British Trust for Ornithology

# An assessment of the feeding requirements of overwintering waterfowl at Hickling Broad

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## EXECUTIVE SUMMARY

1.  During 1998, Hickling Broad held 3,588 tonnes mean wet weight biomass of *Chara intermedia*. As one gramme wet weight of *C. intermedia* converts to 0.156 g dry weight *C. intermedia*, and one gramme dry weight has an energy value of 5.212 kJ, Hickling Broad held 2917 million kJ energy in the form of *Chara*. Some 46.5%, or 1357 million kJ, of this energy was theoretically available to feeding waterfowl.

2.  During the 1998/99 winter, Hickling Broad supported on average 17,190 Mute Swan bird days, 10,289 Gadwall bird days, 46,125 Teal bird days, 53,579 Mallard bird days, 5,085 Shoveler bird days, 29,187 Pochard bird days, 94,313 Tufted Duck bird days and 305,229 Coot bird days. The total energy needs of these birds was 622 million kJ energy.

3.  The equivalent figures estimated from peak counts of each species are 30,814 Mute Swan bird days, 17,794 Gadwall bird days, 118,916 Teal bird days, 131,502 Mallard bird days, 14,280 Shoveler bird days, 49,000 Pochard bird days, 128,464 Tufted Duck bird days and 463,512 Coot bird days. The total energy needs of these birds was 1053 million kJ energy.

4.  Assuming that the birds fed on nothing but *C. intermedia* and that the *C. intermedia* standing crop was that present in 1998, then the waterfowl present on Hickling Broad during the 1998/99 winter would take 46% (based on mean bird counts) or 78% (based on peak bird counts) of the available food.

5.  The four proposed cutting regimes for the *C. intermedia* would lead to the following proportions of the *Chara* being taken by the waterfowl (based on the 1998/99 mean and peak winter waterfowl numbers):

| | 30 cm/1.2 m | 30 cm/1.5 m | 50 cm/1.2 m | 50 cm/1.5 m |
|---|---|---|---|---|
| Mean | 59% | 60% | 55% | 57% |
| Peak | 100% | 102% | 94% | 97% |

6.  Allowing for the assumptions made during the calculations, each cutting regime will potentially have an impact on the the number of overwintering waterfowl that Hickling Broad could hold.

# 1.    INTRODUCTION

Hickling Broad is located within a large area of low-lying land in east Norfolk. Hickling Broad lies within 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 Broadland Special Protection Area (SPA), designated under the European Birds Directive, and of the Broads candidate Special Area of Conservation (cSAC), 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 late 1960s, Hickling Broad was in sound ecological condition. Water was clear and rich in aquatic plant life. In the late 1960s, a large roost of Black-headed Gulls *Larus ridibundus* formed, and the faeces from the birds caused a significant increase in the phosphorous levels in the broad. As a result of the change in water quality, the broad became eutrophic. The rate of sediment deposition also increased as a result of 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.

The predominant macrophytes on the broad since the mid-1990s have been Fennel Pondweed *Potamogeton pectinatus*, Spiked Water Milfoil *Myriophyllum spicatum* and latterly the rare Intermediate Stonewort *Chara intermedia*. 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 *C. intermedia* in the central portion in 1998 has severely jeopardised navigation.

It is well documented that waterfowl populations can have an impact on aquatic ecosystems for example, deposition of faeces (Hussong *et al.* 1979, Mitchell & Wass 1995) and grazing on submerged macrophytes (Sondergarrd *et al.* 1996). Waterfowl may also influence the eutrophication of lakes and have a role in the turnover of nutrients (Gere & Andrikovics 1992). Waterfowl feed extensively on aquatic plants (Jacobs *et al.* 1981, Tubbs & Tubbs 1983, Lodge 1991) but may also take other food types such as invertebrates.

The aim of this report is to estimate the number of overwintering waterfowl that could be supported by the present *C. intermedia* and relate this requirement to the availability of the food source.

## 2. THE RELATIONSHIP BETWEEN OVERWINTERING WATERFOWL NUMBERS AND INTERMEDIATE STONEWORT

### 2.1 Bird Counts

The bird counts used have been collected as part of the Wetland Bird Survey (WeBS). Counters take part in synchronised monthly counts at wetlands of all habitat types, mainly during the winter period. The counts used here cover the period 1971-1999. Intensive use is made of data from the 1991/92, 1997/98 and 1998/99 winters, for which both bird and *C. intermedia* data exist.

Each winter was defined as lasting between September to March (seven months), a period which includes the winter peaks for each species. The analyses made use of peak (the highest monthly count of each species in a winter) and mean bird counts. Peak counts are useful when a site is counted irregularly, but can overestimate the importance of sites counted regularly. For example, peak counts for individual winters at Hickling were 1.3-2.3 times greater than mean counts for Coot, 1.3-2.6 for Gadwall, 1.3-2.6 Mallard, 1.6-4.4 for Mute Swan, 1.3-2.7 for Pochard, 1.3-4.3 for Shoveler, 1.3-6.0 for Teal and 1.1-2.4 for Tufted Duck.

The total bird days, an indication of the foraging pressure on Hickling Broad, was calculated in two ways. The total bird days for a winter based on peak counts, peak total bird days, was estimated by multiplying the peak count for a winter by the number of days in the winter. The mean total bird days was estimated by summing the number of birds counted in each month from September to March multiplied by the number of days in each month. As it was not possible to estimate the critical missing month of September 1998 by averaging the number of birds recorded in September 1997 and September 1999, the next best method was used. For winters with one missing count (February 1978, January 1987, December 1989 and September 1998), the number of birds present in the missing month was estimated by averaging the number of birds present during the other six months. This may slightly overestimate the mean total bird days for the 1998/99 winter, as waterfowl numbers tend to be lower in September, and slightly underestimate the 1977/78, 1986/87 and 1989/90 winter totals which have single missing counts in February, January and December, respectively. A number of years have been excluded from the data set because of inadequate data: those years are: 1974/75, 1975/76, 1978/79, 1981/82, 1984/85, 1993/94, 1995/96 and 1996/97.

Eight species, which overwinter on Hickling Broad and are likely to feed on *C. intermedia* have been identified as key species. The species are Gadwall *Anas strepera*, Mute Swan *Cygnus olor*, Shoveler *Anas clypeata*, Teal *Anas crecca*, Coot *Fulica atra*, Mallard *Anas platyrhynchos*, Pochard *Aythya ferina* and Tufted Duck *Aythya fuligula*.

