Aquat Ecol
DOI 10.1007/s10452-007-9141-z

Response of waterbirds to alternating clear and turbid water phases in two shallow Mediterranean lakes

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Received: 15 March 2007 / Accepted: 5 September 2007

Abstract Albufera de Adra (Southern Spain) constitutes an internationally-recognised marsh for waterbirds; important populations of some endangered species such as White-headed Duck and Red-crested Pochard overwinter and breed in its two shallow permanent lakes (Lake Honda and Lake Nueva). In a recently published article, we revealed the factors responsible for the irregular alternation between phytoplankton-dominated turbid phases and macrophyte-dominated clear water phases in Lake Honda and Lake Nueva. In this note, we try to clarify the impact of such an alternation of equilibrium states on the waterbird dynamics. Marked increments in abundance, and brood recruitment of dabbling and diving waterbirds were recorded during the clear water phases in contrast with the turbid water phases, as the increase of macrophytes associated with increased water transparency attract waterbirds for available food. Implications for ecosystem management, restoration and conservation are identified.

Keywords Albufera de Adra · Alternative equilibria states · Clear water phase · Macrophytes · Plankton · *Netta rufina* · *Oxyura leucocephala* · Shallow lakes · Waterbirds

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Short comment

Albufera de Adra (Southern Spain, Fig. 1) constitutes an internationally recognised marsh for waterbirds. This structurally complex system was declared a Natural Reserve in 1989 by the Andalusian Government, and was registered in the Ramsar Convention of Wetlands of International Importance in 1994 (Castro et al. 1998). Due to its favourable ecological features, populations of endangered species such as the White-headed Duck (*Oxyura leucocephala*, IUCN 2006) and the Red-crested Pochard (*Netta rufina*, Madroño et al. 2004) overwinter and breed in its lakes (Paracuellos et al. 1994).

Following Cruz-Pizarro et al. (2003), research on the wetland water quality and limnological dynamics

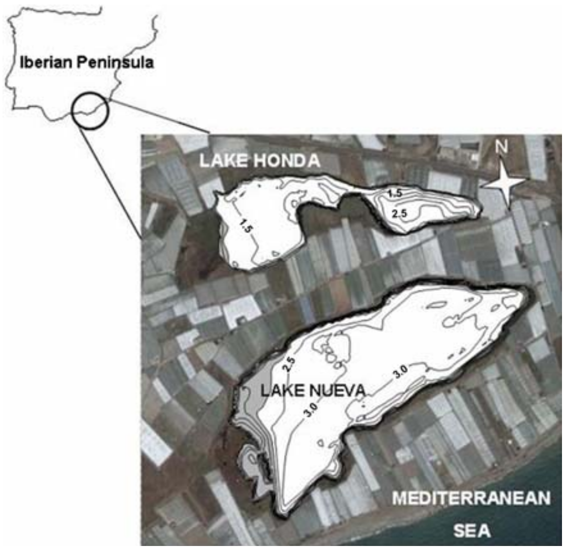

Fig. 1 Location in the Iberian Peninsula (Almería, south Spain) and bathymetric map (depth contours at 0.5 m intervals) of Albufera de Adra wetland. Grey contours represent the area where submerged macrophytes could potentially grow during turbid phases. The lakes are surrounded by a narrow belt (few metres) of *Phragmites australis*

should provide an important tool for the management and conservation of these valuable species. Moreno-Ostos et al. (2007) demonstrated a marked temporal and between-site variability in the development of clear water phases in two shallow lakes within the wetland zone (Lake Honda and Lake Nueva). The study revealed that clear water phases were directly linked with periods of low thermal stability and the dominance of small-edible algae in the phytoplankton community, which allowed a rapid development of the *Daphnia magna* population and the consequent grazing-driven collapse of phytoplankton populations. As a result, enough light reached the lake sediment, which was rapidly colonised by submerged macrophyte populations (*Najas marina* and *Potamogeton pectinatus*) (Paracuellos 2002). In Lake Honda, these conditions occurred during the wet spring 2002, while in Lake Nueva low thermal stability periods resulted from the intense wind-mixing events recorded in spring 2003. The turbid water phase state, which generally dominated these shallow productive lakes, occurred when thermal stability was relatively elevated during spring and large filamentous cyanobacteria governed the phytoplankton community. These turbid phases were characterised by the complete absence of submerged macrophyte populations. These results are in agreement with Scheffer (1998), who demonstrated that the timing of the spring clear water phase can vary quite strongly as a result of annual differences in the weather.

