A new role for pond management in farmland bird conservation

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ABSTRACT

1. Biodiversity declines in agricultural landscapes represent a major conservation challenge. In the UK, some agricultural landscapes contain high pond densities, but many farmland ponds have become terrestrialised since the 1960s, with input of organic material resulting in a decrease in the size and depth of ponds that eventually transform into wet woodland habitats. Pond management, including removal of overhanging scrub and sediment, has proven highly effective in enhancing freshwater biodiversity. However, the implications of this management for farmland bird assemblages are unknown.

2. Bird surveys were undertaken at recently managed, open, macrophyte-dominated and at highly terrestrialised, macrophyte-free ponds in the intensively cultivated farmland of North Norfolk, UK. The diversity, abundance and composition of bird assemblages visiting these ponds were compared to determine responses to pond management by tree and mud removal.

3. Avian species richness, abundance and bird-visit frequencies were all higher at open farmland ponds. The observed patterns of bird occurrence were best explained by management-induced reductions in tree shading that resulted in aquatic macrophyte-dominance likely associated with high emergent invertebrate prey abundance. Moreover, we predict that open-canopy ponds offer greater habitat heterogeneity than overgrown ponds, allowing diversified bird use. Overgrown, terrestrialised ponds were preferred by some woodland bird species. Gamma diversity across the entire pondscape exceeded all individual pond alpha diversity measures by an order of magnitude, suggesting distinct

variation in the bird assemblages visiting farmland ponds during different successional stages.
4. Pond management that generates a mosaic of pond successional stages, including open-canopy, macrophyte-dominated ponds, could help to address the long-term decline of farmland birds. We strongly advocate increased agro-ecological research in this field, combined with greater emphasis on ponds and pond management options in agri-environment schemes.

Keywords: Agri-environment schemes, agro-ecosystems, avian diversity, biodiversity decline, farmland pondscapes, habitat heterogeneity.

1. INTRODUCTION

Landscapes in many parts of the world are dominated by farmland (Foley et al. 2005, Scherr & McNeely 2008). Accordingly, agricultural landscapes have attracted substantial attention from the conservation research community. Historically, agricultural landscapes represented a highly dynamic habitat mosaic characterized by substantial spatio-temporal variations in environmental conditions (Chamberlain et al. 2000, Bennett et al. 2006). The resulting heterogeneity, at both local and regional scales, has been recognised as a primary factor underpinning historical agricultural landscape biodiversity (Benton et al. 2003, Tscharntke et al. 2005, Fahrig et al. 2011). Accordingly, increases in agricultural intensification and associated agricultural habitat homogenization from the 1940s onwards, in combination with encroachments on remaining non-agricultural habitats, have resulted in a marked biodiversity reduction across the European countryside (Fuller 2000, Ford et al. 2001, Robinson & Sutherland 2002, Burel et al. 2004, Stoate et al. 2009, van Zanten et al. 2014).

Nearly 120 European bird species of conservation concern use lowland farmland habitats as either breeding or wintering habitat. A number of conservation priority species like the song thrush *Turdus merula*, yellowhammer *Emberiza citrinella* and reed bunting *Emberiza schoeniclus*, additionally rely on non-crop structures such as meadows, scrubland, woodlands, hedgerows and individual trees in agricultural landscapes as foraging, breeding and nesting sites (Whittingham et al. 2009, Marja & Herzon 2012). Other birds such as skylark *Alauda arvensis* and grey partridge *Perdix perdix* are strongly affected by the quality of cropped habitats and marginal habitats such as fallows and rough ground. Some 83% of European farmland bird species have undergone declines in abundance between 1970 and 1990 as a result of agricultural intensification. For 86% of these species, reductions were significant, and these trends have continued into the 21st century (Fuller et al. 1995, Donald et al. 2001, Barker 2004, Holland 2004, Butler et al. 2007, Baillie et al. 2014). Threats identified as affecting conservation priority bird species include the loss of old hedgerows, permanent pasture and scrub on farmland, changing sowing regimes, loss of variation in grassland swards, declines in abundance and diversity of insect prey, and reductions in seed resources linked to land-use changes and pesticide use (Chamberlain et al. 2000, Hinsley & Bellamy 2000, Perkins et al. 2000, Donald et al. 2001, Benton et al. 2002, Barker 2004, Holland 2004).

While a range of approaches to enhance the farmed environment for wildlife have been taken in the UK and across Western Europe, many bird species populations have failed to recover (Donald et al. 2006). Declining UK Biodiversity Action Plan (BAP) species (JNCC 2007) include skylark, starling *Sturnus vulgaris,* grey partridge and yellow wagtail *Motacilla flava* (Eaton et al. 2013). Aerial insectivorous birds associated with agricultural environments, such as swift *Apus apus* and house martin *Delichon urbicum*, have also shown steep population declines across industrialised European countries (Benton et al. 2002, Rioux Paquette et al. 2014). With farmland bird declines surpassing those in all other environments, serious concerns amongst both the scientific community and the general public have been raised. Currently, the main approach for counteracting farmland bird declines in Europe is the widespread adoption of agri-environment schemes (AES), such as the English Countryside Stewardship Schemes, but these have afforded limited success thus far for agricultural biodiversity (Kleijn et al. 2006, 2011, Baker et al. 2012).

A number of studies have concluded that agricultural management approaches that increase the heterogeneity of the agricultural mosaic will enhance overall species richness across many taxonomic groups at the landscape scale, while simultaneously improving ecosystem services and minimising agricultural yield losses (Pino et al. 2000, Atauri and de Lucio 2001, Weibull et al. 2003, Doxa et al. 2010, Sabatier et al. 2014). Soininen et al. (2015) stressed the importance of aquatic habitats for conservation, not only for aquatic organisms, but also for terrestrial species due to the contribution of potential cross-system subsidies from freshwater ecosystems which enhance terrestrial ecosystem functioning. Small wetlands, and especially ponds, may therefore play a crucial role in improving both aquatic and terrestrial biodiversity at the landscape scale, while also serving to increase habitat heterogeneity (Williams et al. 2004, Davies et al. 2008, Céréghino et al. 2008, Lemmens et al. 2013).

Ponds are of particular significance to biodiversity conservation in agricultural landscapes, forming habitat islands for a wide range of aquatic and semi-aquatic organisms in an otherwise species-poor environment (Declerck et al. 2006, Davies et al. 2008, Ruggiero et al. 2008). Unfortunately, many farmland ponds are threatened by in-filling (via land reclamation) and pollution due to agricultural intensification (Wood et al. 2003, Biggs et al. 2005, Céréghino et al. 2014). In addition, as a consequence of the general cessation of traditional pond management practices over the last 30-40 years (Sayer et al. 2013), a high proportion of UK farmland ponds have undergone terrestrialization, with the accumulation of litter and other organic material over time resulting in a decrease in pond size and depth. Many ponds also become increasingly encroached by woody vegetation and eventually transform into wet woodland, while in the absence of shrub and tree encroachment, pond succession can lead towards fen-swamp habitats. Indeed, in many areas, overgrown, tree-shaded ponds are overwhelmingly dominant, resulting in sharp declines in landscape-scale aquatic diversity (Sayer et al. 2011; 2012). Approaches to combat widespread terrestrialisation include the creation of new ponds through initiatives such as the UK Million Ponds Project (Williams et al. 2010). As an alternative, existing, overgrown farmland ponds can be managed and restored via the removal of encroaching trees, scrub and accumulated pond sediment. The latter process effectively 'resets' succession thereby increasing the quality and quantity of open water habitats. Sayer et al. (2012) determined that macrophyte and invertebrate diversity was greatly enhanced in a managed pondscape comprising a mosaic of ponds at different successional stages set in an intensively managed agricultural landscape. Diversity patterns were strongly driven by degree of shading, with agricultural ponds previously deficient in macrophytes becoming macrophyte–dominated after management, providing habitat for a diverse array of species. Currently, both the UK Countryside Stewardship Scheme (CS) and Glastir Land Management Scheme for Wales offer options for maintaining and buffering ponds on farmland (Welsh Government 2015, Natural England 2015). Nonetheless, pond management itself is only included as a higher tier option within CS, and overall pond management remains relatively poorly promoted within UK AES.

While the influence of pond management on aquatic species assemblages is now established (Gee et al. 1997, Sayer et al. 2012), the links between pond management and the terrestrial environment have been comparatively neglected. Farmland ponds generally harbour substantial numbers of aquatic macroinvertebrates whose adult aerial stages are known to constitute an important food resource for nesting and fledging birds (Newton 1998, Baxter et al. 2005, Richardson et al. 2010, Schummer et al. 2012, Stenroth et al. 2015), and wintering waterbirds (Matuszak et al. 2014). In addition, mixed grassland margins around open ponds may increase the availability and diversity of broad-leaved plants and seeds utilised as a food resource by granivores (McCracken & Tallowin 2004); we believe that these open pond margins are of high importance to birds.

