The sex/age ratio, diving behaviour and habitat use of Goldeneye *Bucephala clangula* wintering in northeast Scotland

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Goldeneye were counted on lochs, rivers and at the coast of northeast Scotland from 1988 to 1990. Wintering birds arrived in October and November and left in April. Arrival times at communal overnight roosts suggested that daylength might have limited foraging time in the shortest days of winter. Mid-winter changes in the numbers at daytime foraging sites, but not at overnight roosts, suggested that the population shifted from feeding on lochs to the lower parts of rivers and to the coast as the winter progressed. Changes in the proportion of adult males in foraging flocks was consistent with such shifts. Overall, foraging flocks at lower elevations, particularly on the coast and the lower sections of rivers, contained more adult males. Adult males dived for longer than females, particularly at estuary foraging sites. It is argued that adult males have a competitive advantage over females where benthic foods are concentrated in deep or fast-flowing water, but that some such sites retain good feeding for longer, and are thus increasingly used by more Goldeneye (including females and first year birds) as the winter progresses. The total population in the area was estimated at between 700 and 850. More than half of these frequented the lower parts of rivers, which should now be considered for 'Nationally Important' status for wintering Goldeneye.

The ecology of wintering Goldeneye *Bucephala clangula* has been studied both in Europe and in North America (reviewed by Sayler & Afton 1981). Although in Britain most Goldeneye are reported at the coast or on standing waters, some occur on rivers (Owen *et al.* 1986). The objectives of the present study were 1) to document the abundance of Goldeneye on rivers, and standing freshwaters in parts of northeast Scotland, to show the importance of rivers as wintering habitats here, 2) to record variation in sex/age ratios between habitats and seasons (Nilsson 1970, Campbell 1977) and 3) to search for patterns in diving behaviour that might suggest explanations for such variation.

Male Goldeneye are larger than females by about 10% in linear dimensions, and 40% by mass (Cramp & Simmons 1977) and 'have significantly superior diving capacity' (von Hartmann 1945). Larger diving ducks have a potentially greater capacity for oxygen storage (Butler & Jones 1982), and are also more powerful, descending faster than smaller ducks of similar morphology (Lovvorn, Jones & Blake 1991). Thus, in theory, male Goldeneye could be more efficient than females when foraging in more demanding conditions, where the water is deeper, or fast-flowing, or where food is sparse. We anticipated that, under such conditions, females would be unable to prolong their dives to the same extent as males and/or prolong their dives, but at the expense of diving efficiency if they extend recovery time on the surface so reducing the overall proportion of their foraging time spent underwater (Dewar 1924). We, therefore, collected data on the diving schedules of males and females within the parts of our study area that consistently held more (lower river and estuary) or fewer (shallow, freshwater lakes) adult drakes.

In winter, Goldeneye congregate to roost overnight (King 1961, Linsell 1969, Reed 1971). In the present study, we collected some data on the timing of flights to communal roosts because this could have influenced the timing of our counts in non-roost habitats.

