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Monitoring the Use Made of *Chara intermedia* Beds by Waterfowl on Hickling Broad During the 1999/2000 Winter

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Executive Summary

1. Approximately 14 hectares of the extensive *Chara intermedia* beds, mainly adjacent to the central navigation channel at Hickling Broad, were cut in 1999. The aim of this study was to determine the impact of the cutting on the abundance and distribution of waterfowl on the Broad during winter 1999/2000.

2. Wetland Bird Survey (WeBS) counts of Coot, Mute Swan, Pochard and Tufted Duck during winter 1999/2000 showed similar patterns of numbers. The very high peak numbers of each species recorded in the first half of the winter decreased rapidly in the latter part of the winter. This effect may have been due to a combination of the rapid removal of the extensive *Chara* beds by the large numbers of waterfowl and bedding down of the vegetation intensified by the removal of a large amount of the plant material through cutting.

3. No difference could be detected between the height of the *Chara* beds in the cut and uncut sectors, thus making it less likely that the experimental set-up would detect differences in the waterfowl usage of the cut and uncut sectors of Hickling Broad. Significant positive relationships were detected between *Chara* height and densities of Coot, Mute Swan and Pochard.

4. All-day and all-night counts carried out during winter 1999/2000 showed no significant differences between the densities of feeding Coot or Tufted on the cut sectors and uncut sectors of the Broad. The densities of Mute Swan and Pochard were significantly higher on the cut areas than the uncut areas. However, it is important to note that most of the cut sectors were adjacent to the more disturbed navigation channel and that birds tended to favour the edge sectors, probably to avoid the disturbance that was greatest in the central part of the Broad. It may be that waterfowl do not favour either the cut or the uncut sectors in the central part of the Broad.

5. The fit of the generalised linear models used to analyse the data for each species was not ideal for the assumed Poisson distribution, probably because of over-dispersion of the data. It may be possible to improve the analyses by fitting alternative distribution models. These would provide a better basis for statistical inference.

6. The dabbling duck species identified as likely to feed on *Chara intermedia* were largely absent from the studied area of Hickling Broad during winter 1999/2000, probably due to the high water levels that kept the plants out of reach of these surface-feeding species.

7. The study has shown that waterfowl using Hickling Broad feed extensively on the *Chara* beds. In order to fully understand the effect of the cutting, further monitoring of the abundance and distribution of waterfowl is recommended. A suite of matched pairs of cut and uncut sectors would ideally be monitored over two winters. To make the analysis very robust the cutting treatment would be reversed during the second winter to make it possible to account for natural differences in the physical nature and geographical position of the sectors. Measurements of the depletion rates of *Chara intermedia* on the cut and uncut sectors would make it possible to estimate whether the decline in waterfowl occurred as a result of food depletion or environmental factors that are unrelated to food supply. It is also advised that foraging rates be measured for each sector type.

1. INTRODUCTION

Hickling Broad is located within a large area of low-lying land in east Norfolk and forms part of a nationally and internationally important area for nature conservation. It lies within a National Nature Reserve (NNR) and forms part of the Upper Thurne Broads and Marshes Site of Special Scientific Interest (SSSI). The latter is a component of The Broadland Special Protection Area (SPA) designated under the European Birds Directive, is a part of the Broads candidate Special Area of Conservation (cSAC), and is proposed for designation under the European Habitats Directive. Hickling Broad also forms part of the Broadland Ramsar site and the Hickling Broad and Horsey Mere Ramsar site.

Until the late 1960s, Hickling Broad was in sound ecological condition, with clear water and rich aquatic plant life. In the late 1960s, large numbers of Black-headed Gulls *Larus ridibundus* began to regularly roost on the Broad, and the faeces from the birds, in addition to nutrient input from land-drainage water, caused a significant increase in the phosphorous levels in the water (George 1992). As a result of the change in water quality, the Broad became eutrophic. The rate of sediment deposition also increased primarily due to the fall-out of dead and dying algae. The size of the gull roost declined during the 1980s, and in the following years the nutrient levels in the Upper Thurne Broads have gradually fallen as a result of flushing action. The declining amounts of phosphorous available for plant life resulted in Hickling Broad beginning to revert to a macrophyte-dominated condition. In 1998, the water in Hickling Broad became clear for the first time since 1969. One likely consequence of the improved water quality has been the recent marked increase in the total mass of aquatic vegetation including the nationally rare alga *Chara intermedia* (henceforth referred to as *Chara*). During winter 1999/2000, however, a bloom of toxic *Prymnesium* algae occurred, causing fairly large-scale mortality of fish (Michael Green *pers. comm.*). Although the algae are permanently present in the Broad, this was the first bloom since the mid-1980s. Another recent negative impact on the Broad occurred in January 2000 when an unprecedented tidal surge pushed saltwater into the local ecosystem. Although the Environment Agency succeeded in stemming the influx of saltwater with a temporary barrage at Potter Heigham, there appears to have been increased fish mortality in Hickling Broad as a result (Michael Green *pers. comm.*).

It is well documented that waterfowl populations can have an impact on aquatic ecosystems, for example, through deposition of faeces (Hussong *et al.* 1979, Mitchell & Wass 1995) and grazing on submerged macrophytes (Sondergaard *et al.* 1996). Waterfowl may also influence the eutrophication of lakes and have a role in the turnover of nutrients (Gere & Andrikovics 1992). Although feeding extensively on aquatic plants (Jacobs *et al.* 1981, Tubbs & Tubbs 1983, Lodge 1991) waterfowl may also take other food types such as invertebrates. Eight species of waterfowl, which spend the winter at Hickling Broad, were identified by Balmer and Rehfisch (1999) as likely to feed on *Chara*: Mute Swan *Cygnus olor*, Gadwall *Anas strepera*, Teal *Anas crecca*, Mallard *Anas platyrhynchos*, Shoveler *Anas clypeata*, Pochard *Aythya ferina*, Tufted Duck *Aythya fuligula* and Coot *Fulica atra*. Pochard, Tufted Duck and Coot can dive for their food, the other five species feed from the surface. The principal food types consumed by each species and their preferred feeding depths are reported by Balmer and Rehfisch (1999).

The predominant macrophytes on the Broad since the mid-1990s have been the Fennel Pondweed *Potamogeton pectinatus*, Spiked Water Milfoil *Myriophyllum spicatum* and *Chara.* The pondweed and milfoil have been cut from the central portion of the Broad since the mid-1990s to aid navigation. The unprecedented growth of *Chara* in the central portion in 1998 has been an impediment to navigation. An assessment has been undertaken by the Broads Authority to consider the possible effects of cutting *Chara* at Hickling Broad. As a result of the assessment, it was considered possible that cutting the *Chara* might affect waterfowl populations on the Broad. Therefore in 1999, an experiment was established to determine the usage of the *Chara* beds by waterfowl on Hickling Broad. As part of the experimental treatment certain areas of *Chara* were cut and the numbers of waterfowl on these areas were compared to those on uncut areas. This report presents the results of this experimental study of waterfowl usage of the cut and uncut areas within Hickling Broad undertaken during the autumn and winter of 1999/2000.

2. METHODS

2.1 Study Design

The experiment involved cutting blocks of *Chara* totalling approximately 14 hectares adjacent to the central navigation channel. Some areas of *Chara* immediately adjacent to the channel were left uncut. The cutting was undertaken in summer 1999. The location of the cut and uncut areas are shown in Figure 2.1.

The main part of the Broad was divided into 36 count sectors according to the cutting regime employed (Figure 2.1). Data were collected individually for these sectors in order to allow detailed analyses of the distribution of waterfowl in relation to the *Chara* cutting. Four types of sector were determined: 'cut' sectors near the central boat channel in which the *Chara* bed were cut during 1999 (sectors 26, 27, 28 and 36); 'uncut' sectors which were in a similar position relative to the central navigation channel as the 'cut' sectors; 'channel' sectors which covered the central navigation channel; 'edge' sectors which were either areas adjacent to the 'cut' and 'uncut' sectors but did not cover part of the main *Chara* beds, or were large areas between the other sectors and the reedbeds at the edge of the Broad. Sector 29 covered an area used in the previous year's trial cutting experiments and was not classified as a particular sector type. The design ensured that comparisons between cut and uncut sectors were not confounded by possible edge effects. If edge sectors had not been identified, it would have been possible that apparent avoidance of cut sectors was, in fact, driven more by a preference for feeding at the edge of the Broad.

Sectors 1 to 11 were counted from a jetty on the north-west side of the Broad at the Whispering Reeds Boatyard. Sectors 12 to 36 were counted from a temporary hide erected on the south side of the Broad (Figure 2.1).

2.2 Count Methodology

All-day and all-night counts were carried out between September 1999 and March 2000 to allow examination of the relative use made of the cut and uncut areas by the waterfowl on the Broad. The all-day counts were made once per month and covered all sectors. Counts of each sector were made once every hour of the day throughout the hours of daylight. Feeding and loafing/roosting birds were counted separately and factors such as disturbance to a sector (*e.g.* boating activities) or impaired visibility (*e.g.* looking into bright sun) were recorded. Counts were excluded if visibility was severely impaired. In addition to individual sector disturbance, a more general disturbance factor to the whole Broad was recorded each hour. This was recorded as the number of windsurfers, sailing boats, cruisers (and motor-powered boats) and rowing boats present on the Broad during each one-hour period. Counts were made simultaneously by two observers at the two observation points when possible. At other times, one observer made the counts from each side of the Broad on different days. Survey dates are shown in Tables 2.1 and 2.2. Note that we refer to the early October counts in this report as September counts for ease of distinction. Observations were made using binoculars and 20-60x magnification telescopes.

The all-night counts were made by a single observer from one of the observation points in alternate months, excluding September, and covered a smaller set of count sectors from both locations (Figure 2.2). The sectors in the north of the Broad were counted in November, December and March. Sectors in the south of the Broad were counted in October, January and February. Counts of feeding and roosting birds on each of these sectors were made once every hour of the night throughout the hours of darkness. Disturbance was recorded as above. Nocturnal observations were made using a LITE direct view thermal imager (for full details see Gill *et al.* 1997) and an infra-red image intensifier with either a 300mm or 500mm lens together with a Nightforce SL170 spotlight. The thermal imager was only available for use during October and November. It was not possible to observe birds on any of the uncut sectors (see Figure 2.2), so the observations were made to assess whether there was any evidence of major shifts in distribution.

Wetland Bird Survey (WeBS) counts are carried out monthly in the United Kingdom on most large inland water bodies during the winter months. The counts are usually made on predetermined dates, to allow counts across the country to be synchronised. To provide background for this study, WeBS counts of waterfowl at Hickling Broad for the winters 1997/98, 1998/99 and 1999/2000 were examined to assess the abundance of birds present in this part of the Norfolk Broads through the winter months.

Data relating to the height of *Chara* and depth of water in the Broad were collected for the Broads Authority by Jane Harris. Sample sites matched the following count sectors: 2, 4, 5, 6, 13, 15, 16, 17, 18, 19, 20, 24, 25, 26, 27, 28, 30 and 36. Sampling was carried out in September, November, January, February and March.

2.3 Data Analysis

2.3.1 Effect of cutting on winter *Chara* height

The heights of *Chara* in the cut and uncut sectors were compared using a nested ANOVA for each of September, November and January. The model related the height of *Chara* to the sector type (cut or uncut) and the sector itself. As such, the design is nested, with sector being nested within sector type (Zar 1999, Sokal & Ralph 1995).

