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THE POSSIBLE IMPACT OF WIND POWER GENERATORS ON FLYING BIRDS

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The possible impact of Wind Power Generators on flying birds

Current research on wind powered generators and the recent announcement that a single machine, with 60m rotors and producing 3MW, is to be built on Orkney have raised the possibility of risk to birds through impact. Plans have been produced for machines with rotors up to 100m (diameter) operating from towers 125m high. Production installations of such machines are likely to take the form of arrays, in areas subject to windy conditions, set across the direction from which the prevailing wind blows. This document sets out to examine the likelihood of direct loss to bird life through impact with the moving rotors of such machines and possible means of avoiding such losses. It does not consider the effect of the structures, their construction or maintenance on the composition of local bird communities.

Four sections follow dealing with particular aspects of the problem.

1) The probability of collision. This examines the likelihood of a bird being struck by a moving rotor in the absence of any attraction to or avoidance of the machine being shown by the bird.
2) Local birds at risk. This section discusses the species that might be at risk, possible behaviour which may affect the risk to which they are exposed and steps which might be taken to reduce the risk.
3) Migrant birds at risk. The height at which migrants fly and the chances of impact, particularly at night, are examined together with the bird's behaviour and possibilities of reducing risk.
4) Summary.

1) The probability of collision

The Central Electricity Generating Board have provided an equation giving the probability of a bird passing through the plane of rotation of a rotor blade being hit by it:

$$P \simeq n.w. \frac{(d + l)}{v} \qquad \text{......... (1)}$$

Where n is the number of rotors, d is the thickness of the rotor plane, l the length of the bird (both measured in metres), v is the velocity of the bird perpendicular to the plane of rotation (ms^{-1}) and w the angular velocity of the rotors ($revs.s^{-1}$).

This expression supposes that there is no deflection of the birds by the airstream through the rotors and, for the moment, that the birds are neither attracted to nor repelled by the rotors. The expression (1) does not allow for the width of the rotor blades nor for the variation in thickness along their length but it gives a good approximation for relatively small and slow-moving species. However there will, theoretically, be a very high probability of collision for birds flying at a small angle to the plane of rotation (thus with a very low v). This will inevitably be different in practice for initial contact is quite likely to be non-fatal possibly allowing the bird to escape. If the rotor is visible (bird flying in daylight or rotor illuminated) it will be very much easier to see for birds approaching at a low angle to the plane of rotation.

The actual probability of collision, as calculated from (1), for a small bird (d + l roughly 1 m) approaching a rotor revolving at 30 rpm is 26% for a speed of $4ms^{-1}$ and 6% for one at $15ms^{-1}$. provided that the bird's flight path intersects the plane of rotation. However it seems most realistic to calculate what may happen, under varying circumstances, to a stream of birds five kilometres wide which happens to be flying at the same height as the rotors of an array of the largest proposed machines (that is the stream of birds flys between 75m and 175m height). The rotors will, presumably, be turned to face the direction of the wind and the birds' track will be at an angle to the wind direction. These two angles are taken as A° (array angle) and B° (bird angle). The speed of the bird flying in still air is taken as v_b so the speed in relation to the rotor plane will be the wind speed $(v_w) + v_b \cos B$. When the flight direction of the birds approaches the alignment of the array of rotors there will also come a point where adjacent rotors lie one within the 'shadow' of the other and the probability of a bird being struck will be slightly decreased - no allowance has been made for this effect. (This comes into play when the separation of adjacent rotor towers is less than the rotor diameter times (cosA + sinA (tan(A + B)).

