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Eprints ID : 10177

**To link to this article :** DOI:10.1007/s10750-009-9886-6  
URL : <http://dx.doi.org/10.1007/s10750-009-9886-6>

**To cite this version :** Santoul, Frédéric and Gaujard, A. and Angélibert, S. and Mastrorillo, Sylvain and Céréghino, Régis. *Gravel pits support waterbird diversity in an urban landscape*. (2009) *Hydrobiologia*, vol. 634 (n° 1). pp. 107-114. ISSN 1573-5117

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# Gravel pits support waterbird diversity in an urban landscape

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**Abstract** We assessed the benefit of 11 gravel pits for the settlement of waterbird communities in an urbanized area lacking natural wetlands. Gravel pits captured 57% of the regional species pool of aquatic birds. We identified 39 species, among which five were regionally rare. We used the Self-Organizing Map algorithm to calculate the probabilities of presence of species, and to bring out habitat conditions that predict assemblage patterns. The age of the pits did not correlate with assemblage composition and species richness. There was a positive influence of macrophyte cover on waterbird species richness. Larger pits did not support more species, but species richness increased with connectivity. As alternative

wetland habitats, gravel pits are attractive to waterbirds, when they act as stepping stones that ensure connectivity between larger natural and/or artificial wetlands separated in space.

**Keywords** Artificial wetlands · Probability of presence · Rare species · Species richness · Self-Organizing Maps · Waterbirds

## Introduction

While human activity has resulted in the destruction of natural wetlands (Hull, 1997), artificial pools, such as farm ponds, rice fields, etc., became important alternative habitats for the pond biota (Declerck et al., 2006; Céréghino et al., 2008). It also becomes increasingly accepted that man-made ecosystems are likely to support biodiversity while they provide resources that have economic values, calling for more attention on the importance of these ecosystems to both wildlife and people (Odling-Smee, 2005). Throughout the world, gravel pits contribute to local economies while they constitute new wetlands for species of conservation interest, notably dragonflies, amphibians and birds (Frochot & Godreau, 1995). In France, gravel pits cover an area of about 90,000 ha, and about 5,000 ha are still created each year to satisfy the demands of the construction trade (Barnaud & Le Bloch, 1998). These new wetlands are colonized by waterbirds, creating a situation which raises new management concerns. We

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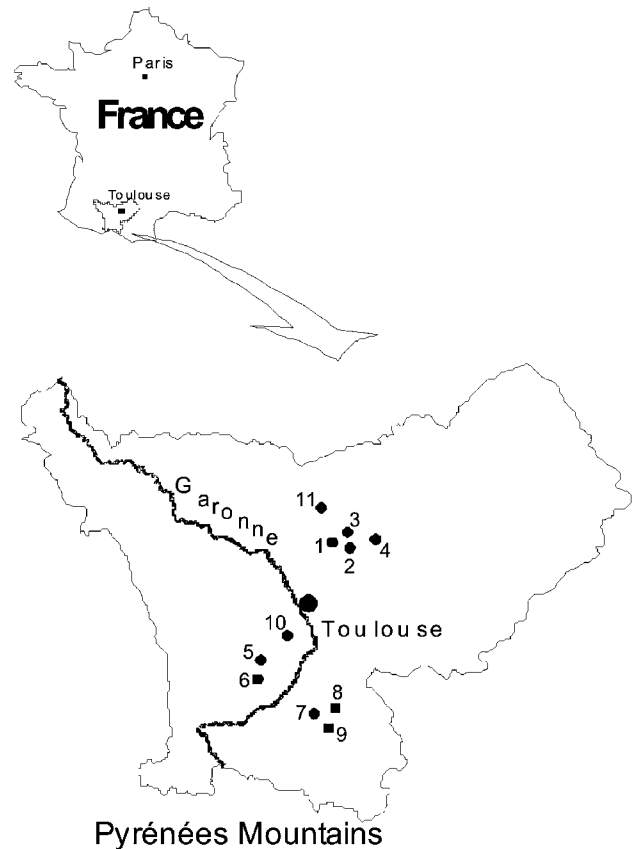
performed a test to verify the hypothesis that gravel pits contribute to waterbird diversity in urban areas. We recorded the species occurring in 11 gravel pits in the suburbs of the city of Toulouse (SW France), and the regional species pool of aquatic birds (gamma diversity, SW France 57,000 km<sup>2</sup>) was used to assess the benefit of gravel pits for the diversity of waterbird communities. In order to maximize the information extracted from “simple” presence–absence data, we used the Self-Organizing Map (SOM, neural network) to calculate the probabilities of the presence of each species in the various clusters of pits. Subsequently, environmental variables were introduced into the SOM trained with biological variables to interpret the variability of waterbird communities with respect to habitat features.