2.3.2 Relationship between *Chara* height, water depth and bird densities

Generalised Linear Models (GLMs: McCullagh & Nelder 1989) were used to relate the number of feeding birds counted during day-time counts to *Chara* height, water depth above the *Chara* bed, month of the winter (September to March) and hours after dawn. Models assumed a Poisson distribution for the number of birds counted, specified a log link function (to ensure non-negative estimated counts under the model) and treated month and hour as categorical variables. All counts which were subject to disturbance in that hour or in the previous hour were removed from the dataset, so that disturbance would not be a confounding factor in the model. Likelihood ratio tests were used to identify significant explanatory variables in the model at the ($\alpha = 5\%$) significance level and to test the relationship between bird density and *Chara* height and water depth (SAS Institute 2000). Inspection of the final models, however, showed that the Pearson χ^2 values were much higher than their degrees of freedom (*e.g.* Coot (day): χ^2/d.f. = 22.7). This indicated that there was over-dispersion of the data, or a poor fit of the Poisson model. The procedure GENMOD (SAS Institute 2000) was therefore used to estimate the scale parameter (PSCALE) and the analyses were repeated, appropriately adjusted. Having estimated the scale parameter, some variables were no longer required in the model. This was carried out for the four most widespread species present: Coot, Mute Swan, Pochard and Tufted Duck. After the modelling procedure above, we acquired the following models:

Coot
ln(count) = $\mu + \alpha$(*Chara* height) + ln(area)

Mute Swan
ln(count) = $\mu + \alpha$(*Chara* height) + β(water depth) + ln(area)

Pochard
ln(count) = $\mu + \alpha$(*Chara* height) + γ_i(hour) + ln(area)

Tufted Duck
ln(count) = μ + ln(area)
i.e. No significant explanatory variables

The estimated values of the model parameter α indicates the relative number of birds for a specific *Chara* height. The estimated values of the model parameter β indicates the relative number of birds for a specific water depth. Similarly, the estimated values of the model parameter γ_i indicate the relative number of birds present for each hour of the day. We report on the relative increase in the number of birds for a 20cm increase in *Chara* height and water depth for each species.

2.3.3 Modelling of bird densities on all sectors

Generalised Linear Models were used to relate the number of feeding birds counted to the sector type, month of the winter, hours after/before dawn, sector and disturbance. Models assumed a Poisson distribution for the number of birds counted, specified a log link function and treated all variables as categorical. Sector 29 was excluded from the analyses in all cases. Likelihood ratio tests were used to identify significant explanatory variables in the model (Wetherill 1981). Inspection of the final models, however, showed that the Pearson χ^2 values were much higher than their degrees of freedom (*e.g.* Coot (day): χ^2/d.f. = 44.2). This indicated that there was over-dispersion of the data, or a poor fit of the Poisson model. The procedure GENMOD (SAS Institute 2000) was therefore used to estimate the scale parameter (PSCALE) and the analyses were repeated. Having estimated the scale parameter, some variables were no longer required in the model. This was carried out for the four most widespread species for the periods when they were most abundant on the Broad. After the modelling procedure above, we acquired the following models:

Coot September to November

ln(count) = μ + α_i(sector type) + β_i(month) + γ_i(hour) + δ_i(sector) + κ_i(RB disturbance) + ζ_i (lag RB disturbancel) + λ_i(M/C disturbance) + η_i(sector disturbance) + φ_i(lag sector disturbance) + ln(area)

Mute Swan September to October

ln(count) = μ + α_i(sector type) + δ_i(sector) + ρ_i (lag WS disturbance) + η_i (sector disturbance) + ln(area)

Note that channel sector 23 and edge sector 33 were removed from the model as no Mute Swans were observed feeding in those months on those sectors.

Pochard September to January

ln(count) = μ + α_i(sector type) + β_i(month) + γ_i(hour) + δ_i(sector) + ε_i(WS disturbance) +ρ_i(lag WS disturbance) + κ_i(Y disturbance) + λ_i(M/C disturbance) + ι_i(lag M/C disturbance) + κ_i(RB disturbance) + η_i(sector disturbance) + φ_i(lag sector disturbance) + ln(area)

Note that channel sectors 7, 9 and 22 were removed from the model as no Pochard were observed feeding in those months on those sectors.

Tufted duck September to January

ln(count) = μ + α_i(sector type) + β_i(month) + γ_i(hour) + δ_i(sector) + ε_i(WS disturbance) + κ_i(Y disturbance) + λ_i(M/C disturbance) + η_i(lag Y disturbance) + φ_i (sector disturbance) + ln(area)

Note that channel sectors 7, 9 and 21 were removed from the model as no Tufted Duck were observed feeding in these months on those sectors.

Factors used are defined as follows:

<u>Site-Specific Factors</u>

- Sector type is 'cut', 'uncut', 'channel', or 'edge' (see Study Site above);

- Sector is the individual count sector (1 to 36), note therefore that 'sector' is nested within 'sector type'. This permits the testing of a constant sector effect within sector types.

- The offset ln(area) was included so that the equation effectively modelled density. The area of each sector was calculated by mapping the Broad on a GIS.

Time-Specific Factors

- Month is between September 1999 and March 2000. The periods tested for each species depends on their abundance in each month;

- Hour is the number of hours after dawn, and takes the values (0, 1, 2,…). The actual time varies depending on the month in which observations were carried out;

Disturbance Factors, Site and Time Specific

- WS is the presence/absence of one or more windsurfers in an hour;

- Y is the presence/absence of one or more yachts in an hour;

- M/C is the presence/absence of one or more motor boats or cruisers in an hour;

- RB is the presence/absence of one or more rowing boats in an hour;

- Sector disturbance is recorded when the disturbance factor occurs in a count sector at the time of counting, therefore a sector is either disturbed or not;

- The lag of each of these types of disturbance is the presence of the disturbance in the previous hour if the same disturbance type is no longer present in the hour of the count;

The estimated values of the model parameter α_i indicates the relative number of birds on sector type i, where i is 'cut', 'uncut', 'edge' or 'channel'. Similarly, the estimated values of the model parameter δ_i indicate the number of birds present on each sector i, where i is 1 - 36. We also considered a direct comparison of the numbers of birds on cut and uncut sites, via a model in which the effects for these two sector types are constrained to be equal. With the scale parameters estimated, it was more appropriate to use F-tests to test for the difference in use of the cut and uncut sectors by feeding birds as follows:

$$F = \frac{D_1 - D_0}{r\phi}$$

where D_0 is the deviance of a GLM, treating 'cut' and 'uncut' differently,
D_1 is the deviance from fitting a sub-model with no difference between 'cut' and 'uncut',
r is the difference in the number of parameters between the model and the sub-model,
ϕ is an estimate of the dispersion parameter (PSCALE).

This test statistic has a F-distribution with (n-p) degrees of freedom, where n is the number of observations and p is the number of parameters in the model that is used to estimate ϕ (Crawley 1993). For all other species recorded, the maximum numbers of feeding and total birds were calculated for each month.

2.3.4 Bird densities on paired sectors

The following sectors were paired for further analysis according to their geographical location and to be sides of the channel: 15 and 26; 18 and 27; 19 and 28; 24 and 36. In this way, disturbance factors can be removed from the models as it can be assumed that disturbance to one sector also affects its paired sector. Generalised Linear Models were used to relate the mean number of feeding birds counted for each hour each month to the sector type, month of the winter, and pair identity. Models assumed a Poisson distribution for the number of birds counted, specified a log link function and treated all variables as categorical. Likelihood ratio tests were used to identify significant explanatory variables in the model (Wetherill 1981). Inspection of the final models, however, showed that the Pearson χ^2 values were much higher than their degrees of freedom (*e.g.* Coot (day): χ^2/d.f. = 11.3). This indicated that there was over-dispersion of the data, or a poor fit of the Poisson model. The procedure GENMOD (SAS Institute 2000) was therefore used to estimate the scale parameter (PSCALE) and the analyses were repeated. Having estimated the scale parameter, some variables were no longer required in the model. This was again carried out for the four most widespread species for the periods when they were most abundant on the Broad. After the modelling procedure above, we acquired the following models:

Coot September to November
ln(density) = $\mu + \beta_i$(month) + δ_i(month*sector type) + γ_i(pair)

Mute Swan September to October
ln(density) = $\mu + \gamma_i$(pair)

Pochard September to January
ln(density) = $\mu + \alpha_i$(sector type) + β_i(month)

Tufted duck September to January
ln(density) = $\mu + \gamma_i$(pair)

where pair is the arbitrary identity given to each of the four pairs. The month*sector type interaction term in the model allows the determination of changes in distribution through time to be identified, but was significant only for Coot.

3. RESULTS

3.1 Analysis of WeBS Data

Figures 3.1 and 3.2 show number of bird days for each month for each of the four main species at Hickling Broad over the last three winters. The number of bird days is calculated by multiplying the monthly WeBS count by the number of days in the month. It should be noted that, as yet, data for winter 1999/2000 have not been validated by the WeBS Secretariat. For all four species, the peak numbers in winter 1999/2000 occurred between September and December and were higher than those made in the previous two winters. By February Tufted Duck and Coot numbers had rapidly declined after the peak to levels lower than those in the previous two winters. By February Mute Swan and Pochard numbers were similar to those of the previous two winters.

3.2 Maximum Counts

The maximum feeding and total (feeding and loafing/roosting) numbers of Mute Swan, Pochard, Tufted Duck and Coot recorded during the all-day and all-night counts each month are shown in Tables 3.1 and 3.2. These counts are for all 36 sectors combined. The pattern of numbers recorded each month largely reflects those of the WeBS counts for winter 1999/2000. Very few birds were recorded during the middle of the night period. Most of the birds recorded at night were present in the hours shortly after dusk and just before dawn. Of the other key species likely to feed on *Chara intermedia*, Gadwall, Teal and Mallard were recorded during the all-day counts (Table 3.3). Shoveler were not observed. Numbers of these dabbling species on the study area were low, as the majority used areas to the east of this part of the Broad. Detailed analyses of their numbers have not been carried out. The maximum feeding and total numbers of all other species recorded by the all-day counts are shown in Table 3.4.

3.3 Mean Densities

The hourly mean density of feeding Mute Swan, Pochard, Tufted Duck and Coot (±s.e.) on each sector each month are tabulated in the Appendices. Figure 3.3 shows the distributions of feeding Coot during all-day counts represented by the mean number of birds per month on each sector between September and November, when Coot numbers were highest. One dot represents the equivalent of one bird placed randomly within the sector. If the mean was less than 0.5, it is not shown on the maps. The highest densities of Coot during the day were found on 'edge' sectors 1, 2, 31, 30, 32, 34 and 35 and 'uncut' sectors 26 and 28. Figure 3.4 shows similar distribution maps for Coot during all-night counts in October and November. Note that sectors in the south of the Broad were counted in October and sectors in the north of the Broad were counted in November. At night, fewer birds were recorded, especially on the southern sectors of the Broad and most birds were found on sector 11.

Similar maps of the distributions of feeding Mute Swan during the all-day counts in September and October, when Mute Swan numbers were highest, are shown in Figure 3.5. None were observed feeding between January and March 2000. There did not appear to be any preference of Mute Swan for a particular sector type, although in October, highest densities appeared to be on 'edge' sectors 1 and 2 and 'cut' sector 5. The distributions of feeding Pochard during the all-day counts in September, October, November, December and January are shown in Figure 3.6. Like Coot, there were fewer feeding birds on the central part of the Broad, with the highest densities on 'edge' sectors 1, 2, 31 and 32. The distributions of feeding Tufted Duck during the all-day counts between September and January are shown in Figure 3.7. Tufted Duck appeared in highest density on the 'edge' sectors 12, 13, 32, 33, 34 and 35, with fewer birds recorded on 'cut' and 'uncut' sectors.

3.4 *Chara* Height

There were no significant differences in the heights of *Chara* between the cut and uncut sectors of the Broad (September: $F_{1,13} = 1.497$, NS; November: $F_{1,13} = 0.460$, NS; January: $F_{1,13} = 0.108$, NS).

3.5 Bird Density Versus *Chara* Height and Water Depth

For Coot, Mute Swan and Pochard, significant, positive relationships were found between bird density and *Chara* height (Coot: $F_{1,406} = 369.45$, $P<0.001$; Mute Swan: $F_{1,241} = 6.06$, $P<0.05$; Pochard: $F_{1,397} = 44.15$, $P<0.001$; Tufted Duck: no relationship).

Mute Swan density also showed a significant negative relationship with the depth of water above the *Chara* ($F=113.26$, $P<0.001$). Although estimated as such, this relationship is unlikely to be linear, but rather that there is some threshold value of water depth at which they no longer feed.

3.6 Bird Densities Across All Sectors

Figures 3.8 and 3.9 show the antilog of the model site-specific parameter estimates of feeding Coot, Mute Swan, Pochard and Tufted Duck during the day on each sector for the periods specified for each species in the methods. This effectively shows the relative densities of birds on each sector, with the day-time density of birds of each species on sector 36 being set arbitrarily to one, to achieve parameter identifiability. Therefore if a sector has a relative model density of two, then the model estimates that the sector holds twice the density of birds found on sector 36.