The probability of an individual bird within a stream five km wide and 100m high being hit by the rotor of one of N machines in an array is given by:

$$P = \frac{\pi . r^2 . N . \cos B}{5000 . 100} \times \frac{n . w . (d + 1)}{(v_w + v_b \cos B)} \quad \ldots\ldots\ldots (2)$$

For a five machine array of the largest machines this becomes:

$$P = 0.079 \frac{\cos B}{v_w + v_b \cos B} \quad \ldots\ldots\ldots\ldots (3)$$

Presumably when v_w is low the rotor arms will not be turning very fast and will therefore not present much of a hazard. Assuming that something like full speed may be attained at wind speeds of about $10 ms^{-1}$ and that small birds fly at about this speed in still air the chance of a bird in the hypothetical stream being hit by a rotor when the stream was flying with the wind would be about 0.4%. Birds with a track at 45° to the wind direction would have this probability reduced by about 20%. With these speeds birds flying directly into the wind would not make any headway at all!

2) Local Birds at Risk

The positions in which such wind power machines would be built are pre-determined by the need for a windy environment. The machines are therefore not likely to be built in sheltered woodland areas nor are the rotors likely to reach so close to the ground that small passerines, like tits (Parus sp.) or finches (Carduelis sp.) which are most likely to be found in such habitats, are at all likely to be affected. Open windy sites are most likely to be found in mountain and moorland situations or on the coast. At coastal sites problems with turbulence are likely to preclude the use of cliff-top sites and so the seabirds that might be affected are most likely to be gulls (Laridae) and terns (Sternidae). In moorland areas open ground species like Skylark* and Meadow Pipit (amongst passerines), Lapwing and Curlew (waders) and other specialist species are most likely to occur. There are also some aerial feeders, like Swallows and Swifts, which might be found anywhere. Results from the British Ringing Scheme (run by the British Trust for Ornithology under contract to the Nature Conservancy Council) have been used to show the percentage of all reports for a range of open-country species which have occured as a result of collisions with wires. These are shown in table 1 - the Laridae results are not currently available.

Collision with wires was chosen since they are necessarily aerial collisions with something not easily seen. Collisions with traffic on the roads may, at first sight, seem to be a better analogy with the moving rotor but road deaths are very often the result of perched birds not moving out of the way of a vehicle in time and a rotating arm is very different from a moving vehicle - not least because the tip of a 100m diameter rotor revolving at 30 rpm will be moving at 157 ms^{-1} as compared with 30 ms^{-1} for quite fast road traffic. Of the species listed one, the Red Grouse, can effectively be discounted since they will very seldom reach the height of 75m - the lowest point reached by the rotor. Most of

* Scientific names are given in the appendix

the other species will also normally fly below rotor height but many of the non-passerines may reach the danger zone, particularly when displaying in the spring. The rotors are unlikely to have an effect on most species during feeding flights but Swifts regularly feed at the 'danger' height. Local birds on roosting flights may be at risk twice a day for weeks or even months on end. Luckily most machines are likely to be placed on hilltops and most roosting flights of birds are likely to be through valleys but it is possible that gulls might regularly flight across an area suitable for wind generation at a height where they could be struck.

Most of the open country species listed are relatively inactive at night and, in any case, locally resident birds are very likely to learn about the presence of the rotors in daylight and avoid them at night. Drifting flocks of roosting Swifts (they sleep on the wing) could easily be at risk but the best evidence to hand suggests that the roosting birds are generally to be found flying at greater heights: Eastwood (1967) suggests heights of 700 - 1500m from radar work in Britain and on the Continent.

3) Migrant Birds at Risk

Almost all parts of Britain are traversed by migrant birds in the spring and autumn and many areas have large-scale movements of winter migrants through the winter. Indeed virtually every species occurring in Britain may take part in migratory flights, either on a regular basis as when summer visitors go to Africa for the winter or winter visitors reach us from the north and east in the autumn, or when they are forced out by cold weather during the winter.

Migrant birds are only likely to be at risk, from a particular installation of machines, at most twice during a year whereas local birds may have the possibility of impact for day after day. On the other hand migrant birds will not encounter the machines day after day and so will not become used to them. Migrant birds are also quite likely to fly relatively high and therefore be in the danger zone. Many migrant birds are also generally on the move at night and may therefore not be able to see the revolving rotors.