We examine the value of a set of open, managed ponds and overgrown, non-managed ponds for bird communities in the intensively farmed agricultural landscape of North Norfolk, Eastern England. We predict that the benefits of pond management will strongly affect terrestrial organisms, as exemplified by the farmland bird community. The term ‘farmland bird’ in this context is used to encompass any species encountered within the agricultural landscape. This includes waterfowl, reed-nesting species, ground-nesting species and birds of prey, as well as open-country, woodland, scrubland and grassland bird species. We hypothesize that managed, macrophyte-dominated ponds attract a greater diversity of bird species than unmanaged, overgrown ponds, since they not only provide a higher diversity and abundance of emerging invertebrates and greater seed provision subsidy, but also increase habitat heterogeneity in the farmland landscape through provision of vegetated water and wet reed/sedge-dominated margins. We furthermore hypothesize that overgrown ponds primarily act as woodland habitat islands, occupied predominantly by woodland bird species. We finally hypothesize that bird assemblages use open and overgrown ponds for different activities in accordance with variations in habitat preference and food availability.

2. METHODS

2.1 Study Site

This study was conducted at four adjacent, intensive, mixed arable and cattle farms located between the villages of Melton Constable, Stody and Briston in North Norfolk (Fig.1). Most ponds in this region were created either for marl extraction or livestock watering between the 17th and 19th centuries (Prince 1964). Of the ~60 small ponds (<20 in diameter) in the ~10km^2 study area, a total of 22 ponds on privately owned farmland were selected for this study, thus allowing us to cover ~36.6% of the pondscape. Selected ponds included 11 open canopy ponds with generally high submerged and fringing aquatic macrophyte cover (Fig.2a, b) and 11 closed-canopy, overgrown ponds dominated by living and fallen trees of *Prunus spinosa*, *Salix* spp. and *Alnus glutinosa,* where aquatic plants were largely absent (Fig.2c). All the ponds located in arable fields were surrounded by grassland buffers of at least 7 m width installed as part of Higher Level Stewardship (HLS) agreements.

The open canopy ponds were located at Manor Farm, Briston. Since the 1960s, most ponds at Manor Farm have been subject to a pond management programme comprising periodic scrub and pond sediment removal undertaken at two to four ponds each year with the aim of arresting terrestrialisation. This approach has created a mosaic of ponds varying in terms of degree of scrub encroachment and macrophyte cover. The resulting managed pondscape at Manor Farm is host to species-rich aquatic communities that include at least 16 breeding dragonfly species and the threatened Great Crested Newt, *Triturus cristatus*, which breeds in around 28 of the 40 ponds (Sayer et al. 2012, Sayer et al. 2013). Moreover, the pondscape supports species-rich (n=24) communities of aquatic plants with frequent dominance of *Potamogeton natans* in open water and fringing emergent vegetation typically including *Sparganium erectum*, *Typha latifolia* and *Epilobium hirsutum*.

2.2 Field surveys

All ponds included in the study were assigned an individual code depending on their location (Manor Farm ponds – W, Stody ponds – S, Daniel’s Farm ponds – D, Melton Constable ponds - M) (Fig.1). Bird surveys were carried out at 11 managed, open ponds at Manor Farm, (W1-W37) and 11 late succession, overgrown ponds on surrounding farmland in the Stody/Hunworth/Melton Constable area (M1, D6, S4-S15). Most ponds formed isolated habitat “islands” on arable cropland or within cattle pastures where livestock were present at the time of the study (W1, W34, W37, S15). A number of ponds were along field boundaries and connected to hedgerow corridors (W34, W37, S4, S13, S15). On two occasions, ponds were situated within fields adjacent to patches of woodland (W1, M1). Three connected open-canopy ponds on Manor Farm were included in this study as a single pond complex, and thus are treated as one pond, termed the W22, 23, 24 cluster.

In June 2014, each of the 22 ponds was visited on five separate occasions, resulting in a total of 110 pond visits. Surveys were conducted during early mornings (5-10 am) and in good weather conditions, to avoid bias from lowered bird activity during periods of wet weather. Visit order was also randomized to avoid survey bias relating to time of day. During each individual pond visit, all birds encountered by sight, song or call were recorded over a set period of 20 minutes. Additional information recorded included the location of each bird individual on or around the pond (e.g. open water, surrounding vegetation, grassland buffer, stands of aquatic macrophytes) and bird behavioural activities: foraging, travelling, sheltering, vocal display, territorial behaviour, group behaviour and parental behaviour (including the provisioning of chicks). The activities and location of bird species for both pond types were subsequently compared by independent samples t-tests to determine differences in behaviour and habitat choice at open and overgrown ponds. Surveys were conducted at a location maximizing the visibility of the open pond surface area and the surrounding vegetation while minimizing disturbance (Bibby et al. 1992). Active searches were also carried out around the circumference of each pond so that particularly large or obstructed sites could be viewed from different angles. All individual birds observed in or around the pond (up to 10 m away), including at directly adjacent trees, shrub and surrounding grassland buffer strips were recorded. Birds flying above the pond were also included, provided that they showed aerial feeding behaviour or flew low over the open water/tree canopy. Where possible, all encountered birds were identified to species level and subsequently grouped into 'guilds' based on avian family, diet (granivorous, insectivorous) and habitat preference (open country, scrubland, woodland, wetland, ground-nesting, reed nesting). In some instances, where sightings were very brief, distinguishing similar, closely-related species resulted in a high risk of misidentification. Species affected were the warbler genera *Phylloscopus* (chiffchaff/willow warbler), *Sylvia* spp. (garden warbler/blackcap), *Anas* spp. (mallard/gadwall) and *Motacilla* spp. (grey/yellow wagtail). Due to habitat preferences and species abundances, it was assumed that the respective unidentified female wagtails were yellow wagtails and female ducks were mallards, whereas in the other two cases, we combined all counts for the sets of two species and treated them as "super-species" in the statistical analysis.

Environmental data for each pond, including pond circumference, % pond surface shaded by trees, % pond circumference covered by trees, % coverage of pond surface by emergent (fringing) macrophytes and % coverage by submerged/floating-leaved macrophytes (assessed visually) were collected in 2012 and 2014. All aquatic plants were recorded on the DAFOR scale (Dominant - 5, Abundant - 4, Frequent - 3, Occasional - 2, Rare - 1) as described by Palmer et al. (1992), via visual assessments assisted by collections made using a double-headed rake.

2.3 Data analysis

Species richness, abundance and Simpson's and Shannon's diversity (Crist et al. 2003) were used to represent α-and γ-diversity, calculated by combining the records of the five individual pond visits. The highest recorded abundance for each bird species from all of the five surveys was used to represent the maximum number of individuals or "abundance" for each pond. Although this approach may still produce an overestimate of total bird abundance, the risk of counting the same individual multiple times is greatly diminished (Toms 2004, BTO 2014). Pond categories were subsequently compared using independent samples t-tests. Bird counts were rarefied using Hurlbert Rarefaction (Hurlbert 1971) to create species accumulation curves for open and overgrown ponds. Correspondence Analysis (CA) was used to examine variation in bird assemblage composition between the ponds and to determine degree of species turnover between ponds (beta diversity) by maximizing the correspondence between species abundance scores and sample scores and measuring how distinct the sampling units were along gradients. Canonical Correspondence Analysis (CCA) was conducted to examine the direct relationships between pond environmental parameters and bird assemblages, again using bird abundance data. In addition, Stepwise Multiple Linear Regression (MLR) was performed to determine the extent to which environmental parameters were linked to overall bird diversity and abundance. Z-transformed environmental data were used in the multivariate analyses. Pearson's correlation analysis showed strong inter-correlations between four of the environmental parameters: submerged/floating and emergent macrophyte cover measures, % shading and % of the pond circumference surrounded by trees ($r \sim 0.7$. Pond circumference was an exception, however, and significantly correlated with percentage shading only ($r = -0.42$). Using the results of the Pearson's correlations a *p*-value threshold for parameter deletion of $p>0.05$ was used, as values larger than this indicated that the effects of the variables upon patterns of avian diversity could not be separated. Subsequently, circumference and submerged/floating macrophyte coverage were chosen for further analysis, while the remaining parameters were omitted from MLR and CCA. It should be noted, however, that a high degree of submerged/floating macrophyte cover can be seen as a powerful proxy for low shading due to the highly negative correlation between these factors (Pearson's Correlation Coefficient, $r = -0.86$). Estimates S 8.2 was used in the calculation of both α-and γ-diversity (Colwell 2009), while rarefaction curves were calculated using Species Diversity and Richness 3.02 (Pisces Conservation Ltd 2002). CANOCO for Windows 4.5 (ter Braak and Smilauer 2002) was used to generate CA and CCA ordination plots, while t-tests, stepwise MLR, and Pearson's Correlation Coefficient were all calculated in SPSS for Windows 20 (IBM Corp 2011) and R: A Language and Environment for Statistical Computing Version 3.2.2 (R Core Team 2015).

3. RESULTS

3.1 Bird observations

In total, 58 breeding bird species were observed visiting or holding territories around the 22 farmland ponds (see Appendix A). Some 28 bird species were exclusive to only one pond type, while large proportions of the species encountered at open-canopy and overgrown ponds showed a very clear affinity to one of these pond type, as reflected by higher visit frequencies and abundances. Waterfowl, reed-associated species and open country species (comprising ground-nesting species, insectivorous open country species and a number of granivorous species) were largely confined to open ponds. Nine of the eleven conservation priority UK BAP species that were recorded at the ponds showed a preference for open rather than overgrown ponds. Overall, the open ponds harboured a much higher diversity of bird species and guilds than overgrown ponds. Nonetheless, typical woodland bird species like the great spotted woodpecker *Dendrocopos major*, treecreeper *Certhia familiaris*, or nuthatch *Sitta europaea*, were exclusively encountered at overgrown ponds. Aside from 10 woodland bird species, all species recorded at overgrown ponds were also found at open ponds.

