Wind farms as obstacles to migrating birds

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Wind turbines present a collision hazard to migrating birds whenever a migration stream is concentrated into the area and the height zone occupied by the moving blades. Current methods for environmental surveys do not address this, failing to detect, for example, that the island of Lewis is a well-known concentration point for migrating Whooper Swans, which are highly vulnerable to collisions with turbines and overhead cables. Future environmental surveys should map known concentration points, and use readily available instruments to measure the flying heights of local species, to determine whether the "clear zone" below the turbine discs is sufficient to accommodate them. Migrants that normally fly high may be forced down by low cloud, into the height zone occupied by turbine blades. Proactive background research with tracking radar is needed to map low-level migration routes, and to determine how and where migration streams are concentrated by low cloud, as measured by a ceilometer.

INTRODUCTION

Wind turbines can present a collision hazard for migrating birds, for the same reasons as other tall structures such as TV towers and high-rise buildings, with additional complications caused by the rotating blades. The probability of a random collision with a tall obstruction is actually quite low for birds that migrate in a dispersed stream, because most of them pass above it, or miss it laterally, or see it and avoid it. An obstruction becomes a hazard to migrating birds if it is sited in a place where a migration stream is liable to become concentrated. Mountain passes are obvious concentration points, and there are also other situations where a migration stream can become concentrated, either horizontally or vertically or both. Once a wind farm is in place, there is not a great deal of scope for remedial measures, but problems may be avoided or minimised in some cases, by careful siting of wind farms or individual turbines. Environmental surveys at the sites of proposed wind farms should try to identify factors that cause birds to concentrate in conflict with the turbines, and also to identify sites for wind farms, and for individual turbines, where no such effects are known to occur. This begins with the characteristics of the turbines themselves.

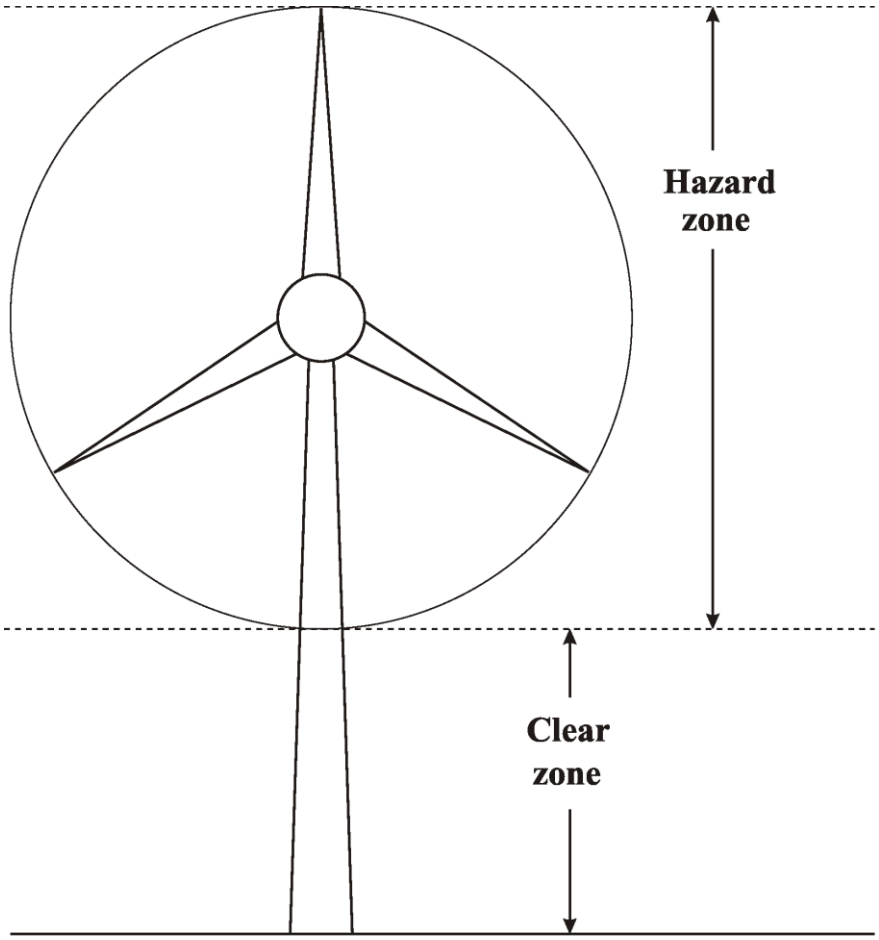


Figure 1. Wind turbines present a collision hazard to birds in the height zone occupied by the moving blades. The height of the hub above the surface is typically about equal to the disc diameter, leaving a clear zone below the blades of about half the disc diameter. Turbine disc diameters range from about 30 m for a 250 kW generator to 100 m for a 3 MW generator.