There are many references in the ornithological literature to the height at which birds fly. These may be based on visual observations from the ground or from aircraft or on radar work. In almost all cases where the birds have been recorded in Britain (or Europe) the observations have been particularly concerned with high birds rather than low ones (e.g. Meinertzhagen, 1955) and have not in any way been designed to give a representative sample of the normal height at which the species concerned fly. Direct observations from aircraft have generally only been of birds over 500 feet as, at lower levels, the pilot of a light aircraft is generally busy landing or taking off (Mitchell 1955, 1957 & 1964). Even radar observations are often unreliable at low altitudes and the lower limit of observation generally used by Lack (1960) was 1000 feet and by Eastwood (1967) 200m. The most useful data from Britain and Europe comes from Eastwood and Rider (1966) using radar installations in southeast England and by Klomp (1956) reporting on visual observations in the Netherlands.

Rather more systematic work on the height of flight of migrants has been undertaken in North America where nocturnal migrants have been investigated using radar, ceilometers (floodlights mounted vertically which are used to measure the height of cloud cover) and even lights mounted on a light aircraft (Bellrose 1971). Particularly valuable radar studies have been published by Able (1970) and Blokpoel & Burton (1975). Many of the species studied in North America have no close relatives in Britain and Europe but there is every reason to suppose that their behaviour is similar. Almost all have equivalent species in the Old World with similar size, shape and even feeding habits - e.g. New World and Old World warblers.

In general the height of migration is much influenced by wind speed. Indeed if the winds are very much against the direction of migration many species may cease to migrate and come down to earth. Since wind speed decreases closer to the ground, an effect known as wind-shear and brought about by the friction of the moving air on the land (or sea) surface, migrants flying into the wind tend to fly lower than those able to take advantage of a favourable wind-component. Eastwood and Rider (1966) show that there is on average throughout the year about 16% of diurnal and 10% of nocturnal migration observed in southeast England at the critical height of 75m to 175m. Their charts, by month, have been converted to percentage at the critical height and are presented as figure 1. The histogram also shows the number of observations made in each month upon which the percentages recorded were based. The cold weather movements in the mid-winter period clearly show more birds at risk than at other times of the year. Since the year when the observations were made was from June 1962 to July 1963 particularly severe conditions were encountered by the birds and the cold-weather movements would have assumed a much greater importance than during a 'normal' year. The only months of heavy migration at night when many birds were within the critical height range were September and November. If 1000 of the largest proposed machines were set up and operating down the east coast of Britain these figures suggest that something like 0.04% of the migrants crossing the east coast might be at risk on each migration.

Eastwood and Rider (1966) have further observations on height of migration related to the cloud cover. More birds were to be found at the risk height on clear days and clear nights (defined as cloud cover of 4/8 or less and no precipitation) compared with nights and days with total overcast. The nocturnal percentage at risk height was, under both conditions, considerably less than the day-time percentage. Higher migration under cloudy conditions is generally thought to allow the birds to fly over the top of cloud cover.

Klomp (1956) working with migrating Chaffinches in daylight in the Netherlands shows that their height of migration depends on the type of flight that they are making and also the sort of ground (or lack of it!) that they are crossing. Over attractive land with trees and woods, but with a contrary wind, migration regularly takes place as low as tree-top level and, even with favourable winds only up to 150 - 200 m. Birds following the coast may also be this low but birds crossing unattractive open areas and, particularly those making a sea-crossing are generally over 200 m and often reach 500 m or more. The probable positioning of wind generators in treeless areas may thus remove the risk to Chaffinches!

Radar studies in North America by Able (1970) and Blokpoel and Burton (1975) have produced a considerable amount of evidence on the height of migration at night. For instance, over Louisiana, between 35% (two hours after sunset) and 65% (11 hours after sunset) of all nocturnal migration took place below 1440 feet. These figures may correspond to 9% and 16% of the migration taking place in the risk zone. At the same site there was a positive correlation between altitude of migration and density of movement: mean altitude being about 800m with heavy migration (25000 birds per mile front per hour - that is ca 15000 $km^{-1}hr^{-1}$) and only 300m with a much lower bird density (ca 500 $km^{-1}hr^{-1}$). The same study also showed a positive correlation between wind direction and the direction of migration. Taking hypothetical fronts of five km with birds at these densities flying at these heights possibly 30 casualties per hour might occur with the high density (75000 birds passing) and two per hour at low density (2500 birds passing) - these figures do not allow for any attraction or repulsion to or from the rotors.