There was no difference between the densities of feeding Coot during the day across all 'cut' sectors and all 'uncut' sectors ($F_{1,1035} = 0.43$, NS) (Figure 3.10). There did not appear to be any major shift in the distribution of Coots on those areas of the Broad investigated at night.

The density of Mute Swan was significantly higher on the 'cut' sectors than on the 'uncut' sectors ($F_{1,709} = 4.21$, $P<0.05$) (Figure 3.10).

The density of Pochard was significantly higher on the 'cut' sectors than on the 'uncut' sectors ($F_{1,1520} = 11.40$, $P<0.001$) (Figure 3.10).

There was no difference between the densities of feeding Tufted Duck during the day across all 'cut' sectors and all 'uncut' sectors ($F_{1,1523} = 0.005$, NS) (Figure 3.10).

In each case, the F-test is used to allow for the estimation of the dispersion parameter. Significance of differences was taken at the five percent level.

3.6.1 Density of birds on paired sectors

The density of Pochard on cut sectors was significantly higher than that on uncut sectors between September and January ($F_{1,34} = 9.84$, $P<0.01$), as also shown by the model above.

There were no significant differences between the densities of Coot, Mute Swan and Tufted Duck on cut and uncut sectors across the periods in which each species was most abundant on the Broad. However, the interaction between month and sector type was significant for Coot, suggesting a shift in distribution over time ($F_{2,18}=5.59$, $P<0.05$). This was demonstrated by plotting the antilog of the parameter estimates of the model densities of Coot (Figure 3.11). It is clear that in September, the density of feeding Coot was higher on uncut sectors than on cut sectors, but switched thereafter.

4. DISCUSSION

Following a single year of monitoring, it is difficult to assess the impact of the cutting of a proportion of the *Chara* beds at Hickling Broad, particularly as there was no significant difference in the height of *Chara* in the cut and uncut sectors, a factor that may explain why no clearly significant decreases emerged in waterfowl usage of cut and uncut sectors. There are, however, issues that need to be considered.

The number of bird days (assumed from WeBS counts) of the four main species examined show similar patterns, with very high numbers in the first part of winter 1999/2000, decreasing more rapidly than usual in the latter part of the winter. This is likely to be linked to the availability of food. The abundance of *Chara intermedia* in the early winter period may facilitate increased numbers of those species that can access the resource by either or upending, diving species, Coot, Pochard and Tufted Duck, Mute Swan. Balmer & Rehfisch (1999) found possible positive relationships across years between the area of the *Chara* beds at Hickling Broad and numbers of Mute Swan, Teal, Coot, Mallard, Pochard and Tufted Duck. At Lake Veluwemeer in Holland, *Chara* re-colonised in 1990 after a decline in the domination of *Potamogeton*. There was an immediate positive response by Coot and Mute Swan, but initially the birds did not remain after September. As the *Chara* biomass increased, the birds were able to remain for a longer period. It was estimated that at least 75% of the *Chara* biomass was consumed by the waterfowl (Noordhuis *in litt.*). Balmer & Rehfisch (1999) estimated that between 55% and 100% of the *Chara* at Hickling Broad could be taken by waterfowl under the current cutting regime (based on waterfowl counts in 1998/99 winter). It is possible that during this winter, the increased numbers of waterfowl present in the early part of winter consumed much of the *Chara*, quickly depleting the amount of *Chara* available, thereby reducing the number of waterfowl that the Broad was able to support in the latter part of winter. With less *Chara* present due to cutting, this effect may have been exacerbated. In addition to this, the *Chara* bedded down sometime in November and throughout the latter part of winter. This could have affected Coot and Pochard at least, which both showed a positive relationship with increasing *Chara* height.

Dabbling duck species were largely absent from the study area. This may have been due to the exceptionally high water levels (Michael Green *pers. comm.*) that left the plants out of reach of these surface-feeding species. Cutting of the *Chara* may also have reduced the availability of the plants to those species. At Lake Veluwemeer, high water levels in November 1998 caused a shift from it being dominated by dabbling duck to it being dominated by diving species, although Mute Swan numbers also increased (Noordhuis *in litt.*).

The intensive study of the distribution of waterfowl at Hickling Broad showed that the highest densities of birds were to be found on the sectors towards the edge of the Broad. This is likely to be as a result of disturbance, which typically occurred in the central portion of the Broad, particularly by the boats that were required to stay in the navigation channel. Windsurfers could cover a much larger area, and caused obvious movement of birds away from the source of disturbance, often away from this part of the Broad altogether. The effect of disturbance was reflected in the models for each species. Unsurprisingly, fewest birds were observed feeding in the navigation channel sectors. Plants in this zone are cut away to prevent fouling of propellers, and these sectors were also subjected to the most disturbance. It should be noted that the design of the experiment resulted in most of the cut and uncut sectors being adjacent to the navigation channel where disturbance was greatest.

Of most importance to this study is the difference between the number of birds using the cut and uncut sectors. As the uncut sectors were chosen to allow direct comparison with the cut sectors they are in a similar position relative to the navigation channel and the edge of the Broad. The models allowed us to take into account the impact of disturbance when making the comparisons, but by the time that our study started there was no difference in the height (but not necessarily biomass) of *Chara* in the cut and uncut sectors. This made it less likely that differences in waterfowl densities would be found between the cut and uncut sectors.

The densities of Coot and Tufted Duck were not significantly different between the cut and uncut sectors during the period when birds were most numerous. However, the significant interaction between month and cutting regime determined by the paired analysis for feeding Coot density shows that there was a shift in distribution over time. In September, when Coot numbers were at their highest, the density of birds was higher on the uncut sectors than on the cut sectors. Thereafter, the Coot appeared to prefer the cut sectors. It is possible that the very high numbers of birds present in the autumn and early winter depleted this food resource on the uncut sectors to the extent that birds moved into other areas to feed. The positive relationship between *Chara* height and Coot density would support this. However, no significant difference was detected in the height of *Chara* on the cut and uncut areas of the Broad during this period. The densities of Mute Swan and Pochard were significantly higher on the cut areas than on the uncut areas. These species may have preferred to feed on *Chara* on the cut sectors, or they may have been feeding on other organisms made more accessible to them by the cutting of the vegetation. It is interesting to note that, as one would expect, a significant negative relationship between Mute Swan (a non-diving species) numbers and water depth above the vegetation was detected.

Waterfowl numbers observed during the night counts were very low. The number of birds present fell sharply soon after dusk and did not build up again until shortly before dawn. Coot were observed apparently heading into the reeds surrounding the open Broad, while duck species were seen flying away from this part of the Broad, not returning until the morning. This may have been due to the large gull roost that amassed on the open Broad at dusk and dispersed soon after dawn.

It may be that waterfowl do not favour certain sectors, whether the *Chara* has been cut or not. In this context, it is important to note that most of the cut sectors were adjacent to the navigation channel. Furthermore, it is possible that cutting the plants back facilitates increased productivity and nutritive value, thereby offsetting any loss of biomass. Alternatively, cutting back the plants may help diving species access parts of the plant that they would otherwise be restricted from. But, again, it is important to emphasise that the experiment was unlikely to detect major associations between waterfowl densities and *Chara* when there was no significant difference in the height of *Chara* on the cut and uncut sectors. If the experiment is to be repeated successfully in future years it will be essential to ensure that the *Chara* height varies significantly between the two treatments.

It should be pointed out that the fit of each model, particularly for Coot, was not ideal to the assumed Poisson distribution, as shown by the high ratio of Pearson's χ^2 value to the degrees of freedom. This is probably due to over-dispersion of the data (*e.g.* high proportion of zero counts and also some relatively very high counts). By having to estimate the scale parameter (PSCALE) for each model, tests were likely to prove less significant. It may be possible to improve the analysis by fitting alternative distribution models and looking for relationships within the data which could improve the model fit. Such models would provide a sounder basis for statistical inference, but take a long time to fit.

5. RECOMMENDATIONS FOR FURTHER WORK

This study has shown that waterfowl using Hickling Broad feed extensively during the day on the *Chara* beds. At night, very few birds were observed and as the whole Broad cannot be monitored, we do not recommend further all-night counts using the present methodology. Instead it may be possible to observe a substantial area of cut and uncut sectors from a stationary boat in the central channel between the cut and uncut sectors.

To confirm the results of this study we propose the following to help fully understand the effect of cutting the *Chara* beds.

1. A suite of matched pairs of cut and uncut sectors would ideally be monitored over two winters. To make the analysis very robust the cutting treatment would be reversed during the second winter to make it possible to account for natural differences in the physical nature and geographical position of the sectors.

2. Measuring the depletion rate of *Chara* on the cut and uncut areas of the Broad would make it possible to estimate whether any decline in waterfowl numbers was related to the depletion of *Chara*, or environmental factors unrelated to food supply.

3. Foraging rates, for at least one of the diving species such as Coot, on the cut and uncut sectors could be measured. These data would make it possible to index the handling time and accessibility of the *Chara* on the different sectors through time. These indices could then be related to any changes in waterfowl numbers occurring on Hickling Broad. This would help assess whether *Chara* availability is a causal determinant of waterfowl numbers on Hickling.

Acknowledgements

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Date	Location	Hours after dawn	Observer
05 October 1999	Main	6 – 12	MJSA
05 October	North	5 – 11	SJH
07 October	Main	1 – 5	MJSA
08 October	North	1 – 4	SJH
19 October	North	0 – 9	SJH
25 October	Main	4 – 9	SJH
26 October	Main	0 – 3	MJSA
23 November	North	9	MJSA
24 November	North	0	MJSA
26 November	North	1 – 5	SJH
26 November	Main	1 – 5	MJSA
29 November	North	6 – 8	SJH
30 November	Main	6 – 8	SJH
21 December	North	1 – 7	SJH
22 December	North	8 – 9	SJH
23 December	North	0	SJH
30 December	Main	1 – 8	SJH
13 January 2000	Main	1 – 8	SJH
17 January	North	1 – 9	SJH
18 January	Main	9	SJH
19 January	Main	0	SJH
14 February	Main	1 – 9	SJH
15 February	North	1 – 9	SJH
9 March	Main	1 – 11	MJSA
9 March	North	1 – 11	SJH

Table 2.1 Dates of daytime surveys carried out at Hickling Broad during winter 1999/2000

Date	Location	Hours before dawn	Observer
26 October 1999	Main	13 – 14	MJSA
27 October	Main	1 – 12	MJSA
23 November	North	0 – 14	MJSA
22 December	North	0 – 14	SJH
18 January 2000	Main	1 – 14	SJH
16 February	Main	0 – 14	SJH
13 March	North	1 – 13	SJH

Table 2.2 Dates of night-time surveys carried out at Hickling Broad during winter 1999/2000

Month	Mute Swan		Pochard		Tufted Duck		Coot	
	feeding	total	feeding	total	feeding	total	feeding	total
September 1999	85	94	47	124	45	120	2460	2823
October	88	114	277	408	202	383	2612	2922
November	10	11	130	171	42	81	942	1057
December	3	3	384	599	30	46	386	501
January 2000	0	0	24	89	32	76	244	298
February	0	7	27	28	17	29	116	138
March	0	0	33	60	20	22	52	65

Table 3.1 The maximum number of feeding and the total number of Mute Swan, Pochard, Tufted Duck and Coot recorded at Hickling Broad during all-day counts each month of winter 1999/2000.

Month	Mute Swan		Pochard		Tufted Duck		Coot	
	feeding	total	feeding	total	feeding	total	feeding	total
October 1999	9	9	10	14	6	34	59	59
November	13	19	18	20	20	40	317	384
December	0	0	36	41	21	8	122	208
January 2000	0	0	0	0	0	0	7	10
February	0	0	6	17	0	7	11	12
March	0	0	3	5	6	15	33	47

Table 3.2 The maximum number of feeding and the total number of Mute Swan, Pochard, Tufted Duck and Coot recorded at Hickling Broad during all-night counts each month of winter 1999/2000. Note that a much smaller area was counted during the night (Figure 2.2).

Month	Gadwall		Teal		Mallard	
	feeding	total	feeding	total	feeding	total
September 1999	3	3	0	0	12	19
October	0	6	0	2	3	13
November	0	0	0	0	5	26
December	0	0	1	50	2	41
January 2000	0	2	0	0	7	31
February	0	4	0	4	0	24
March	0	0	0	0	4	10

Table 3.3 The maximum number of feeding and the total number of Gadwall, Teal and Mallard recorded at Hickling Broad during all-day counts each month of winter 1999/2000.

