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THE USE OF AN ARTIFICIAL WETLAND BY SHOVELER
ANAS CLYPEATA IN WESTERN FRANCE: THE ROLE
OF FOOD RESOURCES

Matthieu GUILLEMAIN*, Hervé FRITZ* & Noël GUILLON*

RÉSUMÉ

Les stations d'épuration sont des zones favorables aux oiseaux d'eau, particulièrement en période de reproduction. La station d'épuration de Rochefort, dans l'ouest de la France, revêt une importance internationale pour le Canard souchet en hivernage (> 400 individus). Durant cette étude, le nombre de Souchets hivernants était lié à la densité de zooplankton. La densité de zooplankton étant différente dans les huit bassins de la station, nous avons testé la relation entre distribution spatiale des oiseaux sur le site et distribution des proies. La taille des bassins et leur densité de zooplankton étaient inversement corrélées. Les canards utilisaient principalement les bassins de taille et de densité de plancton intermédiaires, suggérant que les deux facteurs déterminaient leur distribution. L'évitement des grands bassins semble lié à la faible disponibilité de ressources, alors que les bassins petits pourraient avoir été peu utilisés afin d'éviter un risque de prédation potentiel. Nous proposons un test expérimental de cette dernière hypothèse. Si cette interprétation était vérifiée, les résultats de ce travail pourraient permettre de concevoir les futures stations d'épuration de manière à les rendre pleinement utilisables par les Souchets, en augmentant la taille des bassins (> 5 ha) afin d'assurer une distribution optimale des oiseaux.

SUMMARY

Sewage works are known to be attractive to waterbirds, especially during the breeding season. The sewage works of Rochefort (Western France) regularly hosts internationally important numbers of wintering Shovelers (> 400 individuals). During the present study the number of Shovelers present over the winter period was related to zooplankton density. Since zooplankton density differed between the eight ponds of the station, we tested if the birds' spatial distribution reflected food abundance. Pond size and zooplankton abundance were negatively correlated. Ducks concentrated on ponds of intermediate invertebrate richness and intermediate size, suggesting that pond size as well as food abundance affected their distribution. The relative avoidance of large ponds could be due to low resource availability and the avoidance of small ponds with restricted visibility may be related to minimizing the risk of predation. We propose an experimental test of the second hypothesis. If our interpretation is confirmed, then these results have implications for the planning of future sewage treatment works: where use by Shoveler is an objective, ponds should be large (> 5 ha) in order to allow birds to distribute in an optimal manner and thus to use the site to its full potential.

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INTRODUCTION

Habitat loss is considered to be a major cause of the loss of biological diversity, and may have severe consequences for bird populations, especially in wetland ecosystems (Moser *et al.*, 1994; Dolman & Sutherland, 1995; Weller, 1999). Wetland transformation through drainage or for other human activities is a world-wide phenomenon (Williams, 1990), which can severely affect waterfowl populations (e.g. Bethke & Nudds, 1995; Duncan *et al.*, 1999). In response to habitat loss, and following the growing demand of the public for conservation measures, the number of protected areas in Europe has increased markedly in the last 20 years (IUCN, 1994). Most protected areas in wetlands are dedicated to waterfowl, which use these sites heavily, sometimes concentrating in very large numbers on relatively small reserves (Scott & Rose, 1996).

Some bird species also benefit from artificial habitats such as gravel pits and sewage works (e.g. Baldassarre & Bolen, 1994). In addition to their primary function, some of these sites aim at contributing to the conservation of wildlife. Sewage works are particularly attractive because their eutrophic waters and, in general, the lack of predators of invertebrates (fishes) allows zooplankton populations to develop, providing good feeding opportunities for some bird species (e.g. Uhler, 1964). In particular, Shoveler *Anas clypeata* use artificial wetlands increasingly (Kirby & Mitchell, 1993; Costa, 1997). Shoveler is one of the few dabbling ducks whose diet is mainly composed of aquatic invertebrates, especially zooplankton, throughout the year (Pirot & Pont, 1987; Ankney & Afton, 1988; Thompson *et al.*, 1992; Tietje & Teer, 1996).