The second radar study (Blokpoel and Burton, 1975) using a set aligned vertically in Alberta, Canada was unable to detect birds flying below 1200 feet (ca 350 m). However the distribution of bird echoes plotted showed that it was very unlikely that large numbers were being missed on most nights. This study showed again a positive correlation between favourable wind direction and migration and concluded that migrants mostly flew above low cloud cover. Their evidence strongly supports the supposition that the height of migration may be adjusted to take advantage of the most favourable winds which may, of course, occur at different altitudes on different nights.

Bellrose (1971) reports a novel means of observing nocturnal migration using extra lights mounts on a light aircraft. The lights illuminated an area of about 6.5 m^2 and the aircraft travelled at 120 knots. The speed of the aircraft was thus about 40% of that of the rotor rip of a large wind power generator. Of thousands of encounters with birds at night Bellrose and his associates only recorded three bird-strikes - all of small birds for the larger species were certainly taking earlier avoiding action.

The aircraft was noisy and well illuminated but it does seem very likely that means could be devised to provide warning for birds which might come in contact with a generator rotor at night. Most of the surveys flown were made by steady flights at altitudes with 500 foot vertical intervals. During the spring additional flights were made at 350 and 750 feet as well as the 500 feet levels used in the autumn. In both spring and autumn the main concentration of birds was recorded at 1000 feet regardless of cloud cover and about 20% of all contacts were made at 500 feet - that is approximately the highest level swept by a rotor of the largest planned machine. Records from 750 feet were similar to 500 feet but fewer birds were observed at 350 than 500 feet. Since the main part of the area swept by the rotors will be between 100 and 150 m (over 60%) these results indicate that less than 15% of migrants may be at the danger heights. This, combined with the figures given in section 1, would mean a chance of roughly 1:1700 against any migrant over a five km front being hit by a rotor blade when the front passed five of the largest planned machines in an array.

On the whole these results seem to indicate that there is no serious likelihood of significant bird mortality being caused to migrants by wind power generating machines. They are most likely to be positioned along the west coast of Britain and in remote open areas where, in general, there are fewer birds migrating than along the east coast and certainly many fewer than in the areas of North America where the studies quoted were undertaken. In addition there are good indications that even night migrants are capable of avoiding impact with well lit aircraft travelling much faster than the birds are flying and so it may be possible to repel birds from the rotors. There are however two particular considerations which should be bourne in mind:

1) Potential damage to rotor arms from impact with very large birds.

The great majority of small migrants weigh less than 100 g but there are moderate numbers of medium-large birds migrating weighing ca 1000 g: these include the larger gulls and some ducks and birds of prey. The direct impact of the tip of a rotor on one of these birds will exert a considerable force (over 12KN). There are also an even smaller number of larger migrants with weights of up to 5 kg (Canada Goose, Greylag Goose and Bewick's Swan) or, at a maximum 10 kg (Whooper Swan). These may be numbered in tens of thousands (smaller size) and thousands (larger size) migrating to and from Britain each year. They are all species which are quite likely to be flying at the risk height and a single Whooper Swan would exert a force of about 125 KN if it were hit by the tip of a rotor - this may be visualised as the static rotor being hit by a small car travelling at 25mph. Large numbers of migrant geese and some thousands of Whooper Swans reach northwest Scotland each autumn from their breeding grounds in Iceland and could cause a hazard at generators placed in the Hebrides or on the mainland of north-west Scotland.

2) Species particularly at risk.