	September 1999		October		November		December		January 2000		February		March	
	F	T	F	T	F	T	F	T	F	T	F	T	F	T
Little Grebe *Tachybaptus ruficollis*	1	1	6	6	1	1	1	1	0	0	0	0	1	1
Great-crested Grebe *Podiceps cristatus*	7	9	9	10	6	15	2	3	2	3	2	10	7	13
Black-necked Grebe *Podiceps nigricollis*	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cormorant *Phalacrocorax carbo*	3	3	4	4	4	8	2	2	7	7	7	7	0	0
Bewick's Swan *Cygnus columbianus*	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Greylag Goose *Anser anser*	0	5	0	4	0	15	0	251	2	300	0	2	0	24
Canada Goose *Branta canadensis*	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Egyptian Goose *Alopochen aegyptiacus*	0	0	0	2	0	0	0	5	0	0	0	0	0	0
Shelduck *Tadorna tadorna*	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Wigeon *Anas penelope*	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Red-crested Pochard *Netta rufina*	0	2	2	2	1	2	0	0	0	0	0	0	0	0
Goldeneye *Bucephela clangula*	0	0	3	3	15	16	4	4	8	8	10	10	7	10
Ruddy Duck *Oxyura jamaicensis*	0	0	1	1	2	7	0	4	0	0	0	0	0	0
Moorhen *Gallinula chloropus*	1	1	1	1	0	0	0	0	0	0	0	0	0	0

Table 3.4 The maximum number of feeding (F) and the total (T) number of "other species" recorded at Hickling Broad during all-day counts each month of winter 1999/2000.

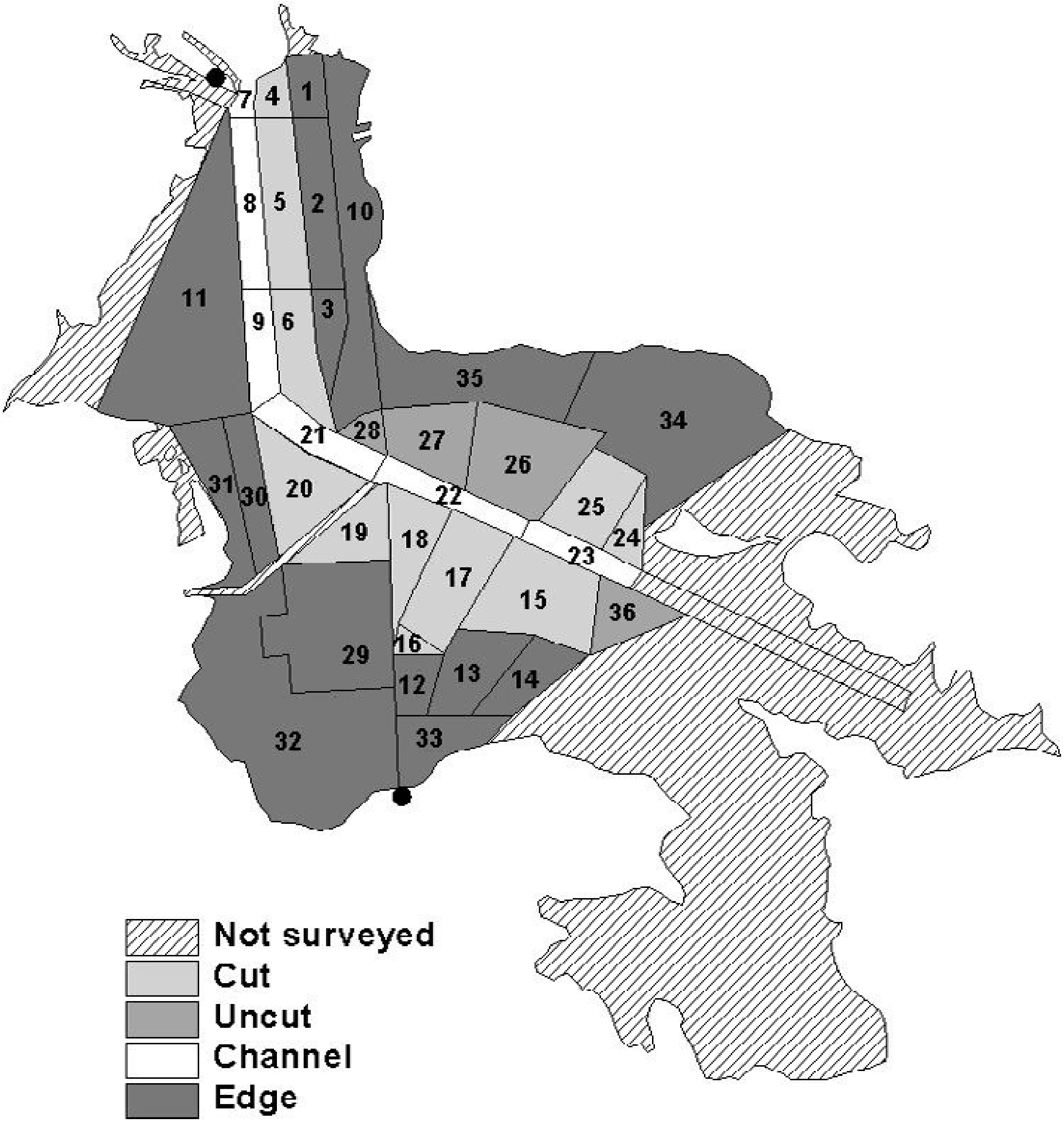


Figure 2.1 Hickling Broad study site showing observation points(●) and numbered count sectors for day-time observations. All the sectors consist of open water *i.e.* they do not include reedbeds.

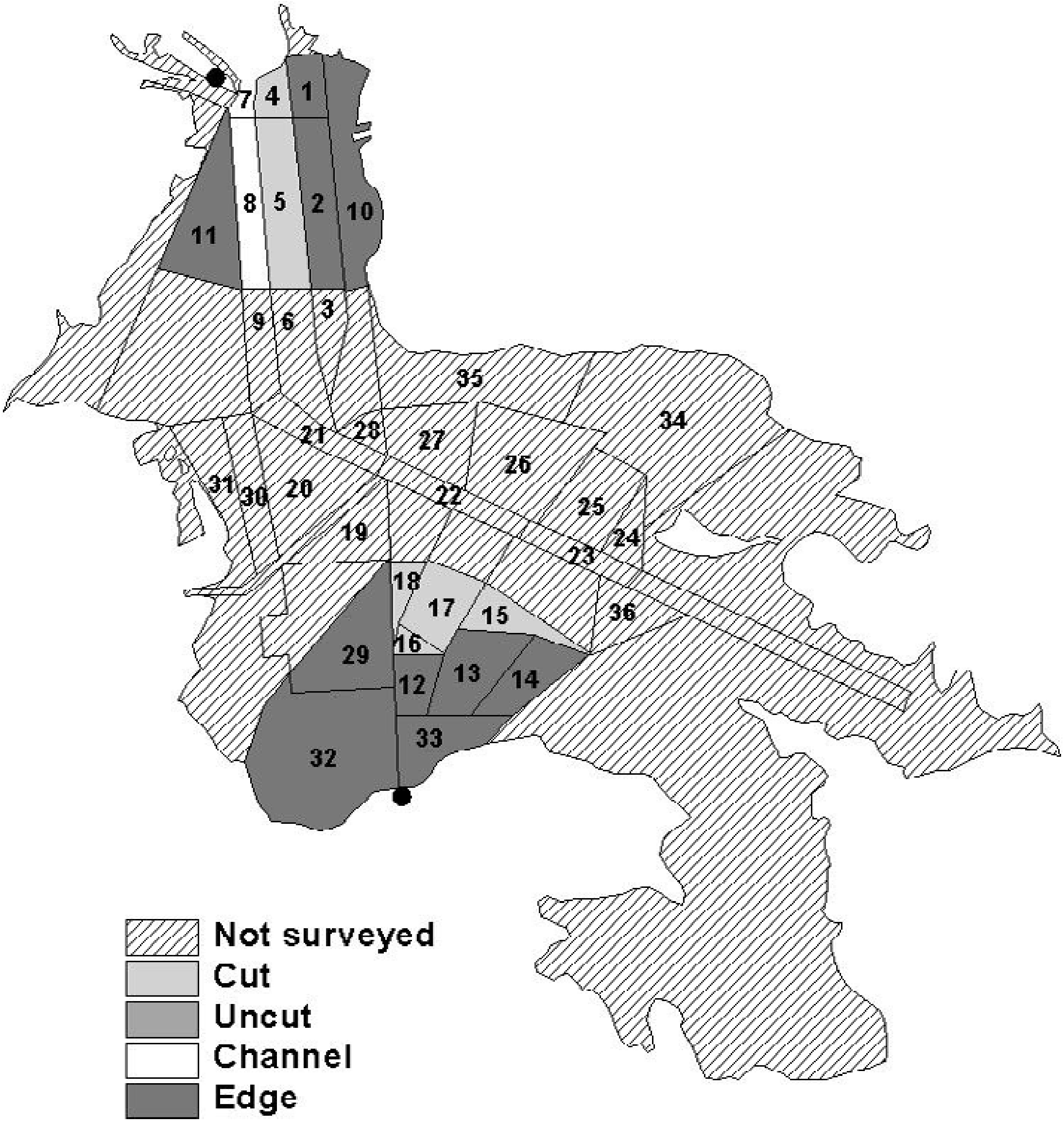
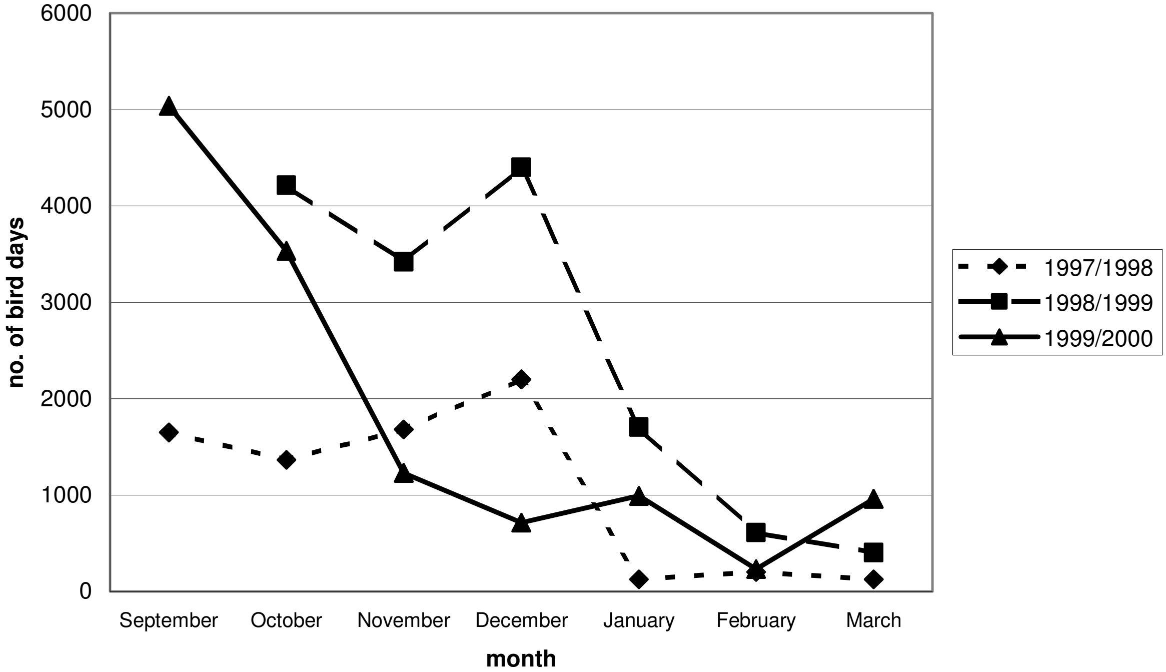


Figure 2.2 Hickling Broad study site showing observation points(●) and numbered count sectors for night-time observations. All the sectors consist of open water *i.e.* they do not include reedbeds.