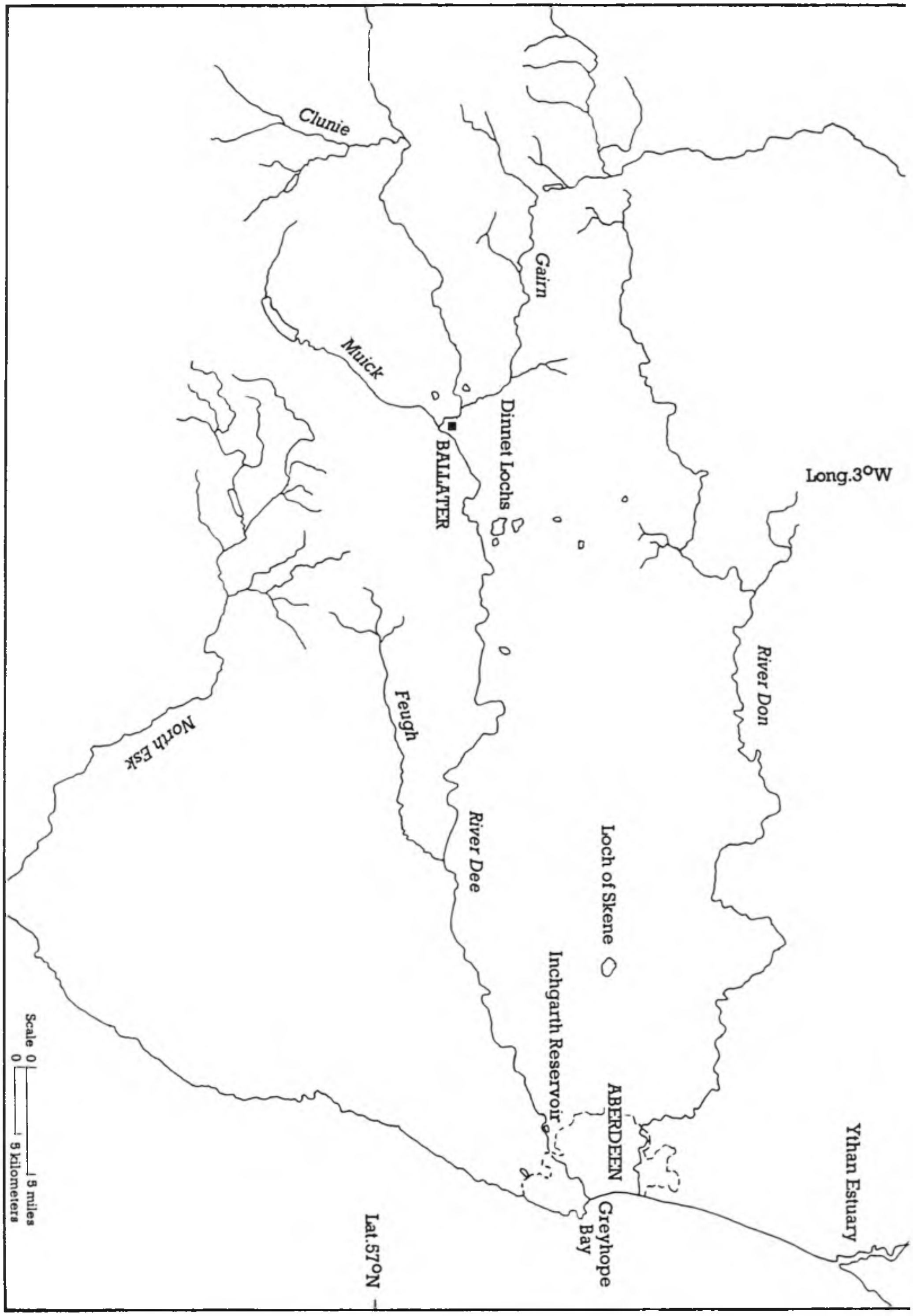

Figure 1. Map of the study area showing the lochs, rivers and coastal sites counted.

Study area

The main study area (Fig. 1) comprised the catchments of the rivers Don, Dee and North Esk. The Dee, Scotland's fourth largest river, runs 140 km from its source, high in the granite massif of the southeastern Cairngorms, to the sea at Aberdeen. The Don, also a major river, runs 130 km from its source in the foothills of the eastern Cairngorms, also to the sea at Aberdeen. The lower part of the Don flows through low-lying, arable farmland and the 10 km of river closest to Aberdeen was polluted by both industrial and sewage effluents (Saunders 1982) although less so at the time of the present study. The North Esk is a shorter river (only about 60 km) but it also flows through arable land before entering the sea just north of Montrose. Observations of Goldeneye diving patterns were also made on the 5 km estuary of the river Ythan, near Newburgh, 15 km north of Aberdeen.

We examined almost all of the standing freshwater sites in the Dee, Don and North Esk catchments, and regularly counted six large (>25 ha) lochs at various altitudes (80-500 m asl), seven lochans (<25 ha, 80-360 m asl) and one reservoir (<25 ha, 10 m asl) at Inchgarth, to the west of Aberdeen. These included all the sites that held Goldeneye regularly in recent years (Buckland *et al.* 1990, Owen *et al.* 1986) - the remaining sites being apparently too small or too high to sustain Goldeneye in large numbers. Two of the standing freshwater sites, the Loch of Skene and Dinnet, were more important than all the rest, holding up to 250 and 60 Goldeneye respectively. At an elevation of 80 m asl, Skene is a 120 ha lowland loch draining agricultural land. It is very shallow (maximum depth 1.8 m) and eutrophic (Owen 1980). Dinnet Lochs are smaller and deeper (maximum depth 3.2 m). Lying at 170 m asl, much of their catchment includes hill ground so there is less 'run off' from arable farmland and the lochs are mesotrophic (Marren 1979).