OBSTRUCTION PROFILE OF WIND TURBINES

Wind turbines differ from other obstructions in their profile. The commonest type has a 2 or 3-bladed turbine that rotates about a horizontal axis through the hub, sweeping out a vertical disc (Fig. 1). The height of the hub above the ground or water surface is usually about equal to the diameter of the disc, or a little less. Most turbines used in wind farms have discs between 30 and 100 m in diameter, with 15-50 m clear space below the blades. The whole assembly rotates about a vertical axis as necessary to keep it facing into the wind. From a distance, the turbine blades appear to move quite slowly, but this is an illusion due to their large size. In a typical medium-sized turbine of 44 m diameter the blade tips move across-wind at an air speed around 60 m s^{-1}, which is faster than any bird can fly. Most birds cruise at air speeds in the range 12 m s^{-1} (passerines) to 25 m s^{-1} (divers). A bird that flies through the outer part of the disc may miss the blades by good luck, but cannot fly fast enough to escape an approaching blade by taking evasive action.

CONCENTRATION OF BIRD ACTIVITY

Any cause that makes birds more likely to fly through turbine discs may be said to "concentrate" birds in the wrong place. Migration streams of many species are

concentrated horizontally by geographical features at particular points, and may also be concentrated upwards as the stream approaches mountains, or downwards by bad weather. Particular features of the behaviour of individual species also cause concentrations in certain cases.

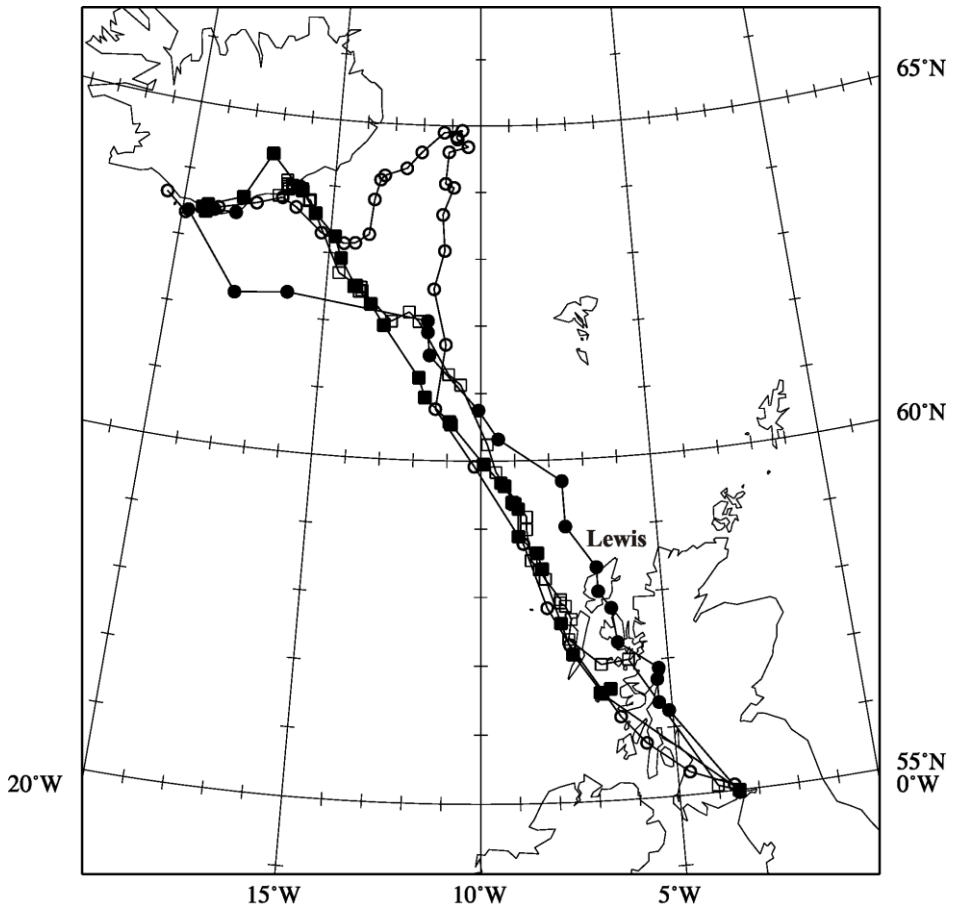


Figure 2. Four Argos tracks of Whooper Swans migrating from Caerlaverock, Scotland to Iceland, from Pennycuick et al. (1999), all of which initiated their sea crossing from the Outer Hebrides. One of them (solid circles) was forced off course by a northerly gale, but recovered by increasing speed. A second (open circles) was forced near to the eastern tip of Iceland by a westerly gale, but returned to his original line before closing with the south-east coast near Höfn.