## Methods

Several gravel pits were excavated in the River Garonne floodplain around the city of Toulouse, SW France (Fig. 1), a highly populated area (over 1 million inhabitants) from which natural wetlands were largely eliminated by drainage during the nineteenth and twentieth centuries. Eleven gravel pits were characterized with four environmental variables: age (years), surface area (ha), % macrophyte cover (estimated from point 30 samples using an Eckman grab, each year at the end of the spring period), and an index of connectivity  $C$ , calculated as  $C = \sum_{i=1}^n S_i \times D_i$  where  $S$  (surface) and  $D$  (distance) are divided into classes defined in Oertli et al. (2000). The use of simple variables was intended to keep models broadly applicable for management applications. All gravel pits had a similar mean depth of 3–4 m.

Bird censuses were carried out weekly from October 1996 to October 1998 using binoculars (8 × 30) and telescopes (20 × 60). Waterbirds were selected according to Gillier et al. (2000). The adequacy of sampling was assessed by plotting the cumulative frequency of species against sampling effort (sample-rarefaction curve with 500 randomizations) (Colwell et al., 2004). The regional species pool (after Maurel et al., 2004) consists of 68 waterbird species occurring in SW France (see Table 1).

A full description of the SOM modelling procedure was given in Céréghino et al. (2008). The structure of the SOM consisted of two layers of neurons



**Fig. 1** Location of the 11 gravel pits (1–11) around the city of Toulouse, SW France

connected by weights (connection intensities): the input layer constituted by 39 neurons (one by species) connected to the 11 gravel pits, and the output layer constituted by 15 neurons (visualized as hexagonal cells) organized on an array with five rows and three columns. The SOM plots the similarities of the data in a 2D grid, by grouping similar data items together through an iterative learning process. At the end of the training, the connection intensity between input and output layers calculated during the learning process can be considered as the probability of occurrence of each species in the area concerned (see Céréghino et al., 2005). The occurrence probabilities of each species were visualized on the SOM map in grey scale, and allowed us to analyse the effect of each species on the patterning input dataset (sites). The SOM was clustered using Ward’s algorithm (Leroy et al., 2009). In order to bring out relationships between biological and environmental variables, we introduced the environmental variables into the SOM previously trained with bird occurrences