The characteristics of these key species are summarised in Table 2.1.1. Three species of waterfowl can dive for their food (Coot, Pochard and Tufted Duck), and five feed from the surface (Gadwall, Mute Swan, Shoveler, Teal and Mallard).

### 2.2 Area of *C. intermedia*

The distribution of *C. intermedia* has been mapped by Jane Harris between 1994 and 1998. A map showing the distribution of *C. intermedia* in 1991 was provided by Nick Stewart. Table 2.2.1 tabulates the area of Hickling Broad covered by *C. intermedia*, excluding Heigham Corner and the east 'arm' to the river. Between 1994 and 1998, *C. intermedia* occupied on average 25.8

ha, but from 1991 to 1998 the area of *Chara* increased. Throughout the analyses, most emphasis is placed on the 1998 figure as being the most recent and case study year.

## 2.3    Trends in Waterfowl Data

Bird days plotted against time for key species at Hickling Broad are shown in Figure 2.3. Between 1971/72-1998/99, there were significant long-term declines in the mean and peak total bird days of Teal and Mallard, and increases in those of Coot between 1983/84-1998/99 (Table 2.3.1). No strong relationships existed for the other species with time, though there is weak evidence for recent increases in overwintering Mute Swan, Tufted Duck and even perhaps Pochard numbers.

Time series of waterfowl counts are autocorrelated as the counts are non-independent as a result of waterfowl returning to the same site each winter (Robertson & Cooke 1999, Mitchell *et al.* 1995, Rehfisch *et al.* 1996) so that a large count in one year is likely to be followed by a large count the following year. Thus, no detailed analyses of time trends were attempted.

## 2.4    Relationship Between Waterfowl and *C. intermedia*

Bird days plotted against cover of *C. intermedia* for key species at Hickling Broad are shown in Figure 2.4. Data only existed for both waterfowl counts and *C. intermedia* cover in 1991, 1997 and 1998.

There may be a positive relationship between peak and mean bird days and area of *C. intermedia* for Mute Swan, Teal, Coot, Mallard, Pochard and Tufted Duck. There may be a negative relationship between *C. intermedia* and Shoveler. Results based on three data points are impossible to interpret with any degree of certainty.

# 3. THE BIOMASS OF INTERMEDIATE STONEWORT REQUIRED TO SUPPORT OVERWINTERING WATERFOWL

## 3.1 Daily Energy Expenditure of Waterfowl

The Basal Metabolic Rate (BMR) was calculated for each of the key species using an equation in Aschoff & Pohl (1970) (Appendix 1). Average weights for the key species were taken from Birds of the Western Palearctic (Cramp 1977). Weights used were Gadwall (800 g), Mute Swan (10 kg), Shoveler (650 g), Teal (325 g), Coot (800 g), Mallard (1 kg), Pochard (800 g) and Tufted Duck (800 g). BMR (kcal h$^{-1}$) was then converted to kJ day$^{-1}$ assuming 1 calorie equals 4.1868 joules.

Woakes & Butler (1983) calculated that the energy used during feeding was between 2.7 and 3.5 times BMR. We have assumed daily energy expenditure (DEE) to be three times BMR for all species, though this must be taken to be approximate. In the better studied waders this conversion factor would tend to the high side (Kersten & Piersma 1987) but the BMR of waders tends to be higher than that predicted by Aschoff & Pohl (1970). See Appendix 1 for an example of how the DEE of a species is calculated.

The daily energy expenditure of key species of waterfowl are given in Table 3.1.1 and their energy needs over the 1998/99 winter. The DEE is greatest for the large Mute Swan and lowest for the small Teal.

## 3.2 Biomass and Energy Content of *C. intermedia*

At Hickling Broad, *C. intermedia* biomass is estimated to be 92 tonnes per hectare (Jane Harris, *Biomass estimations for* C. intermedia *lawns*). Therefore, during the 1998/99 winter Hickling held 3,588 tonnes of *C. intermedia* wet weight biomass.

Wet weight of *C. intermedia* was converted to dry weight using the conversion factor of 0.156 supplied by the Environment Agency (Table 3.2.1). The total energy content of *C. intermedia* for Hickling Broad was calculated by multiplying its dry weight by 5.212 kJ g$^{-1}$ dry weight (Table 3.2.2), the conversion factor estimated by the Butterworth Laboratory.

Regarding the calorific value of 5.212 kJ g$^{-1}$ for *C. intermedia*, it should be noted that this estimate is much less than the 17-20 kJ g$^{-1}$ normally quoted for plant material (Hall *et al.* 1993). In view of the sensitivity of our calculations to the calorific value used, we recommend a check on the above estimate, by further sample analyses.

Not all of *C. intermedia* is likely to be available in the form of energy to feeding waterfowl. The only relevant estimates for adult birds found in the literature were in Dobrowolski *et al.* (1996). The assimilation coefficient for Mallard was 53% and that for Coot 40% (Table 4 in Dobrowolski *et al.* 1996). We have taken the average, 46.5%, for all species. There is a degree of uncertainty about this figure as *Chara* has high calcium carbonate levels in particular at certain times of the year which may affect the results. Furthermore, the values given in the article are given in grammes, not energy.

## 3.3 The Biomass of *C. intermedia* Required to Support Key Waterfowl

The amount of *C. intermedia* taken by the waterfowl (termed offtake) has been calculated for the key waterfowl species (Table 3.3.1). During the 1998/99 winter, we estimate that Coots took 22% or 33% of *C. intermedia*, Mute Swans 8% or 14%, Tufted Duck 7% or 9%, and Mallard 5% or 11%. The estimated offtake for the other species was smaller. These, and the following figures, are based on the assumptions that the waterfowl are feeding solely on *C. intermedia* and that all of the *C. intermedia* is available to the birds. Both of these assumptions are simplistic. For example, Tufted Ducks feed extensively on invertebrates (Cramp 1977) and surface feeders will not have access to the *C. intermedia* in deeper waters.

Offtake by key species of waterfowl (all species combined) during the 1998/99 winter was estimated at 46% or 78% for mean and peak counts respectively (Table 3.3.2). During the same winter, the diving species were responsible for a greater proportion of the offtake (31% or 46%) than the surface feeding species (15% or 32%) largely due to the large numbers of Coot on Hickling (Table 3.3.3). The vegetarian species which include Coot and Mute Swan were estimated to take a larger proportion of the total offtake (30% or 48%) than omnivorous species (15% or 29%) (Table 3.3.4). The assumptions listed above play an important role in interpreting all of these results.

