986; pers. com.; Skinner et al., 1986; Smart, pers.com.).

(2) Since 1982, regular monthly counts covering the whole of the lake and marshes were made from September or October to February or March, providing the total size and the species composition of the wintering waterbird populations as well as their diurnal distribution. Simultaneously, field observations were performed on time budget activities of the main 4 waterfowl species, and some data were collected on their most important food resources (Bredin et al., 1986; Tamisier, 1987; 1990; Tamisier et al., 1992). In spring and summer, additional data were collected at the species level (Maamouri & Maatallah, 1986).

The annual cycle is divided into 2 main periods wintering from September 15th to March 15th and breeding from March 15th to September 15th. The migrating period (4 months) which includes both autumn and spring migrations, overlaps the 2 former periods. These respective durations will be used for interperiod comparisons on species diversity and biomass. When dealing with the annual cycle, calculations are made according to the following schedule which takes into account the overlap of the successive periods:

\[
\text{I year} = 4B + 4W + 2(B + M) + 2(W + M),
\]

where numbers = number of months;
B = Breeding;
W = Wintering;
M = Migrating.

The same species may occur over several periods. Waterbirds include Grebes (Podicipedidae), Cormorants (Phalacrocoracidae), Herons (Ardeidae), Ibis and Spoonbills (Threskiornithidae), Storks (Ciconiidae), Geese and Ducks (Anatidae), Rails and Coots (Rallidae), Shorebirds (Haematopodidae, Recurvirostridae, Charadriidae, Scolopacidae) and Gulls and Terns (Laridae). We also added 2 raptors because of their functional link to wetlands (the Marsh Harrier Circus aeruginosus and the Fish-Eagle Pandion haliaetus).

Numbers of birds for the winter period come from the monthly counts for the years 1982–83 to 1988–89 (n=69 counts); thereafter numbers on the lake changed drastically as a consequence of both the effectiveness of the first 2 dams and an exceptional rainfall deficit. Data after 1989 are not considered representative of the natural situation at Ichkeul Lake and are excluded here.
Table 1. Specific richness according to groups of families and periods.

<table>
<thead>
<tr>
<th></th>
<th>Breeding</th>
<th>Wintering</th>
<th>Migration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grebes, Cormorants</td>
<td>6</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Geese, Ducks, Coots</td>
<td>3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Herons, Storks etc.</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Raptors</td>
<td>3</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Shorebirds</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>41</td>
<td>22</td>
</tr>
</tbody>
</table>

These numbers were obtained from regular counts performed by the same experienced team on the same observation points. Numbers for the periods of breeding and migration are less precise (several independent observers) and documented. They are surely underestimated by lack of exhaustive observations, mostly for the migrating period.

Biomasses of birds were calculated from mean weights for each species (Cramp & Simmons, 1977; 1980; 1982). The specific trophic levels are from Cramp & Simmons (loc. cit.) and from local observations, mostly for wintering species.


Table 2. Specific diversity (Shannon Index) in terms of numbers and biomass for the 3 periods of the year.

<table>
<thead>
<tr>
<th></th>
<th>Breeding</th>
<th>Wintering</th>
<th>Migration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers</td>
<td>3.25</td>
<td>2.02</td>
<td>2.50</td>
</tr>
<tr>
<td>Shannon Index</td>
<td>2.83</td>
<td>2.76</td>
<td>1.04</td>
</tr>
<tr>
<td>Biomass</td>
<td>502.2</td>
<td>502.2</td>
<td>502.2</td>
</tr>
</tbody>
</table>

Results

Within the community of waterbirds we observed about 50 species belonging to 13 families grouped in Table 1. However his specific richness is rather variable along the periods. The maximum occurs in winter for all families except for those included in Shorebirds which occur in similar species’ numbers in winter and in migration. Conversely the specific diversity index, either calculated from numbers or from biomass, was highest during the breeding period (Table 2).

