Consequences of fish farming cessation on carrying capacity for ducks breeding on French fishponds

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Abstract

The demise of fish farming is one of several hypotheses proposed to explain the decline of Common Pochard *Aythya ferina* (hereafter Pochard) in Europe. Here we study habitat changes at Pochard breeding sites in Forez, central-eastern France, where traditional fish farming has been abandoned at many ponds since the 1990s. We compared variation in water and sediment physicochemical characteristics in ponds stocked with Common Carp *Cyprinus carpio*, versus ponds abandoned by fish farmers for ≥ 5 years, during early April to July 2016, as well as contrasting development of phytoplankton (measured as chlorophyll a), macrophytes, duck pair density and the brood:pair ratio. Carp stocking (biomass density usually ≥ 200 kg/ha) was associated with elevated June phosphate (PO_4) pond water concentrations and with a decreased nitrogen loading, while PO_4 and nitrogen levels remained stable in abandoned ponds throughout the study period. Carp stocking was also linked to lower phytoplankton density (chlorophyll a) in June and higher macrophyte cover, together with higher diving duck pair density and a higher duck brood:pair ratio. Such results suggest that bioturbation of pond sediment by foraging carp may favour macrophyte development by mobilising sediment phosphorus into pond water, thereby improving primary productivity of the aquatic ecosystem, and thus habitat conditions for ducks breeding at these sites.

Keywords: breeding ducks, carp, fishpond, macrophytes, phosphorus.

Common Pochard *Aythya ferina* is declining in Europe (Fox *et al.* 2016), probably as a result of a decreasing productivity (Folliot 2018). For instance, the brood:pair ratio has declined over the two last decades across all fishpond regions in France, which provide the species' main breeding areas in the country (Broyer 2019). Similar trends reported for Mallard *Anas platyrhynchos* led Broyer (2020) to the hypothesis that consumption of emergent vegetation by Coypu *Myocastor coypus* at these sites was adversely affecting duck nesting habitat. This hypothesis was based on the same trends being observed across regions under different pond management regimes, yet each one had been colonised by the Coypu during the 1990s. There was however an exception in Forez (central-eastern France) where many ponds were abandoned by fish farmers during the 1990s, and where the brood:pair ratio declined for Pochard but not for Mallard. The objective of this study therefore was to analyse the consequences of the abandonment of fish farming in Forez on pond use and breeding success by ducks in the region.

The presence or absence of stocked fish theoretically could affect primary productivity in a pond, because foraging Cyprinids may elevate: 1) phosphorus concentration in water by stirring up pond sediment, and 2) nitrogen concentration through excretion (Lamarra 1975; Breukelaar *et al*. 1994; Driver *et al*. 2005; Chumchal *et al*. 2005). In principle, fertilisation of fishponds may benefit breeding ducks (Broyer & Curtet 2011; Broyer & Bourguemestre 2020), but on the other hand Cyprinids may also trigger a shift from a clear water state dominated by submerged macrophytes to a turbid state dominated by phytoplankton (Matsuzaki *et al*. 2007; Adàmek & Marsàlek 2013; Francová *et al*. 2019), thereby adversely affecting duck habitat. In Forez, the observed density of duck pairs increased between 1992 and 2012, perhaps reflecting a short-term effect of reduced competition between fish and waterfowl, in the absence of high carp density following the cessation of fish farming (McEadie & Keast 1982; Hill *et al*. 1987; Winfield & Winfield 1994). Lower duck pair densities and brood:pair ratios however were subsequently recorded (in 2013–2015) at ponds without stocked fish (Broyer *et al*. 2017).

In 2016, the physico-chemical characteristics of water and sediment, macrophyte development, and the abundance of duck pairs and broods, were recorded for two pond groups – either stocked with fish, or abandoned by fish farmers for ≥ 5 years – to compare pond conditions in relation to duck occurrence and breeding success. Macrophyte development was considered both as an indicator of favourable trophic status of the aquatic ecosystem (Blindow *et al*. 1993; Scheffer *et al*. 1993; van Donk *et al*. 1993) and, more specifically, as an important component of waterfowl habitat during the breeding season. In French fishponds, for instance, the biomass of invertebrate-prey available for breeding ducks in macrophytes was found to be optimal when the vegetation covers ≥ 20% of pond surface area (Broyer & Curtet 2010).