Integrating artificial wetlands into conservation programmes at the regional level requires an understanding of the ecological factors affecting bird species at these sites. In particular, little is known about predator-prey relationships in such particular habitats, although this can profoundly affect the carrying capacity of the sites. The municipal sewage works of Rochefort (hereafter STEPRO), western France (45° 60' N, 01° 00' W), offers a good opportunity to study such relationships, since the site regularly host several hundreds of wintering Shovelers (see below). Because the site is made up of eight distinct ponds, we worked at two spatial scales: first, we test the hypothesis that Shoveler abundance on the whole site is determined by the overall abundance of zooplankton. At a finer scale, we then analyse the use of the eight ponds by the birds in relation to the distribution of invertebrates.

METHODS

STUDY SITE

Sewage is treated at the STEPRO by the “extensive lagooning” process (Blanchon, 1992), based on the gradual sedimentation of the organic matter in a succession of eight ponds (Fig. 1). The first ponds receive water rich in organic matter and are anoxic. Ponds have to be large for the water to become oxygenated by the waves that wind creates. Aerobic bacteria then develop and mineralize the organic matter. This allows phyto- and zooplankton to develop, and these invertebrates are more abundant in the last ponds of the process. The STEPRO is the largest sewage works of this type in France.

Legend:

- : Pond
 - 1A (9.5) : Pond number and size (in ha.)
 - : Buildings
 - ▨ : Hide
 - : Surrounding marshes
 - : Road (closed at night)
 - ▶ : Direction of water flow
- 0 100 200 300m

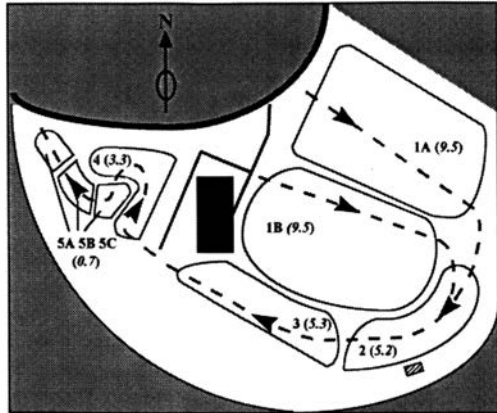


Figure 1. — Plan of the STEPRO. The water moves gradually from pond 1A to pond 5C.

The site frequently hosts more than 400 Shovelers in winter, and is thus of international importance for this species (the 1 % Ramsar criterion is 400 birds, Scott & Rose, 1996). In addition to sewage treatment, bird conservation is an official goal for the STEPRO.

SHOVELER OBSERVATIONS

We counted Shovelers and recorded their behaviour each Monday for 28 weeks from 02.IX.1996 to 10.III.1997. Exceptionally poor weather prevented observations on some occasions, reducing sample size for some variables, especially in the cold spell from 20.XII.1996 to 07.I.1997: surrounding marshes and shores of the ponds froze over during the whole period, while the eight ponds of the station were totally taken in ice from 27.XII.1996 to 04.I.1997. Ponds 4, 5A, 5B and 5C remained completely frozen until 07.1.1997.

Behavioural data come from two sets of instantaneous scan sampling of Shoveler behaviour (Altmann, 1974), which were performed each Monday 2 hours before dawn and in mid-morning. Periods were chosen so as to get data from related periods of the night and the day, i.e. comparable food stocks and weather conditions. In addition, this allowed us to test for the existence of diurnal complementation of nocturnal feeding during a given day. The same route was followed during all nights of observation (line transect, Gibbons *et al.*, 1996), and allowed us to record the behaviour of all individuals over the station. A $\times 4$ binocular light amplifier (Thomson TTD Optronique UGO) was used for these nocturnal observations. Daylight observations were performed using a $\times 20$ telescope. Except pond 2, where ducks were observed from a hide, diurnal observations were performed from the roof of the technical buildings. Data thus represent a complete monitoring of all bird behaviour, both for diurnal and nocturnal periods. We noted the behaviour of each Shoveler on each pond, recording total number of individuals and proportion of individuals performing

different activities. We distinguished feeding individuals (i.e. foraging with their bill, head or neck underwater, or by upending) from those vigilant, swimming or in comfort (i.e. preening and resting) on each pond.