Geographical concentration of a migration stream

Birdwatchers are familiar with such famous migration concentration points as the Straits of Gibraltar and the Bosphorus, where migrating land birds are concentrated by their tendency to follow a coastline, until they can no longer avoid venturing out over a water crossing. Migration streams also concentrate on some longer sea crossings. For example, all Whooper Swans (*Cygnus cygnus*) of the Icelandic population spend the summer months in Iceland, whether they are breeding or not, and most of them migrate to the British Isles or Ireland for the winter (Cranswick *et al*. 2002). Transient concentrations of flying Whoopers are seen during the spring and autumn migration seasons, at both ends of the shortest sea crossing (about 800 km). This joins the middle of the south-east coast of Iceland (around Höfn) to the northern end of the Outer Hebrides, and it appears that Whoopers are able to navigate along this comparatively narrow track, compensating for wind drift (Pennycuick *et al*., 1996, 1999). Satellite tracks of Whoopers tagged at Caerlaverock in southern Scotland

(Figs. 2 and 3) showed that the birds made their way in the spring through the western Scottish Highlands to the northern end of the Outer Hebrides, and departed from there direct for Höfn, which is well known to local residents as a concentration area for incoming Whoopers. Likewise, southbound birds in autumn showed a clear concentration of tracks crossing the Outer Hebrides. They did not necessarily stop there, but usually continued to the Inner Hebrides or the Scottish mainland.

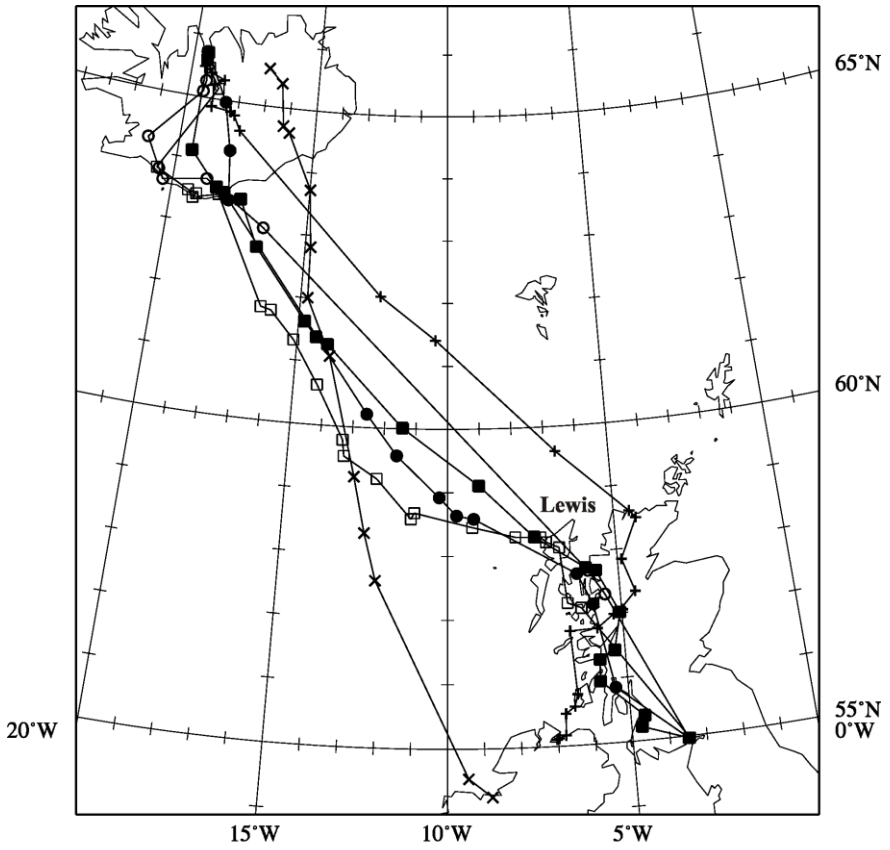


Figure 3. Six Argos tracks of Whooper swans migrating from Iceland to Scotland or Ireland, from Pennycuick et al. (1999). Four of them passed through, or very close to the proposed wind farm site on Lewis.