# 4.    THE IMPACT OF DIFFERENT CUTTING REGIMES ON THE FEEDING REQUIREMENTS OF OVERWINTERING WATERFOWL

## 4.1    Cutting Regimes

Four cutting regimes have been considered in this analysis:

a)    *C. intermedia* cut 30 cm above the bed of the broad with a water depth of 1.2 m
b)    *C. intermedia* cut 30 cm above the bed of the broad with a water depth of 1.5 m
c)    *C. intermedia* cut 50 cm above the bed of the broad with a water depth of 1.2 m
d)    *C. intermedia* cut 50 cm above the bed of the broad with a water depth of 1.5 m

Assuming that zones A, B and C are cut (total 11.57 ha) (see *Management of aquatic plants in Hickling Broad: cutting and monitoring proposals for 1999*) and that the total area of *C. intermedia* in the proposed cutting zone is 39.01 ha, the area cut represents 30% of the total area of *C. intermedia* on Hickling Broad.  As detailed data do not exist we assumed that the biomass per unit area was the same throughout the *C. intermedia* bed and that all (Michael Green, *pers. comm.*).

The likely impact of the cutting regimes is given in Table 4.1.1.  A cutting regime that would involve leaving the *C. intermedia* 30 cm above the bottom of the broad when flooded to 1.5 m water depth would lead to the greatest loss of the stonewort (24%).  A cutting regime based on cutting the plant to 50 cm above the bottom of the broad kept flooded to 1.2 m would have least impact (17.4%).

## 4.2    Summary of the Impact of Different Cutting Regimes on the Feeding Requirements of Key Waterfowl

During the 1998/99 winter, the greatest estimated offtake of 60% or 102% would occur with a cutting regime of 30 cm above the bed of the broad given a 1.5 m water depth (Table 3.3.2).  The various cutting regimes make relatively little difference to the estimated offtake.  In all cases, as expected, the least favourable regime for diving and surface-feeding species, and vegetarian and omnivorous species involves cutting the *Chara* 30cm above the bed of the broad assuming a 1.5m water depth (Tables 3.3.3 and 3.3.4).

# 5.    THE IMPACT OF WATER QUALITY AND ORGANIC ENRICHMENT ON OVERWINTERING WATERFOWL

Wetland systems are complex.  They are dependent for their high productivity on a regular input of energy and nutrients from the outside, but too much can have a deleterious effect on some aspects of the system.  Often due to man's influence, wetlands may become eutrophic as a result of unusually high inputs of nutrients, which can be the result of sewage and agricultural run-off. Some of these inputs can be absorbed into the system, but when present in *excess* the character of the wetland may change: biodiversity may decrease, but there may be an increase in animal and plant biomass.

There are recognised major pathways for the assimilation of Particulate Organic Carbon (POC) and Dissolved Organic Carbon (DOC) resulting from human waste into the wetlands.  Such extra inputs have three possible fates (Figure 5.1), namely conversion into additional living biomass, incorporation and storage in the sediment, or when in wetlands linked to the sea (Wilson 1988). The organic matter that is converted into living biomass can attract high densities of waterfowl to wetlands where they feed on high plant and invertebrate biomass.

In Hickling Broad, changes in phosphorus levels, salinity and eutrophication have affected the animal and plant communities (Bales *et al.* 1993, Irvine *et al.* 1993).  Salinity, by itself, whether natural or resulting from human activities, can be a major determinant of faunal biomass in wetlands (Rehfisch 1994).  The nutrient status and salinity of a wetland can be limiting because species may not have developed the necessary physiological mechanisms to survive under certain conditions.  Often the main factor limiting colonisation of apparently suitable regions is the larval stage of many invertebrates which is usually less tolerant to stress than the adult. Larvae may be particularly intolerant of unfavourable temperatures, salinity and other physiochemical characteristics of the water (including its nutrient and pollutant loads).  These factors interact; high temperatures, low oxygen levels, or the presence of toxic wastes may reduce the ability to tolerate low salinity while, conversely, animals existing towards the limit of their salinity tolerance will be more susceptible to pollution.  The species that can survive eutrophic brackish waters face relatively little inter-specific competition and therefore may have a high biomass and productivity resulting from exploitation of often rich supplies of organic material found in wetlands.

Water quality and associated changes in prey populations can impact on waterfowl populations (Hill *et al.* 1993).  Decreases in organic inputs would be expected to lead to decreases in invertebrate biomass and therefore result in fewer waders as their food source declines (Milne & Campbell 1973; McIntyre 1977; Nelson-Smith 1977; van Impe 1985; Carpenter *et al.* 1998). Under changing water quality conditions the invertebrate community may change, the biomass of organisms may decrease and there may be less food for predators which include waterfowl (McIntyre 1977).  This has been observed in the shallow Baltic Sea where as a result of organic sewage there has been a decline in oxygen and macroscopic life (Nelson-Smith 1977), and on the Firth of Forth where Scaup *Aythya marila* numbers crashed after closure of a sewage outfall, possibly as a result of invertebrate prey declines (Milne & Campbell 1973).  Van Impe (1985) found that increasing organic pollution was associated with lowered invertebrate diversity, but increased invertebrate biomass and waterfowl numbers. There are anecdotal examples of sewage discharges into estuaries being stopped and local waterfowl numbers decreasing (Spray 1998).  It is possible to speculate that waterfowl (and other forms of life) have a curvilinear response to organic sewage inputs with intermediate "pollution" levels supporting the maximal numbers of birds (Figure 5.2).  At optimal organic input levels the invertebrates will have plentiful food and

tolerable oxygen concentrations, and their high biomass will potentially support high predator densities. At lower organic inputs the invertebrates may be food-limited and therefore unable to express their maximal growth potential leading to lower biomass. Similarly, smaller waterfowl concentrations may be supported in areas with very high organic input levels as a result of too great oxygen demand and too low oxygen concentration to support many invertebrates.