INVERTEBRATE SAMPLING AND ABIOTIC PARAMETERS

Invertebrate sampling was performed once a week in each pond by night, after the duck count. A net (0.3 mm mesh size, 21 × 15.5 cm opening) was immersed in the evacuation tube of the pond for ten seconds. Hydraulic works at the entry of these tubes collect and mix water from the whole water column, which prevented us to discriminate zooplankton densities at various depths. On the other hand, this gave us a standardized index that allowed to compare zooplankton densities between ponds and monitor the evolution of invertebrate populations across weeks in each waterbody. The mesh size equalled the minimum space between the bill lamellae of Shoveler (Thomas, 1982). In the laboratory, the invertebrates of each sample were spread homogeneously in a 52 cm² Petri dish placed on a grid. The number of individuals was sub-sampled in five 1 cm² squares, and we calculated the total number and variance of invertebrates in each water sample. We used the rate of water flow through the ponds (monthly data from managers of the STEPRO) to calculate the volume of water intercepted by our net. The rate of water flow is the same in all ponds for each week since the successive waterbodies of the treatment process pour one in another by gravity. Since pond area and depth were known, this enabled the invertebrate density per litre of water for each pond each week to be calculated. Insects (mainly notonecta and chironomid larvae) were found only occasionally in the samples, which were dominated by zooplanktonic crustaceans (i.e. Cladocerans: *Daphnia* sp. and Copepods: *Cyclops* sp.; these two types of prey were of approximately the same size).

Water depth varied from 1.40 to 1.00 m between ponds, which prevented benthic feeding by dabbling ducks and the rocky shore and lack of emergent vegetation prevented peripheral feeding. Two parameters of pond morphology were included in the analyses because they could affect their use by ducks: i) the area of ponds, as waterfowl avoid small waterbodies with restricted visibility (Owens, 1977), and ii) for analysis of daylight data, the distance of ponds from the works buildings (i.e. possible sources of disturbance during daylight hours). Among water parameters, only the density of particles in suspension (expressed in mg/l, hereafter DPS) was included in the analyses because this could affect the feeding efficiency of Shoveler, since the bill lamellae could become clogged when particulate non-dietary items are too abundant (cf. Australian Shoveler *Anas rhynchos* in Crome, 1985). DPS data come from the managers of the STEPRO, values refer to the mass of particles > 0.7 mm; this was measured monthly in each pond.

STATISTICAL ANALYSES

The activity of Shovelers is presented as relative frequency of each type of behaviour, i.e. the percentage of individuals performing each activity. The relative use of each pond by Shovelers in a particular activity was calculated using the ratio of the number of ducks with this behaviour observed on a pond to the total number

of ducks in the same behaviour on all ponds. Only the distribution of individuals involved in the main activity was analysed: foraging individuals during the night, and birds in comfort activities during daylight hours.

The relative abundance of zooplankton in each pond was calculated as for duck distribution. Spearman rank correlation coefficients between the relative use of each pond by feeding Shovelers and the relative abundance of zooplankton in the same pond were calculated each week to assess if the nocturnal distribution of foraging Shovelers was related to the distribution of their prey.

RESULTS

SHOVELER NUMBERS AND ACTIVITY

The average number of Shovelers present during daylight hours from 02.IX.1996 to 16.XII.1996 was 394 ± 121 s.d. ($n = 16$), and there was no trend over this period (Spearman rank correlation: $r_{14} = -0.09$, $P > 0.05$). Numbers declined after December (average 24 ± 17 s.d., Mann-Whitney U-test: $Z_{16,10} = 17.78$, $P < 0.0001$; Fig. 2A). Nocturnal Shoveler numbers decreased from 02.IX.1996 to 16.XII.1996 ($r_{13} = -0.58$, $P < 0.05$), and were lower after the cold