One marine site was included - Greyhope Bay, on the south side at the mouth of the Dee at Aberdeen. This was the only sea coast site in the area where a Goldeneye flock has been recorded regularly, formerly holding a large concentration feeding from a coastal sewage outfall (Bell 1989).

Methods

Goldeneye were counted from viewpoints without disturbing the birds, which were classed using plumage characteristics, as either adult male (black and white) or adult females and first winter birds (grey with 'brownheads').

Roosting

Goldeneye were counted as they assembled at the two largest communal roosts in the area. At Loch of Skene counts were at about 2-weekly intervals from September 1988 to late April 1989. More detailed roosting behaviour was observed at Inchgarth reservoir, weekly from November 1988 through to April 1989. The morning departure of Goldeneye from the site was rapid - all had left the reservoir (or started foraging nearby) before sunrise. The evening return was more prolonged with birds arriving from an hour before sunset to an hour after it. The timing of arrivals was correlated with daylength (Fig. 2), most birds arriving earlier on the longest days in April but much later, near dark, on the short days of mid-winter (Fig. 3). The first adult males usually arrived earlier than the first 'brownheads', although there was no significant difference in the proportions of males and 'brownheads' arrived by sunset (data for 18 evenings, 'paired' $t = 0.481$, n.s.).

Considering these results, no counts away from roost sites were done within one hour of first light or within the two hours before last light to avoid confusion as birds flew to and from roosts.

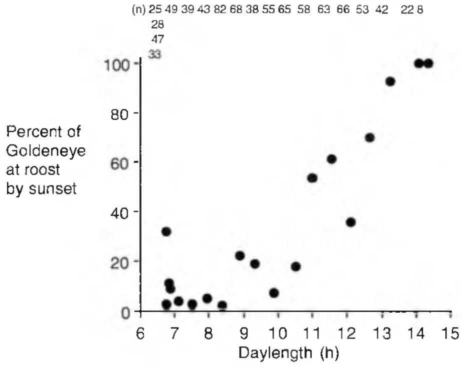

Figure 2. The proportion of roosting Goldeneye that had arrived at the overnight roost site (Inchgarth Reservoir) by sunset, on days of differing length, in the winter of 1988-1989.

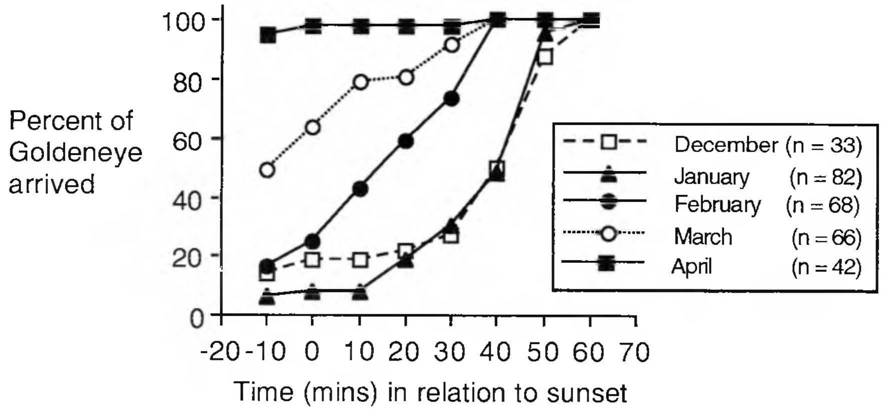

Figure 3. The pattern of Goldeneye arrivals at the overnight roost site (Inchgarth Reservoir) in relation to sunset, for different months of the 1988-1989 winter.

Daytime counts

To investigate seasonal trends in abundance, we counted Goldeneye every week for a year (1988-89) on the 11.3 km of the River Dee upstream of Aberdeen, and the lowest 5.5 km of the North Esk. Four tributaries of the River Dee (the Feugh, Muick, Gairn and Clunie) were counted once every two weeks throughout the winter of 1988-89. Complete counts of Goldeneye along the whole mainstems of rivers were done in the winters of 1988-89 and 1989-90, in December (Dee) or January (Don and North Esk). Counts on standing freshwaters and at Greyhope Bay were done weekly from September 1988 to April 1989.