Methods

The Forenz study region (45°44'N 4°13'E), with its 250 fishponds, was traditionally productive for aquaculture, but fish farming activity started to decline from the 1990s, continuing through the 2000s and into the early 2010s. A growing proportion of fishponds were no longer stocked with fish, or the fish were not harvested annually. The Forez region is also a major breeding area for ducks in France, with important populations of Pochard, Mallard, Gadwall *Anas strepera*, Tufted Duck *Aythya fuligula*, Red-crested Pochard *Netta rufina* and Garganey *Anas querquedula*, whilst Common Teal *Anas crecca* and Shoveler *Anas clypeata* breed there more rarely.

Data were collected from 18 ponds, of which eight had been abandoned by fish farmers for ≥ 5 years (FFO ponds; mean ± s.d. surface area = 6.1 ± 4.8 ha), and 10 were still regularly stocked with fish (FF1 ponds; mean surface area = 5.9 ± 3.1 ha). All water bodies included in the study were located within a limited area (60 km^2), with no evidence of a spatial pattern in abandonment. The main objective of the analysis was to compare concentrations of dissolved nutrients in water, phytoplankton density, macrophyte cover and duck abundance, between the two fishpond categories: with (FF1) and without (FF0) stocked fish.

Fish farming in French fishponds is dominated by Common Carp *Cyprinus carpio* production. In Forez, large amounts of phosphorus, in the form of industrial residues, were added to ponds from the 1930s to the 1980s to increase pond productivity (Robin 1999). Traditionally, Forez fishponds therefore were highly productive (yielding 400 kg/ha of fish each year). Nowadays however, fish biomass yields vary between 200–400 kg/ha. To provide a quantitative contrast between the two pond categories, the abundance of fish was measured for a subset of ponds included in the study – four abandoned ponds and one fishpond stocked with fish, selected at random – which were sampled by the Technical Service of the "Fédération de la Loire pour la Pêche et la Protection du Milieu Aquatique". Fish samples were caught in May in each of the ponds, by hauling a 50 m × 2 m net (35 mm mesh) through the water over a total surface area of 300 m^2. Each caught individual was identified, measured, weighed and released into the same pond.

Pond water was collected from each pond, using a 5-litre water sampler on four successive dates: 1) between 30 March 2016 and 6 April 2016, 2) 4 May 2016, 3) 8 June 2016, and 4) 20 July 2016. The water samples were analysed by the Laboratory CARSO in Vénissieux (Rhône Department) to measure the dissolved orthophosphate (PO_4), Kjeldahl nitrogen and chlorophyll a levels in the water. We also described physicochemical characteristics of pond sediment from sediment samples collected in March 2016 (*i.e.* before the early growth of aquatic vegetation), using a Van Veen dredge to take a 5–7 cm layer from three different parts of each pond (usually at the upper extremity of the water body, near the main water inflow area where sediment accumulation occurs). The three sediment samples per pond were pooled prior to analysis by the Laboratory CESAR in Cézeyriat (Ain), which tested for pH, exchangeable calcium and phosphorus, total Kjeldahl nitrogen and organic carbon.

Macrophyte cover (measured as the percentage of the pond's surface area) was assessed along five transects across the entire width of the ponds. Floating and submerged vegetation density was measured within 4–8 (depending on pond size) 2 m × 2 m quadrats per transect. Data on macrophyte cover are however missing for one of the FF0 ponds (resulting in $n = 7$ for this variable) and for two of the FF1 ponds ($n = 8$).