**Table 1** List of the waterbird species occurring at the regional scale (SW France)

Regional species pool	Regional distribution	Gravel pit										
		1	2	3	4	5	6	7	8	9	10	11
<i>Actitis hypoleucos</i> (Linnaeus, 1758)	Common	+			+				+			
<i>Anas acuta</i> Linnaeus, 1758	Common	+			+			+	+			
<i>Anas clypeata</i> Linnaeus, 1758	Common	+		+	+	+	+	+	+	+		
<i>Anas crecca</i> Linnaeus, 1758	Common	+	+	+	+	+	+	+	+		+	+
<i>Anas penelope</i> Linnaeus, 1758	Common	+			+			+	+	+		
<i>Anas platyrhynchos</i> Linnaeus, 1758	Common	+	+	+	+	+	+	+	+	+	+	+
<i>Anas querquedula</i> Linnaeus, 1758	Common	+			+			+	+	+		
<i>Anas strepera</i> Linnaeus, 1758	Common	+	+		+	+	+	+	+	+	+	
<i>Anser anser</i> (Linnaeus, 1758)	Common											
<i>Ardea cinerea</i> Linnaeus, 1758	Common	+	+	+	+	+	+	+	+	+	+	+
<i>Ardea purpurea</i> Linnaeus, 1758	Rare	+		+	+		+	+	+	+		
<i>Ardeola ralloides</i> (Scopoli, 1769)	Rare											
<i>Aythya ferina</i> (Linnaeus, 1758)	Common	+		+	+	+	+		+	+		
<i>Aythya fuligula</i> (Linnaeus, 1758)	Rare	+		+	+	+	+		+	+		
<i>Aythya marila</i> (Linnaeus, 1758)	Rare	+			+							
<i>Aythya nyroca</i> (Gûld, 1769)	Rare											
<i>Bubulcus ibis</i> (Linnaeus, 1758)	Common		+	+	+	+	+	+	+	+		+
<i>Bucephala clangula</i> (Linnaeus, 1758)	Common											
<i>Calidris alpina</i> (Linnaeus, 1758)	Common				+							
<i>Calidris minuta</i> (Leisler, 1812)	Common											
<i>Charadrius dubius</i> Scopoli, 1786	Common				+		+		+		+	
<i>Chlidonias hybridus</i> (Pallas, 1811)	Common											
<i>Chlidonias niger</i> (Linnaeus, 1758)	Common											
<i>Egretta alba</i> (Linnaeus, 1758)	Common											
<i>Egretta garzetta</i> (Linnaeus, 1758)	Common	+	+	+	+	+	+	+	+	+	+	+
<i>Eudromias morinellus</i> (Linnaeus, 1758)	Rare											
<i>Fulica atra</i> Linnaeus, 1758	Common	+	+	+	+	+	+	+	+	+		+
<i>Gallinago gallinago</i> (Linnaeus, 1758)	Common				+				+		+	+
<i>Gallinula chloropus</i> (Linnaeus, 1758)	Common		+	+		+		+	+	+	+	+
<i>Gelochelidon nilotica</i> (Gmelin, 1789)	Rare											
<i>Glareola pratincola</i> Linnaeus, 1766	Common				+							
<i>Grus grus</i> (Linnaeus, 1758)	Common				+				+	+		
<i>Himantopus himantopus</i> (Linnaeus, 1758)	Common				+			+	+			
<i>Ixobrychus minutus</i> (Linnaeus, 1766)	Rare											
<i>Larus cachinnans</i> (Pallas, 1826)	Common	+		+	+	+	+	+	+	+	+	+
<i>Larus canus</i> Linnaeus, 1758	Common											
<i>Larus fuscus</i> Linnaeus, 1758	Common											
<i>Larus minutus</i> Pallas, 1776	Common											
<i>Larus ridibundus</i> Linnaeus, 1758	Common	+	+		+			+	+	+		
<i>Limosa lapponica</i> (Linnaeus, 1758)	Common				+							
<i>Limosa limosa</i> (Linnaeus, 1758)	Common											
<i>Lymnocyptes minimus</i> (Brûnn, 1764)	Common											
<i>Mergus albellus</i> Linnaeus, 1758	Rare				+							