Diving

Diving behaviour was followed in good light conditions and at close distances (<200 m) where adult females could be distinguished from first winter birds by the colour of soft parts or plumage (detailed in Linsell 1969, Cramp & Simmons 1977). A stopwatch was used to time ten consecutive dives, and the intervening surface 'pauses', for ten adults of each sex, at each of three sites (lochs at Skene and Dinnet, and the Ythan Estuary) over eight days in February 1990.

Diving efficiency increases as time underwater increases relative to time on the surface - the 'dive/pause' ratio (Dewar 1924). As a measure of diving efficiency we used the proportion of the time between the start of a dive and the start of the subsequent dive that was spent underwater. These proportions were arcsin transformed for statistical analysis. There was less variation within consecutive dives by the same bird than there was between birds (e.g. ANOVA for ten dives by each of ten males at Skene, $F_{9,90}$ = 17.9, P = 0.0001) so comparisons within and between sites were made using mean values for each bird.

Results

Seasonal trends

Goldeneye were mainly winter visitors to the area; only one or two spent the summer there. Most lochs held only a few Goldeneye in winter so it was difficult to detect overall trends except at the two main sites - Dinnet Lochs and Loch of Skene. There, some Goldeneye arrived in October but the main influx at Skene (and on the rivers) occurred in November (Fig. 4). Birds left the area between late March and late April. The marine site at Greyhope Bay was used sporadically by a few birds, though a larger flock was present in April. Within the winter, there were changes in abundance at all sites. Numbers at Skene decreased whereas numbers elsewhere increased. There was a marked increase in numbers on the River Dee in February.

Counts at two major roost sites (Fig. 5) showed a similar overall pattern, with numbers increasing in October and November, and decreasing in April. However, counts at roosts did not show the same mid-winter

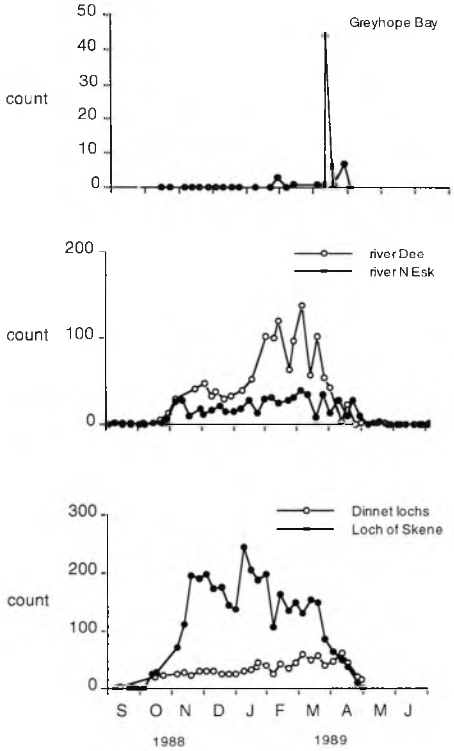

Figure 4. Variation with season in the counts of Goldeneye at daytime foraging sites in three habitats.

changes that occurred nearby in daytime counts. Large numbers continued to roost at Skene in March despite a decrease in daytime numbers then, compared with earlier in the winter. Similarly, numbers of Goldeneye roosting at Inchgarth did not increase substantially in February and March despite a pronounced increase on the River Dee nearby.

Whole river counts

On the River Don, 272 Goldeneye were counted in the winter 1988-89 and 246 in 1989-90. On the Dee there were 78 in 1988-89 and 236 in 1989-90. There was also a threefold increase on the River North Esk, from 12 in 1988-89 to 39 in 1989-90. Few Goldeneye were found on the upper parts of rivers (Fig. 6). Bimonthly surveys of the tributaries of the Dee in the winter of 1988-89 only ever located one Goldeneye and on the mainstems of all three rivers 96% of Goldeneye were found on the lower sections (<100 m altitude) where the rivers were wider, deeper and slower-flowing. Even at these lower elevations there were significant inverse correlations between altitude and counts on all three river systems (Spearman's correlation coefficient for North Esk data, $r_s = -1$, $Z = -2$, $P = 0.05$, for Dee, $r_s = -0.74$, $Z = -2.23$, $P = 0.03$ and for Don, $r_s = -0.82$, $Z = -2.60$, $P = 0.01$).