The Lewis wind farm proposal

The proposed wind farm on the island of Lewis coincides exactly with the concentration point at the British end of this sea crossing. This proposal calls for 234 very large turbines, each of 3 MW capacity. Each turbine would have a disc 100 m in diameter, with its hub supported by a conical tower, 90 m above the surface. The blades would constitute a collision hazard in a height band extending from 40 m to 140 m above the surface. Birds would be able to pass safely below 40 m, and this might conceivably allow sufficient clearance for low-flying swans coming in from the sea. However a network of power cables connecting the turbines, which is part of the proposal, would be a lethal obstacle for swans, which are notorious for colliding with power lines, pylons and other obstructions (Perrins and Sears 1991). This results indirectly from their large size, which leads to them being "underpowered", meaning that they have only just enough muscle power for level flight (Pennycuick 1989), and very little to spare for sudden evasive manoeuvres.

The developers' Environmental Statement (www.lewiswind.com/es/) failed to identify this problem, owing to inappropriate survey methods. The surveyors recorded the numbers of different species seen, and the amounts of time that they spent in

different habitats, noting that Whoopers were mostly seen in small numbers, and that they did not stay for long. They concluded (wrongly) that the proposed wind farm would not pose a threat to this species, although an unknown, but probably large fraction of the Icelandic Whooper population flies right through the area of the proposed wind farm twice in each year. They would certainly suffer significant mortality from collisions with the turbines, and especially with the associated overhead cables, at each passage through the area. Migrating Whoopers usually fly low, continuing by day and night, but stopping from time to time to rest on the water. A line of turbines appearing out of the sea ahead would be a formidable obstacle to tired swans coming in from Iceland, especially in the dark. The network of overhead cables would be even more lethal, being harder to see, and too near the ground for swans to pass safely underneath. Even if it can be shown that the turbine discs are at a safe height (doubtful), it would be absolutely essential to put all cables underground. This should be a non-negotiable requirement.

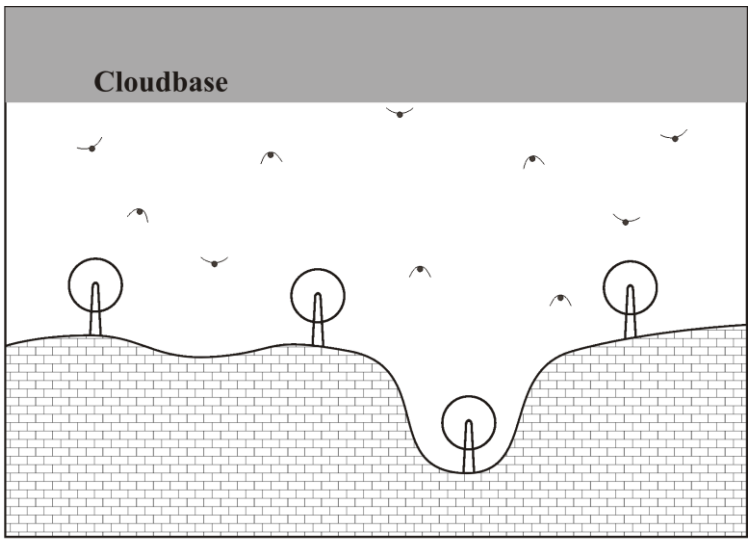


Figure 4. As a low-pressure system approaches a ridge with wind turbines along the top, cloudbase may initially be high enough to allow migrating birds to disperse above the turbines.

Effect on the population

The long-term effect of this particular wind farm on the population would depend on whether the Whoopers' reproductive rate is sufficient to offset the additional annual mortality due to twice-yearly passage through the obstacle. This is analogous to the case of albatross species that are subject to additional mortality caused by long-line fishing operations. Being long-lived birds with low reproductive rates, some albatross species are in danger of eventual extinction because of this (Croxall *et al*. 1990), even though the additional mortality rate is quite low. Swans have higher reproductive rates than albatrosses, but on the other hand the proposed Lewis wind farm appears to be perfectly designed and sited as a trap for migrating Whoopers. Adverse reaction to such a serious threat to this population can be expected, especially from Iceland, where Whooper Swans are well known to the public, protected, and highly valued.