3.2 Avian diversity

Two of the largest, open-canopy farmland ponds, W10 and the W22/23/24 cluster, harboured the highest avian diversity (Species Richness, Abundance, Shannon's diversity, Simpson's Diversity); while the bird assemblage recorded at overgrown pond S7 was least diverse. However, Shannon's and Simpsons Diversity did not differ significantly between individual ponds of each type (Table 1). Nonetheless, both the recorded and estimated species richness was significantly higher at open ponds compared to overgrown ponds (p<0.05, Table 1). This trend was further supported by rarefaction curves combining samples of the two groups (Fig.3). Gamma diversity across the agricultural pondscape was considerably higher than both the alpha diversity of any one individual pond, and of the combined open and overgrown ponds, indicating important diversity contributions by both pond types (Table 1).

In the CA bi-plot, axis 1 explained 15.3% of species data variance, whereas axis 2 explained a further 10.5%. Species turnover between the overgrown ponds was relatively low, as illustrated by the small area of ordination space generally occupied by these sites in the CA (Pond S7 is an outlier due to a record of tawny owl *Strix aluco,* Fig.4). In contrast, a greater bird species turnover was observed at the open ponds, meaning that these are more heterogeneous in the bird assemblages they support. The bird community structure showed significant variation in relation to the measured environmental gradients in the agricultural pondscape. In the CCA bi-plot (Fig.5), axis 1 was positively related to macrophyte coverage (and thus negatively correlated with shading) and explained 9.99% of bird species' variance. Axis 2, which explained an additional 4.43% of bird species' variance, was strongly associated with pond circumference. Bird species were widely distributed across axis 1, showing varying preferences for macrophyte coverage and associated shading, but generally the species most prevalent at open ponds, such as aerial insectivores (swift, swallow, house martin), open country species (e.g. whitethroat *Sylvia communis*, linnet *Carduelis cannabina*), granivores (e.g. greenfinch *Chloris*, skylark, house sparrow *Passer domesticus)*, dabbling ducks (mallard *Anas platyrhynchos* and gadwall *Anas strepera*) and wetland passerines (reed bunting, reed warbler *Acrocephalus scirpaceus* and sedge warbler *Acrocephalus schoeniclus*), preferred lower levels of tree shading (and thus high macrophyte coverage), whereas woodland birds such as robin *Erithacus rubecula*, nuthatch and treecreeper were associated with increased tree shading (and thus lower macrophyte coverage).

Birds associated with ponds of intermediate macrophyte coverage and partial shading (e.g. coal tit, long-tailed tit), as well as species equally abundant at both open and overgrown ponds (e.g. chaffinch, yellowhammer, blue tit), clustered towards the centre of the plot.

MLR indicated that pond circumference and macrophyte coverage were both significant predictors of overall avian species richness (F = 11.82, Adjusted R^2 = 0.51, p = 0.0004), and abundance (F =12.32, Adjusted R^2 = 0.52, p = 0.0003) (Table 2). While circumference was a significant predictor for Shannon's Diversity (estimate = 0.04, t value = 2.74, p = 0.01), this was not true for macrophyte coverage (estimate = 0.35, t value = 1.22, p = 0.35). In addition, the model failed to explain the patterns in Simpson's Diversity (p = 0.95).

3.3 Pond use by farmland birds

In addition to vegetated open water, the open agricultural ponds afforded a variety of associated habitats that were utilised by birds, and a number of bird behaviours were observed more frequently at open ponds (Table 3, Appendix B.1, B.2). At the open ponds, foraging was a particularly important activity, and was significantly more prevalent at open ponds compared to overgrown ponds (t = 2.44, df = 10, p = 0.03), especially amongst open country, insectivorous species such as swallows, swifts and whitethroats. Further, many open-country bird species such as linnet, yellowhammer, reed bunting, house sparrow and greenfinch, as well as the ground-nesting grey partridge and skylark, were strongly associated with the grassland buffer strips around open ponds, but did not show a similar affinity to buffer strips at overgrown ponds (t = 2.97, df = 10, p = 0.01). Emergent plant stands (e.g. sedge beds), which were utilised at open ponds by ducks (*Anas* spp.) and warblers (*Acrocephalus* spp.) were furthermore widely lacking at overgrown ponds, leading to an associated absence of these species. Tree vegetation at both pond groups was important for refuge and as a perch for singing and territorial displays (t = -0.61, df = 10, p = 0.55). However, breeding pairs and family groups, occasionally even nesting within the pond cluster, were observed more frequently at open ponds (t = 3.74, df = 10, p = 0.003), and evidence of chick provisioning was recorded on more occasions at open ponds (t = 2.5, df = 10, p = 0.03). Aside from a few aquatic species such as moorhen *Gallinula chloropus*, the bird species encountered at overgrown ponds were largely confined to the surrounding wet woodland vegetation rather than the waterbody itself.

4. DISCUSSION

4.1 Drivers of avian diversity at farmland ponds

Similar to previous studies (Froneman et al. 2001, Sebastián-Gonzaléz et al. 2010), larger ponds possessed a larger pool of bird species. The most species-rich ponds however were not only large, but also harboured abundant and spatially heterogeneous macrophyte communities. Macrophytes are extremely important components of pond ecosystems, with high macrophyte coverage exerting a significant positive influence on overall aquatic diversity (McAbendroth et al. 2005, Thomaz & da Cunha 2010, Florencio et al. 2014). Generally, the influence of open-canopy, macrophyte-dominated ponds on both aquatic and terrestrial species has to date largely evaded scientific research. Our results show that the abundance and diversity (species richness) of birds encountered in the direct vicinity of ponds was strongly positively influenced by macrophyte coverage, and strongly negatively associated with high levels of shading, although it is difficult to identify underlying causal relationships.

Under conditions of high tree/scrub shading at late-successional unmanaged ponds, aquatic plants are typically eliminated. By contrast, management-induced reductions in shading lead to a rapid, positive response of aquatic macrophytes in terms of both species cover and diversity (Sayer et al. 2012). Presence of vegetation within ponds is cited as an important factor for waterbirds when selecting wetland habitat (Cody 1985, Sebastián-González et al. 2010), since increased macrophyte cover provides benefits such as food, nesting material, habitat and refuge from predators (McKinstry & Anderson 2002, Santoul et al. 2009). Our results show that such benefits extend beyond water-birds to birds encountered across agricultural landscapes more generally, covering open country, ground nesting, reed nesting, granivorous and insectivorous guilds, all of which appeared to associate with, and potentially benefit from, open-canopy, macrophyte-dominated ponds and their connected grassland buffers. Notably, open-canopy ponds appeared to offer suitable habitat for a number of UK BAP conservation-priority farmland species and species undergoing declines on farmland, such as skylark, grey partridge and reed bunting, all of which were primarily associated with open ponds, but were absent at overgrown ponds. The habitat associations of these species suggest that individuals can find some of the nesting or foraging resources required for their persistence in or around open ponds.

4.2 Pond habitat and food resources for birds

The higher richness and abundance of bird species using open-canopy ponds could be the result of a variety of ecological mechanisms, particularly those relating to habitat complexity, the high degree of habitat variation among individual managed ponds and increased food availability. Aquatic invertebrates are known to establish much more diverse communities in structurally-complex macrophyte stands associated with open ponds, which results in both a greater diversity and abundance of adult stages (Gee et al. 1997, McAbendroth et al. 2005, Hinden et al. 2005), and following emergence and dispersal from the pond may form an important food subsidy for foraging insectivorous birds (Schummer et al. 2012, Dreyer et al. 2015, Fig.6). Key potential invertebrate prey taxa include the orders Odonata, Ephemeroptera and Coleoptera, and the family Chironomidae. In our study, we did not quantify emergent invertebrate abundance or diversity; however, our previous research showed that, with the exception of molluscs, managed Manor Farm ponds showed higher invertebrate diversity than unmanaged ponds, with invertebrate diversity steadily increasing for 3-5 years after management (Sayer et al. 2012). In our present study, observations at open ponds suggested that adult invertebrate prey were abundant. Aerial insectivores such as swallows, swifts and house martins seemed primarily driven by emerging invertebrates, and pairs or groups were frequently observed hovering, diving and catching insects on the wing over open water (as in Fig.2b). Invertebrate resources offered by ponds may become particularly important during the breeding season, when nutritional requirements are elevated. A number of whitethroat nests were encountered in the bushes fringing open canopy ponds and adults were regularly observed provisioning young. Nesting sites adjacent to open ponds may have been favoured by this species to allow better access to invertebrate-rich foraging sites when provisioning offspring.