Duck adults and broods were censused every week from mid-April to the end of July, by one comprehensive, very slow, scanning of the entire pond area with a ×40 telescope. Observations were limited to mornings and late afternoons to avoid the hottest time of day, when the birds may seek shelter within vegetation cover. The time spent on each pond was proportionate to the surface area surveyed (scan length) and to the abundance of aquatic vegetation likely to constitute visual obstacles (scan slowness). Pairs, isolated adults and groups of Pochard, Tufted Duck, Red-crested Pochard, Mallard and Gadwall were counted separately and brood size and age were recorded systematically for each species. Duckling age was assessed according to Fournier & Cordonnier (1982).

Data analysis

Large groups of males, females or both sexes were excluded from the assessment of the number of duck pairs per pond. For each weekly count at each pond, we added to the number of duck pairs observed, either lone females, or males alone and in small groups (< 5), and used the highest total number ("pairs + females" or "pairs + males") as the measure of duck pairs present at the site. As a rule, the total number of pairs estimated for each pond corresponded to the highest number recorded at least three times across the study period (April 15–May 25, *i.e.* over at least 5 visits). We also calculated for each pond category an index of nesting success, by dividing the number of different < 4 week-old broods observed by the total number of pairs, to generate an overall value of the brood:pair ratio for each of the pond categories. To standardise pair abundance across ponds of differing sizes, we transformed pair numbers into densities by dividing pair numbers by the square root of the surface area of the pond (for details, see Broyer *et al.* 2017).

The study does not aim to explain the variation in duck abundance or breeding success, which may be influenced by parameters not included in the analysis. The objective here was to investigate the hypothesis of different physicochemical conditions between ponds with and without fish stocking, potentially leading to contrasting development of aquatic vegetation, which may have consequences for ducks breeding at these sites. The data were analysed graphically and statistically, using linear regression, Mann–Whitney and Wilcoxon signed-ranked tests.

Results

Fish presence in abandoned ponds

The total biomass of Common Carp sampled in the pond stocked with fish was 7.007 kg (9 individuals, mean ± s.d. total body length = 335.6 ± 128.9 mm, range = 150–600 mm), which corresponds to 231 kg/ha. Including other fish species (*e.g.* Tench *Tinca tinca* and European Perch *Perca fluviatilis*) gave a total biomass of 344 kg/ha. In contrast, at the four abandoned ponds, the numbers of carp caught were respectively: 0 individual, 1 individual (350 mm), 1 individual (490 mm), 2 individuals (550 and 700 mm). The presence of other fish species in abandoned ponds was somewhat anecdotal – *e.g.* one pike *Esox lucius* 860 mm in length was reported in one pond – except for another pond where shoals of small-sized Stone Moroko *Pseudorasbora parva*, Brown bullhead *Ictalurus nebulosus*, Pumpkinseed *Lepomis gibbosus* and Common Rudd *Scardinius erythrophtalmus* were recorded.

Physicochemical characteristics of sediment and water

The two pond categories did not differ in the organic carbon, phosphorus or nitrogen content of the sediment (Mann–Whitney tests: $Z < 0.3$, $P > 0.35$, n.s. in each case). Calcium content tended to be higher in FF0 ponds, but differences did not attain statistical significance (3.7 ± 2.2 mg/l *vs.* 2.1 ± 1.2 in FF1 ponds, $Z = -1.688$, $P = 0.09$, n.s.), and there were no observed differences in pH values (5.7 ± 0.3 *vs.* 5.7 ± 0.8).

Nitrogen content in the water was quite stable throughout the study period in the FF0 ponds but tended (albeit not statistically significant) to decrease in FF1 ponds, for instance on comparing April with June (Wilcoxon test: $Z = -1.887$, $P = 0.059$, Fig. 1). Orthophosphates remained low in FF0 ponds, but increased between April and June in FF1 ponds (Fig. 2), so that PO_4 concentrations of > 0.15 mg/l in June were recorded in only one FF0 pond (12.5%,