Concentration due to bad weather

In clear weather, small and medium-sized migrants (passerines and waders) typically spread out vertically in a height band that extends at least to 3000 m above the

surface, and often higher (Alerstam 1990). The pilot's concept of a "safe minimum height" applies equally to migrating birds. By flying at a safe height (i.e. high enough), the danger of colliding with obstacles is kept to an acceptably low level. Conversely, flying low is dangerous. Because birds depend on visual references for spatial orientation in flight, the upper limit of the height band available for migration under a cloudy sky is the "cloudbase" level, defined as the height above which a bird or pilot loses visual contact with the surface (Fig. 4). Cloudbase typically comes steadily down as a low-pressure weather system approaches, forcing migrating birds to fly nearer the ground. Eventually the migration stream is concentrated into the height band where birds may hit TV towers or bridges, or be forced to fly through a large array of turbines in a wind farm (Fig. 5). A migrating bird that is surrounded by turbines, whose blades are disappearing into cloud at the tops of their arcs, and reappearing at a speed too fast for evasive action, has very limited options for escape, especially at night.

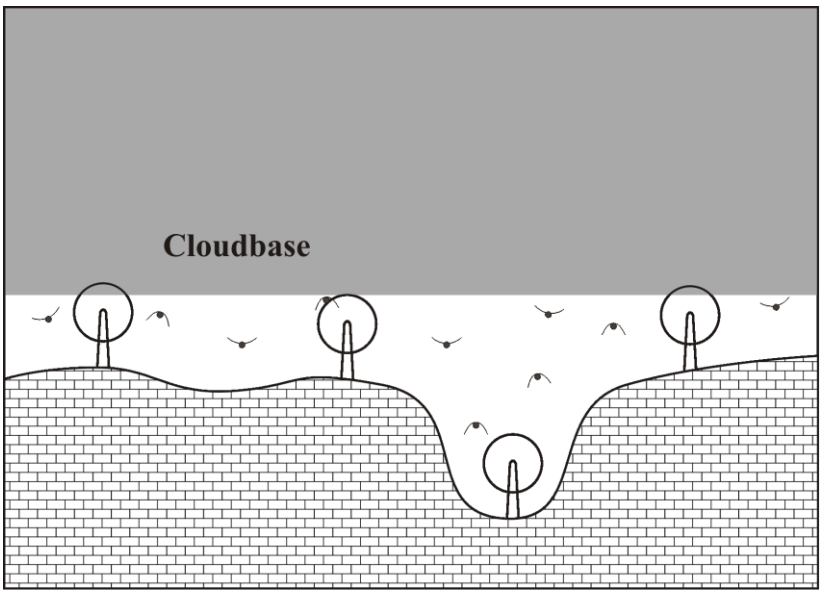


Figure 5. As cloudbase comes down, the migration stream is compressed into the height band occupied by the turbines.

The effect of low cloud in causing massive kills of migrating birds by collisions with TV towers was described and analysed by Karlsson (1977), and the same thing happens at obstructions of other kinds, including bridges. The new Öresund road and rail bridge linking Denmark and Sweden is supported by towers 205 m above the water surface, and the bridge itself blocks a layer extending from about 55 to 70 m above the water surface at the centre of the span. This causes massive kills of passerines on nights in the autumn migration season when the cloud comes down to this level, probably exacerbated by a tendency for migrants to fly along the sound when forced down by low cloud. Of course, the bridge has to pass across the sound because that is its purpose. However, it might be possible to avoid siting wind farms in places where migrants tend to concentrate in bad weather, if research were undertaken on the density of migration at low level on cloudy nights, rather than relying on counting kills at existing obstructions, as at present.