A variety of grasses, sedges, rushes and herbs of different heights and structures were encountered around the open ponds (Fig.2a, b), which may offer nesting materials, seed resources, refuge from predators and resting and perching habitat, as well as important habitat for invertebrate prey. Josefsson et al. (2013) observed that fields with grassland buffer strips supported significantly more skylark territories than fields without buffer strips, with such sites characterized by increased densities of spiders and beetles. Thus, for farmland birds that rely on the cropped area of fields for both breeding and foraging (such as skylark), grassland buffer strips around isolated, open farmland ponds could play an important supplementary role in terms of food resources, provided that there is a sufficient density of ponds in the landscape. In a pondscape setting, we suggest that surrounding grassland margins may act as recipients of particularly high numbers of invertebrate prey originating from the pond, with invertebrate assemblages in these buffers further enhanced by the presence of humidity gradients from the pond margin towards agricultural habitats on higher ground (Fig.6a). Seeds associated with pond marginal areas may also form an important part of the diet of many conservation priority granivores on farmland, including house sparrow, yellowhammer and linnet (Atkinson et al. 2004, Robinson et al. 2004, McCracken & Tallowin 2004). A key, known bottleneck for farmland birds is starvation in late winter, a phenomenon known as the “winter hungry gap” (Siriwardena et al. 2008). It is possible that particularly open, plant-rich ponds may provide a seed-rich area that persists through winter and thus assists bird survival. In contrast, the grass and dicot seeds involved would not be available in overgrown habitats because both the plants and birds concerned are open country species: the plants are not found in shaded conditions and the birds forage in open areas, not within woody vegetation.

The lower species diversity observed at overgrown ponds is probably due to the relative homogeneity of habitats offered by such ponds, which essentially mimic small wet woodland sites. Although the overgrown ponds were also surrounded by grassland buffers, these apparently failed to offer birds the same benefits as grassland buffers around open ponds, possibly because the grassland was heavily shaded and separated from the pond by a dense barrier of woody vegetation (Fig.2c, 6b). Open country species often avoid vertical structures (Sparks et al. 1996), rendering areas immediately around densely wooded ponds unattractive to these species. It follows that another possible cause of lower avian diversity at overgrown ponds is a perceived heightened risk of ambush from predators around dense cover, particularly for open country species (Cresswell 1996). Although it will not have represented a real predatory threat, a tawny owl observed at overgrown pond S7 may have affected what was detected there: this pond was distinct from the other overgrown ponds not least in supporting the lowest number of bird species.

It could be argued that a lack of bird diversity observed amongst the overgrown ponds was partly an artefact of reduced visibility at overgrown ponds. However, while birds may not always have been seen at these ponds, hidden birds still had a high chance of detection by their vocalisations. Clearly, overgrown ponds also afforded good habitat for woodland birds. In this respect, they may be used as stepping stones for species travelling between larger woodland sites (Neuschultz 2013). Therefore, maintaining some overgrown ponds should have positive implications for habitat connectivity, promoting the dispersal of woodland species (Lawton et al. 2010).

4.3 Pond management and farmland bird conservation

This study suggests that pond management can be considered to be a valuable tool for bird conservation in farmland. It also alludes to the importance of maintaining a mosaic of pond successional stages within agricultural landscapes in order to support a wide variety of bird guilds. However, the relative value of each successional stage will depend on the extent to which it contributes to the existing habitat heterogeneity in a given landscape. The continued terrestrialisation of entire agricultural pondscapes risks eliminating the contribution of open ponds to landscape-level avian diversity. Equally, simultaneous, uniform pond management with associated loss of wet woodland habitat and homogenisation of the pondscape could have detrimental effects for woodland guilds, particularly declining wet woodland species such as marsh tit, which was uniquely associated with semi-overgrown ponds in this study. We recommend that a high level of environmental variability should be maintained across agricultural pondscapes, taking resource and habitat requirements of specialist bird groups most at risk from future declines into account (Gregory et al. 2004, Le Viol 2012).

Clearly, the Manor Farm approach of arresting succession at just a few ponds every year, with some ponds left to natural development, ensures the existence of a pond mosaic comprising ponds of varying stages of succession, which could provide an ideal scenario for farmland bird conservation. In other regions, where ponds are less abundant, creation of new ponds could be required to provide new habitat for local bird populations. We predict that the benefits of pond management for biodiversity are by no means confined to the aquatic environment or even the immediate vicinity of the pond. Instead, where many open ponds are present, high rates of aquatic invertebrate deposition and dispersal may significantly increase invertebrate abundance and diversity across the entire landscape through a strong “chimney effect” (Fig.6a). As aquatic and terrestrial ecosystems are tightly linked (Knight et al. 2005), increasing the interchange of resources between aquatic and terrestrial habitats might be of paramount significance to regional biodiversity (Baxter et al. 2005, Richardson et al.

2010), with cross-system subsidies, represented here by aquatic insect deposition and food-plant resources, being of significant importance to ecosystem functioning in farmland environments (Allen et al. 2012, Bartels et al. 2012, Dreyer et al. 2015, Soininen et al. 2015).

Further study is needed to quantify emergent invertebrate abundance and diversity at managed and un-managed ponds, as well as to determine how pond management may be optimized to enhance both breeding and overwintering of farmland birds. Our study is limited in its spatial and temporal coverage, and we suggest that future bird, macrophyte and invertebrate surveys are carried out at different times of the year to account for seasonal variability. This should lead to much improved understanding of the role of ponds for farmland bird conservation. Nevertheless, our study strongly suggests that pond management has a very important role to play in this respect. Ponds are cheap and simple to manage compared to other habitats, yet they remain a rarely promoted option within AES. We propose that more emphasis be placed on the value of ponds and their management within agricultural policy, environmental education and conservation strategies, within and across the farmed landscape.

Acknowledgements

We wish to thank all the landowners of the farms used in this study for permitting us to survey their ponds, E.Smith for assistance with field work and D. and J.Sayer for much logistical support. We also thank the UCL Environmental Change Research Centre for financial support, G.Hilton (WWT) and S.Newson (BTO) for advice on bird survey methods, and the UCL MSc in Conservation for general facilitation. We dedicate this study to R.Waddingham at Manor Farm, who came up with all the ideas that underpin this work. The dedication and care he demonstrates towards his ponds show that nature conservation and modern agriculture can coexist in a highly sustainable way – a powerful and much needed message.

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List of Figure Captions

Fig.1 Map of the farmland study area in Norfolk, eastern England, highlighting the open, managed ponds (W prefix) and overgrown ponds (D, M, S prefix) included in the study.

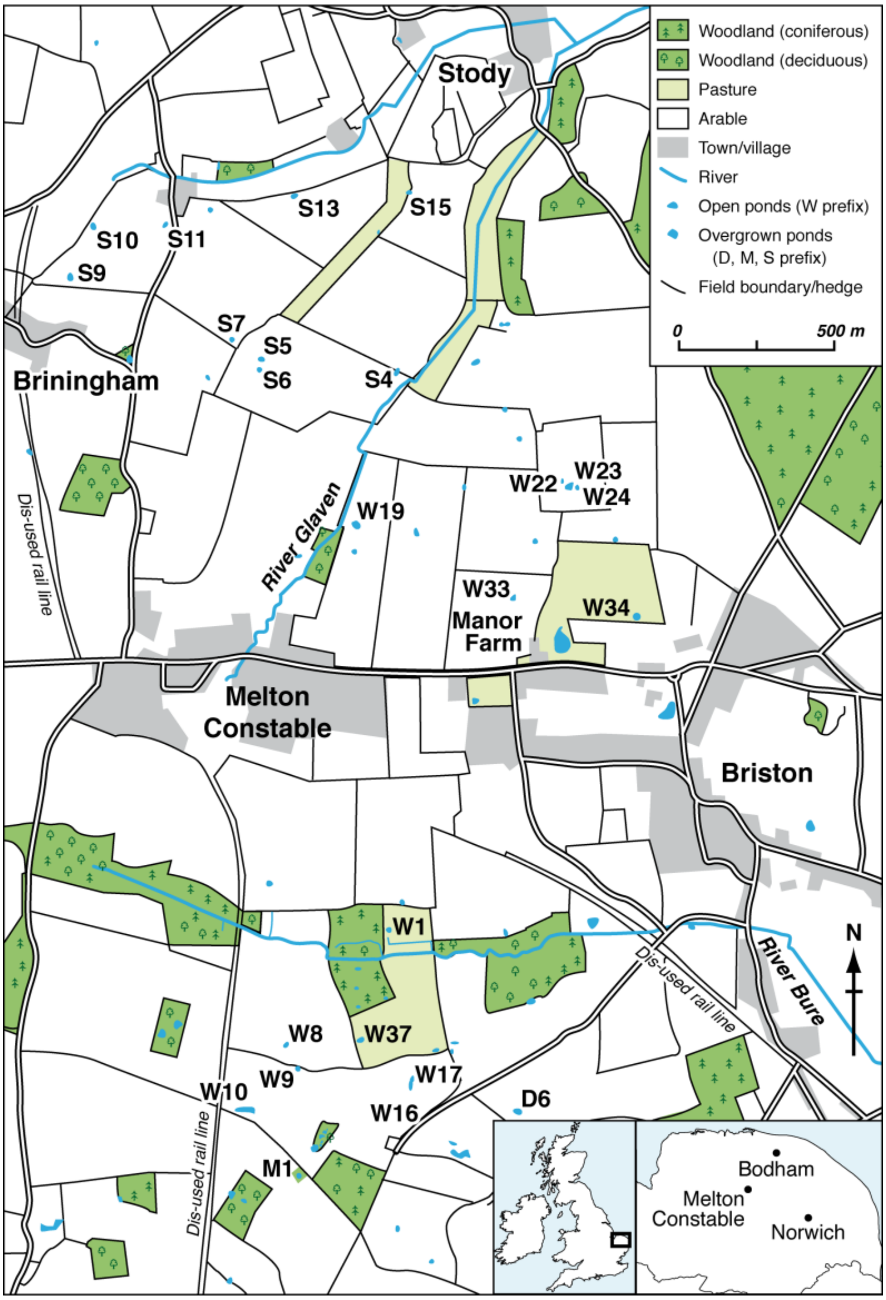
Fig.2 An open, managed pond (pond W10 in Fig.1) at Manor Farm (a); swifts (*Apus apus*) feeding over pond W10 in May 2015 after a hatch of mayflies (b); a typical overgrown, highly terrestrialised pond in the study area (c)