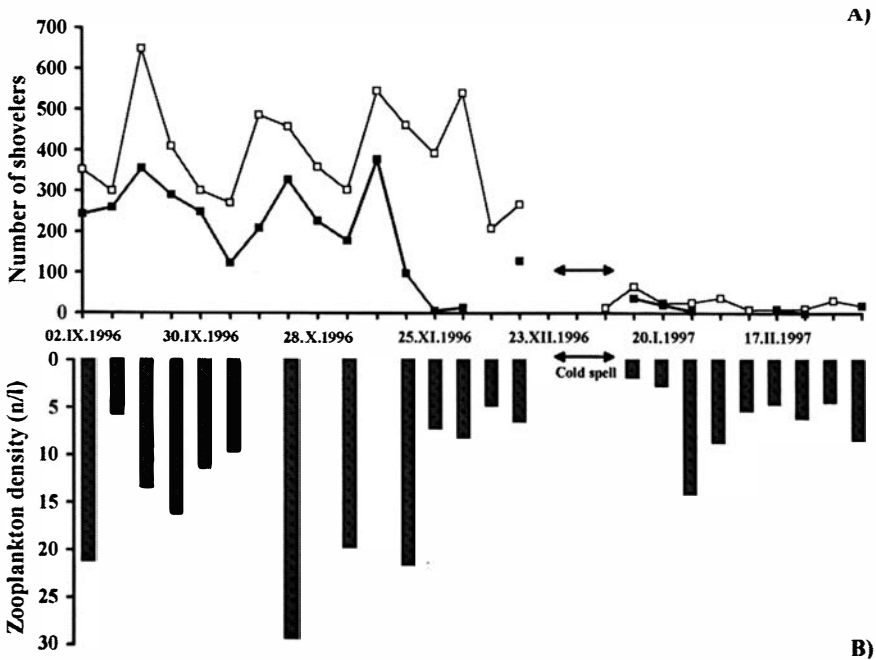


Figure 2. — The number of Shovelers at the STEPRO in autumn-winter 1996-1997 during daylight hours (A, white squares, $n = 26$) and during the night (A, black squares, $n = 21$), and the mean density of zooplankton in the ponds (B, $n = 22$). Weeks with no square or no column are missing data. See text for statistics.

spell than before ($Z_{15,6} = 8.75$, $P < 0.01$; Fig. 2A). Numbers counted at night represented on average 54 % (± 30 % s.d., $n = 21$) of those present by day.

The eight ponds were classified in three groups based on different zooplankton densities: large ponds 1A and 1B had lower zooplankton densities than the medium-sized ponds 2, 3 and 4 (1.18 ± 0.85 ind/litre s.d. and 6.96 ± 6.64 ind/litre s.d. respectively; $Z_{22,22} = -4.87$, $P < 0.0001$), which themselves had lower densities than the small ponds 5A, 5B and 5C (20.20 ± 15.01 ind/litre s.d.; $Z_{22,22} = -3.93$, $P < 0.0001$). The temporal variations of mean zooplankton densities in these three groups of ponds were significantly correlated (large versus medium-sized ponds: $r_{20} = 0.66$, $P < 0.001$; large versus small ponds: $r_{20} = 0.42$, $P = 0.05$; medium-sized versus small ponds: $r_{20} = 0.78$, $P < 0.0001$), so we used the mean density of zooplankton over the eight ponds in the analyses at the STEPRO level. The density of zooplankton decreased significantly through the winter ($r_{20} = -0.55$, $P < 0.01$), being significantly lower after the cold spell than before ($Z_{13,9} = 6.27$, $P < 0.05$). However, densities after the cold spell did not differ from the densities of late November and December ($Z_{9,5} = 1.28$, $P > 0.05$; Fig. 2B). Diurnal Shoveler numbers, and to a lesser extent nocturnal numbers, were positively related to the density of zooplankton ($r_{20} = 0.63$, $P < 0.01$ and $r_{16} = 0.46$, $P = 0.05$, respectively; Fig. 3). The significance of the relationship was mainly due to the low numbers of Shovelers when the density of zooplankton was under 10 individuals per litre.

Activities of Shovelers differed strongly between night and day (Table I): preening and resting occurred mainly during daylight hours, while feeding was primarily a nocturnal activity. "Bill underwater" was the most frequent foraging behaviour during daylight (44 % of the feeding behaviours ± 43 s.d., $n = 21$) and dominated night feeding (92 % ± 26 s.d., $n = 15$). Neither the nocturnal nor the diurnal frequency of feeding behaviours showed a trend over the winter ($r_{16} = -0.09$, $P > 0.05$ and $r_{24} = 0.01$, $P > 0.05$, respectively).

TABLE I

Average frequency (\pm s.d.) of the different behaviours at night and during daylight hours (data from scan samples on the eight ponds of the STEPRO).