Decreases in organic inputs into wetlands as a result of the Bathing Waters (BW) and Urban Waste Water Directives (UWWT) may already have impacted on wader densities (Rehfisch & Austin in press, Austin & Rehfisch 1998, Austin *et al*. in prep). Sewage (described in terms of three sewage determinands: BOD, ammoniacal nitrogen and percentage dissolved oxygen) has helped determine wader densities on UK estuaries from the 1980s onwards. It would appear that every increase of 1 mg/l O BOD was associated with a 5.8% increase in Curlew density and a 4.7% increase in total wader density. With an increase of 1 *mg/l* N ammoniacal nitrogen concentration, Curlew density decreased by 1%. From the Redshank model, a 1% increase in percentage saturation oxygen lead to a 0.5% increase in Redshank density. Consequently, under certain conditions, nutrients can have a beneficial effect on the UK's waterfowl populations. It is possible that the first effects of the BW and UWWT Directives are already being witnessed in SE England where for the last few years numbers of waders have decreased after a period of continued increase.

Austin and Rehfisch's (1998) total wader by BMR model predicted that in the Anglian region, where the greatest relative improvement in water quality has occurred, the increase in total wader numbers may have been depressed by about 14% to the expected had water quality remained stable. Similarly, the Curlew population could have been depressed by over 17% in the same region (Austin & Rehfisch 1998). The Redshank model predicted that densities in the Anglian regions would have increased by 5% during the past two decades given the observed increases in percentage dissolved oxygen. Thus, improvements in water quality may explain part of the increase in Redshank numbers in the Anglian region. Over the past two decades, the concentration of ammoniacal nitrogen has decreased by about 1 *mg/l* N in Anglian region. The decrease in ammoniacal nitrogen may have contributed towards the rapid increase in Curlew numbers witnessed in Anglia from the mid-1980s to the early 1990s.

The findings of Austin and Rehfisch (1998) are backed up by previous research which has highlighted situations in which a degree of pollution may be necessary for the maintenance of bird populations (Merne 1985; van Impe 1985). It is possible that changes in sewage inputs or high nutrient levels could affect waterfowl numbers over the long term for at least two reasons. First, the invertebrate and plant biomass response to any change in nutrient status will take time. Second, the waterfowl response to the increased availability of food will also take time as these birds tend to be very site faithful (Rehfisch *et al*. 1996) and are therefore unlikely to detect new food sources immediately.

In summary, eutrophication need not necessarily have the widely accepted totally negative impact on ecosystems. Whereas, undoubtedly, it will lead to a decline in biodiversity it may in some instances lead to an increase in the densities of certain species and overall biomass.

## 6.    DISCUSSION AND CONCLUSION

The primary aim of this report was to assess the proportion of *C. intermedia*, a high quality food for waterfowl, that would be taken by the waterfowl present on Hickling Broad in the winter of 1998/99.  Throughout, we have assumed that the waterfowl fed only on the stonewort.  This has therefore been a conservative assessment, likely to overemphasise the proportion of the plant taken and necessary for the total waterfowl energy demands, as vegetarian species could feed on other plant species and the omnivorous species are also likely to feed on the Hickling Broad invertebrates (Bales *et al.* 1993, Irvine *et al.* 1993).

The major point of interest was to assess whether the waterfowl were taking a high proportion of the *C. intermedia*, in which case the proposed cutting regime would be likely to have a major direct impact on the numbers of waterfowl that the site could hold, or a small proportion, in which case the direct impact was likely to be of less local importance.  Nor has it looked at the effect of the cutting regime on the invertebrates within the *Chara* beds which may be important in their own right and as food items for fish and waterfowl.  Nor has this assessment considered the impact of removing *C. intermedia*, a plant with a high biomass per unit volume and a highly structured growth form, which is effective at trapping suspended sediment and blue-green algae on broader habitat quality issues.  *C. intermedia* is also effective at taking up nutrients directly from the water column which may impact on the quality of the site for waterfowl (see Chapter 5).  The assessment has not considered the impact of cutting some of the *Chara* beds on the remaining plants.  Finally, no attempt has been made to look at density dependent factors which will affect the availability and attractiveness of the *Chara* to the waterfowl.  As the *Chara* biomass declines through the winter as a result of rotting and offtake it will become a more energetically expensive source of food to access and therefore birds are likely to switch to other food sources.

We have estimated that 46% (mean total bird counts) or 78% (peak total bird counts) of the *C. intermedia* is presently taken by waterfowl if they feed only on this plant.  Under the proposed cutting regimes we would estimate that between 55-60% (mean) or 94-102% (peak) of the *C. intermedia* standing crop would be removed.

Clearly, even taking into account the fact that some of the waterfowl may not be feeding extensively on the plant, a considerable proportion of the *C. intermedia* standing crop is taken at present and would be taken under any of the proposed cutting regimes.

We suggest that it is therefore likely that cutting of the *C. intermedia* could be a factor in limiting the numbers of waterfowl on Hickling Broad based on present and recent populations.

### 6.1    Factors that may have Affected the Accuracy of the Overall Assessment of Likely Impact

Several factors are likely to have impacted on the accuracy of the assessment.  These are listed below in suspected order of importance.

The difference between using mean and peak waterfowl counts to estimate the number of bird days spent on Hickling during the winter affected the offtake estimate by a factor of 1.7 (Table 3.3.2).  Hickling is regularly surveyed and therefore the monthly counts are likely to give a good estimate of the number of birds making use of the site at present.  Even though there is scant evidence of long-term increases in waterfowl numbers at Hickling at present, it may be sensible

to assume that it has the potential to attract more wintering waterfowl if the biomass of *Chara* continues to increase and therefore an assessment based on peak counts may be reasonable.

The assumption that the waterfowl fed only on stonewort is simplistic as most species eat a variety of plant and animal matter. In this respect the assessment will have overestimated the amount of *Chara* that is taken by the waterfowl, perhaps by several tens of percent.

There is a great deal of uncertainty as to how much of the energy held by *Chara* will be assimilated by the waterfowl. It has been suggested that the figure of 46.5% used in this report may be very pessimistic (John Eaton, *pers*. *comm*.). This value affects the results in an approximately linear manner *ie* for every 10% increase in *Chara* assimilation there will be a 10% decrease in offtake.

The BMR to DEE conversion factor is unlikely to affect the estimates by more than 33% (range of two to three).

The *Chara* may be flattened near the bottom of the broad during the winter (John Sharpe, *pers. comm.*). This could affect the estimates of offtake to an unquantifiable extent. The surface feeders may not be able to reach the plant but the diving birds may have denser mats to forage from at a relatively shallow depth of generally no more than 1.5 m.