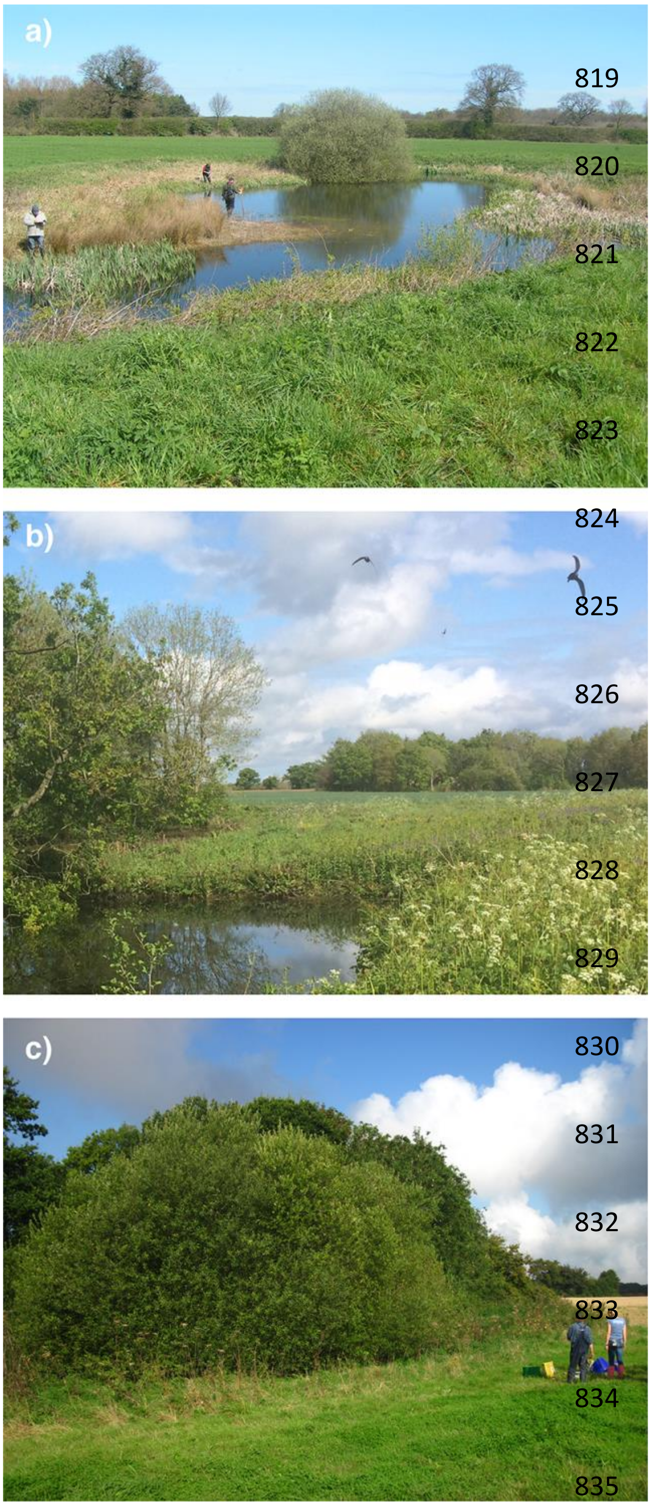
Fig.3 Hurlbert rarefaction curves for overgrown ponds, open ponds and all ponds combined. Number of individuals sampled plotted against number of species encountered with error bars representing the standard error (±SE)

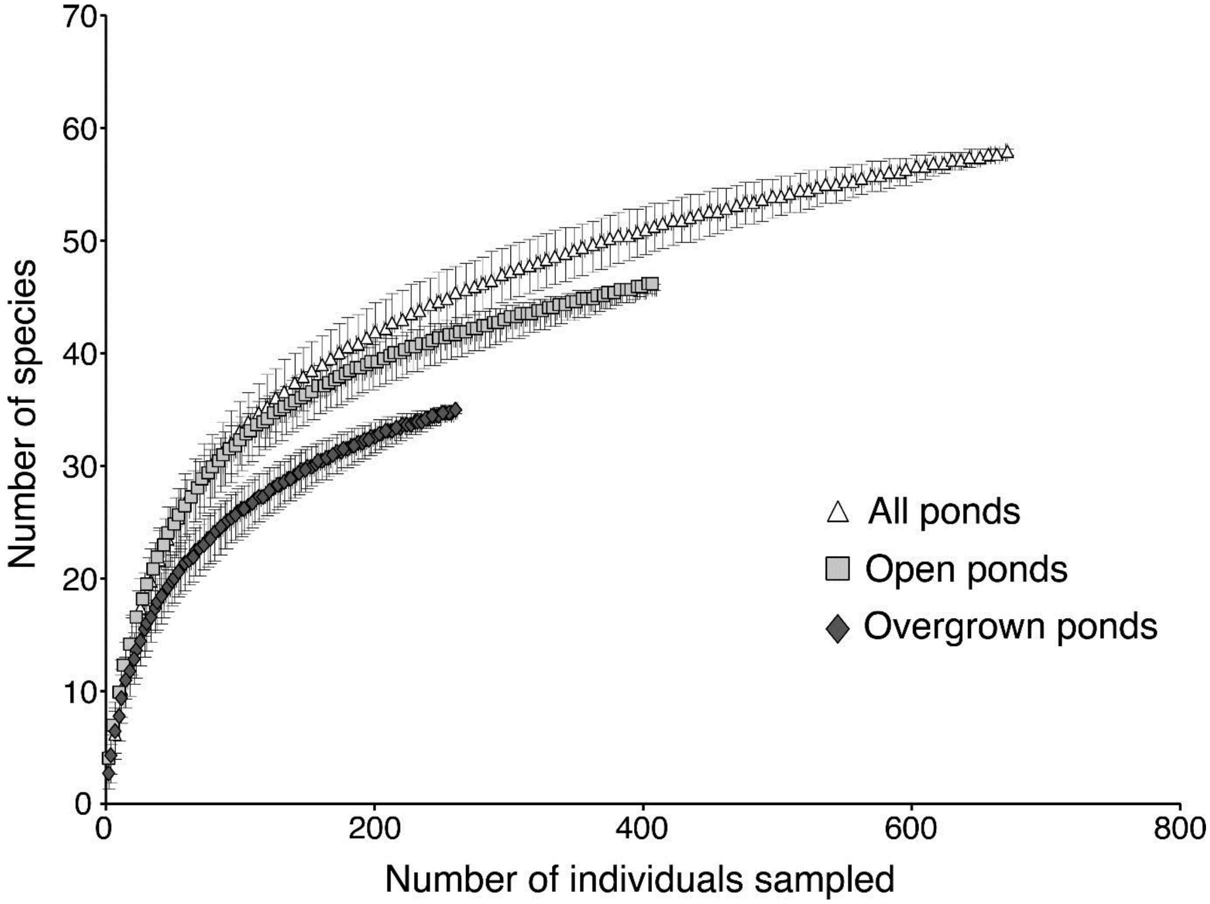
Fig.4 Correspondence Analysis (CA) of pond sites (a) and bird species (b) data. Ponds are coded according to treatment (open, managed or overgrown, unmanaged)

Fig.5 Canonical Correspondence Analysis (CCA) showing site (a) and species (b) data. Ponds are coded according to treatment (open, managed or overgrown, unmanaged)

Fig.6 Conceptual diagrams depicting habitat features and resources for farmland birds at typical a) open managed ponds (a) and overgrown ponds (b)


Woodland (coniferous)
Woodland (deciduous)
Pasture
Arable
Town/village
River
Open ponds (W prefix)
Overgrown ponds (D, M, S prefix)
Field boundary/hedge
0
500 m
Stody
Briningham
S13
S15
S10
S11
S9
S7
S5
S6
S4
River Glaven
W19
W22
W23
W24
Dis-used rail line
W33
Manor Farm
W34
Melton Constable
Briston
W1
W8
W37
W9
W10
W17
W16
D6
M1
Dis-used rail line
Dis-used rail line
River Bure
N
Bodham
Melton Constable
Norwich


a)
b)
c)