	Night (n = 18)	Day (n = 26)	Mann-Whitney U-test
Feeding	0.65 \pm 0.40	0.14 \pm 0.19	Z = 11.98 P < 0.001
Swimming	0.30 \pm 0.41	0.40 \pm 0.25	Z = 3.39 n.s.
Preening	0.00 \pm 0.01	0.08 \pm 0.07	Z = 22.64 P < 0.0001
Resting	0.02 \pm 0.06	0.32 \pm 0.31	Z = 16.36 P < 0.0001
Vigilance	0.01 \pm 0.03	0.02 \pm 0.03	Z = 1.66 n.s.
Undetermined	0.01 \pm 0.02	0.02 \pm 0.10	Z = 0.15 n.s.

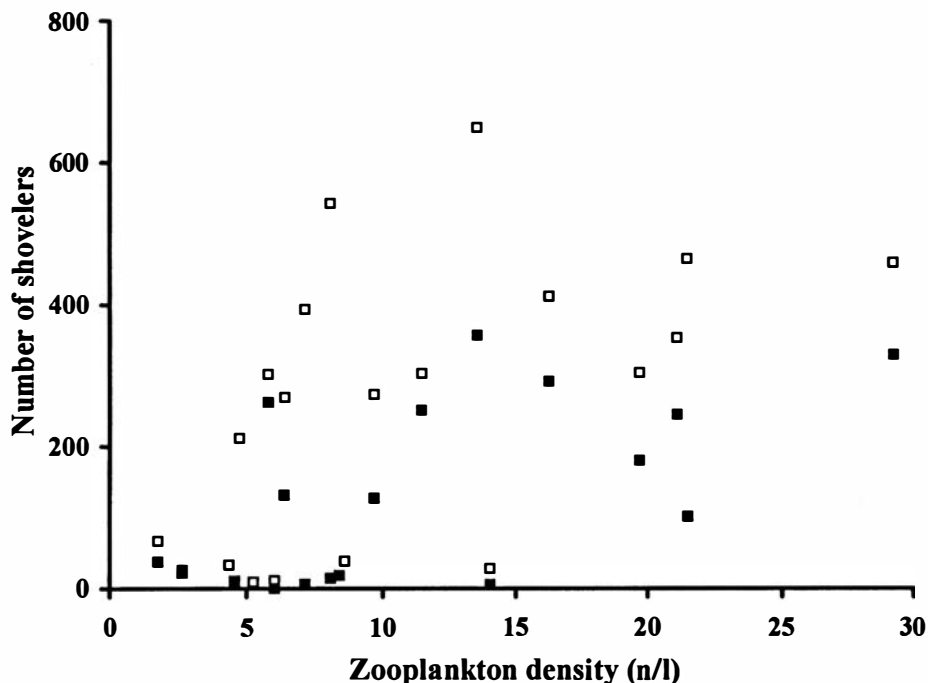


Figure 3. — Relationships between the mean zooplankton densities in the 8 ponds of the STEPRO and the number of Shovelers on the STEPRO the same week during daylight hours (white squares) and by night (black squares).

SHOVELER DISTRIBUTION

During the night the use of the ponds by feeding Shovelers differed significantly (Kruskal-Wallis test: $H_7 = 26.43$, $P < 0.001$), but no consistent trend was found with pond size alone ($r_6 = -0.07$, $P > 0.05$), since ponds of intermediate size were most frequented (Table II). The density of particles in suspension did not differ between ponds ($H_7 = 13.66$, $P > 0.05$, average 89.55 mg/l). The relative abundance of zooplankton differed between ponds ($H_7 = 128.59$, $P < 0.0001$), decreasing significantly with increasing pond size ($r_6 = -0.80$, $P < 0.05$; Table II). For most weeks, the correlation between the distribution of feeding Shovelers during the night and that of the zooplankton was positive (10 nights on a total of 12 nights where zooplankton data were available and some Shovelers were foraging). However, the correlation coefficients were low, and were significant for only 3 weeks.

At night, feeding Shovelers used predominantly ponds of medium size and with intermediate densities of zooplankton. During daylight hours Shovelers in comfort behaviour were not equally distributed over the eight ponds either ($H_7 = 59.28$, $P < 0.0001$). The relative use of ponds was not related to their

TABLE II

Average use of the eight ponds by feeding Shovelers during the night, and relative abundance of zooplankton. Values with the same letter did not differ significantly at the 0.05 level (Mann-Whitney U-tests, n = 15 sets of nocturnal Shoveler observations, n = 22 sets of zooplankton samplings).