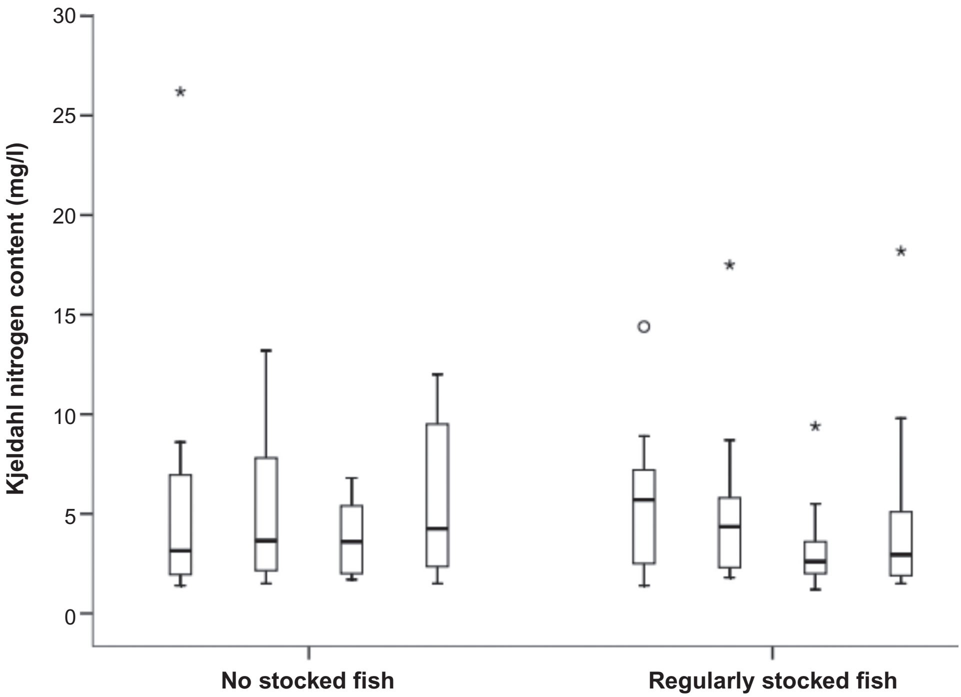

Figure 1. Changes in Kjeldahl nitrogen levels recorded in water samples over the study period taken from two pond categories: without ($n = 8$) and with ($n = 10$) stocked fish, in Forez, central-eastern France. From left to right: early April, 4 May, 8 June and 20 July 2016. Note: symbols above the bars indicate outliers.