Mute Swan



Pochard

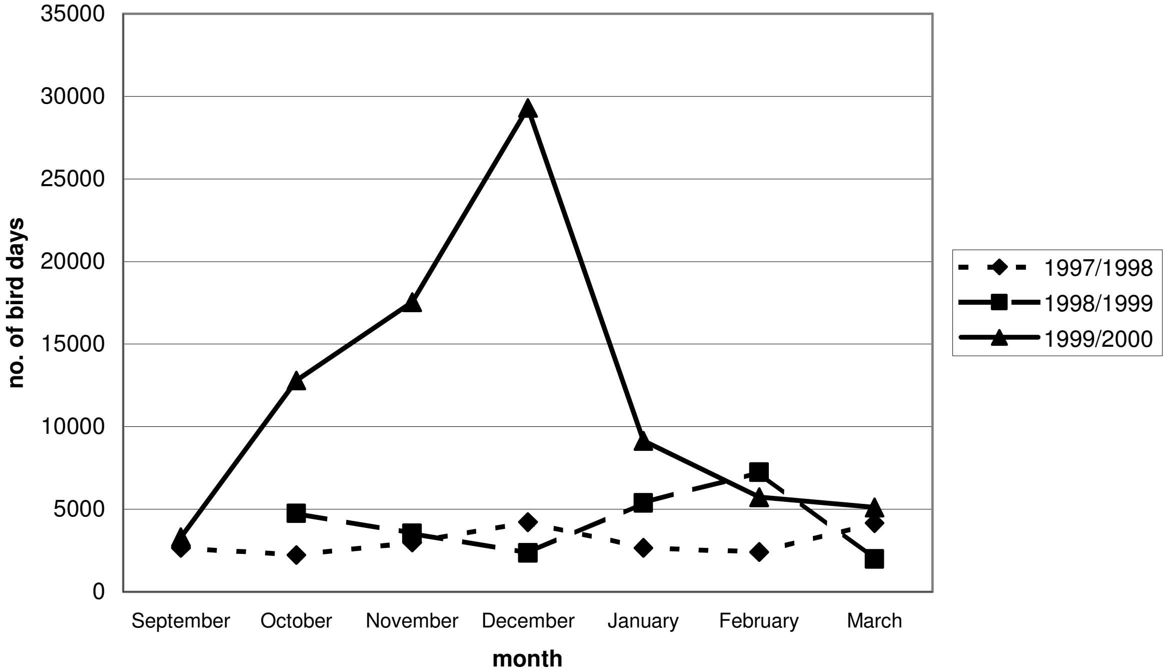
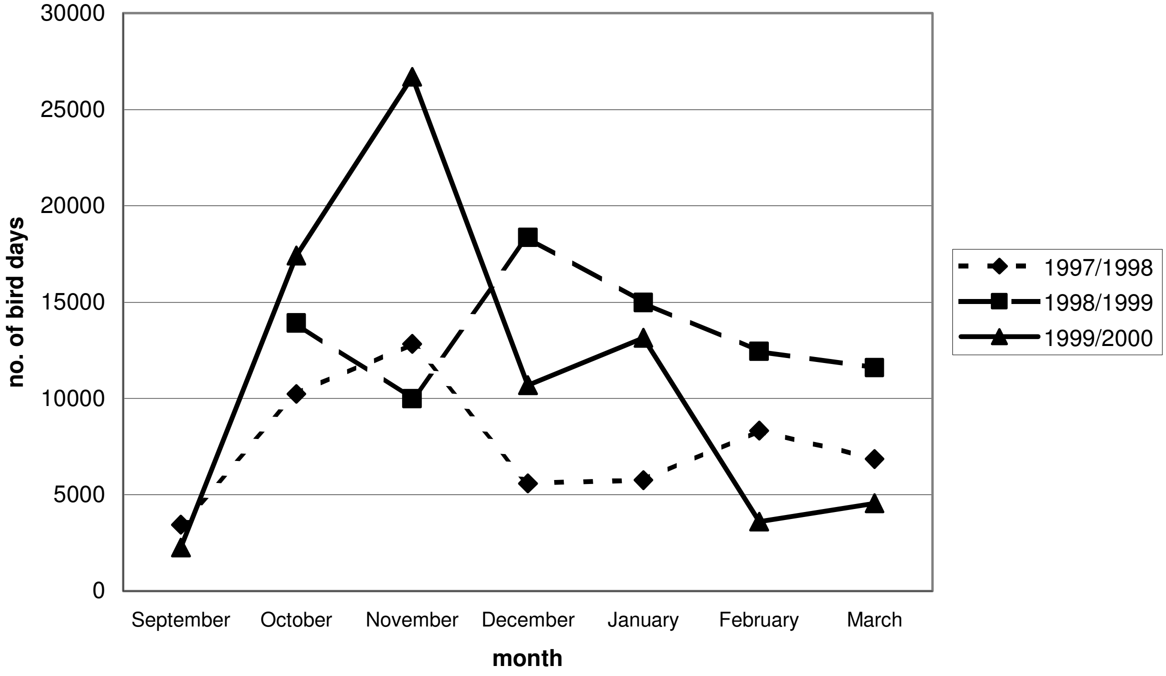


Figure 3.1 The number of bird days of Mute Swan and Pochard at Hickling Broad during winters 1997/98, 1998/99 and 1999/2000. Bird days have been calculated using the WeBS count made in each month

Tufted Duck



Coot

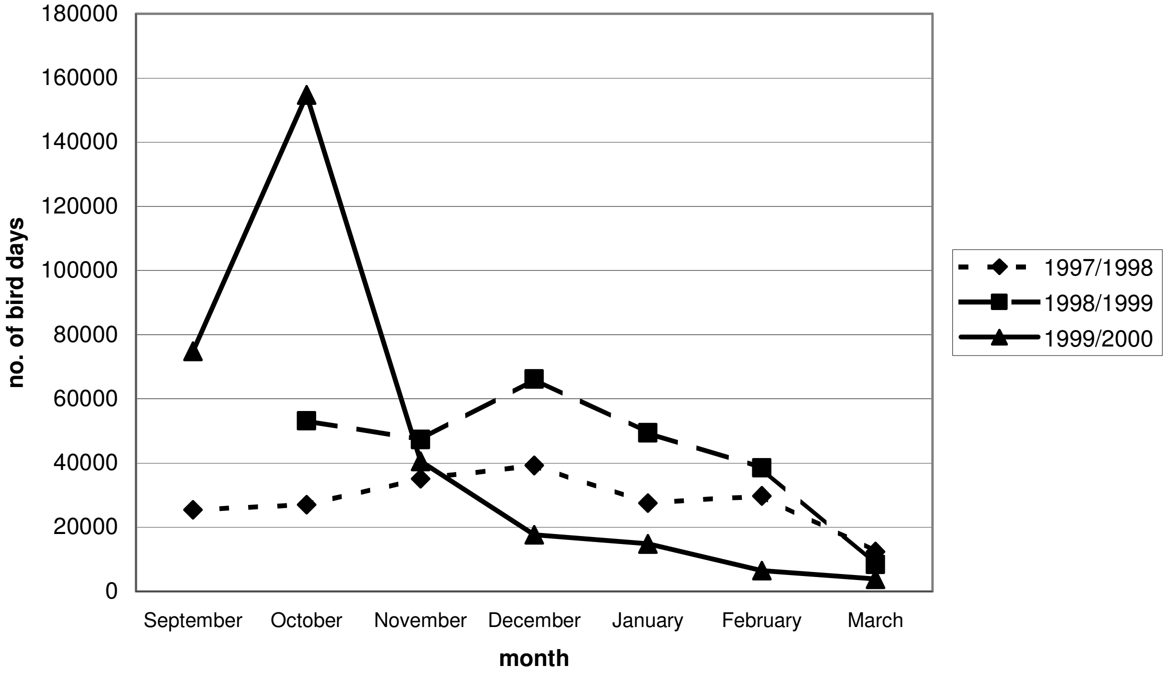
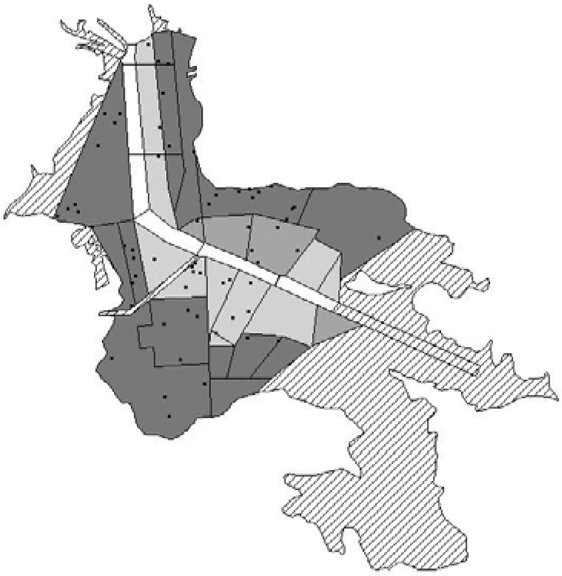


Figure 3.2 The number of bird days of Tufted Duck and Coot at Hickling Broad during winters 1997/98, 1998/99 and 1999/2000. Bird days have been calculated using the WeBS count made in each month.

Figure 3.3 Mean number of Coot on each sector for the months September, October and November 1999 during day-time observations. One dot represents the equivalent of one bird placed randomly within each sector.

Figure 3.4 Mean number of Coot on each sector for the months October and November 1999 during night-time observations. One dot represents the equivalent of one bird placed randomly within each sector. Note that only the sectors in the south of the Broad were counted in October and only the sectors in the north of the Broad were counted in November.

September



October

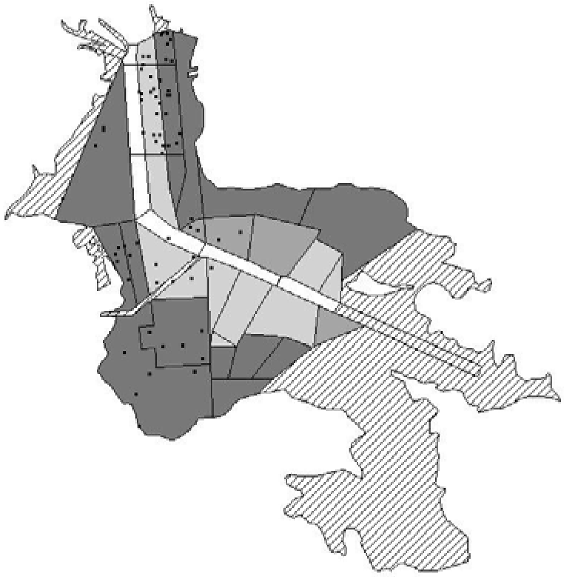


Figure 3.5 Mean number of Mute Swan on each sector for the months September and October 1999 during day-time observations. One dot represents the equivalent of one bird placed randomly within each sector.