Pond	Size of ponds	Relative use by feeding shovelers	Relative abundance of zooplankton
5C	0.7ha	0.00 a	0.08 c
5B	0.7ha	0.07 bc	0.31 d
5A	0.7ha	0.07 bc	0.33 d
4	3.3ha	0.18 cd	0.11 c
2	5.2ha	0.30 cd	0.03 b
3	5.3ha	0.38 d	0.09 c
1A	9.5ha	0.00 a	0.02 ab
1B	9.5ha	0.00 a	0.01 a

distance from buildings ($r_6 = 0.38$, $P > 0.05$) or to their size ($r_6 = 0.65$, $P > 0.05$): the unequal distribution of individuals was due to the avoidance of ponds < 5 ha (Table III).

TABLE III

Average use of the ponds of the STEPPO by Shovelers for comfort behaviour during daylight hours. Values with the same letter did not differ significantly at the 0.05 level (Mann-Whitney U-tests, n = 26 sets of diurnal Shoveler observations).

Pond	Size	Distance from buildings	Relative use by shovelers in comfort
2	5.2ha	594 m	0.34 a
3	5.3ha	287 m	0.32 ab
1A	9.5ha	425 m	0.17 ab
1B	9.5ha	606 m	0.13 b
5A	0.7ha	225 m	0.04 c
4	3.3ha	244 m	0.00 c
5C	0.7ha	412 m	0.00 c
5B	0.7ha	319 m	0.00 c

DISCUSSION

The STEPPO is an internationally important site for Shovelers as a day-roost in winter (1 % of the flyway population, Scott & Rose, 1996). Interestingly, nocturnal numbers of individuals represented a large proportion of diurnal numbers: although wintering dabbling ducks generally rest in numbers on large

waterbodies during the day and disperse in small groups at night in distinct feeding habitats (Tamisier & Dehorter, 1999), numbers counted at night at the STEPPO represented more than 50 % of diurnal numbers. These individuals were foraging for 65 % of the night. The STEPPO thus provides good feeding conditions and is an important site for Shoveler in western France, at least for a part of the winter: apart from the Camargue, which traditionally supports the largest population of wintering Shoveler, only two sites were of international importance for this duck species at the International Waterfowl Census of January 1997 (i.e. the Marais d'Orx, South of Bordeaux: 616 ind. and the river Loire: 534 ind., Deceuninck *et al.*, 1998). Other studies of the use of sewage works in the breeding season have reached similar conclusions, showing that the main value of these artificial wetlands is their high availability of food (Murkin *et al.* 1982; Nudds & Bowlby, 1984; Piest & Sowls, 1985; Murkin & Kadleck, 1986). In our case, more than 90 % of the Shovelers foraging at night fed at the surface of the water with only their bill immersed, a behaviour commonly used when foraging on zooplankton (Matsubara *et al.* 1994; DuBow, 1985).

Both diurnal and nocturnal numbers of Shovelers on the STEPPO were positively correlated to zooplankton density over the whole winter period. The relationship disappeared in the last weeks of the season, and it is likely that Shoveler deserted the site because of the cold spell (Ridgill & Fox, 1990). The whole marshes of Rochefort were deserted by Shoveler during the freeze, but birds rapidly came back at the other protected sites of the area during January, and not at the STEPPO. The same pattern of site abandon was observed at the STEPPO the previous year (1995-96) in absence of any cold spell. Zooplankton data for that winter are not available, but the fact that the same pattern occurred both in a cold and a temperate winter suggests that the pattern of Shoveler abundance is more likely to be a consequence of a gradual resource depletion than a meteorological problem.

The nocturnal distribution of feeding Shovelers did not match closely the distribution of their prey. These results differ from those of Matsubara *et al.* (1994) at Lake Teganuma (Japan). A major difference between these two studies is the structure of the feeding habitat: in Japan Shovelers foraged in one large lake (6.5 km²), while at the STEPPO the birds had to choose between ponds. In the two cases, Shovelers avoided sites which hosted few zooplankton (i.e. the larger ponds at Rochefort), but at the STEPPO duck densities were low on the richest ponds too, which were also the smallest. Since all the ponds of the STEPPO had banks of the same height, the distance at which a Shoveler can detect a potential danger is closely linked to the size of the pond: large ponds are likely to be subject to a lesser predation risk than small ones. This could explain why smaller ponds were under-used, while the avoidance of large ponds could be due to low resource availability, suggesting that the nocturnal distribution of Shovelers over the STEPPO was the result of a trade-off between predation risk and food abundance. Such a trade-off between food abundance and habitat safety has also been suggested in another French wintering quarter, the Camargue (Dehorter & Tamisier, 1996). The density of particles in suspension, which could potentially affect filter-feeding by Shovelers through a clogging of the bill lamellae (Crome, 1985), did not differ between ponds and could therefore not explain the distribution of feeding individuals.