Total numbers and biomass were much higher in winter than in migration and breeding periods (Table 3). The annual trophic impact derived from this biomass is largely concentrated in the winter months (92.0%), and it comes almost totally from 4 waterfowl species, Greylag Goose Anser anser, European Wigeon Anas penelope, Common Pochard Aythya ferina and European Coot Fulica atra (Fig. 3). Even though there may be large biases associated with our estimations of both migrating and breeding populations, the overwhelming importance of winter populations is clearly evident.

The community is almost exclusively phytophagous in winter (96.2% of the biomass) and mostly

Table 3. Numbers of bird-days and biomass (in t) of phyto- and zoophagous waterbird communities. Monthly mean according to the period of the year and annual. The annual total is derived from the formula: 1 year = 4B + 4W + 2(B + M) + 2(W + M) (see in the text).

<table>
<thead>
<tr>
<th></th>
<th>Breeding</th>
<th>Wintering</th>
<th>Migration</th>
<th>Annual total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. bird-days</td>
<td>35,670</td>
<td>2307,360</td>
<td>256,650</td>
<td>15154,780</td>
</tr>
<tr>
<td>Phyto- biomass</td>
<td>4.8</td>
<td>2041.4</td>
<td>138.0</td>
<td>12829.2</td>
</tr>
<tr>
<td>Zoo- biomass</td>
<td>15.1</td>
<td>53.2</td>
<td>23.1</td>
<td>502.2</td>
</tr>
</tbody>
</table>
zoophagous in spring. During the migration period which overlaps the others, transient birds are essentially zoophagous but most counted birds still belong to the wintering community, so the community as a whole is mostly phytophagous. Along the annual cycle, phytophagous species represent 96.2% of the mean total biomass (Table 3). Among them 58.6% feed on stems and leaves of the major plant species (Potamogeton pectinatus for European Wigeon and European Coot), 36.4% on bulbs of Scirpus maritimus and Potamogeton pectinatus (Greylag Goose and Common Pochard respectively). Granivorous species (Teal Anas crecca and Pintail A. acuta) account for only 1.3%. Among zoophagous species, Cormorant Phalacrocorax carbo (fisheater) and Shoveler Anas clypeata (planktonophagous) predominate in winter.

Discussion

The summarized available hydrobiological data suggest (Boudouresque, 1990) that lake Ichkeul is fed in P and N (Fig. 4) by oueds and possibly in P by Channel Tindja (seawater) (Ben Rejeb, 1986). During the period September–February, additional nutritive enrichment surely comes from the defecation of birds and from carcasses (the winter mortality rate of geese, ducks and coots usually reaches values as high as 30–50%, Cramp & Simmons, 1977). Defecation is supposed to have an impact on the development of the aquatic beds. Powell et al. (1991) conclusively showed the positive effect of birds roosting half a day at a subtropical estuary in Florida on the productivity of aquatic beds over a 200 m wide crown around the colonies (estimated value for a mean year of bird biomass/surface = 1 t km²). At Ichkeul, the value is about 2 times lower but birds stay and feed on the spot day and night (Tamisier, 1990); so nutrients brought in by defecation might have some effect on the aquatic plant beds of Ichkeul. However since these nutrients were taken off by the feeding birds from the Ichkeul system itself, it suggests that they are recycled between plants and feces.