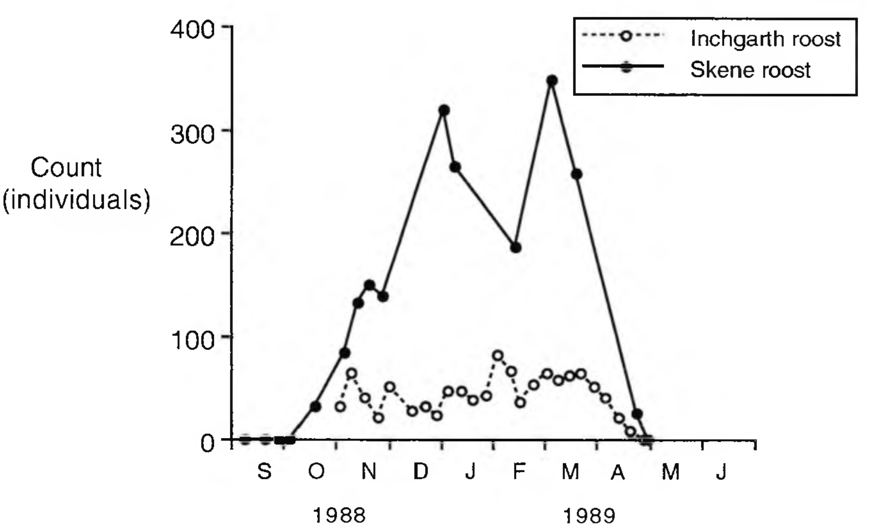

Figure 5. Variation with season in the counts of Goldeneye at two communal overnight roosts.

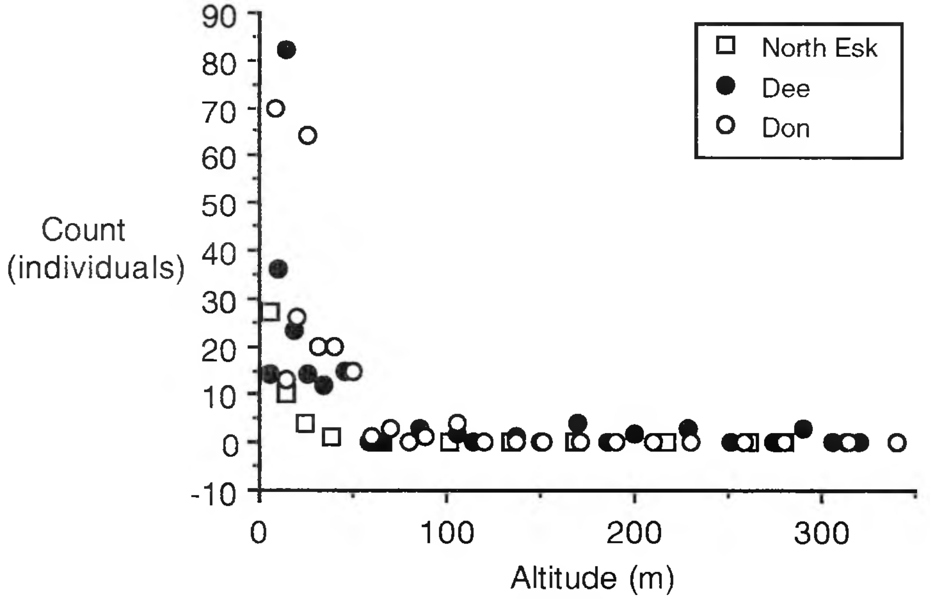

Figure 6. Counts of Goldeneye on 5 km sections of three rivers, in relation to altitude. Data from whole river counts in December 1989 ((Dee) and January 1990 (Don and North Es). The altitude of the mid-point of each 5 km section was taken from 1:50,000 O.S. maps.