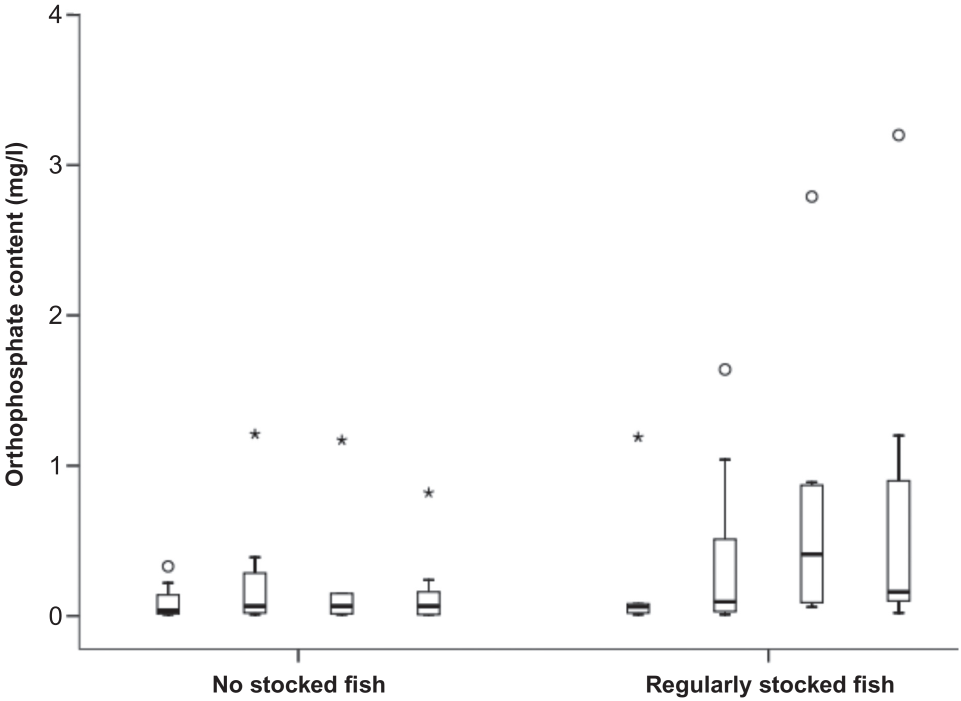

Figure 2. Changes in orthophosphate loading in water samples over the study period taken from two pond categories: without (n = 8) and with (n = 10) stocked fish, in Forez, central-eastern France. From left to right: early April, 4 May, 8 June and 20 July 2016. Note: symbols above the bars indicate outliers.

n = 8) against seven of the FF1 ponds (70.0%, n = 10). The difference between FF0 and FF1 ponds was statistically significant in June (Mann–Whitney test: Z = –2.091, P = 0.037) while being not significant in April or in May (Z = –0.63, P = 0.53, n.s. in both cases). The orthophosphate levels in the water in June correlated with the phosphorus content of the sediment for FF1 ponds (linear regression: $F_{1,9}$ = 6.416, P = 0.035), but not for FF0 ponds ($F_{1,7}$ = 0.000, P = 0.997, n.s.).

Biotic factors

Chlorophyll a levels in the water decreased after April, probably as an effect of the clear water phase, reaching their lowest values in May for FF0 ponds, and in June for FF1 ponds (Fig. 3). In June, chlorophyll a therefore was significantly higher in the FF0 ponds (Mann–Whitney test: Z = –2.497, P = 0.013), and macrophyte cover (which develops mainly in June) was higher at the FF1 than the FF0 ponds at that time (Z = –2.605, P = 0.009, Fig. 4).

Diving duck pairs (*i.e.* Pochard, Tufted duck and Red-crested Pochard as a group) had higher densities in ponds where fish were regularly stocked in comparison with the unstocked ponds (Mann–Whitney test: Z = –2.107, P = 0.03, Fig. 5), but the difference was not significant for dabbling

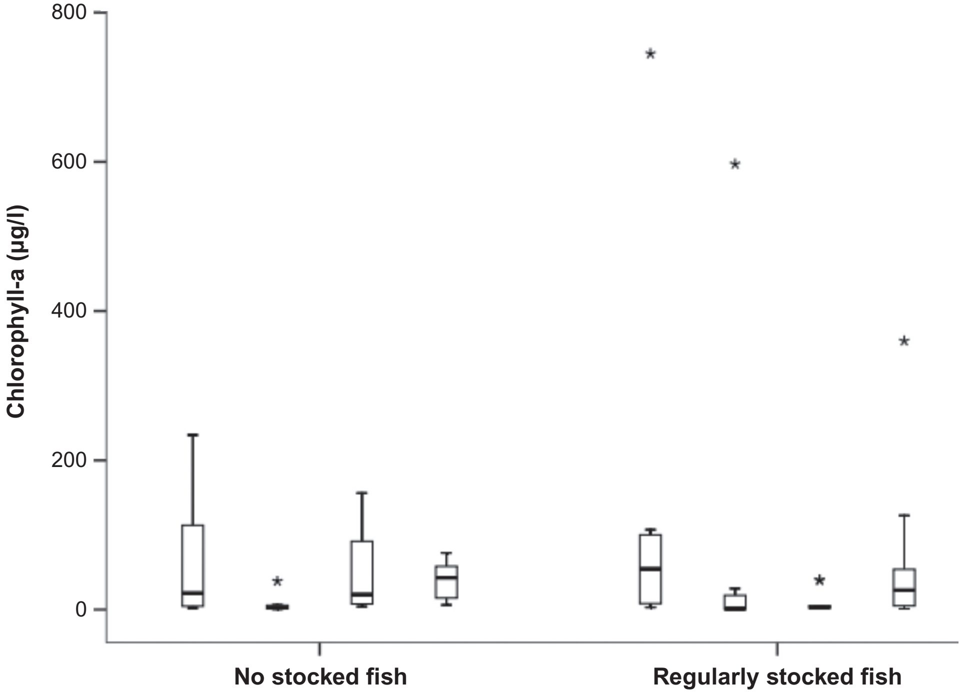

Figure 3. Changes in Chlorophyll a recorded in water samples over the study period taken from two pond categories: without (*n* = 8) and with (*n* = 10) stocked fish, in Forez, central-eastern France. From left to right: early April, 4 May, 8 June and 20 July 2016. Note: symbols above the bars indicate outliers.