Table 1 continued

Regional species pool	Regional distribution	Gravel pit										
		1	2	3	4	5	6	7	8	9	10	11
<i>Mergus merganser</i> Linnaeus, 1758	Rare											
<i>Mergus serrator</i> Linnaeus, 1758	Common											
<b><i>Netta rufina</i> (Pallas, 1773)</b>	Common	+			+				+			
<i>Numenius arquata</i> (Linnaeus, 1758)	Rare											
<b><i>Nycticorax nycticorax</i> (Linnaeus, 1758)</b>	Common	+		+	+	+		+	+			+
<b><i>Phalacrocorax carbo</i> (Linnaeus, 1758)</b>	Common	+	+	+	+	+	+	+	+	+	+	+
<i>Philomachus pugnax</i> (Linnaeus, 1758)	Common											
<b><i>Platalea leucorodia</i> Linnaeus, 1758</b>	Rare				+							
<i>Pluvialis apricaria</i> (Linnaeus, 1758)	Common											
<b><i>Podiceps auritus</i> (Linnaeus, 1758)</b>	Common	+			+							
<b><i>Podiceps cristatus</i> (Linnaeus, 1758)</b>	Common	+	+	+	+	+	+	+	+	+	+	+
<i>Podiceps nigricollis</i> Brehm, 1831	Common											
<i>Porzana porzana</i> (Linnaeus, 1758)	Rare											
<i>Rallus aquaticus</i> Linnaeus, 1758	Common											
<i>Recurvirostra avosetta</i> Linnaeus, 1758	Common											
<i>Sterna albifrons</i> Pallas, 1764	Common											
<b><i>Sterna hirundo</i> Linnaeus, 1758</b>	Common				+			+				
<b><i>Tachybaptus ruficollis</i> (Pallas, 1764)</b>	Common	+	+	+	+			+				
<b><i>Tadorna tadorna</i> (Linnaeus, 1758)</b>	Common	+			+				+	+		
<i>Tringa erythropus</i> (Pallas, 1764)	Common											
<i>Tringa glareola</i> Linnaeus, 1758	Common											
<b><i>Tringa nebularia</i> (Gunnerus, 1767)</b>	Common				+				+			
<i>Tringa ochropus</i> Linnaeus, 1758	Common											
<b><i>Tringa totanus</i> (Linnaeus, 1758)</b>	Common				+				+			
<b><i>Vanellus vanellus</i> (Linnaeus, 1758)</b>	Common				+	+						

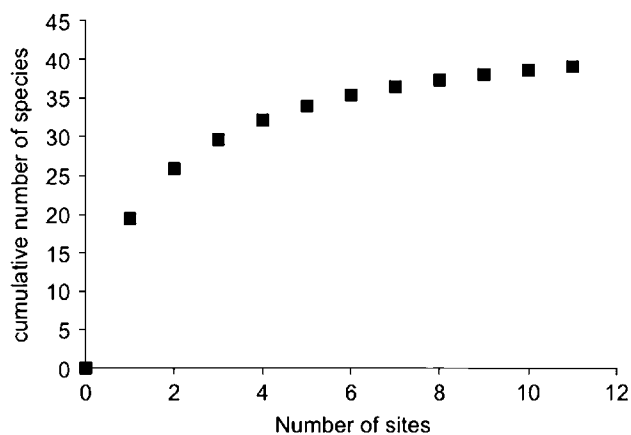
The 39 species recorded in our 11 gravel pits (Toulouse suburbs) appear in bold, + = presence. Information on rarity and commonness at the regional scale is given (after Maurel et al., 2004)

(see Park et al., 2003). All mean values of environmental variables assigned on the SOM map were visualized in grey scale.

## Results

Fifty-seven percent of the regional species pool was captured by our 11 gravel pits (Table 1). The number of species per pit ranged from 12 to 38. Among the 39 species recorded, five species were regionally rare, and the remaining ones were common. Accumulation of new species reached its asymptote (Fig. 2); we could thus consider that our sampling was satisfactory. After training, the SOM with species occurrences, Ward's algorithm helped to derive three clusters of sites

(gravel pits) according to waterbird assemblages (Fig. 3a). The ordinate of the SOM represented the number of species, from low (top areas of the SOM) to high (bottom) (Fig. 3b). Eleven species (*Podiceps auritus*, *Platalea leucorodia*, *Aythya marila*, *Netta rufina*, *Mergus albellus*, *Glareola pratincola*, *Tringa totanus*, *Tringa nebularia*, *Actitis hypoleucos*, *Limosa lapponica*, and *Calidris alpina*) only occurred in cluster C (Fig. 4). Five species (*Podiceps cristatus*, *Phalacrocorax carbo*, *Ardea cinerea*, *Egretta garzetta*, and *Anas platyrhynchos*) occurred in all the gravel pits, and the remaining 23 species occurred in two clusters of sites. When environmental variables were introduced into the SOM (Fig. 5), the ordinate on the SOM showed a gradient of connectivity and macrophyte cover [from low (top area) to high (bottom)].