In this article, we add to our results showing that the alternation between turbid and clear water phases also influences the waterbird dynamics in the Albufera de Adra lakes by the control of the macrophyte populations. We explored the relationships between abiotic and biotic characteristics by examining the seasonal changes in water transparency, macrophyte coverage and average abundance of individuals, different clutches and young of waterbirds. Water transparency was measured every 2 weeks using a 20-cm-diameter Secchi disk. Macrophyte coverage (%) was monthly determined from (at least) 60 randomly distributed quadrate sample (1 m by 1 m) observations. Finally, for obtaining the average abundance of waterbird individuals, we made direct censuses of adult and subadult for each species, using binoculars and a telescope at selected points along the edges of the two lakes (Bibby et al. 2000). We made three counts per lake during each season, and used the average value as representative of the whole season. We also quantified the clutches and young per species during the breeding season. We considered only the most abundant and frequently found species i.e. those with more than 20 individuals present during at least one month in the study period and present in the lakes within the spring–summer interval. As a result, just the *Podicipedidae*, *Anatidae* and *Rallidae* dabbling and diving birds were considered. These constitute the dominant guild in the study area (Paracuellos et al. 1994), and are characterised by certain homogeneity in their use of the wetland resources (Nilsson 1978; Savard et al. 1994). Since all the birds included in this study are large and easily detectable, and all the counts were replicated thrice per lake and period, there are few detection errors in our study, and the direct counts showed a high level of accuracy (Tellería 1986; Bibby et al. 2000).

As observed by Rip et al. (2006) in a shallow temperate lake in the Netherlands, the seasonal dynamics of water transparency, and the intense growth and high macrophyte coverage of the lake bottom both in Lake Honda and Lake Nueva were

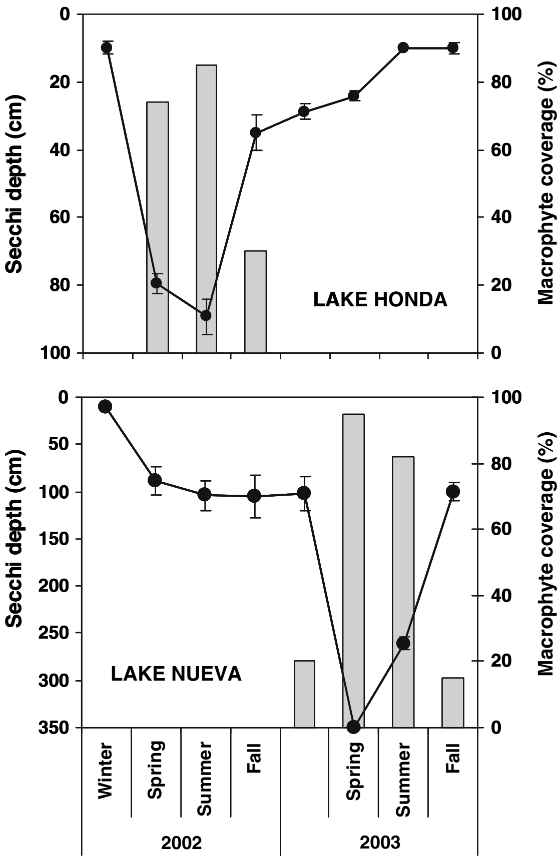

Fig. 2 Seasonal changes in Secchi-disc transparency depth (solid line with ±SD, cm.) and macrophyte coverage (vertical bars, %) in Lake Honda and Lake Nueva during 2002 and 2003

positively and significantly ($p < 0.001$) correlated (Fig. 2) with the occurrence of clear water phases. Throughout the study period, five waterbird species namely Little Grebe (*Tachybaptus ruficollis*), Mallard *(Anas platyrhynchos)*, Red-crested Pochard (*Netta rufina*), White-headed Duck (*Oxyura leucocephala*) and Common Coot (*Fulica atra*) were observed feeding frequently in Albufera de Adra. The waterbirds generally increased markedly when the macrophyte-dominated clear water phase occurred (Fig. 3). The abundance of most species correlated positively with water transparency at a significant level ($p < 0.05$) throughout the whole study period (Table 1). Our results revealed that the birds with higher proportion of herbivorous diet, such as Red-crested Pochard and Common Coot (Perrins and Ogilvie 1998), strongly respond to the alternating clear and turbid water phases, while direct correlations were weak for White-headed Duck and non-significant for Mallard, both these species are characterised by a more omnivorous diet (Perrins and Ogilvie 1998). The Little Grebe is an effective visual predator on small animals throughout the water column. Its visibility to hunt during the clear phases increases, and the elevated faunal biomass associated with the submerged macrophytes (Gregg and Rose 1985) contribute to support higher populations of the waterbird during this state. There are reports of notable relationships between water transparency or plant food supply, and herbivorous waterbird abundance in a variety of shallow lakes (Amat 1981; Kerekes 1994; Perrow et al. 1997).