ducks (*i.e.* the Mallard and Gadwall) (Z = –0.454, P = 0.65, n.s.). This may perhaps be ascribed to the correlation between diving duck pair density and macrophyte cover (linear regression: $F_{1,13}$ = 9.726, P = 0.008, Fig. 6). Moreover, the brood:pair ratio (for diving and dabbling ducks combined) was 0.88 in FF1 ponds (*n* = 107 broods in 10 ponds) *vs.* 0.23 in FF0 ponds (*n* = 8 broods in 8 ponds).

Discussion

Higher orthophosphate concentrations found in the water of ponds stocked with fish in June, in comparison with unstocked ponds, possibly indicates an effect of carp on nutrient dynamics, as their foraging activity becomes more intense during the spring. According to Lamarra (1975), a carp population at a biomass level of 200 kg/ha can internally load a lake with orthophosphate at 0.52 mg P/m^2/day and this threshold corresponds to the lowest density of carp biomass usually harvested annually by fish farmers in Forez. Previous studies have reported that sediment bioturbation by carp has a negative effect on nutrient enrichment of water, with a correlative shift from clear water state and developed macrophyte stands to more turbid waters dominated by micro-algae (Philips *et al.* 1978; Meijer *et al.* 1994;

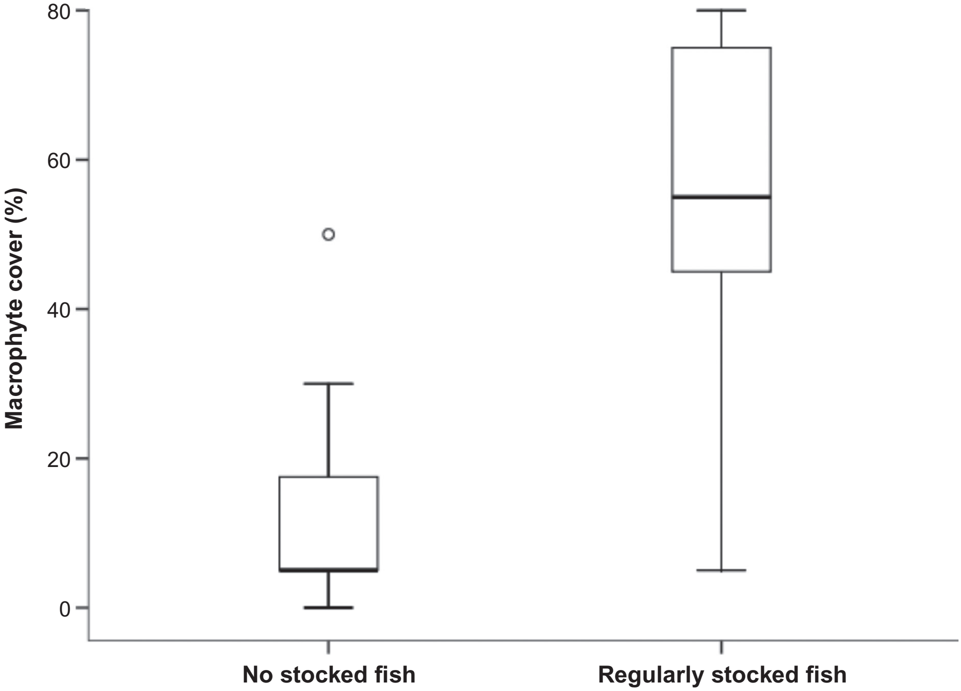

Figure 4. Macrophyte cover recorded in June 2016 for the two pond categories: without (n = 7) and with (n = 8) stocked fish, in Forez, central-eastern France. Note: symbol (○) above the bar indicates an outlier.