The ratio of adult males to 'brownheads' within and between habitats

At four different sites (Dinnet Lochs, Loch of Skene, the lower 5 km of the Dee and Greyhope Bay) we counted flocks of over 30 Goldeneye on up to 18 occasions, giving us a series of estimates of the proportion of adult males present. An analysis of variance on arcsin transformed data showed that there was far less variation in the proportions of adult males within counts for the same site than there was between sites ($F_{48,3}$ = 10, P = 0.0001). The main difference was a lower proportion of adult males at inland sites, so we plotted a proportion against altitude for a much larger number of sites by including those with counts of fewer than 30 birds. We included all 13 freshwater lochs that held Goldeneye in the 1988-89 winter. Data from rivers were segregated into 5 km sections, starting at the river mouth. On the Don and the Dee there were four such sections - 0 to 5 km, 6 to 10 km, 11 to 15 km and beyond 15 km. On the North Esk that winter all Goldeneye were within 5 km of the river mouth, and on the Ythan only the estuary was counted. There was a strong tendency for a higher proportion of adult males at lower elevation sites (Spearman's correlation coefficient, r_s = -0.701, Z = -3.364, P = 0.0008). The relationship was mainly due to differences between habitats with the greatest proportion of adult males on the lower sections of rivers and on the sea (Fig. 7).

Three regularly counted sites, Dinnet, Skene and the River Dee, held sufficient birds overwinter to search for seasonal trends (Fig. 8). There was no suggestion of long-term changes in the proportion of adult males at the lochs (Dinnet r_s = -0.024, Z = 0.098, P = 0.92; Skene r_s = -0.294, Z = -1.176, P = 0.24) but on the river there was a decline overwinter (r_s = -0.759, Z = -2.939, P = 0.003) correlated with the increase in numbers (r_s = -0.613, Z = -2.373, P = 0.02). There was no such relationship between the proportion of adult males and the numbers of Goldeneye at Loch Skene as the numbers fell there overwinter (r_s = -0.09, Z = -0.358, P = 0.72).

Diving behaviour

Adult male Goldeneye dived for between 14 and 35 seconds, and adult females for between 9 and 33 seconds, although most (80%) dives by males were 19-29 seconds and by females 18-26 seconds. Surface pauses were

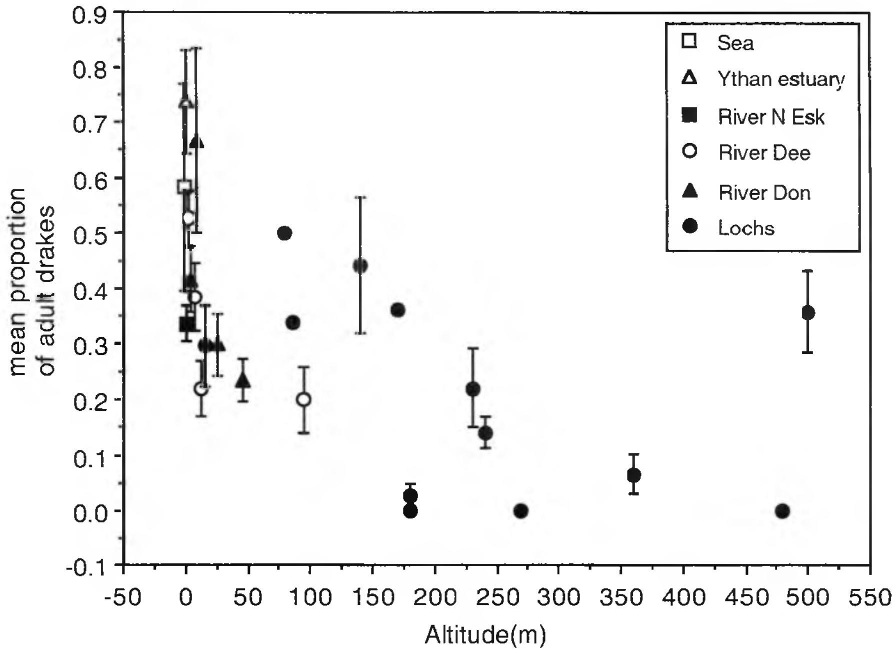

Figure 7. The mean proportion of adult males in counts of Goldeneye at sites at various altitudes; data from 24 sites in four main habitat types. Bars denote one standard error above and below mean values.

more variable but 80% fell between 5 and 13 seconds (both sexes). The diving rate of 30 different males ranged from 1.2 to 2.5 dives per minute, their spending between 58 and 82% of their time underwater. Rates of 30 females ranged from 1.3 to 2.3 dives per minute and they spent 54 to 79% of their time below the water surface.