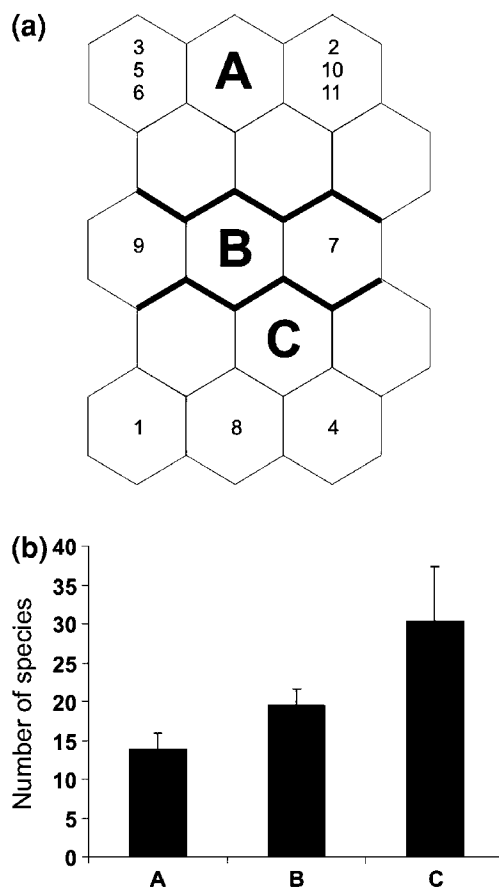
**Fig. 2** Sample-based rarefaction curves representing the number of species accumulated by sampling the 11 gravel pits

Site 4, which had the highest index of connectivity and a macrophyte cover of 90%, hosted 38 waterbird species. Other variables under consideration (age and surface area) did not show clear patterns and were thus not considered as structuring variables.

When clusters of gravel pits were compared to their distribution on the geographical map of the study area, the species hosted by some pits within the same sub-areas tended to be similar (gravel pits 7 and 9 in cluster B; 5, 6 and 10, and 2, 3 and 11 in cluster A, 1 and 4 in cluster C, see Fig. 1) and those characteristics tended to differ when sites belonged to more distinct areas. However, gravel pits from distinct areas also had very similar assemblages (e.g., 8 and 4; 3 and 5–6; 11 and 10), thus suggesting that local factors (e.g., macrophyte cover) interacted with connectivity to shape bird assemblages.