The greater overall brood recruitment of breeding waterbirds observed in the two lakes when clear phases occur, resulting from a higher food supply for young (Fig. 4), is in agreement with the previously exposed results. In this context, Brinkhof and Cavé (1997) showed that the seasonal variation in the European Common Coot offspring production was, in essence, the result of seasonal variation in food availability, i.e. macrophyte abundance.

Moreno-Ostos et al. (2007) demonstrated that the change from the usual turbid phase to the clear water phase in the Albufera de Adra lakes is caused by complex bottom–up interaction between physical factors such as wind-induced or hydrologically-induced turbulent mixing and planktonic communities. The present study clarifies the impact of such a process on macrophyte populations and waterbird dynamics. The study shows that clear water phases stimulate the development of aquatic plants, which form the food for waterbird populations in the study lakes, influencing both their increased abundance and brood recruitment. Thus, in addition to the beneficial effects of high densities of submerged macrophytes on aquatic ecosystems (Schriver et al. 1995; Van den Berg et al. 1998; Kufel and Kufel 2002; Horppila and Nurminen 2003), the macrophytes also attract waterbirds by providing food and shelter (Noordhuis et al. 2002; Rodríguez-Villafañe et al. 2007). Establishment and/or recolonisation of submerged vegetation in these shallow lakes must be considered as an important management goal to improve the restoration and conservation of these (and probably other) wetlands (Ramsar Convention 1987).

Fig. 3 Seasonal changes during 2002 and 2003 in the abundance of birds: Little Grebe *(Tachybaptus ruficollis)*, Mallard *(Anas platyrhynchos)*, Red-crested Pochard *(Netta rufina)*, White-headed Duck *(Oxyura leucocephala)* and Common Coot *(Fulica atra)* in the Albufera de Adra lakes