During the day the use of the ponds by Shovelers in comfort activities was not related to their distance from buildings, since pond 3 hosted one-third of the total

number of birds on the STEPPO despite its proximity to technical works, while pond 5C, much farther, was not used by Shoveler during daylight hours. This suggests that these ducks, like other waterbirds in protected areas, habituated to some extent to the presence of man (Smit & Visser, 1993). We did not find any significant relationship between the size of ponds and their relative use by Shovelers in comfort activities, but ponds smaller than 5 ha were not used during daylight hours. Shovelers avoided small ponds during the day as they did at night. The restricted visibility remains a good explanation for this pattern during daylight since aerial predators such as Marsh Harrier (*Circus aeruginosus*) were recorded in the area on occasions. Ponds smaller than 5 ha were seldom used, and all ponds over 5 ha were used regularly: this suggests a threshold of pond size below which the birds avoid them. It thus appears that Shoveler did not compromise between pond size (safety) and food abundance in the same way during the night and daylight hours, since ducks selected larger (i.e. safer) ponds during the day for comfort activities, while the need for foraging lead to a greater use of ponds of intermediate size (and higher food richness) during the night. In particular, ponds 4 and 5 were avoided during daylight, while some birds used them as nocturnal foraging habitats. In addition to its size, the particular 'V' shape of pond 4 probably affected its use by Shoveler: birds could not benefit from the whole area in terms of safety, since in most parts of the pond they could only see half the waterbody.

Data from two days (09.IX.1996 and 28.X.1996) were responsible for the high variability of diurnal feeding frequency: on 09.IX.1996, the frequency of diurnal feeding was 0.59. The density of zooplankton at the STEPPO at this date was 6 individuals per litre (i.e. four times lower than the week before and three times lower than the week after). A very strong wind at that time probably constrained Shoveler foraging activities, particularly through the mixing of water which is likely to reduce the number of zooplanktonic prey close to the surface and hence decrease food accessibility. This may explain why the frequency of foraging with head and neck underwater or upending was 0.67 on this date, while the frequency of foraging with bill underwater was only 0.23. On 28.X.1996, the frequency of diurnal feeding was 0.64 and the frequency of foraging before sunrise was 0.24, which was the lowest observed during all the winter. The observations made during these two particular days suggest that Shovelers compensate for poor feeding conditions at night by increasing diurnal foraging activities. This is also supported by the fact that the frequency of diurnal feeding was inversely correlated with the frequency of nocturnal feeding over the whole winter period ($r_{17} = -0.45$, $P = 0.05$).

This study shows that sewage works, which are good sites for dabbling ducks in the breeding season (Uhler, 1964), can also be good sites for Shovelers in winter. In both cases, the major value of these habitats for waterbirds appears to be the large amounts of invertebrate food, due to lack of predators (fishes) and the high nutrient concentrations of the waters (Kirby & Mitchell, 1993). The use of the STEPPO by wintering Shovelers seems to be limited by the small size of some ponds. The "extensive lagooning" treatment needs large ponds at the beginning of the process, while pond size has a minor importance at the end of the treatment. At the STEPPO the last ponds, which host larger quantities of zooplankton and have cleaner water, were made small so as to allow potential commercial uses in addition to sewage treatment (i.e. exploitation of the plankton for fish breeding nurseries, exploitation of chironomid larvae for fish bait, in-situ fish breeding...).

The results of this study suggest that the use of the last small ponds by Shoveler would be increased if they were larger, and that the total number of Shovelers at the STEPPO would increase consecutively. Since these ponds are not used for such commercial purposes, this hypothesis could be tested by removing the internal banks of the last three ponds and monitoring the distribution and numbers of Shovelers over one or more winter seasons.

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