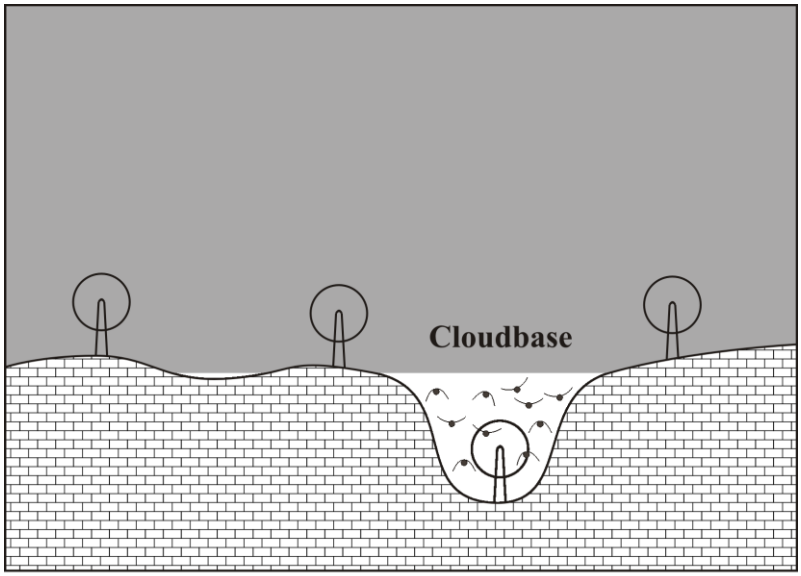


Figure 6. When cloudbase descends below the ridge top, the stream is further compressed laterally into any gaps that remain clear of cloud. Turbines should not be sited in gaps in ridges.

The gap effect

Some engineers favour placing turbines in gaps or notches in a line of hills, because the wind accelerates as it funnels through these. However, such gaps are the worst places to site turbines, because they are the points where migration is concentrated, when the cloud comes down on the tops. Over a land surface, a lowering cloudbase engulfs the hill tops first, causing a migration stream to divert around high ground, and concentrate in gaps and passes (Fig. 6). Turbines sited on the tops of ridges are more conspicuous but less hazardous, since if the weather allows birds to fly above the tops, they are also free to disperse horizontally. Research is needed on the distribution of migration density at very low levels in bad weather and at night, when birds are forced down by low cloud. Such information could be obtained by systematic studies with portable tracking radar, designed to identify areas of low migration density, where wind farms could be located without causing problems.

Soaring birds and ridges

Soaring birds are mostly large species like storks and vultures, and they typically migrate in daylight by climbing in thermals to heights that keep them well clear of surface obstructions. However, they are not always immune to the danger of collision with wind turbines. One of the spectacles that attract birdwatchers to Tarifa at the southern tip of Spain is the arrival of White Storks (*Ciconia ciconia*) returning from Africa on their spring migration. These storks never resort to flapping flight unless it is absolutely unavoidable. As the straits of Gibraltar are about 13 km wide at the narrowest point, and the storks' best glide ratio is about 15:1, they need a height of about 2 km over the Moroccan coast to arrive on the Spanish side with enough height to begin looking for thermals. If conditions are not good enough to achieve this, they may come in below the top of the first ridge inland from the Spanish coast, so that they are forced to climb up the ridge in slope or anabatic lift, passing close over the crest. This particular ridge crest is now lined with wind turbines. Barrios and Rodriguez (2004) did not observe any close encounters between storks and turbines in this area during the spring migration of 1994, but that was before the turbines were installed on the first ridge. They did report that Griffon Vultures, which breed and

forage in the area, were injured or killed in collisions with both turbine blades and power cables at two wind farms on ridges further inland. These accidents occurred especially in the autumn and winter, when thermals were weak, and vultures tended to climb up a ridge in slope lift, passing through a turbine disc as they cleared the crest.

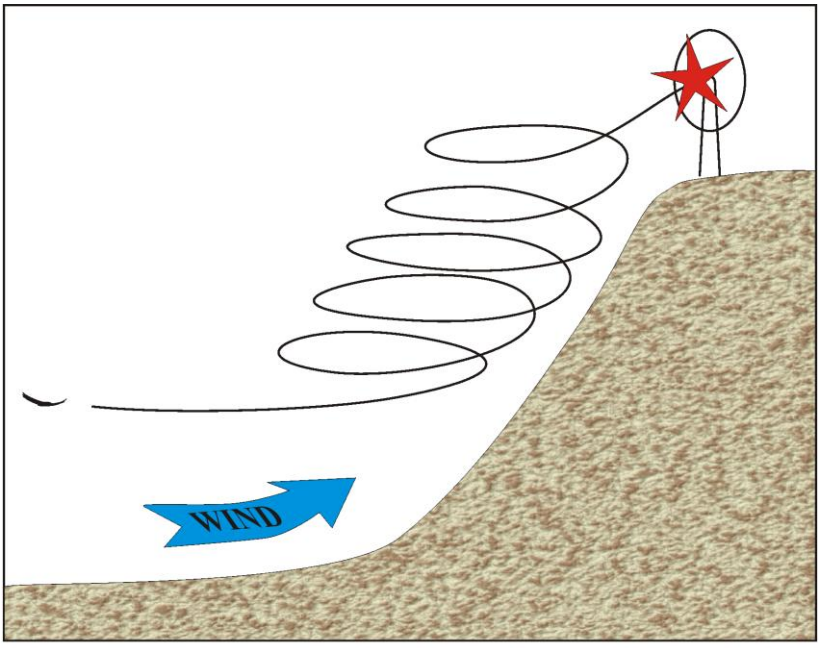


Figure 7. A vulture joins a thermal forming on a windward slope, and climbs straight into a turbine disc on the crest. This is a common cause of mortality in Griffon Vultures in Spain.