In summary, due to the level of uncertainty surrounding several of the factors that contribute to this overall assessment it is necessary to treat the results with caution. Whereas, undoubtedly, *Chara* is an important potential food source for the wintering waterfowl that make Hickling a site of conservation importance, its exact importance could only be determined after further studies. These studies would include at the very least specific observations of the feeding behaviour and food selection of the waterfowl and estimates of how much of the energy held within the plant is assimilated by the birds. Were time not a constraint, this could provide an interesting post-graduate challenge. Our assessment has simply demonstrated that the biomass of *Chara* on Hickling during the 1998/99 winter could support the overwintering waterfowl present and that if the birds are dependent on the plant the proposed mowing regime could possibly lessen the carrying capacity of the site.

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| Species | Feeding method | Diet | Feeding depth |
|---------|----------------|------|---------------|
| Mute Swan | Surface | Vegetation | Up ends in depths up to 1 m and dips 20-45 cm |
| Gadwall | Surface | Vegetarian | Just under surface |
| Teal | Surface | Omnivorous | Surface feeding & just under surface |
| Mallard | Surface | Omnivorous | On surface and up ends in depths up to 48 cm. |
| Shoveler | Surface | Omnivorous | Just under surface |
| Pochard | Diving | Omnivorous | Generally 1-2.5 m |
| Tufted Duck | Diving | Omnivorous | Up to 6 m |
| Coot | Diving | Vegetarian | Generally 1-2 m, but up to 6.5 m |

**Table 2.1.1**    Summary of feeding methods, diet and feeding depths of key species.

| Year | 1991 | 1994 | 1995 | 1996 | 1997 | 1998 |
|------|------|------|------|------|------|------|
| Area *ha* | 5 | 13.6 | 17.1 | 25.8 | 33.3 | 39 |

**Table 2.2.1**    Area of Hickling Broad occupied by *C. intermedia*.

a)

| Species | Mute Swan | Gadwall | Teal | Mallard | Shoveler | Pochard | Tufted Duck | Coot |
|---------|-----------|---------|------|---------|----------|---------|-------------|------|
| $r_s$ | 0.014 | 0.471 | -0.863 | -0.826 | -0.533 | -0.018 | 0.254 | 0.800 |
| *p* | NS | NS | 0.0001[***] | 0.0001[***] | 0.02[*] | NS | NS | 0.003[**] |
| *n* | 19 | 17 | 19 | 19 | 19 | 19 | 19 | 11 |

b)

| Species | Mute Swan | Gadwall | Teal | Mallard | Shoveler | Pochard | Tufted Duck | Coot |
|---------|-----------|---------|------|---------|----------|---------|-------------|------|
| $r_s$ | 0 | 0.525 | -0.670 | -0.765 | -0.219 | 0.157 | 0.349 | 0.782 |
| *p* | NS | 0.03* | 0.002[**] | 0.0001[***] | NS | NS | NS | 0.005[**] |
| *n* | 19 | 17 | 19 | 19 | 19 | 19 | 19 | 11 |

Levels of significance: *P≥0.05 NS, P<0.05 *, P<0.01 **, P<0.001 ***.*

**Table 2.3.1**    Spearman correlation coefficients ($r_s$) summarizing the relationship between a) bird days, and b) peak bird days through time for key species.

| Species | DEE | Winter energy needs based on mean counts | Winter energy needs based on peak counts |
|---|---|---|---|
| | *kJ day $^{-1}$* | *kJ $\times 10^6$* | *kJ $\times 10^6$* |
| Mute Swan | 6136.37 | 105.4822 | 189.0862 |
| Gadwall | 973.34 | 10.0145 | 17.3196 |
| Teal | 504.75 | 23.2817 | 60.0226 |
| Mallard | 1145.28 | 61.3631 | 150.6066 |
| Shoveler | 836.61 | 4.2546 | 11.9469 |
| Pochard | 973.34 | 28.4083 | 47.6936 |
| Tufted Duck | 973.34 | 91.7989 | 125.0391 |
| Coot | 973.34 | 297.0915 | 451.1544 |

**Table 3.1.1**   Daily energy expenditure (DEE) of key species of waterfowl on Hickling Broad and their energy requirements over the 1998/99 winter, based on mean and peak winter counts.

| Sample | Wet weight g | Dry weight g | % |
|---|---|---|---|
| 1 | 53.72 | 8.46 | 15.8 |
| 2 | 58.63 | 8.99 | 15.3 |
| 3 | 56.33 | 8.49 | 15.1 |
| 4 | 54.43 | 9.01 | 16.6 |
| 5 | 55.53 | 8.34 | 15 |
| **Mean** | | | **15.6** |

**Table 3.2.1**    Wet weight to dry weight conversion for *C.intermedia*.

| Sample | Gross calorific value $kJ\ g^{-1}$ |
|---|---|
| 1 | 5.5 |
| 2 | 5.16 |
| 3 | 5.03 |
| 4 | 5.32 |
| 5 | 5.05 |
| **Mean** | **5.212 kJ g⁻¹** |