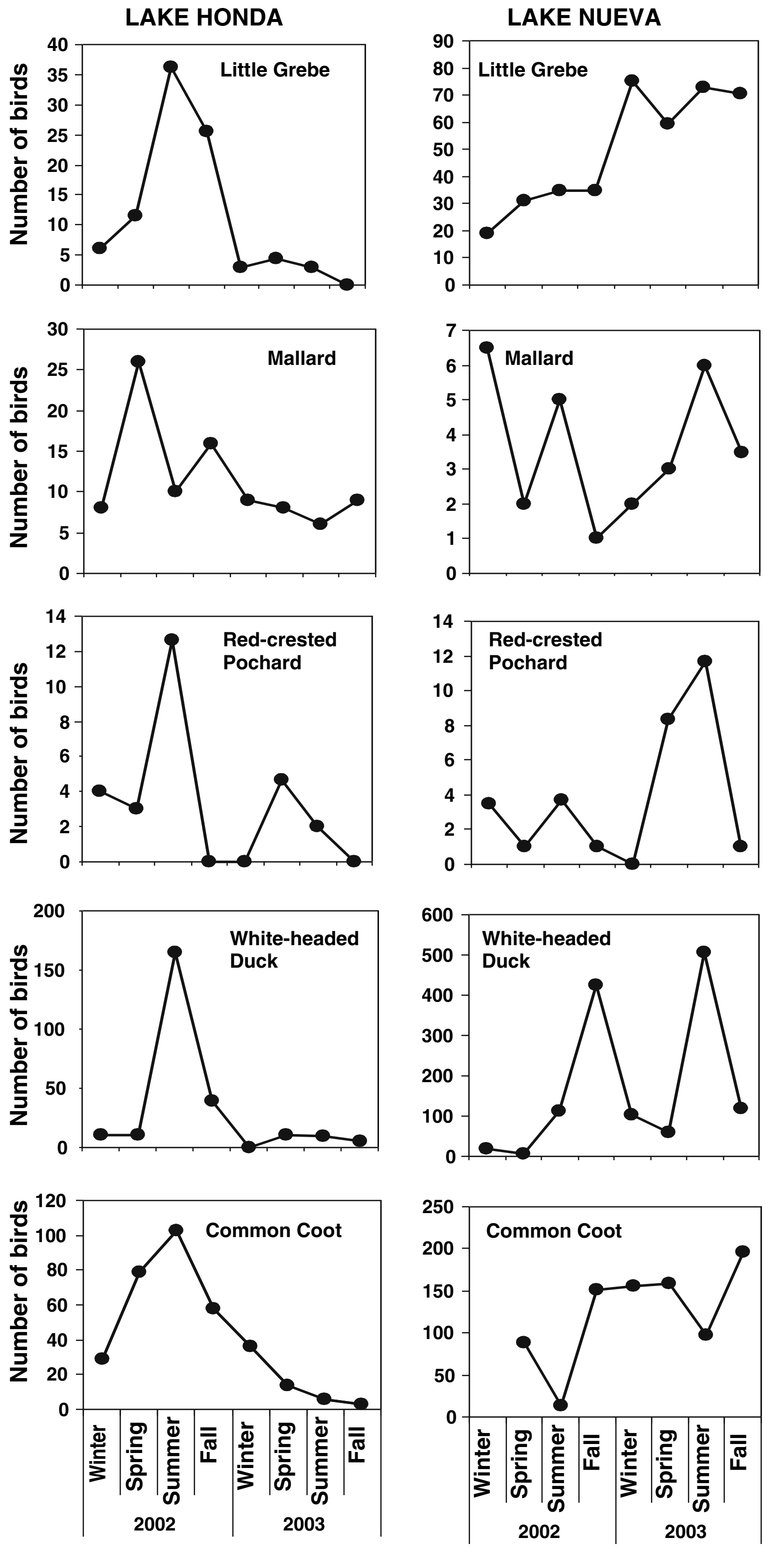

Table 1 Pearson coefficient of correlation computed between water transparency and numbers of Little Grebe, Mallard, Red-crested Pochard, White-headed duck and Common Coot individuals in the Albufera de Adra wetland (Almería, south Spain)

Waterbird species	Pearson coefficient of correlation
Little Grebe (*Tachybaptus ruficollis*)	0.72*
Mallard (*Anas platyrhynchos*)	0.30
Red-crested Pochard (*Netta rufina)*	0.58*
White-headed Duck (*Oxyura leucocephala*)	0.59*
Common Coot (*Fulica atra)*	0.83*

N = 16 in all cases. * Significant regressions at $p < 0.05$

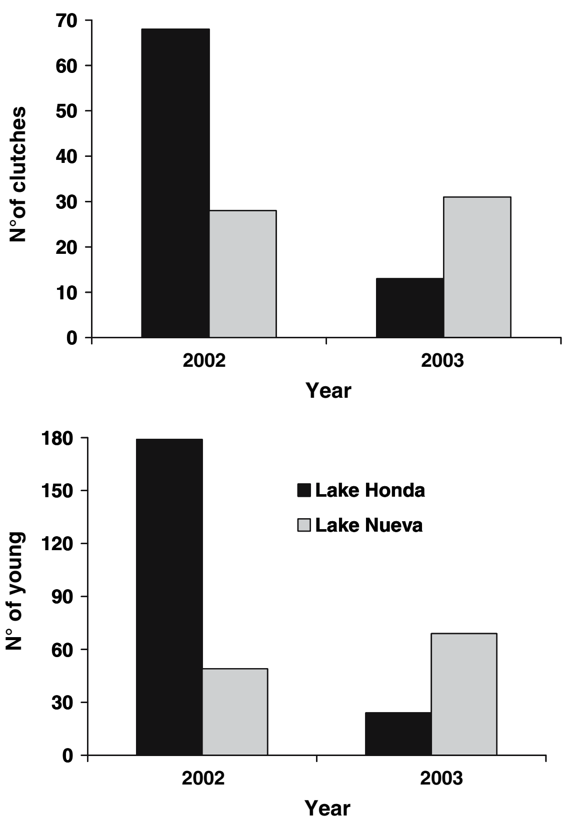

Fig. 4 Total number of the different clutches (top) and young (below) observed for the more abundant dabbling and diving waterbirds (Little Grebe *Tachybaptus ruficollis* + Mallard *Anas platyrhynchos* + Red-crested Pochard *Netta rufina* + White-headed Duck *Oxyura leucocephala* + Common Coot *Fulica atra)* in the breeding periods of 2002 and 2003 in both Albufera de Adra lakes

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