On the other hand a periodic lack of nutrients
is suspected, which would explain (1) the observed monthly and annual variations in biomass of the aquatic beds of *Potamogeton pectinatus*, (2) the absence of vegetal species characteristic of eutrophic lakes, mostly benthic algae, and (3) the non-occurrence of the dystrophic phenomenon (so called ‘malague’) characteristic of most eutrophic Mediterranean lakes and lagoons in summer (Boudouresque, 1990). The origin of this lack of available nutrients is unknown. However, it could include actual deficit, adsorption by sediments, storage in sediments and/or in plants (bulbs of *Potamogeton pectinatus* and *Scirpus maritimus*) and exportation. Adsorption of phosphate by sediments has been demonstrated (Ben Rejeb-Jenhani, 1989). Moreover, the roots of *P. pectinatus* which can favor the uptake of nutrients of the sediment, are not found deeper than 0.40 m under the ground level (Nièri et al., 1992). Storage in bulbs would allow the development of aquatic beds in poor waters. Exportation could involve the transport of sediments carrying nutrients from lake Ichkeul to the sea; it also involves removal from fish (210 t wet weight year caught by commercial fishing, Kartas & Zaouali, 1990) and mostly waterbirds migrating back to their breeding grounds: the exported biomass is about 13 000 t (wet weight, see Table 3), among which ca 20 to 30% (−2600 to 3900 t) were gained from the aquatic beds of lake Ichkeul between the arrival and the departure date of the birds.

Moreover, it is suspected that the usual depletion of the aquatic beds at the end of the winter season is directly linked to the part removed by waterbirds: as long as waterlevels are favorable for feeding, the date of departure of most ducks and coots varies accordingly to the amount of food resources which are still available in the lake. Once the food depletion happens as early as November or December, birds are forced to leave and scatter over much less favorable wetlands in Tunisia and Algeria; food resources seem to be
the limiting factor for ducks and coots that winter at Ichkeul Lake (Tamisier, 1990; Tamisier et al., 1992).

So many more questions are raised than answers are provided to the functioning of the ecosystem. Yet waterbird populations, playing an indicator role, put the emphasis on the fact that lake Ichkeul appears as a Mediterranean aquatic ecosystem where limits are reached every year either at the nutrient or at the population level, maybe at both. It differs quite fundamentally from most other Mediterranean lagoons. There, the phytomass is not fully exploited by herbivorous species, it can accumulate on the bottom and remain the year long, showing seasonal variations of abundance (Mercier, 1973; Dubois & Lauret, 1991). It is decomposed by detritrophic species and/or bacteria. In this case, anoxic situations can occur in summer with an accumulation of nutrients in the system which is more or less eutrophic. On the contrary at Ichkeul lake, the phytomass (at least for macrophytes) is quite completely exploited by herbivorous migrating species. And these birds, when they leave, export N and P taken off from the lake; consequently they might maintain the functioning of a rather oligotrophic system.

The perspective of the dam construction prompts reflection on Ichkeul’s unique ecosystem: as a matter of fact, lake Ichkeul deprived of most of its freshwater and nutrient input will lose the essential components of its originality and become a rather standard man-managed impoundment. In this context, one of the objectives of the management plan is to focus the remaining energy of the ecosystem towards a maximum production of the aquatic macrophyte beds in order to maintain as much as possible its carrying capacity for the wintering waterbird community. That objective must be attained, since the rate of decline of the duck populations wintering in the Mediterranean basin has already reached 46% in the last 15–20 years (Van Vessem et al., 1992). This may not avoid impoverishment of the natural functioning of Ichkeul lake nor prevent a major loss in the biodiversity of the aquatic ecosystems of the region.

Acknowledgements

We wish to thank the Tunisian authorities, in particular the Agence Nationale pour la Protection de l’Environnement (Ministère de l’Environnement), the Direction Générale des Forêts (Ministère de l’Agriculture) and the Faculté des Sciences of Tunis for stimulation and/or permission to carry out the research at Ichkeul Lake, M. M. A. El Hili, President of the Fondation Nationale de la Recherche Scientifique, H. Baraket, Director of the Parc National de l’Ichkeul and J. P. Sallei, Head of the Centre National de la Recherche Scientifique in Tunis. We are grateful to many collaborators who helped us in several ways, in particular Mrs E. Allouche, M. Gerbal, E. B. Trabelsi and S. Valin, and M. M. A. Allouche, F. Aubry, V. Gravez, F. Kartas, F. Maamouri, M. Niéri, A. Shili and O. Sloeck.

References