**Table 3.2.2**    Calorific value of *C.intermedia* per g dry weight.

| Species | Winter | *Chara* biomass *tonnes* | Offtake (mean count) *%* | Offtake (peak count) *%* | Feeding method |
|---|---|---|---|---|---|
| Mute Swan | 1991-92 | 460.0 | 9.11 | 22.29 | Surface |
| Mute Swan | 1997-98 | 3063.6 | 3.89 | 8.16 | Surface |
| Mute Swan | 1998-99 | 3588.0 | 7.78 | 13.94 | Surface |
| Gadwall | 1991-92 | 460.0 | 6.49 | 16.64 | Surface |
| Gadwall | 1997-98 | 3063.6 | 1.92 | 4.13 | Surface |
| Gadwall | 1998-99 | 3588.0 | 0.74 | 1.28 | Surface |
| Teal | 1991-92 | 460.0 | 6.08 | 19.52 | Surface |
| Teal | 1997-98 | 3063.6 | 1.75 | 3.14 | Surface |
| Teal | 1998-99 | 3588.0 | 1.72 | 4.42 | Surface |
| Mallard | 1991-92 | 460.0 | 11.92 | 21.29 | Surface |
| Mallard | 1997-98 | 3063.6 | 3.92 | 6.96 | Surface |
| Mallard | 1998-99 | 3588.0 | 4.52 | 11.10 | Surface |
| Shoveler | 1991-92 | 460.0 | 6 | 19.50 | Surface |
| Shoveler | 1997-98 | 3063.6 | 0.59 | 2.53 | Surface |
| Shoveler | 1998-99 | 3588.0 | 0.31 | 0.88 | Surface |
| Pochard | 1991-92 | 460.0 | 2.44 | 6.44 | Dive |
| Pochard | 1997-98 | 3063.6 | 1.79 | 2.48 | Dive |
| Pochard | 1998-99 | 3588.0 | 2.09 | 3.52 | Dive |
| Tufted Duck | 1991-92 | 460.0 | 4.51 | 7.64 | Dive |
| Tufted Duck | 1997-98 | 3063.6 | 4.43 | 7.55 | Dive |
| Tufted Duck | 1998-99 | 3588.0 | 6.77 | 9.21 | Dive |
| Coot | 1991-92 | 460.0 | 18.06 | 35.49 | Dive |
| Coot | 1997-98 | 3063.6 | 16.42 | 23.10 | Dive |
| Coot | 1998-99 | 3588.0 | 21.90 | 33.26 | Dive |

**Table 3.3.1**   Biomass of *C. intermedia* required to support mean and peak counts of the key waterfowl through the winter.  (See assumptions in text).

| Count | *Chara* | | Offtake | Offtak | Offtak | Offtak | Offtake | |
|---|---|---|---|---|---|---|---|---|

| estimate | biomass | | e | e | e | 1.5 m |
| | | | 1.2 m | 1.5 m | 1.2 m | 50 cm |
| | tonnes | % | 30 cm | 30 cm | 50 cm | % |
| | | | % | % | % | |
| Mean | 3588 | 45.83 | 59.13 | 60.30 | 55.48 | 57.14 |
| Peak | 3588 | 77.61 | 100.15 | 102.12 | 93.96 | 96.78 |

Note: i) The numbers of waterfowl are estimated from the 1998/99 winter mean or peak counts.

ii) The mean *Chara* biomass is taken to be that present in 1998.

iii) Cutting regimes are based on 1.2 m or 1.5 m water depth and leaving *Chara* either 30 cm or 50 cm above the bed of the broad.

**Table 3.3.2**   Estimated percentage offtake of *C. intermedia* by mean and peak numbers of Hickling Broad waterfowl under various cutting regimes.

| Count estimate | Feeding method | *Chara* biomass | Offtake | Offtake 1.2 m 30 cm | Offtake 1.5 m 30 cm | Offtake 1.2 m 50 cm | Offtake 1.5 cm 50 cm |
|---|---|---|---|---|---|---|---|
| | | *tonnes* | *%* | *%* | *%* | *%* | *%* |
| Mean | Dive | 3588 | 30.76 | 39.69 | 40.48 | 37.24 | 38.36 |
| Mean | Surface | 3588 | 15.07 | 19.44 | 19.83 | 18.24 | 18.79 |
| Peak | Dive | 3588 | 45.99 | 59.34 | 60.51 | 55.68 | 57.35 |
| Peak | Surface | 3588 | 31.62 | 40.80 | 41.61 | 38.28 | 39.43 |

Note: i) The numbers of waterfowl are estimated from the 1998/99 winter mean or peak counts.
ii) The mean *Chara* biomass is taken to be that present in 1998.
iii) Cutting regimes are based on 1.2 m or 1.5 m water depth and leaving *Chara* either 30 cm or 50 cm above the bed of the broad.

**Table 3.3.3** Estimated percentage offtake of *C. intermedia* based on 1998/99 bird data according to feeding method (diving or surface) and according to cutting regime. (See assumptions in text).

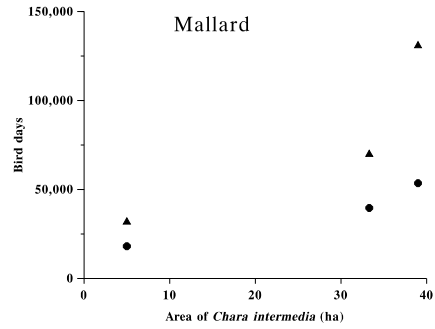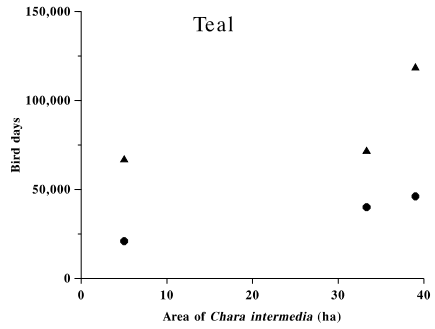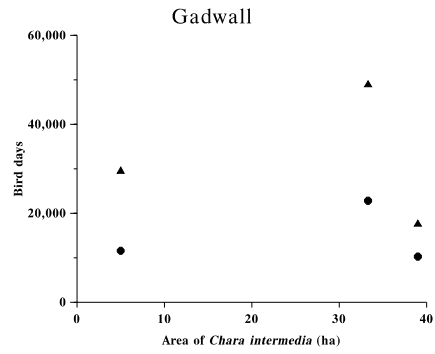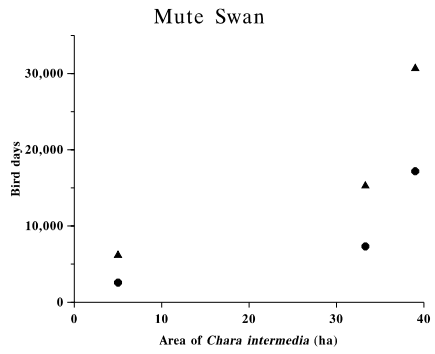| Count estimate | Diet | *Chara* biomass | Offtake | Offtake 1.2 m 30 cm | Offtake 1.5 m 30 cm | Offtake 1.2 m 50 cm | Offtake 1.5 cm 50 cm |
|---|---|---|---|---|---|---|---|
| | | *tonnes* | *%* | *%* | *%* | *%* | *%* |
| Mean | Omnivore | 3588 | 15.41 | 19.89 | 20.28 | 18.66 | 19.22 |
| Mean | Vegetarian | 3588 | 30.41 | 39.24 | 40.02 | 36.82 | 37.92 |
| Peak | Omnivore | 3588 | 29.14 | 37.60 | 38.34 | 35.28 | 36.34 |
| Peak | Vegetarian | 3588 | 48.47 | 62.55 | 63.78 | 58.68 | 90.44 |

Note: i)   The numbers of waterfowl are estimated from the 1998/99 winter mean or peak counts.
ii)   The mean *Chara* biomass is taken to be that present in 1998.
iii)   Cutting regimes are based on 1.2 m or 1.5 m water depth and leaving *Chara* either 30 cm or 50 cm above the bed of the broad.