## Discussion

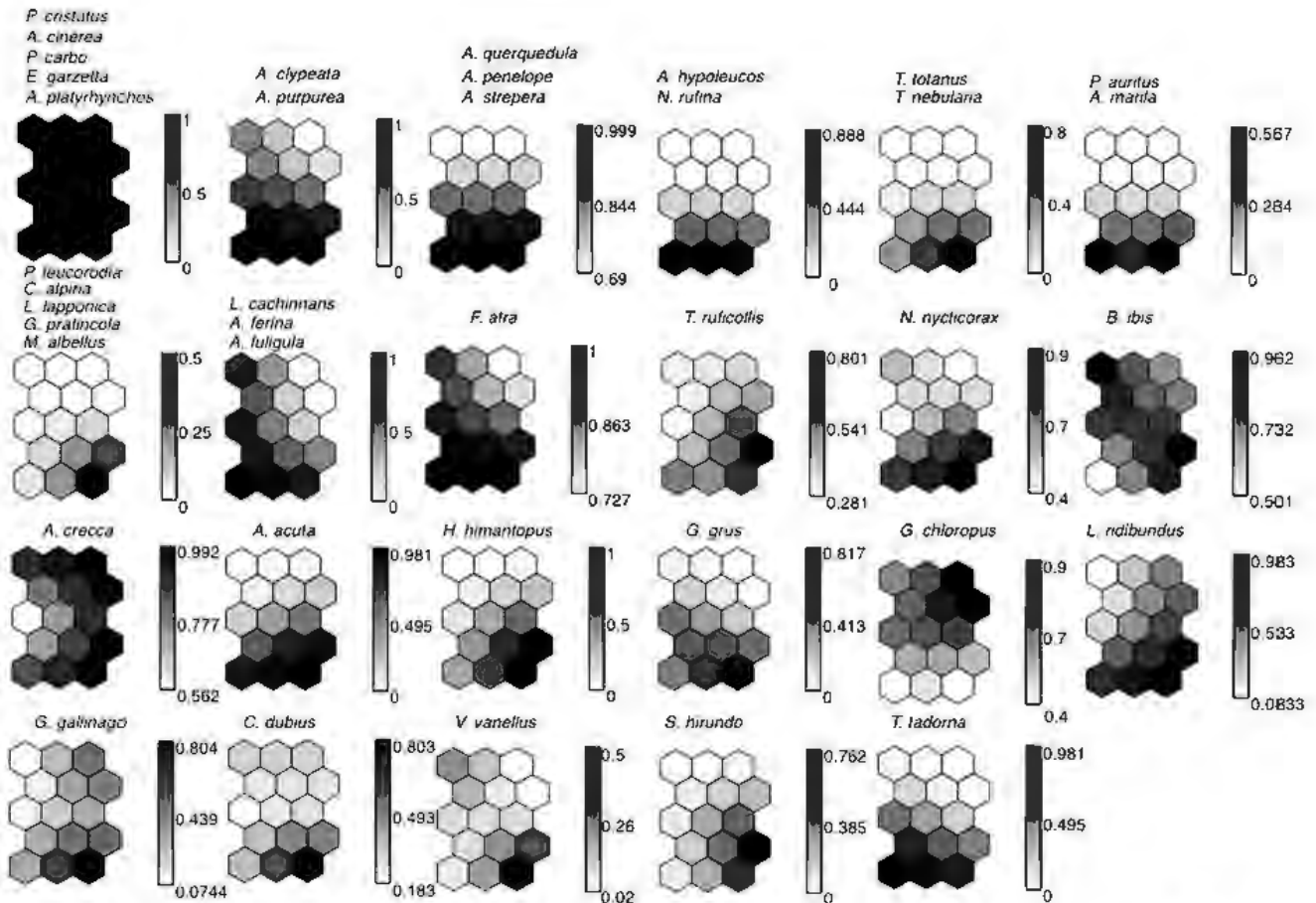
While the potential pool of colonists in our study region was made of 68 waterbird species, 11 gravel pits allowed the presence of 39 species in the Toulouse city suburbs. Our observations therefore highlight how a small set of artificial wetlands may sustain an important fraction (57%) of the larger regional species pool in landscapes where natural wetlands are lacking. Other observations in France and UK showed increases in population densities of several waterbirds during the past decades (*Aythya fuligula*, *Anas strepera*, *Phalacrocorax carbo*, *Podiceps cristatus*, *Sterna hirundo*), as a result of the



**Fig. 3** a Distribution of gravel pits on the self-organizing map (SOM) according to the presence or absence of 39 waterbird species. *Solid lines* show the cluster boundaries (i.e., for clusters A, B, C), delineated according to Ward's algorithm. Gravel pits that are neighbors within clusters are expected to have similar waterbird assemblages. Codes (1–11) correspond to gravel pits. b Mean number of species ( $\pm$ SE) per cluster

creation of gravel pits and reservoirs (Frochot et al., 2008; Fuller & Ausden, 2008).

Species richness and the presence of rare species are frequently cited criteria for site selection by conservationists (Myers et al., 2000). If man-made habitats only attract the common (widespread) species, one may argue that they do not make a significant contribution to biodiversity. Conversely, rare species are of special interest to environmental managers (Rey-Benayas et al., 1999), and it was recently demonstrated that areas which carry rare species may also concentrate an important fraction of the regional biodiversity (Cucherousset et al., 2008). For instance, some species were exclusive to gravel pit 4, which also hosted the highest species richness. Such artificial wetlands might therefore benefit from