Kleeberg *et al.* 2013; Tarkowska-Kukuryk 2013). Søndergaard *et al.* (2007) have however pointed out that this effect of benthivorous fish is characteristic of the nutrient rich shallow lakes of Denmark and the Netherlands. Moreover, Pokorny and Pechar (2000) described the progressive nutrient enrichment of Czech fishponds across the 20th century, with an initial phase of macrophyte increase at moderate nutrient levels and a subsequent period of macrophyte decline with increasing eutrophication of the water bodies. In the Forez ponds, higher chlorophyll a and lower macrophyte development were recorded for those without stocked fish, in which the orthophosphate loading was lower in June. These contrasted results may reflect the hump-shaped pattern proposed for relationships between biodiversity and productivity in aquatic ecosystems (Dodson *et al.* 2000; Mittelbach *et al.* 2001).

Submerged macrophytes obtain phosphorus both from the surrounding water and from the substrate. Only during a short period in June when the shoot biomass is high, is the uptake of phosphorus by shoots in the water greater than the uptake by roots in the sediment (Graneli & Solander, 1988). Consequently in the Forez ponds, increasing orthophosphate concentrations in the water in June coincide chronologically with the nutrient needs of growing plants, with a corresponding

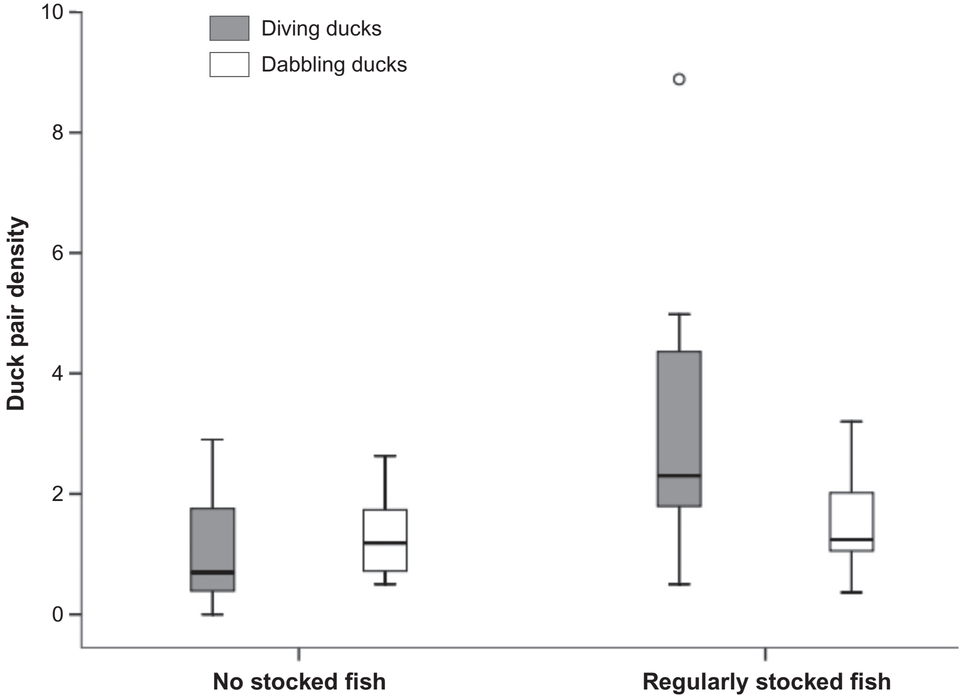

Figure 5. Density of duck pairs (number of pairs divided by the square root of the surface area of the pond) recorded for two pond categories: without (n = 8) and with (n = 10) stocked fish, in Forez, central-eastern France, in 2016. Note: the symbol (○) above the bar indicates an outlier.

decrease of nitrogen loading possibly linked to a mobilisation for plant growth. The decrease in chlorophyll a during a clear water period in May was observed both in ponds with and without stocked fish. Chlorophyll a levels did recover in June, but only in ponds that had not been stocked with fish, perhaps reflecting stronger competition for nutrients between more developed macrophytes and phytoplankton in the ponds with carp (Scheffer *et al.* 1993; Jeppesen *et al.* 1997; Søndergaard *et al.* 2007).