**Table 3.3.4**   Estimated percentage offtake of *C. intermedia* based on 1998/99 bird data according to diet (omnivore or vegetarian) and according to cutting regime. (See assumptions in text).

|  | Broad at **1.2 m** water depth | Broad at **1.5 m** water depth |
|---|---|---|
| Cut **30 cm** above bed | 90 cm cut<br>75% of total *Chara* available<br><br>*Chara* lost = 22.5%<br>*Chara* remaining = 77.5% of total *Chara* | 120 cm cut<br>80% of total *Chara* available<br><br>*Chara* lost = 24%<br>*Chara* remaining = 76% of total *Chara* |
| Cut **50 cm** above bed | 70 cm cut<br>58% of total *Chara* available<br><br>*Chara* lost = 17.4%<br>*Chara* remaining = 82.6% of total *Chara* | 100 cm cut<br>67% of total *Chara* available<br><br>*Chara* lost = 19.8%<br>*Chara* remaining = 80.2% of total *Chara* |

**Table 4.1.1**    The impact of the different cutting regimes on the percentage of *C. intermedia* remaining.  (See details in text).
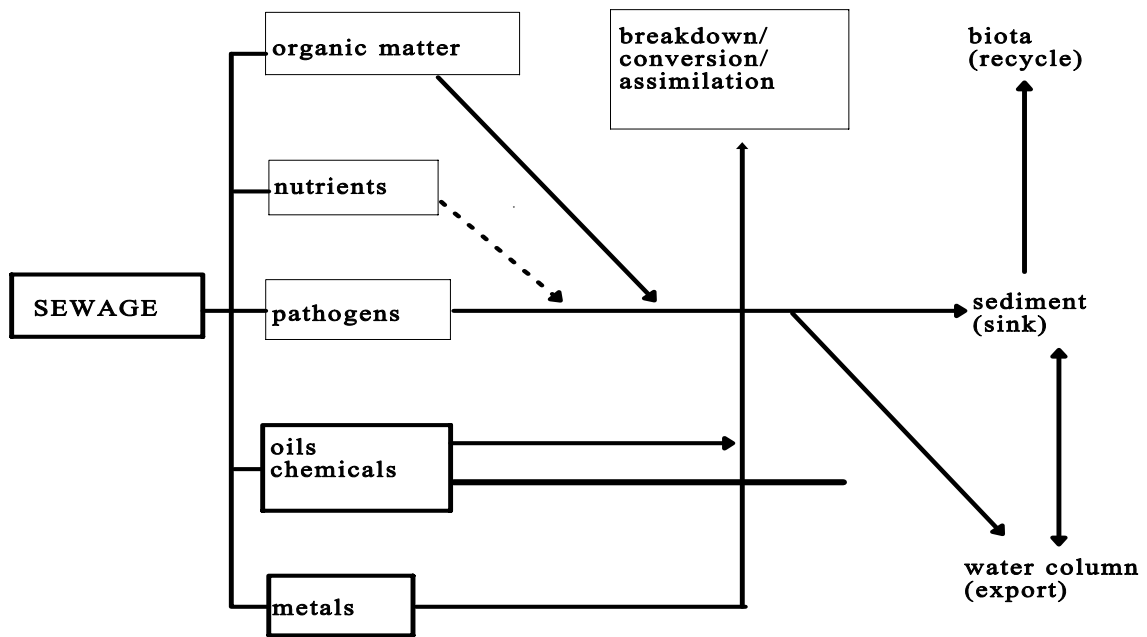
**Mute Swan**