70
60
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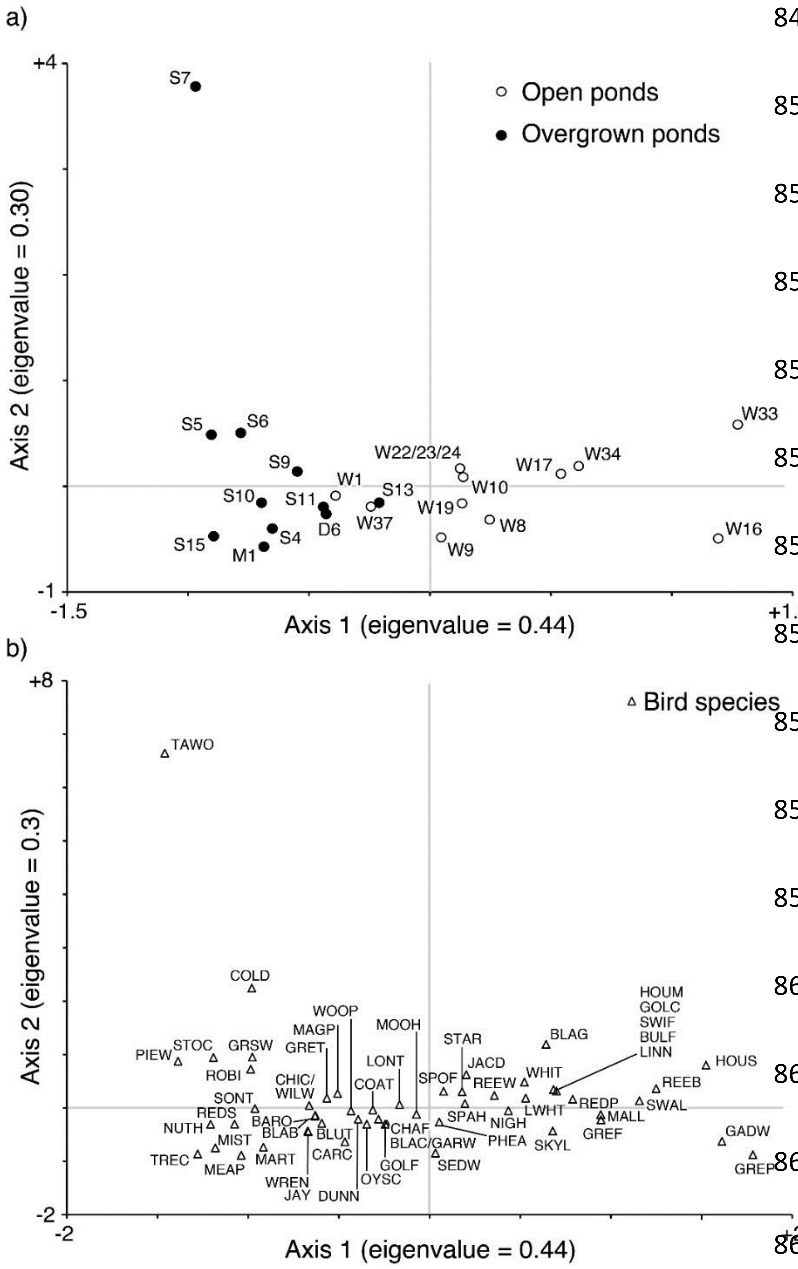
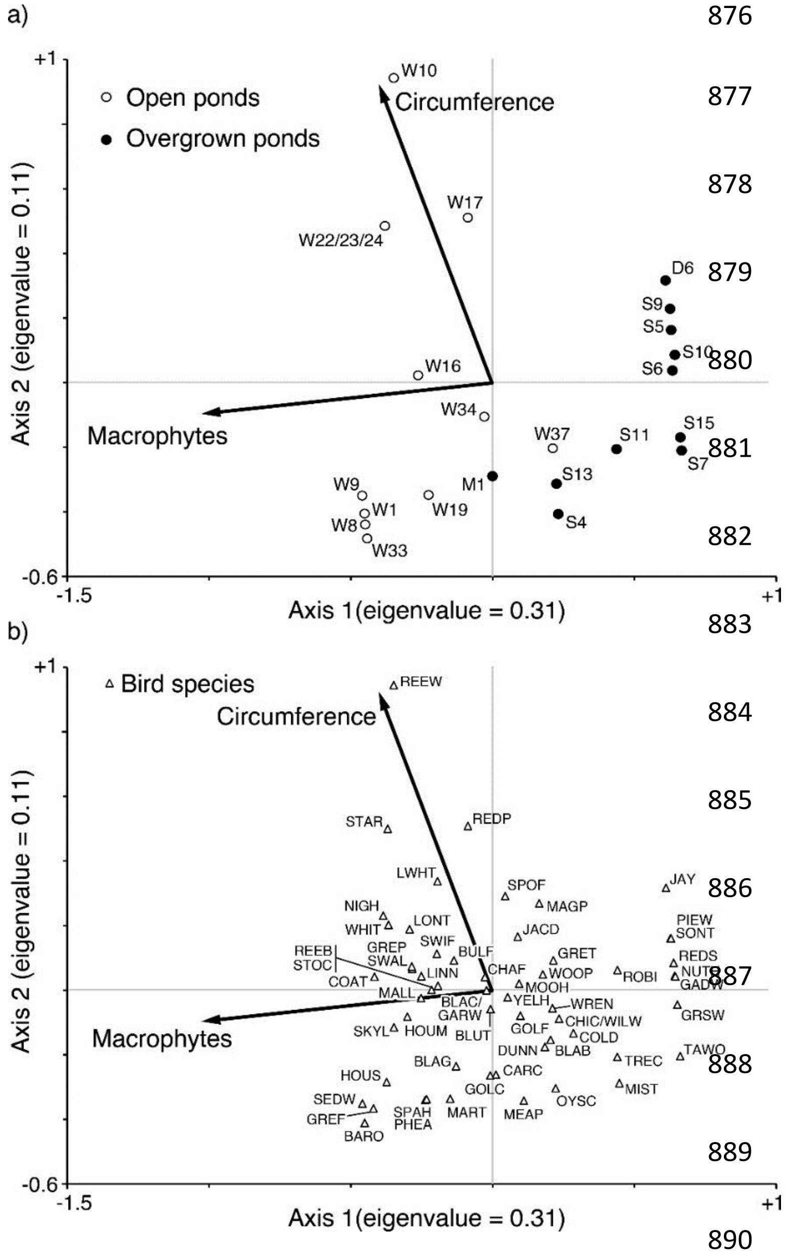
0
Number of species
0
200
400
600
800
Number of individuals sampled
All ponds
Open ponds
Overgrown ponds



Key to species codes: BARO: barn owl, BLAB: blackbird, BLAC: blackcap, BLAG: black-headed gull, BLUT: blue tit, BULF: bullfinch, CARC: carrion crow, CHAF: chaffinch, CHIC: chiffchaff, COAT: coal tit, COLD: collared dove, DUNN: dunnock, GADW: gadwall, GARW: garden warbler, GOLC: goldcrest, GOLF: goldfinch, GREF: greenfinch, GREP: grey partridge, GRET: great tit, GRSW: great-spotted woodpecker, HOUM: house martin, HOUS: house sparrow, JACD: jackdaw, JAY: jay, LINN: linnet, LWHT: lesser whitethroat, LONT: long-tailed tit, MAGP: magpie, MALL: mallard, MART: marsh tit, MEAP: meadow pipit, MIST: mistle thrush, MOOH: moorhen, NUTH: nuthatch, NIGH: nightingale, OYSC: oystercatcher, PHEA: pheasant, PIEW: pied wagtail, REDP: red-legged partridge, REDS: redstart, REEB: reed bunting, REEW: reed warbler, ROBI: robin, SEDW: sedge warbler, SKYL: skylark, SPAH: sparrowhawk, SPOF: spotted flycatcher, SONT: song thrush, STAR: starling, STOC: stonechat, SWAL: swallow, SWIF: swift, SYLV: Sylvia/unidentified warbler (genus), TAWO: tawny owl, TREC: treecreeper, WHIT: whitethroat, WILW: willow warbler, WOOP: wood pigeon, WREN: wren, YELH: yellowhammer, YELW: yellow wagtail.



Key to species codes: BARO: barn owl, BLAB: blackbird, BLAC: blackcap, BLAG: black-headed gull, BLUT: blue tit, BULF: bullfinch, CARC: carrion crow, CHAF: chaffinch, CHIC: chiffchaff, COAT: coal tit, COLD: collared dove, DUNN: dunnock, GADW: gadwall, GARW: garden warbler, GOLC: goldcrest, GOLF: goldfinch, GREF: greenfinch, GREP: grey partridge, GRET: great tit, GRSW: great-spotted woodpecker, HOUM: house martin, HOUS: house sparrow, JACD: jackdaw, JAY: jay, LINN: linnet, LWHT: lesser whitethroat, LONT: long-tailed tit, MAGP: magpie, MALL: mallard, MART: marsh tit, MEAP: meadow pipit, MIST: mistle thrush, MOOH: moorhen, NUTH: nuthatch, NIGH: nightingale, OYSC: oystercatcher, PHEA: pheasant, PIEW: pied wagtail, REDP: red-legged partridge, REDS: redstart, REEB: reed bunting, REEW: reed warbler, ROBI: robin, SEDW: sedge warbler, SKYL: skylark, SPAH: sparrowhawk, SPOF: spotted flycatcher, SONT: song thrush, STAR: starling, STOC: stonechat, SWAL: swallow, SWIF: swift, SYLV: Sylvia/unidentified warbler (genus), TAWO: tawny owl, TREC: treecreeper, WHIT: whitethroat, WILW: willow warbler, WOOP: wood pigeon, WREN: wren, YELH: yellowhammer, YELW: yellow wagtail.