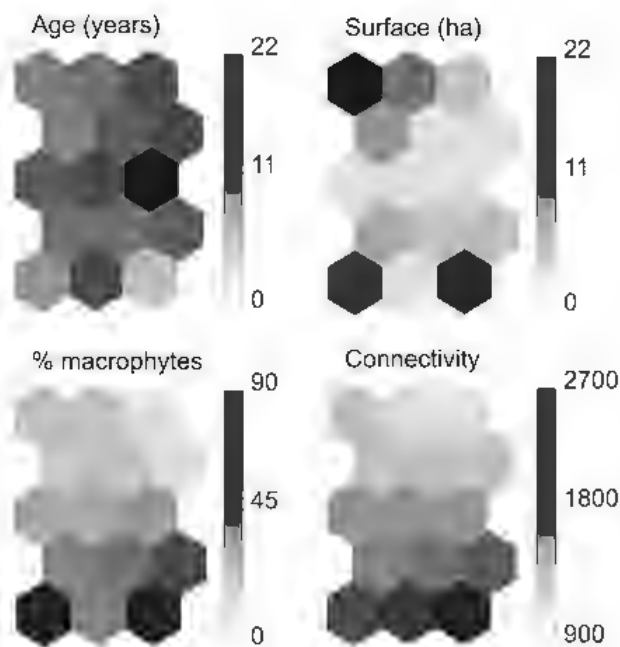


**Fig. 4** Gradient analysis of the probability of occurrence of each waterbird species on the trained SOM (see Fig. 3a), with visualization in shading scale (dark = high probability of occurrence, light = low probability of occurrence). Each map

is superimposed on the map representing the distribution of sites presented in Fig. 3a. See Table 1 for full species names and authorities

higher management priorities. We thus support the idea that urban landscapes containing man-made wetlands make a significant contribution to freshwater biodiversity. Larger gravel pits did not support more waterbird species. This absence of species–area relationship suggests that larger gravel pits were not more easily colonized by immigrants, and/or were not likely to show a higher diversity of ecological niches facilitating the coexistence of a larger number of species. Smaller but well-connected gravel pits ( $\approx 4$  ha) had the greatest susceptibility to host more taxa, and more rare species. They potentially had higher conservation value for waterbirds than larger gravel pits, although small surface may become a limiting factor if the carrying capacity becomes insufficient for waterbirds. Thus, gravel pits were certainly attractive to waterbirds when they acted as stepping stones that ensured connectivity between

larger natural and/or artificial wetlands separated in space (Bournaud et al., 1982). Species-poor assemblages were subsets of richer assemblages, suggesting nested patterns of waterbird assemblages. We assume that such patterns would be colonization-driven because most waterbirds did not live at the gravel pits throughout the year. The geographical location of the study area near the Pyrenees mountainous barrier makes the region important as a stop-over for migrant birds (Hoyer, 1994). Rare species were specifically present during the stop-over period, and therefore they probably preferred those connected sites which allowed them to find quieter sites in case of disturbance. There was a positive influence of the extent of the macrophyte cover on the number of waterbird species present at a site. Aquatic plants over large areas are attractive to many birds, such as charophytes, and the many invertebrates living on



**Fig. 5** Visualization of environmental variables on the SOM trained with waterbird species. The mean value of each variable was calculated in each output neuron of the trained SOM. Dark represents a high value, while light is low

them provide food for ducks and other waterbirds (Knapton & Petrie, 1999; Blindow et al., 2000). In turn, aquatic birds may have a negative impact on macrophyte abundance, and may be important determinants of the aquatic system dynamics (reviewed in Lodge et al., 1998). The age of the gravel pit was not a structuring factor for waterbird assemblages, at least within the range of 3–22 years considered in this study (no gravel pits older than 22 years in the area). Nevertheless, Frochot & Godreau (1995) emphasized that gravel pits over 30 years are less attractive for waterbirds, due to their more homogeneous and dense habitats, although some species such as herons may benefit from the development of trees.

In conclusion, gravel pits should be seen as a network of habitats integrated within the broader network of natural and artificial wetlands. We must enlarge the spatial scale needed to manage/survey these particular habitats, and we should primarily pay attention to wetland networks rather than attempting to target some species and/or bodies of water for particular management actions. The lack of fundamental knowledge needed to implement management plans usually limits the conservation potential of gravel pits. Restoration is generally carried out to transform gravel pits into recreational areas or fishing

lakes, and only rarely into habitats favorable to waterbirds. Owing to the continuing loss of natural wetlands, there is a need to enhance the contribution of artificial wetlands such as gravel pits for future conservation of waterbirds, and probably other taxa such as amphibians, insects, or plants. Therefore, further understanding of the distribution of biological diversity in non-natural systems may facilitate the adoption of positive solutions for wildlife, with limited costs for human activities.

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