**Gadwall**

**Teal**

**Mallard**

**Shoveler**

**Pochard**

**Tufted Duck**

**Coot**

## Mute Swan



## Gadwall



## Teal



## Mallard



## Shoveler



## Pochard



## Tufted Duck



## Coot
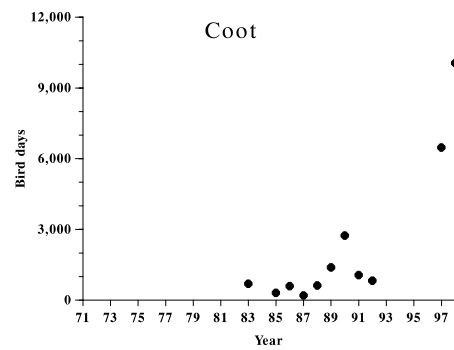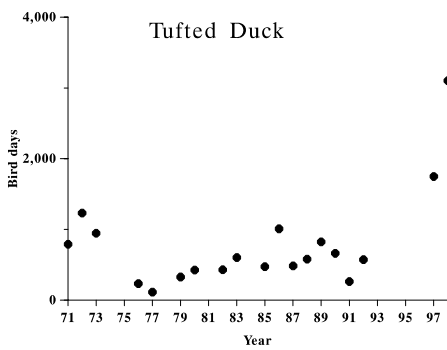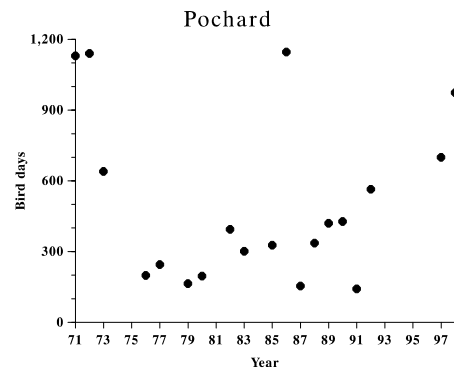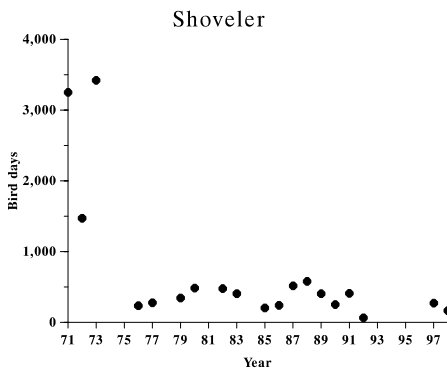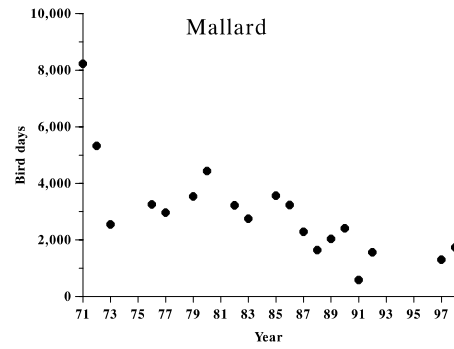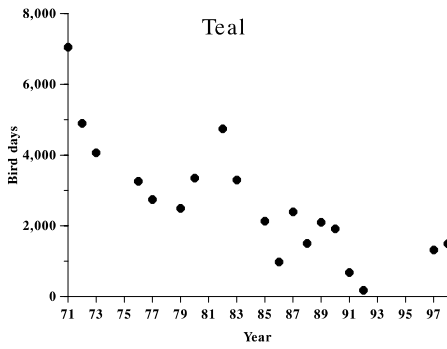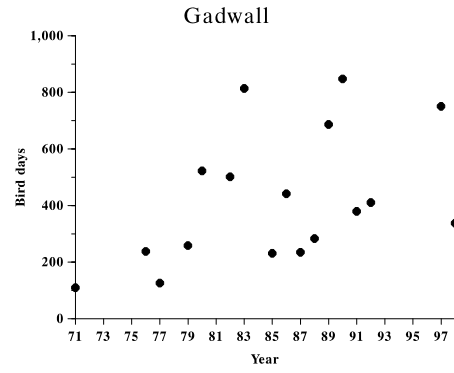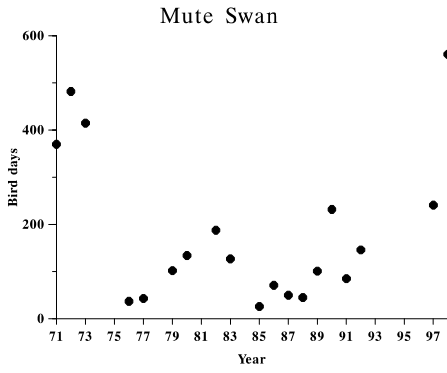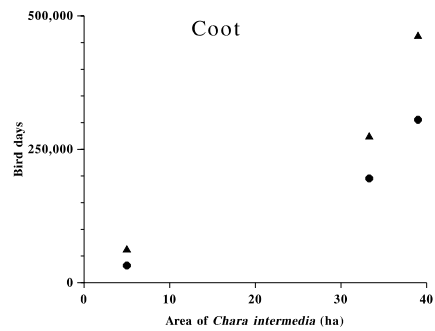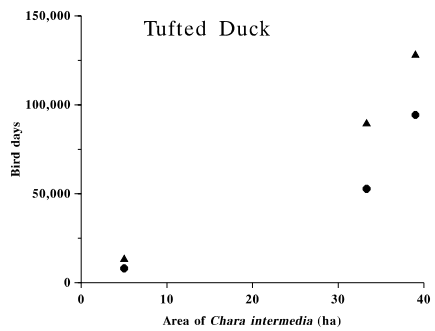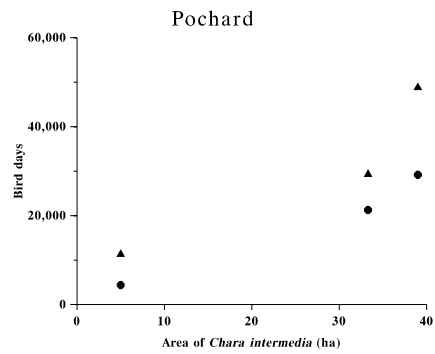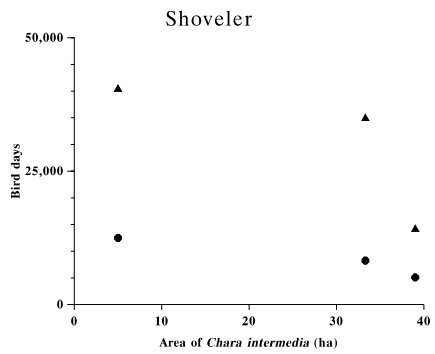
**Figure 5.1    Fate of wastes (from Wilson 1988).**
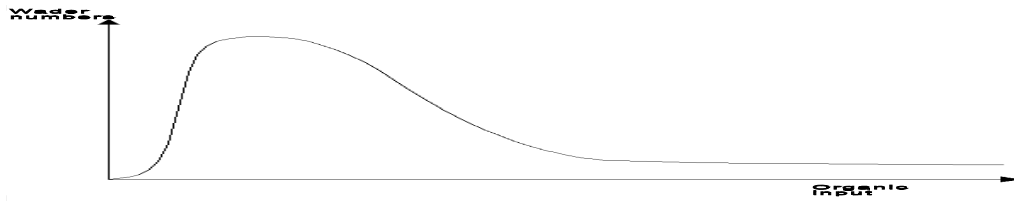
**Figure 5.2**      **Possible relationship between wader numbers (or biomass) and organic inputs into estuarine waters (adapted from Pearson & Rosenberg 1978).**

**Appendix 1**   The calculation of Daily Energy Expenditure (DEE) using Coot, a bird that weighs 800 g, as an example.

$$\text{BMR}^1 = e^{(\ln a + b \ln \text{body weight})} \text{ kcal h}^{-1}$$
$$= e^{(\ln 0.0247 + 0.729 \ln 800)} \text{ kcal h}^{-1}$$
$$= e^{1.172} \text{ kcal h}^{-1}$$
$$= 3.2289 \text{ kcal h}^{-1}$$

$$\text{BMR} = 3.2289 \times 4.1868 \text{ (calorie to joule conversion)} \times 24 \text{ (hours in a day)}$$
$$= 324.4464 \text{ kJ day}^{-1}$$

$$\text{DEE} = \text{BMR} \times \text{(DEE conversion factor)}$$
$$= 324.4464 \times 3$$
$$= 973.3393 \text{ kJ day}^{-1}$$

[1] Upper BMR value for an active, non-resting bird used (see Aschoff & Pohl 1970).