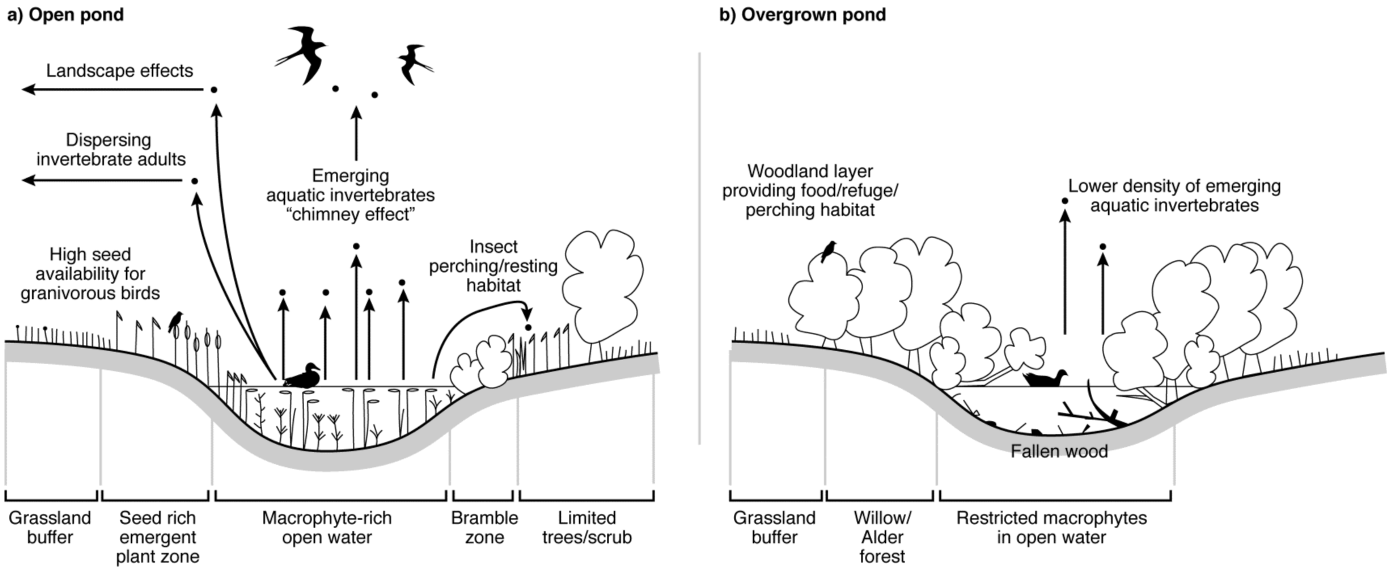

a) Open pond
Landscape effects
Dispersing invertebrate adults
Emerging aquatic invertebrates "chimney effect"
High seed availability for granivorous birds
Insect perching/resting habitat
Grassland buffer
Seed rich emergent plant zone
Macrophyte-rich open water
Bramble zone
Limited trees/scrub
b) Overgrown pond
Woodland layer providing food/refuge/ perching habitat
Lower density of emerging aquatic invertebrates
Fallen wood
Grassland buffer
Willow/ Alder forest
Restricted macrophytes in open water

Table 1. Diversity and abundance measures comparing avian alpha diversity of open and overgrown ponds and gamma diversity of birds from all ponds, where figures for alpha diversity measures represent mean values ± standard error of the mean.

Pond category	Species Richness (x ± SE)	Abundance (no. individuals) (x± SE)	Shannon's Diversity (x ± SE)	Simpson's Diversity (x ± SE)
Alpha Diversity				
Open	17.5 ± 1.4*	38.3 ± 3.8[a]	13.7 ± 0.9[b]	16.6 ± 1.5[b]
Overgrown	13.3 ± 0.7*	24.4 ± 1.8[a]	11.5 ± 0.7[b]	18.2 ± 1.8[b]
Gamma Diversity				
All Ponds	58	679	31.4	24.1
Combined Open	46	421	28.8	23.2
Combined Overgrown	35	268	21.1	17.6

Statistical significance of independent samples t-tests comparing alpha diversity means of open and overgrown ponds are based on the p-value threshold of p<0.05 and are denoted by *, [a], [b]

*p = 0.02, [a]p =0.00072 [b]p >0.05

Table 2. Stepwise Multiple Linear Regression (MLR) showing results for effects of i) Submerged/floating macrophyte coverage and ii) Circumference on test variables a) Species richness, b) Abundance and c) Shannon's diversity.

Test Variable and Predictors	Beta Coefficient	t-value	p-value
a) Species richness			
i) Submerged/floating macrophyte coverage	0.74	2.15	0.044*
ii) Circumference	0.06	3.51	0.0002*
Adjusted R^2 = 0.51, $F_{(2,19)}$ = 11.82, p = 0.0004*			
b) Abundance			
i) Submerged/floating macrophyte coverage	2.31	2.32	0.03*
ii) Circumference	0.18	3.51	0.002*
Adjusted R^2 = 0.52, $F_{(2,19)}$ = 12.32, p = 0.0003*			
c) Shannon's diversity			
i) Submerged/floating macrophyte coverage	0.35	1.22	0.35
ii) Circumference	0.04	2.74	0.01*
Adjusted R^2 = 0.32, $F_{(2,19)}$= 5.96, p = 0.009*			

Statistical significance is based on the *p*-value threshold of $p < 0.05$ and is denoted by *

Table 3. Frequencies of behaviours and locations of birds recorded at open and overgrown ponds. Values are given as means ± standard error of the mean (SEM) of the 11 open ponds and 11 overgrown ponds, along with corresponding t-values from the independent samples t-tests.

	Behaviours observed		*Recorded locations of birds*		
	Foraging	Provisioning offspring	Pair/family groups	Grassland buffer	Tree vegetation
Open	15.6 ± 4.1	4.18 ± 1.4	25.5 ± 4	6.45 ± 2.2	33.8 ± 6.2
Overgrown	5.36 ± 1.3	0.63 ± 0.3	8.27 ± 1.6	0.1 ± 0.1	38.7 ± 2.7
t- value	2.44*	2.5*	3.74[a]	2.97[a]	-0.61

Statistical significance for independent samples t-tests is based on the *p*-value threshold of $p < 0.05$ and is denoted by *, [a]

*$p < 0.05$, [a]$p < 0.01$

Appendix A

Table A.1 Species records for both open managed and overgrown, non-managed ponds. Species are grouped according to guild or habitat preference and sub-divided into families and allies.

Habitat/Guild	Species Name	Common Name	Open Ponds [b]	Overgrown Ponds [b]
Waterfowl and Rallids	*Anas platyrhynchos*	Mallard	W9(1), W16(3), W17(3), W19(2), W33(1), W22/23/24(1), W34(1)	
	Anas strepera	Gadwall	W16(2), W34(1)	
	Gallinula chloropus	Moorhen	W8(1), W9(4), W10(4), W16(3), W17 (4), W19(3), W22/23/24(2), W33(3), W34(2), W37(3)	S5(1), D6(1), S9(4), S10(2), S11(3), S13(4)
Seed Eating[a] Finches and Allies	*Carduelis cannabina*	Linnet*	W10(1), W22/23/24(1), W33(2), W34(1)	
	Carduelis carduelis	Goldfinch	W1(1), W10(1), W16(3), W19(1), W22/23/24(3), W34(1), W37(3)	M(1), S4(2), D6(1), S9(1), S11(1), S13(1)
	Chloris chloris	Greenfinch	W8(1), W9(1), W16(1), W33(1),	
	Emberiza citrinella	Yellowhammer*	W8(3), W9(1), W10(2), W16(3), W17(4), W19(1), W22/23/24(2), W33(3), W37(1)	S4(3), S5(1), D6(1), S6(1), S7(3), S9(1), S10(1), S11(2), S13(1), S15(3)
	Fringilla coelebs	Chaffinch	W1(2), W8(4), W9(2), W10(5), W16 (3), W17(4), W19(1), W22/23/24(4),	M1(1), S4(1), S5(2), D6(4), S6(1), S7(4), S9(4), S10(4), S11(4), S13(2), S15(5)

			W33(2), W34(3), W37(3)	
	Passer domesticus	House Sparrow*	W23(2), W33(1) W34(2)	
Reed Nesting	*Pyrrhula pyrrhula*	Bullfinch*	W22/23/24(1), W4(1)	
	Emberiza schoeniclus	Reed Bunting*	W16(1), W17(3), W23(1), W33(2), W34(1)	
Seed Eating[a] Grass Nesting	*Alauda arvensis*	Skylark*	W1(1), W8(1), W9(1), W10(2), W16(4), W17(2), W19(1), W33(2)	
	Alectoris rufa	Red-Legged Partridge	W17(1)	
	Perdix perdix	Grey Partridge*	W16(1)	
	Phasianus colchicus	Pheasant	W19(1)	
Insectivorous Woodland	*Dendrocopos major*	Great Spotted Woodpecker		S5(1), S6(1)
Insectivorous Woodland (Thrushes and Allies)	*Erithacus rubecula*	Robin	W10(1), W22/23/24(2)	M1(2), S4(4), S5(4), D6(3), S6(1), S11(4), S10(5), S9(3), S15(1)
	Luscinia megarhynchos	Nightingale	W8(1), W22/23/24(1), W17(1)	
	Phoenicurus phoenicurus	Redstart		S10(2)
	Turdus merula	Blackbird	W1(2), W8(1), W22/23/24 (2), W33(1)	M1(3), S4(2), S5(2), D6(3), S9(2), S10(2), S13(2)
		Song Thrush*		S9(1), S10(1)