Lattice towers as perches

In some wind farms turbine towers have been made of a lattice of steel girders, like electricity pylons, and the horizontal members of these provide convenient perches for birds, especially raptors such as eagles and buzzards which use them to scan the surrounding ground for prey. It is all to easy for an eagle perched low down on the tower to launch through the outer part of the turbine disc, where the speed of the blades is faster than an eagle can fly, and this has caused significant mortality in some American wind farms. The use of tubular towers reduces the risk, because the only perch is then on top of the hub, at the centre of the disc. There is no risk in flying through the disc at this point, because the blades move slowly near the centre, although collisions can still occur if the bird returns to its perch through the outer part of the disc. Lattice towers seem to have fallen out of favour in recent years, in favour of the tubular variety, and this trend should be encouraged.

SURVEYS AND MITIGATION MEASURES

Any new wind farm project invariably requires an environmental impact survey, which should include an assessment of the likely long-term effect on any bird population that is expected to acquire a new source of regular and continuing mortality. Issues of disturbance and destruction of habitat are covered by current survey methods, but the same cannot be said about the collision hazard, and this is due to deficiencies in basic knowledge about the behaviour of migrating birds. In particular, the way in which nocturnal migrants behave under conditions of low cloudbase and poor visibility is not currently well understood. The environmental impact survey for a proposed new installation is the responsibility of the developer,

and it is not realistic or reasonable to expect developers to undertake new science, especially when the implications might result in additional expense. In practice, it is up to conservation organisations to initiate and fund general studies, whose results can then be applied by environmental surveyors to particular instances. Some such studies, such as the identifications and mapping of known migration bottlenecks, can be based on a literature search, while others, especially the bad-weather behaviour of migrants, call for field studies, using methods that are not currently in use.

Proactive mapping of migration "hot-spots"

Some geographical features that concentrate migration streams of different species have become the sites of famous bird observatories such as Fair Isle, Helgoland, Falsterbo and Ottenby, and there are many other regular concentration points that are well known to birdwatchers, such as passes through the Alps and the Pyrennees. It would be useful to identify all such known migration bottlenecks and hot-spots from the bird literature, and map them, so that developers could anticipate which sites would provoke objections, before undertaking expensive surveys.

Bad-weather concentration points

Places where migration streams concentrate under low cloud are not so easy to identify, especially at night, unless some obstruction like a bridge or a wind farm is already in place to sample passing birds. It is actually more useful to identify places where migration streams do *not* concentrate. For example, birds migrating over coastal waters may concentrate into some bays and channels when forced down near the surface by low cloud, but not into others, depending on the general direction of the migration. If the factors that determine this were understood, offshore wind farms could be sited where they would be least likely to cause heavy mortality in bad weather. This could be addressed by tracking low-level migration by day and night, in both clear and cloudy weather, using portable tracking radar.

Measuring cloudbase and visibility

Two weather variables in particular make it difficult for birds and pilots to avoid obstacles. These are low cloudbase and poor visibility. Any survey that is designed to assess the effect of bad weather on the probability of collisions needs explicit measurements that include these two variables. It is not sufficient to rely on subjective assessments of "weather conditions".

Instruments that continuously record cloudbase and visibility are available "off the shelf" from suppliers of equipment for airports. Early "ceilometers", which measured cloudbase by simply directing a spotlight upwards, have featured in studies of nocturnal migration, for example by Avery *et al*. (1976), but they used the beam to illuminate birds rather than to measure cloudbase. The brilliant beam confuses the birds, and this type of instrument is in any case now obsolete. Modern ceilometers work by directing infra-red laser pulses upwards, and detecting and analysing the reflected pulses. Such instruments are normally used in fixed installations, but could be adapted for portable use.

Continuous visibility measurements at airports usually take the form of "Runway Visual Range" (RVR) which is a measure of the distance ahead that a landing pilot can see the runway lights at touchdown. RVR is most often measured by detecting back-scattering of infra-red pulses by water droplets in the atmosphere, and this method can be adapted to portable instruments. Another type of instrument,

which would be suitable for fixed installations at existing wind farms, determines how many of an array of light sources at different distances can be detected.