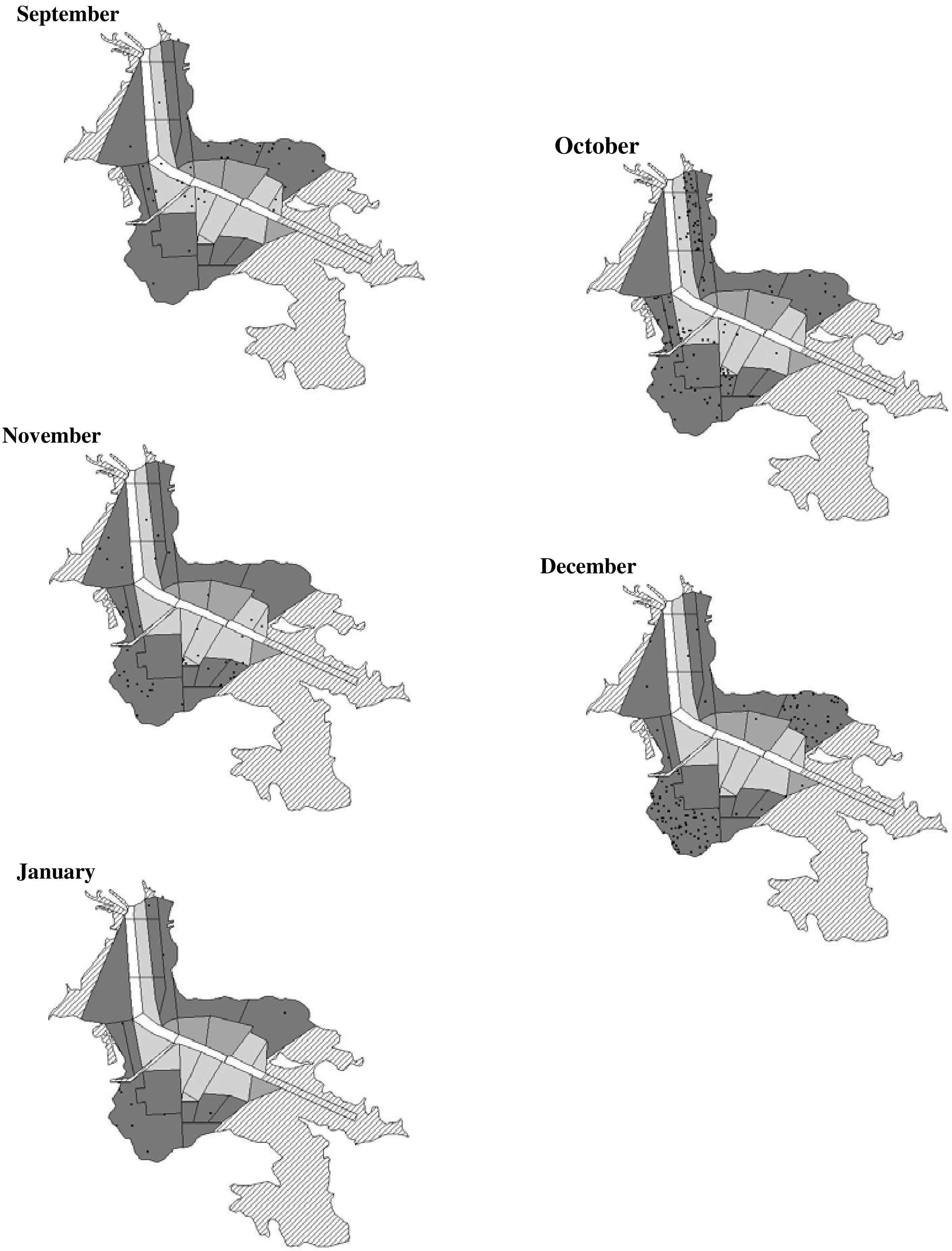


Figure 3.6 Mean number of Pochard on each sector for the months September 1999 to January 2000 during day-time observations. One dot represents the equivalent of one bird placed randomly within each sector.

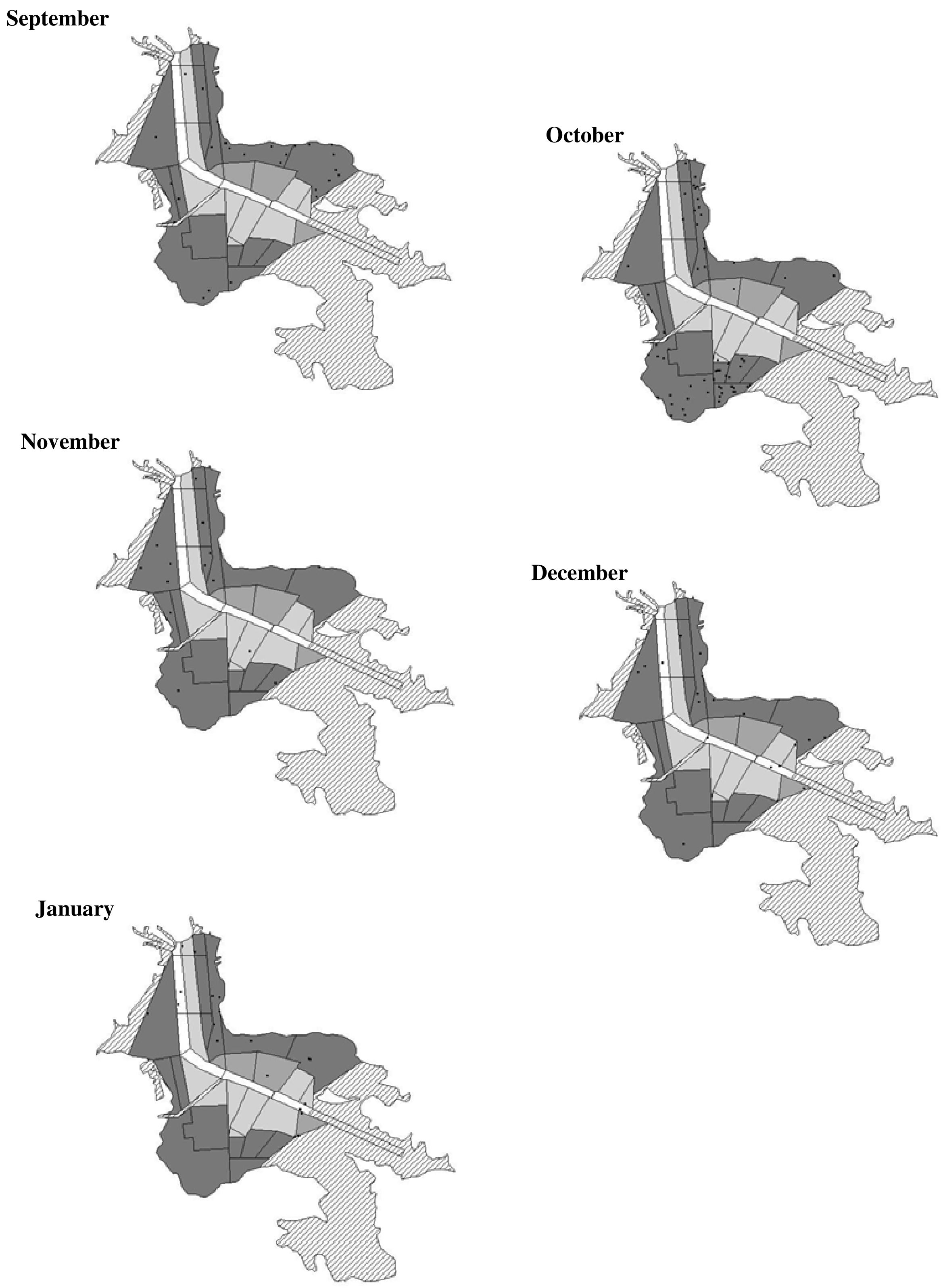
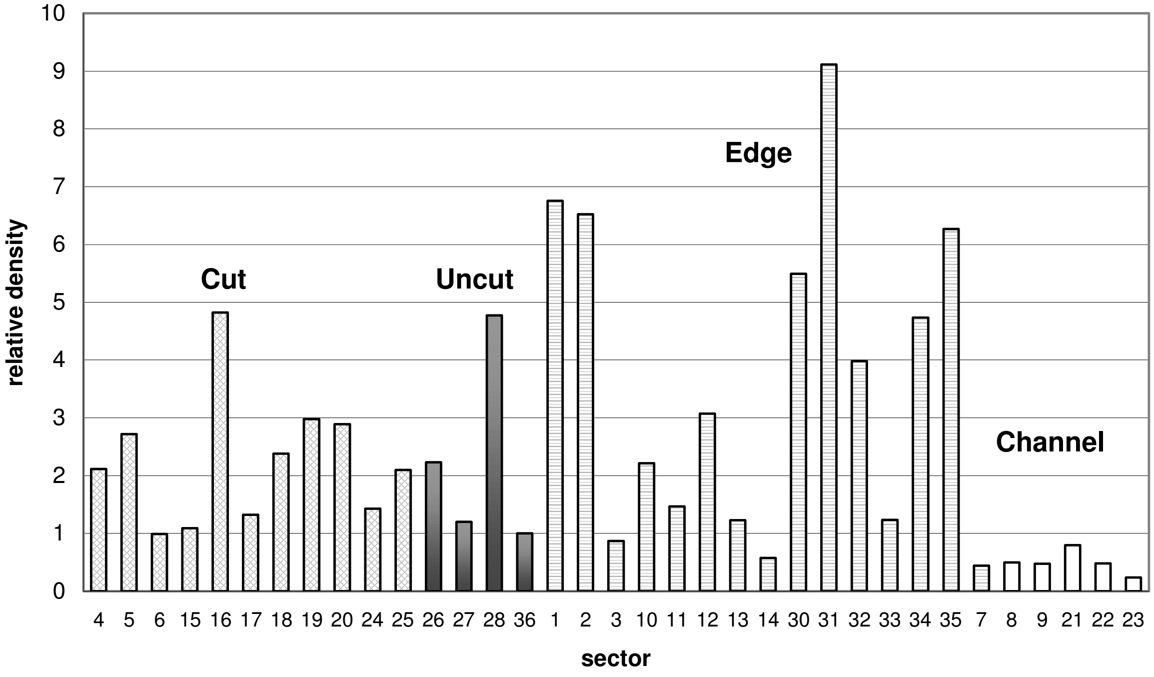


Figure 3.7 Mean number of Tufted Duck on each sector for the months September 1999 to January 2000 during day-time observations. One dot represents the equivalent of one bird placed randomly within each sector.

Coot (day)