Observations at lighthouses and of corpses below wires have shown that some species are particularly at risk. For example both are very hazardous to small migrant rails and the Corncrake, being a small migratory rail, may be a potential victim. This bird's populations are at a very low level and decreasing (Cadbury, 1980). Its strongholds are now in western Britain and Ireland in the very areas that wind power generators are likely to be placed. However there is unlikely to be a continuing local threat to the breeding populations but simply a risk to migrating birds arriving at and leaving the breeding grounds.

Quantification of the risk of impacts with Whooper Swans or Greylag Geese if there were eventually a hundred of the largest machines operating across north Scotland from the Outer Hebrides to Shetland can be attempted. The larger birds have a flight speed of about $20ms^{-1}$ and are roughly one metre long. If half the birds passing over are at risk height (probably an over-estimate) and they pass over both in the autumn and in spring the risk of impact will depend on the populations using Scotland. The Scottish wintering population of Whooper Swans from Iceland is about 2500 and of Greylag Geese about 65000 (Cramp & Simmons, 1977). The front they are likely to pass on is about 500 km wide and about one bird in a thousand might be hit. This is probably very much an over-estimate, as most of the generators are likely to be on hilltops and migrating swans and geese are likely to choose to fly up valleys, but the risk is clearly not negligible. The figures above, given random distribution of the birds, would amount to a Whooper Swan impact per generator every 40 years of operation and a Greylag impact every year or so. The effect of a Whooper Swan at the end of a rotor has already been calculated at 125kN but this would be less the nearer to the rotor's centre the bird struck. Unfortunately the force would be more than 50kN over almost two thirds of the swept area. The Corncrake is now a local speciality on the Outer Hebrides - some 260 breeding pairs were discovered on the last survey (Cadbury 1980). Even if all these birds (and their progeny in the autumn) flew at the risk height and had to pass, say, ten of the largest generators over a 100 km front they would only be likely to have a single casualty every two years.

4. Summary.

The proposed wind power generators are large structures which could potentially cause bird casualties. The tips of the rotors move very fast but there is probably little reason to expect that there will be collisions during daylight conditions with good visibility. Collisions at night or at dawn and dusk are much more likely to occur especially if the rotors are left unlit. The likely siting of such machines will probably be on windy hill-top areas which will probably have rather low densities of local species the majority of which are unlikely to fly at night at the levels needed to collide with the rotors (minimum height of 75m on the largest proposed machine).

Wind Power Generators

The risk to migrant birds is probably very much more real. Many species migrate on a broad front at heights which range through that of the rotors. In the future it is possible that large numbers of these machines might be built but, provided that birds are neither attracted to nor repelled from the machines even as many as 1000 machines installed down the east coast of Britain (a less likely case than the west coast where migration is less heavy) would only be likely to kill about one bird in every 2500. This would still result in tens or possibly hundreds of birds dying each year at individual machines and some might be large birds, like swans or geese, which could cause damage to the machine. Some form of illumination of the rotor would probably allow birds to avoid it although, of course, bright illumination (floodlights etc) would probably attract birds. A system of lighting the tip of the rotor at the top of its sweep may well be needed for aircraft safety but, from the bird's point of view a glowing strip along the rotor-shaft (both sides) would be the best solution - this would probably not be intrusive for humans either.

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Ringing recoveries due to collisions with wires for moorland and open country species.

Species	Total recovered	Hit wires	% against wires
Heron	1463	112	7.7%
Hen Harrier	177	18	10.2%
Montagu's Harrier	32	2	5.3%
Kestrel	1659	63	3.8%
Merlin	199	10	5.0%
Red Grouse	177	16	9.0%
Golden Plover	59	4	6.8%
Lapwing	2371	88	3.7%
Curlew	782	18	2.3%
Common & Arctic Terns	558	10	1.8%
Cuckoo	69	3	4.3%
Short-eared Owl	69	2	2.9%
Swallow	2838	74	2.6%
Swift	586	24	4.1%
Meadow Pipit	395	6	1.5%
Pied Wagtail	1810	17	0.9%
Wheatear	175	4	2.3%

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Figure 1. Percentage of migrants passing across south-east England in each month at the risk height.