Declerck *et al.* (2005) postulated that the unimodal richness responses to phosphorus which are frequently reported for many organism groups in the literature, may be partly mediated by the unimodal response of macrophyte vegetation to lake productivity. This theory was supported in this study by the higher density of diving duck pairs and the higher duck brood:pair ratio recorded for the FF1 ponds, which also had higher macrophyte development. The higher brood:pair ratio indicates either better nesting success for pairs breeding at the ponds, or that the pond provides more favourable conditions for ducklings and therefore attracts broods coming from neighbouring ponds, or a combination of both factors. In the extensively managed and usually unfertilised Forez fishponds, the presence of carp seems to improve pond

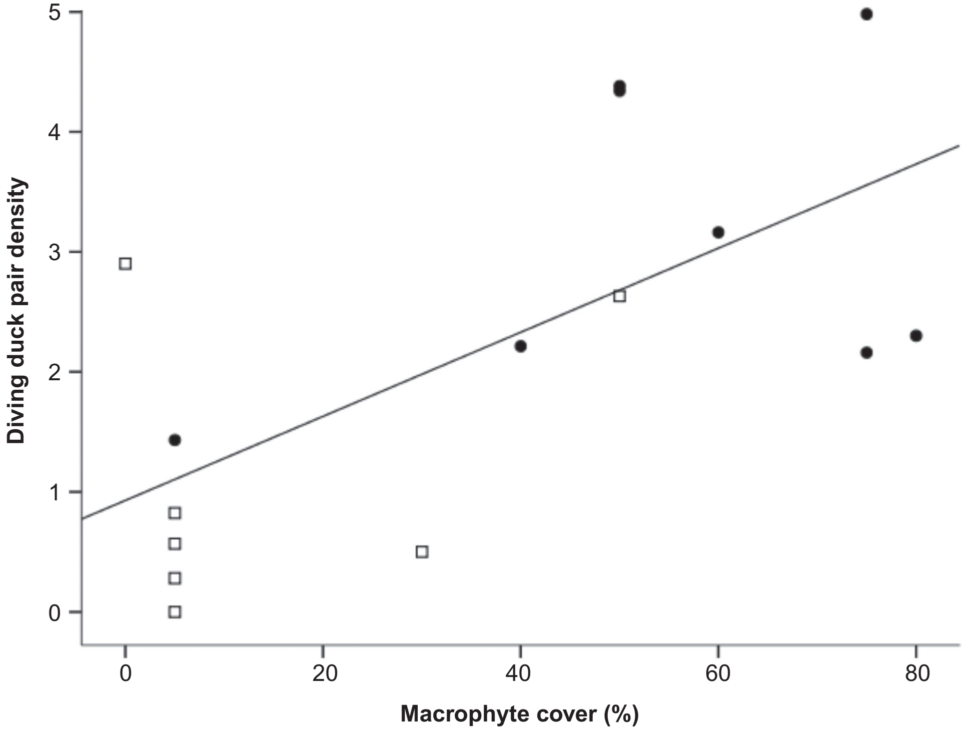

Figure 6. Relationship between macrophyte cover and diving duck pair density in Forez, central-eastern France, in 2016. White squares = FF0 (unstocked) ponds; black dots = FF1 (stocked) ponds.

carrying capacity for diving ducks, especially since, in French fishpond systems, invertebrate biomass density within macrophyte stands tends to increase with higher trophic levels (Broyer & Calenge 2010). This result may contribute to understanding the observed decrease in duck breeding densities following the cessation of fish farming (Broyer *et al.* 2016, 2017), and help contribute towards understanding the main reasons for the ongoing decline of Pochard in Europe.

Acknowledgements

The authors thank J. Marcoux and M. Celette for their contribution to the fieldwork, and E. Rees and two anonymous referees for helpful comments on the manuscript.

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