Mute Swan

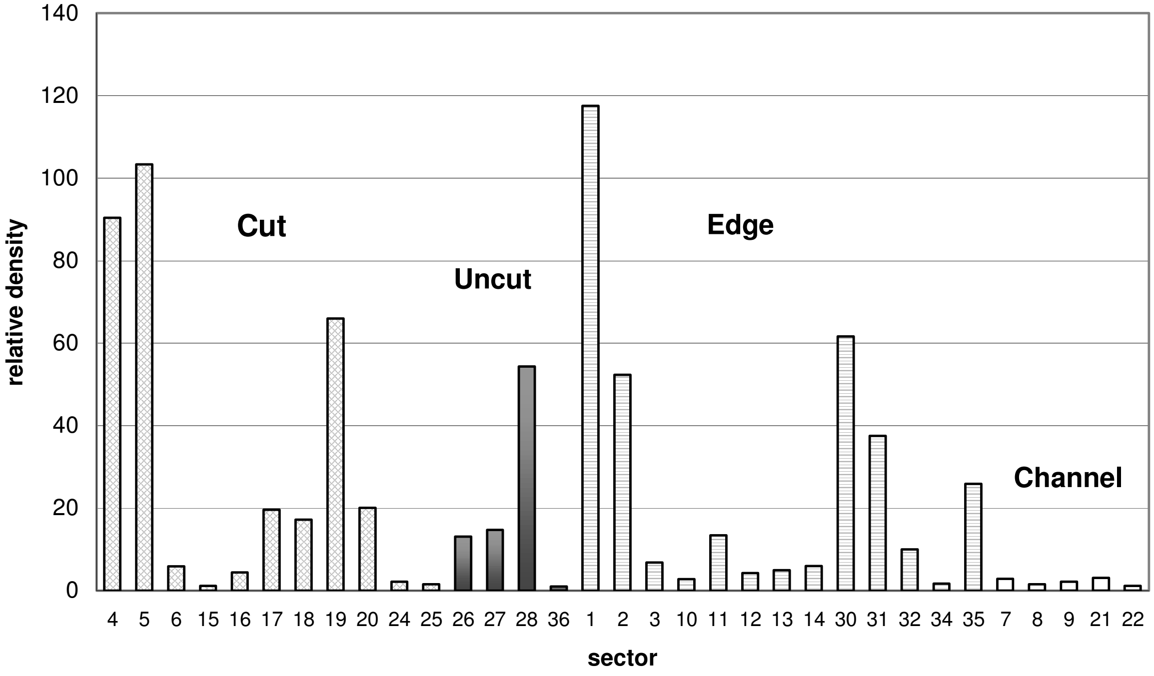
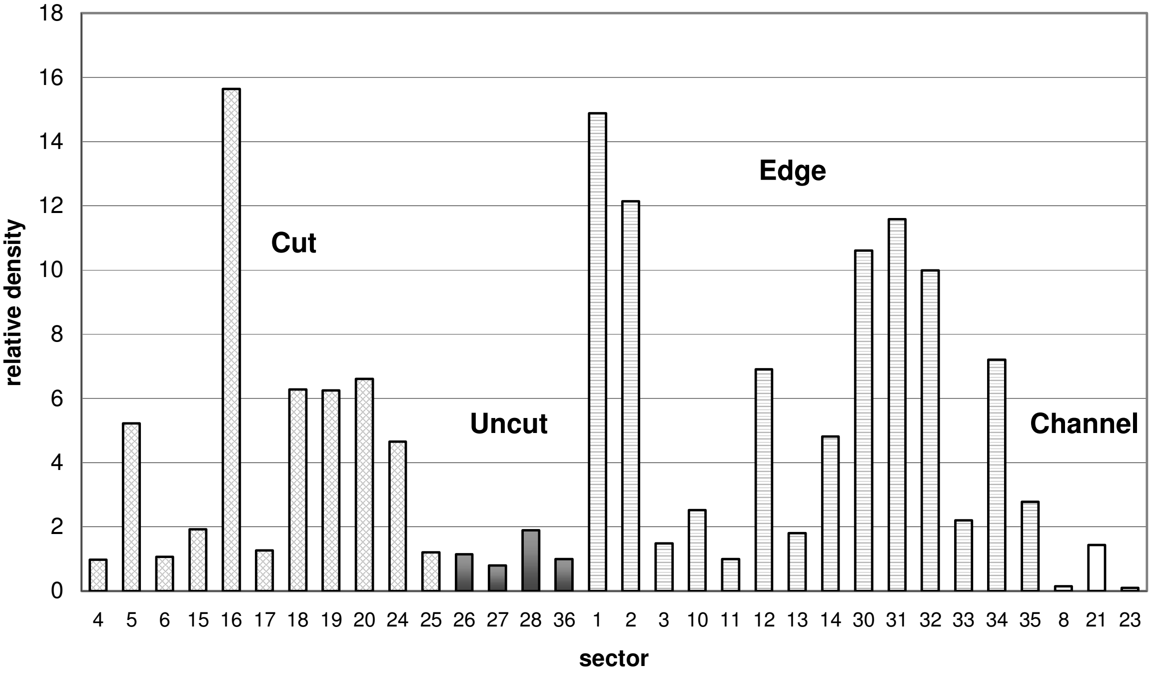
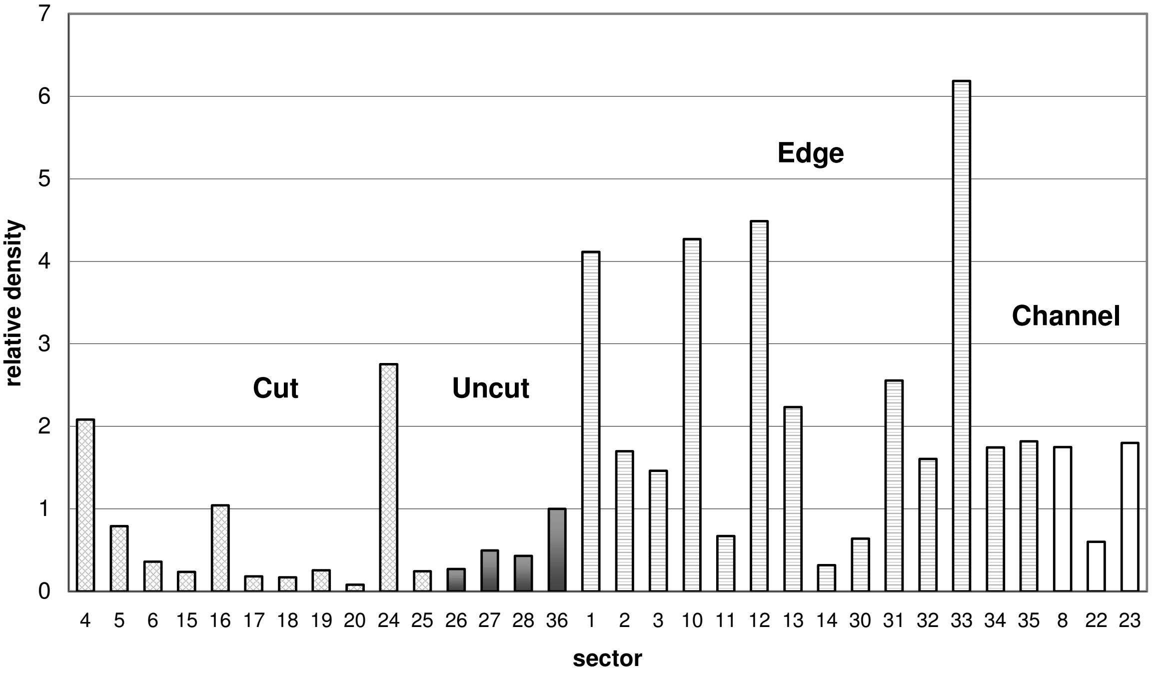


Figure 3.8 Relative model densities of Coot (September to November) and Mute Swan (September and October) on each sector across the whole winter during all-day counts. Note that density values are relative to the density on sector 36 which has been arbitrarily set at 1.

Pochard



Tufted Duck



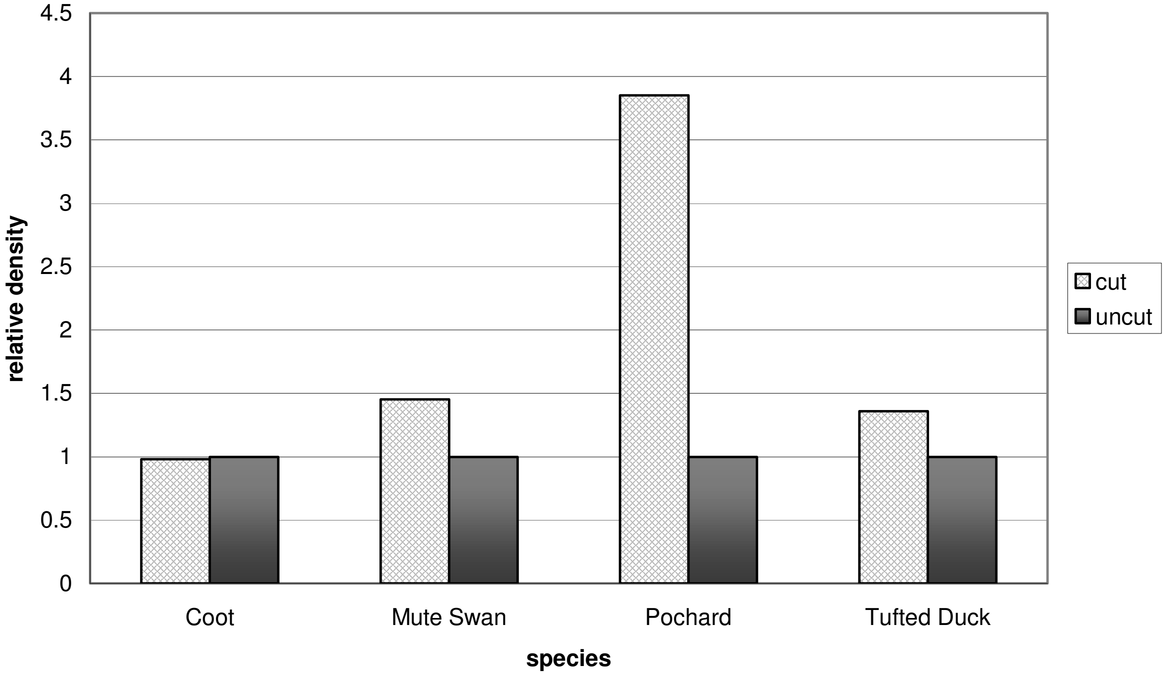


Figure 3.10 The relative day-time model densities of Coot, Mute Swan, Pochard and Tufted Duck across cut and uncut sectors at Hickling Broad. In each case, the density of birds of each species on the uncut sectors has been set arbitrarily to one. There is no comparison between species. The densities of Mute Swans ($F_{1,709} = 4.21$, $P<0.05$) and Pochard ($F_{1,1520} = 11.40$, $P<0.001$) are significantly greater on the cut than the uncut sectors, but no significant differences were found for Coot or Tufted Duck.

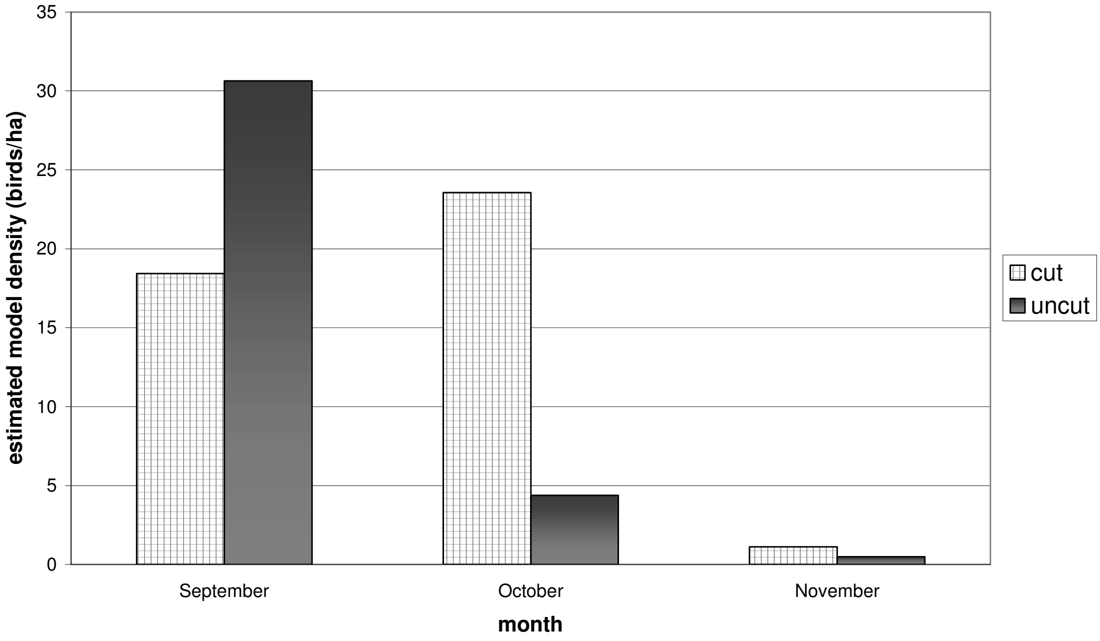


Figure 3.11 Estimated model densities of Coot in September, October and November, based on paired sectors. As the interaction between month and sector type was significant ($F_{2,18} = 5.59$, $P<0.005$) there is evidence of a shift in Coot distribution over time from uncut to cut sectors.