There was little difference in the dive times of either sex between freshwater sites, but on the estuary dive times were longer - significantly so for males (Table 1). At all three sites males dived for longer than did females, but differences between the sexes at Skene were small (1.6 s) compared with the differences at Dinnet (3.1 s) and the estuary (4 s).

Despite these differences in dive times, there was no significant variation in diving efficiency (the proportion of dive/pause time spent underwater) associated with sex or site ($F_{9\,50}$ = 1.2, n.s.), nor was there any evidence of reduced diving efficiency as a result of longer dives. Data from all dive/pause sequences were plotted showing that, as dive times increased, so did diving efficiency up to dives of about 25 seconds' duration (Fig. 9). Thereafter increased dive time was matched by increased surface time so that diving efficiency levelled off. There was not even evidence of reduced efficiency for the very long-

Table 1. The average dive times, in seconds spent underwater (mean of 10 dives per bird), of 10 male and 10 female Goldeneye at each of three sites where the proportion of adult males in flocks varied.

	Proportion of adult males	Mean dive times +/- standard error (range) adult males	adult females
Loch of Skene	0.35	23.15+/-0.970(19.8-27.6)	21.60+/-0.596(18.2-23.8)
Dinnet Lochs	0.45	23.30+/-1.090(19.9-28.7)	20.36+/-0.810(17.4-23.7)
Ythan Estuary	0.74	26.65+/-1.021(20.5-30.4)	22.64+/-1.224(17.2-30.0)

There were significant differences between groups (ANOVA $F_{5\,45}$ = 4.23, P = 0.003). Males dived for longer than females, significantly so at Dinnet ('t'$_{18}$ = 2.17, P = 0.04) and at the Ythan Estuary ('t'$_{18}$ = 2.52, P = 0.02). Males at the estuary dived for longer than those at Dinnet ('t'$_{18}$ = 2.30, P = 0.03) or at Skene ('t'$_{18}$ = 2.41, P = 0.03).

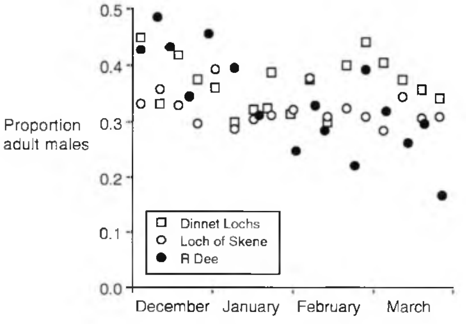

Figure 8. The seasonal decline in the proportion of adult males in Goldeneye flocks on the River Dee compared with no trend at two loch sites.

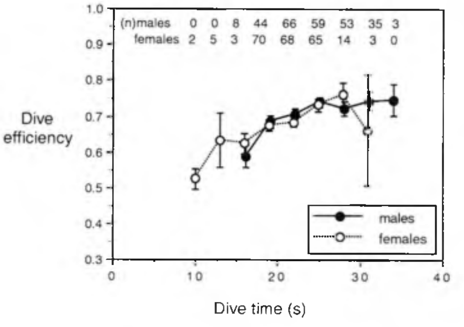

Figure 9. The increase in mean dive efficiency (time spent underwater as a proportion of the total dive and surface time) with increasing dive time for male and female Goldeneye. Bars denote one standard error above and below mean values.

est of dives - the mean efficiency of dives greater than 31 seconds by males was 0.81 (n = 9, se = 0.04) and greater than 27 seconds by females was 0.82 (n = 11, se = 0.06).

Discussion

Population shifts

Goldeneye are chiefly winter visitors to Britain. In the present study area they arrived in October and November, left in April and peaked at different times in different places. Within the winters of our observations there was little evidence for mass movements in or out of the area - the counts at nearby communal roost sites did not change in parallel with changes in nearby habitats. Rather it seemed that Goldeneye foraging on lochs (predominantly 'brownheads') moved to foraging on the lower parts of rivers in February and March, causing an increase in numbers there associated with a decrease in the proportion of adult males. National Wildfowl Count data show, in most years, a shift in the population from inland to coastal sites as the winter progresses (Salmon *et al.* 1989).