	Turdus viscivoros	Mistle Thrush		S4(1), S15(1)
Insectivorous Woodland (Paridae and Allies)	*Aegithalos caudatus*	Long Tailed Tit	W10(1), W22/23/24(2)	S11(1), S13(1)
	Cyanistes caeruleus	Blue Tit	W(3) W8(1), W9(3), W10(3), W16(1), W17(1), W19(2), W22/23/24 (4), W34(1), W37(2)	M1(2), S4(5), S5(2), D6(2), S6(3), S7(3), S13(3), S9(2), S10(3), S11(5), S15(3)
	Parus major	Great Tit	W1(2), W8(1), W9(1), W10(3), W16(1),W17(1), W22/23/24(1), W34(2), W37(1)	S4(3), S5(1), S6(1), S9(2), S10(1), S11(2), S13(3), S15(2)
	Periparus ater	Coal Tit	W1(1), W10(1) W22/23/24(1)	
	Poecile palustris	Marsh Tit*	W1(1)	M1(2)
Insectivorous Woodland (Certhioidia)	*Certhia familiaris*	Treecreeper		M1(1), S15(2)
	Sitta europaea	Nuthatch		S5(1), D6(1), S15(2)
	Trogloydes trogloydes	Wren	W1(1), W8(1), W9(2), W10(4), W19(2),W22/23/24(2),W34(4), W37(4)	M1(4), S4(1), S5(1), D6(3), S6(3), S7(5), S9(4), S10(4), S11(4), S13(5), S15(4)
Insectivorous Woodland (Warblers and Allies)	*Muscicapa striata*	Spotted Flycatcher*	W10(2), W22/23/24(1), W33(1) W34(1)	D6(1), S6(1), S9(1)
	Phylloscopus colybita/ trochilus	Chiffchaff/Willow Warbler	W1(1), W10(4), W19(1), W22/23/24(1), W37(1)	M1(1), D6(1), S4(2), S7(1), S9(3), S10(3), S11(3), S13(2), S15(4),

	Prunella modularis	Dunnock	W10(1), W33(2), W34(1)	S4(1), S11(1), S13(1), S15(2)
	Regulus regulus	Goldcrest	W33(1), W34(1)	S11(1)
	Sylvia borin/atricapilla (G)	Garden Warbler/Blackcap	W8(2), W9(1), W10(1), W16(1), W17(1), W22/23/24(3), W33(1),	M1(1), D6(3), S4(1), S10(3), S11(1), S13(1)
Insectivorous Open Country (Warblers)	*Sylvia communis*	Whitethroat	W1(2), W9(2), W10(3), W16(1), W17(1), W19(1), W22/23/24(4), W33(4) W34(1)	D6(2), S7(3)
	Sylvia curruca	Lesser Whitethroat	W17(1), W22/23/24(4), W34(1), W37(1)	
Reed Nesting Warblers				
	Acrocephalus schoenobaenus	Sedge Warbler	W9(3)	
	Acrocephalus scirpaceus	Reed Warbler	W10(1)	
Insectivorous open country (Pipits and Wagtails)	*Anthus pratensis*	Meadow Pipit		M1(1), S4(1)
	Motacilla alba	Pied Wagtail		S5(1)
	Motacilla flava	Yellow Wagtail*	W33(1)	
Insectivorous open country (swifts and swallows)	*Apus apus*	Swift	W10(3), W22/23/24(1), W33(1), W34(1)	S13(1)
	Delichon urbicum	House Martin	W10(1), W19(2), W33(1)	
	Hirundo rustica	Swallow	W16(2), W9(1), W10(3), W17(3), W33(3), W34(4), W37(1)	S13(1)
Corvids	*Corvus corone*	Carrion Crow	W9(1) W19(1)	M1(1), S10(1), S11(1), S13(1), S15(1)

	Corvus monedula	Jackdaw	W17(1), W19(1), W34(1)	S9(1), S13(2)
	Garrulus glandarius	Jay		D6(1)
	Pica pica	Magpie	W10(2)	S5(1), S13(2)
Doves	*Columba palumbus*	Woodpigeon	W1(3), W8(2), W9(3), W10(2), W16(1), W17(1), W19(1), W22/23/24(3), W34(2)	M1(1), S13(4), S5(5), D6(1), S6(2), S7(2), S9(2), S10(2), S11(2), S15(5)
	Streptopelia decaocto	Collared Dove	W1(1)	S9(1)
Birds of Prey	*Accipiter nisus*	Sparrowhawk	W19(1)	
	Strix aluco	Tawny Owl		S7(1)
	Tyto alba	Barn Owl	W1(1)	
Shorebirds	*Haematopis ostralegus*	Oystercatcher		S13(1)
	Larus melanocephalus	Black-Headed Gull	W19(1), W22/23/24(1), W33(2), W34(1)	S13(1)

W = Manor Farm ponds, S = Stody/Hunworth ponds, M = Melton Constable ponds, D = Daniel's ponds. * indicates UK Biodiversity Action Plan (BAP) species.

[a] Seed eaters which become insectivorous during the breeding season and when provisioning young

[b] Values inside brackets indicate frequency of visits i.e. number of surveys present out of a total of five (scores = 1-5).

G Classification to genus level only.

Appendix B

Table B.1 Observations of the activities and locations of 12 observed bird species at open, managed ponds.

Species Name	*Hirundo rustica*	*Alauda arvensis*	*Gallinula chloropus*	*Anas platyrhynchos*	*Emberiza schoeniclus*	*Emberiza citrinella*	*Fringilla coelebs*	*Cyanistes caeruleus*	*Troglodytes troglodytes*	*Phylloscopus collybita*	*Sylvia communis*	*Turdus merula*
Common Name	Swallow	Skylark	Moorhen	Mallard	Reed Bunting	Yellowhammer	Chaffinch	Blue Tit	Wren	Chiffchaff	Whitethroat	Blackbird
Foraging/ hunting	39(1)[a]	0	0	4	0	0	5	19	0	0	20(5)	1(1)
Pair/ group behaviour	35	9	8	16	4	2	29	36	0	0	16	0
*Evidence of provisioning chicks	2	0	2[b]	4[b]	0	0	4	2	0	0	18	1
Sheltering/ using cover	1	11	31	8	8	15	35	37	23	4	34	5
Perching	1	5	4	0	9	14	44	53	24	4	29	5
Territorial behaviour; singing	2	16	0	0	2	18	21	28	19	4	12	2
Calling	15	0	24	5	3	1	7	14	4	0	21	4
Riparian vegetation; shrubs and trees	1	6	18	8	6	14	54	55	21	4	30	6
Reeds/rushes	0	1	17	1	2	0	0	0	0	0	7	0
Grassland buffer	0	8	0	0	5	3	2	3	3	0	9	0
Bank/pond edge	0	0	16	4	1	0	8	2	2	0	4	1
Swimming in open water	0	0	13	13	0	0	0	0	0	0	0	0

*Evidence of provisioning chicks was determined by the occurrence of repeated visits to a site suspected to contain a nest or chicks by pairs of groups to the same site.

Includes observations of individuals bringing food items to the site and/or taking turns to forage and guard territory.

[a] For foraging data, brackets indicate number of times individuals were observed with prey items in mouth.

[b] Confirmation of young accompanied by adults in the case of waterfowl and rallids.

Table B.2 Observations of the activities and locations of 12 observed bird species at overgrown, terrestrialised ponds.

Species Name	*Hirundo rustica*	*Alauda arvensis*	*Gallinula chloropus*	*Anas platyrhyncos*	*Emberiza schoeniclus*	*Emberiza citrinella*	*Fringilla coelebs*	*Cyanistes caeruleus*	*Trogloydes trogloydes*	*Phylloscopus colybita*	*Sylvia communis*	*Turdus merula*
Common Name	Swallow	Skylark	Moorhen	Mallard	Reed Bunting	Yellowhammer	Chaffinch	Blue Tit	Wren	Chiffchaff	Whitethroat	Blackbird
Foraging/ hunting	1	0	0	0	0	0	4	6	4	2	0	3(1)[a]
Pair/ group behaviour	0	0	2	0	0	2	8	19	0	6	0	0
Evidence of provisioning chicks	0	0	5[b]	0	0	0	0	0	0	0	0	1
Sheltering/ using cover	0	0	14	0	0	19	29	39	41	21	2	16
Perching	1	0	0	0	0	19	40	52	31	24	5	18
Territorial behaviour; singing	0	0	0	0	0	20	23	34	35	21	5	3
Calling	0	0	15	0	0	0	6	32	15	3	0	12
Riparian vegetation; shrubs and trees	0	0	11	0	0	22	41	59	53	24	5	17
Reeds/rushes	0	0	14	0	0	0	0	0	3	1	0	0
Grassland buffer	0	0	0	0	0	0	0	0	0	0	0	0
Bank/pond edge	0	0	13	0	0	0	0	1	17	4	1	5
Swimming in open water	0	0	7	0	0	0	0	0	0	0	0	0

*Evidence of provisioning chicks was determined by the occurrence of repeated visits to a site suspected to contain a nest or chicks by pairs of groups to the same site.

Includes observations of individuals bringing food items to the site and/or taking turns to forage and guard territory.

[a] For foraging data, brackets indicate number of times individuals were observed with prey items in mouth.

[b] Confirmation of young accompanied by adults in the case of waterfowl and rallids.