	Sector	Area (ha)	September 1999	October	November	December	January 2000	February	March
Cut	4	0.4	21.25±6.03	4.73±1.87	28.11±7.19	12.61±3.13	2.92±1.72	0	1.09±0.88
	5	1.6	21.04±9.02	26.05±8.03	18.39±6.01	28.21±5.75	16.39±4.18	11.38±1.64	0.77±0.31
	6	1.3	11.71±6.57	5.32±3.45	9.49±5.4	9.82±1.69	8.57±1.58	3.33±0.96	0
	15	1.6	12.51±6.54	8.4±4.52	0	0.48±0.2	0.19±0.1	0	0
	16	0.4	33.91±14.7	81.63±20.39	1.25±1.25	1.25±0.94	0.25±0.25	0	0
	17	2	7.85±2.86	21.09±8.76	0.06±0.06	0.06±0.06	0	0	0.04±0.04
	18	1.3	25±10.48	27.83±9.38	0.19±0.13	0	0	0.52±0.26	2.81±0.95
	19	1.1	14.68±4.89	55.09±16.19	4.25±1.75	0.11±0.11	1.09±0.33	5.66±0.8	4.23±1.22
	20	1.7	20.74±7.25	32.98±10.91	21.88±3.76	5.31±1.05	4.65±1.1	8.49±0.93	3.54±0.74
	24	0.8	24.4±5.22	3.24±1.37	0.45±0.45	1.95±0.55	0.84±0.4	1.6±0.45	0.55±0.19
	25	1.8	29.27±9	9.76±6.48	0.07±0.07	0.21±0.15	0.06±0.06	0.31±0.19	0.3±0.12
Uncut	26	3.3	36.49±12.05	3.84±1.92	0.19±0.15	0.35±0.14	0.03±0.03	0.03±0.03	0.06±0.04
	27	1.9	19.88±7.46	2.97±1.64	0.07±0.07	0.46±0.21	0.31±0.18	0.57±0.2	0.14±0.07
	28	0.4	73.19±34.02	5.96±3.82	3.24±1.94	6.48±2.5	3.63±1.29	11.14±1.1	0
	36	0.9	13.32±4.69	8.92±4.36	1.3±1.3	3.62±0.83	1.85±0.74	0.23±0.23	0.53±0.36
Edge	1	0.7	51.65±6.14	95.39±3.9	27.49±6.6	11.5±2.56	5.46±1.91	0.78±0.62	0.12±0.12
	2	2	38.36±9.79	105.72±6.87	17.65±5.41	12.51±1.66	5.83±1.29	0.45±0.16	0.04±0.04
	3	0.9	6.97±4.16	6.13±2.58	9±5.31	11.68±3.47	7.54±1.48	1.46±0.55	0
	10	4.1	23.02±4.6	16.2±2.34	13.18±2.49	4.18±1.25	1.61±0.3	0.16±0.08	0.14±0.06
	11	7.9	8.02±1.73	6.49±0.86	20.22±3.05	8.7±1.1	9.14±0.63	2.22±0.23	0.76±0.08
	12	0.8	24.4±5.9	52.03±19.11	2.67±1.2	0	0.63±0.28	0	0
	13	1.7	12.9±4.78	16.9±4.21	1.1±0.46	0.17±0.17	0.94±0.27	0.12±0.08	0
	14	1.3	7.05±2.17	6.6±2.44	0.58±0.38	2.13±0.48	0.47±0.21	0.26±0.13	0
	30	1.4	45.82±9.27	70.6±12.43	20.81±7.29	1.11±0.5	1.48±0.33	0.37±0.2	1.75±0.43
	31	1.3	40.96±8.86	115.95±27.8	91.55±20.46	2.11±0.59	1.3±0.16	1±0.51	3.28±1.09
	32	8.4	43.95±9.01	35.93±6.68	13±2.32	0.4±0.09	0.62±0.15	0.26±0.06	0.57±0.05
	33	1.5	14.69±2.62	11.49±3.95	4.04±0.38	0.89±0.27	0.45±0.19	0.52±0.19	0.88±0.18
	34	6.6	61.97±9.88	40.04±5.24	11.87±0.98	2.09±0.49	1.88±0.38	1.08±0.2	0.37±0.08
	35	3.9	83.57±13.13	49.88±9.58	10.68±2.33	2.73±0.4	0.36±0.1	0.83±0.17	0.26±0.08
Channel	7	0.3	5.5±1.84	1.44±0.64	2.88±2.01	0.58±0.58	2.24±1.34	0	0.24±0.24
	8	1.9	2.21±1.11	0.63±0.53	8.23±3.16	4.86±0.93	1.82±0.44	0.41±0.19	0.13±0.07
	9	1.4	1.94±1.36	0	9.5±3.45	6.41±1.3	4.34±0.91	0.16±0.11	0
	21	1.5	7.69±5.35	2.01±1.18	7.23±2.52	5.6±0.96	4.42±1.1	3.31±0.47	0
	22	1.6	6.16±4.01	1.89±1.23	1.18±0.57	2.37±0.44	1.2±0.24	1.68±0.57	0
	23	1.4	3.54±2.44	0.64±0.45	0.09±0.09	3.1±0.64	2.12±0.71	1.02±0.17	0
Exclude	29	5.3	6.35±1.9	31.13±5.75	0	0.02±0.02	0	0	0.03±0.03

Appendix 1 Mean densities (±s.e.) of Coot (birds/ha) during the day on each sector during each month of winter 1999/2000. Means have been calculated from the hourly counts made each month.

	Sector	Area (ha)	October 1999	November	December	January 2000	February	March
Cut	4	0.4		2.25±1.23	0.75±0.58			0
	5	1.6		3.13±1.65	2.66±2.37			0.15±0.11
	15	1.6	0.18±0.18			0	0	
	16	0.4	0.18±0.18			0	0	
	17	2	0.67±0.67			0	0	
	18	1.3	0.22±0.15			0	0	
Edge	1	0.7		4.41±2.82	0.2±0.2			0
	2	2		5.01±2.81	0.36±0.32			0.13±0.13
	10	4.1		1.55±0.58	0.02±0.02			0.04±0.04
	11	7.9		5.04±1.6	0.56±0.54			0.31±0.26
	12	0.8	2.6±1.58			0.68±0.31	0	
	13	1.7	0.67±0.26			0.34±0.24	0	
	14	1.3	1±0.3			0	0	
	32	8.4	0			0.17±0.07	0.06±0.04	
	33	1.5	0.09±0.09			0	0.14±0.07	
Channel	7	0.3		0	0.21±0.21			0
	8	1.9		0.83±0.43	0			0
Exclude	29	5.3	0.57±0.33			0	0	

Appendix 2 Mean densities (±s.e.) of Coot (birds/ha) during the night on each sector during each month of winter 1999/2000. Means have been calculated from the hourly counts made each month.

	Secor	Area (ha)	September 1999	October	November	December	January 2000	February	March
Cut	4	0.4	0.04±0.02	0.06±0.02	0	0	0	0	0
	5	1.6	0.01±0	0.1±0.02	0	0	0	0	0
	6	1.3	0	0	0	0	0	0	0
	15	1.6	0	0	0	0	0	0	0
	16	0.4	0	0	0	0	0	0	0
	17	2	0.02±0.01	0	0	0	0	0	0
	18	1.3	0.01±0	0	0	0	0	0	0
	19	1.1	0.05±0.01	0.02±0.01	0	0	0	0	0
	20	1.7	0.01±0	0.02±0.01	0	0	0	0	0
	24	0.8	0	0	0	0	0	0	0
	25	1.8	0	0	0	0	0	0	0
Uncut	26	3.3	0.01±0	0	0	0	0	0	0
	27	1.9	0.01±0	0.01±0	0	0	0	0	0
	28	0.4	0.01±0.01	0.04±0.02	0	0	0	0	0
	36	0.9	0	0	0	0	0	0	0
Edge	1	0.7	0.03±0.01	0.1±0.03	0	0	0	0	0
	2	2	0.01±0.01	0.05±0.01	0	0	0	0	0
	3	0.9	0	0	0	0	0	0	0
	10	4.1	0	0	0	0	0	0	0
	11	7.9	0.01±0	0	0	0	0	0	0
	12	0.8	0	0	0	0	0	0	0
	13	1.7	0	0	0	0	0	0	0
	14	1.3	0.01±0	0	0	0	0	0	0
	30	1.4	0.04±0.01	0.03±0.01	0	0	0	0	0
	31	1.3	0.01±0	0.03±0.01	0.02±0.01	0	0	0	0
	32	8.4	0	0.01±0	0	0	0	0	0
	33	1.5	0	0	0	0	0	0	0
	34	6.6	0	0	0	0	0	0	0
	35	3.9	0.02±0.01	0	0	0	0	0	0
Channel	7	0.3	0	0	0	0	0	0	0
	8	1.9	0	0	0	0	0	0	0
	9	1.4	0	0	0	0	0	0	0
	21	1.5	0	0	0	0	0	0	0
	22	1.6	0	0	0	0	0	0	0
	23	1.4	0	0	0	0	0	0	0
Exclude	29	5.3	0.01±0	0.01±0	0	0	0	0	0

Appendix 3 Mean densities (±s.e.) of Mute Swan (birds/ha) during the day on each sector during each month of winter 1999/2000. Means have been calculated from the hourly counts made each month.

	Sector	Area (ha)	September 1999	October	November	December	January 2000	February	March
Cut	4	0.4	0	0	0	0.01±0.01	0	0.01±0.01	0
	5	1.6	0.01±0	0.03±0.01	0	0.01±0	0	0	0
	6	1.3	0	0	0	0	0	0	0
	15	1.6	0	0	0.01±0.01	0	0	0	0
	16	0.4	0	0.12±0.04	0.04±0.04	0	0	0	0
	17	2	0	0	0.01±0.01	0	0	0	0
	18	1.3	0.02±0.01	0.03±0.01	0	0	0	0	0
	19	1.1	0.02±0.01	0.03±0.01	0	0	0	0	0.01±0.01
	20	1.7	0.02±0.01	0.04±0.02	0	0	0	0	0
	24	0.8	0.02±0	0	0.01±0.01	0	0	0	0
	25	1.8	0	0	0	0	0	0	0
Uncut	26	3.3	0	0	0	0	0	0	0
	27	1.9	0	0	0	0	0	0	0
	28	0.4	0.01±0.01	0	0	0	0	0	0
	36	0.9	0	0	0	0.01±0.01	0	0	0
Edge	1	0.7	0.01±0	0.13±0.02	0.01±0	0.01±0	0.01±0.01	0	0
	2	2	0	0.12±0.03	0	0	0	0	0
	3	0.9	0	0	0.01±0.01	0	0	0	0
	10	4.1	0	0.02±0.01	0	0	0	0	0
	11	7.9	0	0	0.01±0	0	0	0	0
	12	0.8	0	0.08±0.03	0	0	0	0	0
	13	1.7	0	0	0.01±0.01	0.01±0	0.01±0	0	0
	14	1.3	0	0	0.05±0.03	0.01±0.01	0	0	0
	30	1.4	0.02±0.01	0.06±0.02	0.01±0.01	0	0	0	0
	31	1.3	0	0.07±0.03	0.01±0.01	0.01±0.01	0.01±0	0	0
	32	8.4	0	0.02±0	0.02±0	0.08±0.05	0.01±0	0	0
	33	1.5	0	0.02±0.01	0	0	0	0	0
	34	6.6	0.01±0	0.01±0.01	0	0.05±0.03	0	0.01±0	0
	35	3.9	0.02±0	0.01±0	0	0	0	0	0
Channel	7	0.3	0	0	0	0	0	0	0
	8	1.9	0	0	0	0	0	0	0
	9	1.4	0	0	0	0	0	0	0
	21	1.5	0.01±0	0	0	0	0	0	0
	22	1.6	0	0	0	0	0	0	0
	23	1.4	0	0	0	0	0	0	0
Exclude	29	5.3	0	0.01±0	0	0	0	0	0

Appendix 4 Mean densities (±s.e.) of Pochard (birds/ha) during the day on each sector during each month of winter 1999/2000. Means have been calculated from the hourly counts made each month.

	Sector	Area (ha)	September 1999	October	November	December	January 2000	February	March
Cut	4	0.4	0	0	0	0.01±0.01	0.02±0.01	0.01±0.01	0.01±0.01
	5	1.6	0	0	0	0	0	0	0
	6	1.3	0	0	0	0	0	0	0
	15	1.6	0	0	0	0	0	0	0
	16	0.4	0	0.01±0.01	0	0	0	0	0
	17	2	0	0	0	0	0	0	0
	18	1.3	0	0	0	0	0	0	0
	19	1.1	0	0	0	0	0	0	0
	20	1.7	0	0	0	0	0	0	0
	24	0.8	0	0	0	0.02±0.01	0.01±0.01	0	0
	25	1.8	0	0	0	0	0	0	0
Uncut	26	3.3	0	0	0	0	0	0	0
	27	1.9	0	0	0	0	0	0	0
	28	0.4	0	0	0	0	0.01±0	0	0
	36	0.9	0	0	0	0.01±0.01	0.01±0	0	0
Edge	1	0.7	0.01±0	0.02±0.01	0.02±0.01	0.01±0	0.01±0	0	0
	2	2	0	0.01±0	0	0	0	0	0
	3	0.9	0	0	0.02±0.02	0	0	0	0
	10	4.1	0.01±0	0.03±0.01	0	0.01±0	0.01±0	0	0
	11	7.9	0	0	0	0	0	0	0
	12	0.8	0	0.07±0.05	0	0	0	0	0
	13	1.7	0	0.03±0.02	0	0	0	0	0
	14	1.3	0	0	0	0	0	0	0
	30	1.4	0	0	0	0	0	0	0
	31	1.3	0.01±0	0.01±0.01	0.01±0	0	0	0	0
	32	8.4	0	0.02±0	0	0	0	0	0
	33	1.5	0.01±0.01	0.08±0.04	0	0	0	0	0
	34	6.6	0.01±0	0	0	0	0	0	0
	35	3.9	0.02±0	0	0	0	0	0	0
Channel	7	0.3	0	0	0	0	0	0	0
	8	1.9	0	0	0	0.01±0	0.01±0	0	0
	9	1.4	0	0	0	0	0	0	0
	21	1.5	0	0	0	0	0	0	0
	22	1.6	0	0	0	0.01±0	0	0.01±0	0
	23	1.4	0	0	0	0.01±0	0.01±0.01	0	0
Exclude	29	5.3	0	0	0	0	0	0	0

Appendix 5 Mean densities (±s.e.) of Tufted Duck (birds/ha) during the day on each sector during each month of winter 1999/2000. Means have been calculated from the hourly counts made each month.