Obstruction lights and nocturnal migrants

Obstruction lights are legally required in most countries on masts and wind turbines, not that these serve any useful purpose to modern pilots and mariners, who have other means of avoiding obstacles. Cochran and Graber (1958) studied passerine migration past a 300 m high TV mast in Illinois, illuminated at 43 m intervals by steady red lights, and found that birds gathered and milled around the lights when cloudbase was below the top of the tower, but not in clear conditions. The density of birds could be judged from their calls, and it was found that the birds dispersed if the lights were switched off, and came back when they were switched back on. Avery et al (REF) obtained some evidence that passerines migrating on clear nights avoided a TV tower in North Dakota which was illuminated by both fixed and flashing red lights. However, in poor visibility individual birds could be seen flying a "racetrack" pattern, repeatedly approaching a light against the wind, then circling back downwind and approaching the light again. These observations suggest that caution is needed with mitigation schemes such as floodlighting wind turbines, as the effect might be to attract birds. This could be investigated experimentally with radar, at a site where lights could be switched on and off. It would be essential in any such experiment to monitor cloudbase and visibility with appropriate instruments, as above.

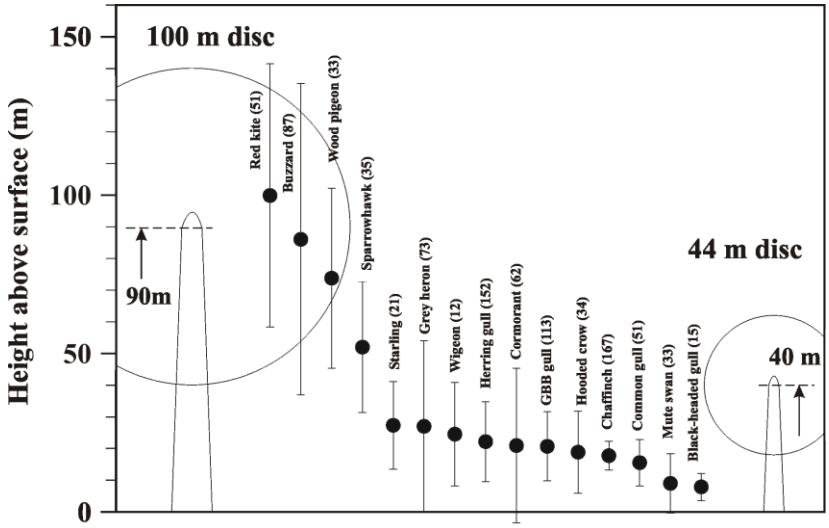


Figure 8. (Was 5) Flying heights of 15 species of birds observed at Falsterbo Lighthouse, Sweden during autumn migration. 11 of them flew low enough to pass below the very large (100 m) turbine discs proposed for the Lewis wind farm (left), but all would be in conflict with smaller (44 m) turbines (right) which are more common. Site-specific flying height measurements of this type should be a standard component of environmental surveys for proposed wind farms.

Flying height surveys

When surveying the site of a proposed wind farm, to determine whether local birds, or birds that migrate through the area, are likely to be at risk from collisions with the turbine blades, measurements are needed of the heights at which different species normally fly. If it can be shown that local birds seldom or never fly higher than the bottom of the turbine discs, then there is no collision hazard for them. The ground clearance below the blades is usually about half the diameter of the disc, or a little less, which means that the larger the turbine, the more space there is to fly safely

below it. Fig. 8 shows heights taken from a data set collected (for a different purpose) in two weeks at Falsterbo, Sweden in October 2000 (Pennycuick 2001), compared with profiles on the same scale of a very large (100 m) wind turbine as proposed for the Lewis wind farm, and a more typical 44 m turbine. If these data had been part of an environmental survey for a proposed wind farm, they would have shown that 11 of the 15 species that were observed flew mostly below the disc of the larger turbine, but would have been at risk from collisions with the blades of the smaller one. The remaining four species comprise three soaring raptors and the Wood Pigeon, which migrates out of Sweden in dense flocks at this season. In daylight, data of this type can easily be collected with Leica "Vector" rangefinding binoculars, interfaced to a laptop computer, but portable tracking radar, positioned at the site, would be needed to survey the flying heights of night-flying birds (Alerstam 1990). Besides night migrants in transit, surveys at coastal sites should include transient aggregations of geese and swans, which fly around at night when preparing to migrate, and nesting sea birds such as Manx Shearwaters, which only come ashore at night.

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