It has been argued that severe weather, with freezing inland waters causes such movements (Barrett & Barrett 1985, Sayler & Afton 1981), and in the present study the movements took place with the onset of cold weather in February. Moreover the larger numbers of Goldeneye on the River Dee in December 1989-90 occurred during an early bout of severe weather, as some lochs were temporarily frozen then. However, in the 1988-89 winter there was no decline on rivers in March as temperatures rose, and overwinter population shifts seem to take place even in mild winters when lochs remain free of ice, which argues for an alternative explanation of gradually depleted food resources at preferentially used sites (Sayler & Afton 1981).

Foraging behaviour

In Britain, Goldeneye eat benthic invertebrates (Olney & Mills 1963) or industrial waste, such as grain and vegetables associated with sewage effluent (Pounder 1976, Campbell & Milne 1977, Barrett & Barrett 1985, Campbell, Barrett & Barrett 1986). Major concentrations of Goldeneye in Britain have been at sewage outfalls on the coast. In the present study, the freshwater loch with the largest wintering flock was at Skene which was eutrophic. The river with the consistently greatest numbers was the Don, which was more polluted than the Dee or North Esk, and on the River Dee local concentrations were centred on small effluent outfalls.

The range of dive times we recorded was similar to those given for Goldeneye in general by Cramp & Simmons (1977). In the present study, as predicted from their greater size, adult males dived for longer than females and more so at the estuary where adult males were predominant. There was no evidence that females could improve on the proportion of their time spent underwater. Their dive times were not extended by increasing surface recovery periods - rather, for any given dive time, the proportion of foraging time spent underwater was almost identical to that of males.

Major factors affecting food availability for Goldeneye are 1) the types of food items taken from the benthos and whether they are moving, immobile or hidden, 2) the concentration of items, and 3) the depth or current of water above them. With shorter dive times, females must be disadvantaged where food items are evasive or sparse, and where the water is deeper or fast flowing. However, they may also be disadvantaged in any situation where food is so concentrated that they forage in direct competition with males (Choudhury & Black 1991). Tidal river sections and effluents provide rich concentrations of food that are replenished continuously, attracting good numbers of Goldeneye. However, at least in our study area, such sites attract many adult males, so foraging may be easiest for females in shallow eutrophic lochs, where food is abundant but dispersed, at least until ice or a depleted food supply later in the winter makes foraging on rivers relatively more attractive.

Female Goldeneye that move to river or coastal sites might have to forage for longer to get their daily food requirements. Goldeneye feed diurnally. In late December 1988, an adult male and a 'brownhead' were observed foraging after dark on a stretch of the River Dee, lit up by streetlights in Aberdeen, but opportunities for such nocturnal foraging are scarce. Daylength could have limited foraging time in the northeast of Scotland in December and January when the days were shortest, and most Goldeneye did not arrive at the roost until it was almost dark. By March this did not seem to be the case because many Goldeneye were present on the roost site, preening and loafing an hour before dark.

The importance of the area for Goldeneye

It was difficult to estimate the total number of Goldeneye wintering in the region. They gathered to roost, but intermittently used several other sites including some river backwaters which we did not count. A maximum figure (854) was calculated using peak winter counts at the major foraging sites in 1988-89, but this method overestimates a population that shifts between sites. A conservative estimate (709) was the total for all sites counted in late December 1988 and January 1989. Of these 379 (53%) were on rivers. From changes in numbers we observed on the Dee alone, by March at least 440 (62%) of the region's Goldeneye were on rivers, even though most standing freshwaters used by Goldeneye remained largely free of ice.

In Britain, the wintering Goldeneye population has been estimated (at about 10 to 15 thousands) from counts at standing water sites and a few very large, coastal concentrations (Owen *et al.* 1986). Some of these coastal flocks have declined as the effluent of sewage 'solids' has been curtailed (Campbell 1984). The population has changed and from the present study it seems that Goldeneye are numerous enough on some specific sections of rivers to warrant at least 'National Importance' status (Kirby *et al.* 1991, Table 55).

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