Bird Migration and Wind Turbines: Migration Timing, Flight Behavior, and Collision Risk

by

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Introduction

Seasonal migration is one of the main activities of birds that can bring them into the proximity of wind turbines. Several studies in the U.S.A. and Europe have focussed on the possibility that significant numbers of migrating birds might be killed by collisions with wind turbines either during the daytime or at night. Many types of birds migrate primarily at night, when they may be less able to see and avoid tall structures intersecting their flight paths. It is well known that large numbers of night-migrating birds are occasionally killed by collisions with tall towers, buildings, smokestacks, etc. Ever since the first “modern” wind turbines were built, there has been concern that significant numbers of migrating birds might collide with them, notwithstanding the fact that wind turbines are not as tall as the structures commonly associated with large kills of night migrants.

Some presentations in the earlier “geographic” section of these Proceedings describe studies of migration that have been conducted recently during projects to assess the impacts on birds of wind plants in the U.S.A. and Europe. Several subsequent presentations concern methodology for studying migration in association with windpower developments, especially night migration that is difficult to study by simple visual methods. As background for these methodological papers, I was asked to present a brief introduction or “primer” on some of the main features of bird migration that could be relevant to windpower developments.

The presentation summarized here reviewed existing knowledge about seasonality, hourly timing, and flight behavior of migrating birds, emphasizing aspects likely to affect the risk of collisions with wind turbines. Many studies of flight behavior have been done in the U.S.A., Canada and Europe over the past 40-45 years, both by radar and by direct visual methods. During the 1960s and 1970s, I spent about 15 years conducting radar and visual studies of bird migration both by day and by night, with emphasis on flight behavior and effects of weather on numbers aloft and flight orientation. Most of the migration research that has been done had no direct link to the “avian/wind turbine” issue. Nonetheless, many of the results are relevant in assessing collision risk. The published literature on bird migration in North America and especially in Europe is very large, amounting to many thousands of references. The following brief overview rarely cites individual sources. However, the concluding bibliography lists some of the most useful books and Proceedings volumes that summarize and review various aspects of migration.

Seasonal Timing

Seasonal timing of migration varies with location. In the Northern Hemisphere, as one goes farther north, the date of peak migration tends to become somewhat later in spring and earlier in autumn.
However, this is a weak trend. At any one location, migration extends over many weeks, especially in autumn. Different species, and often different age and sex categories of the same species, migrate through the same area at different dates. In spring, males and adult birds of many species tend to migrate northward earlier than females and subadults. In autumn, patterns are more variable among species.

Although long-distance migration occurs predominantly in spring and autumn, long-distance migratory flights are not limited to those seasons. In winter, there are often southward (or westward in Europe) hard-weather movements during and following unusually cold periods. There can also be northward movements in mid-winter, normally during warmer periods. These types of mid-winter movements have been documented in many areas, including some surprisingly northerly locations.

In summer, there can be northward movements of subadult birds that are too young to reproduce; northward migration of these subadults is often delayed until summer. (Indeed, subadults of some species, e.g. some shorebirds, may spend the summer on southerly wintering grounds, not returning to the northerly breeding grounds until they are mature.) In summer, there can also be early movements of failed breeders to staging areas or other places where they will spend the remainder of the summer. Some types of birds, especially waterfowl, engage in post-breeding molt migrations to areas where large numbers may congregate to molt. Other groups, most notably herons, engage in post-breeding dispersals that can extend for hundreds of kilometers (or more). Molt-migrations and post-breeding dispersals during summer can occur in a wide variety of directions, including northward, depending on the directions of suitable staging areas relative to the breeding area. Finally, southward “autumn” migration of some landbirds and many adult shorebirds actually occurs in mid-late summer.

Although long-distance migratory movements can occur in any month of the year, the periods of peak migration in most regions are in spring and autumn, with the peak dates of migration being weakly related to latitude.

**Hourly Timing**

The hourly timing of migration varies among species. The majority of species of landbirds travel at night, usually taking off within ½-1 hour after sunset and continuing to fly for several hours. There is typically a gradual reduction in the numbers aloft after midnight. Some species of landbirds, such as corvids and Starlings, generally migrate by day, usually taking off around sunrise. (At least in Europe, Starlings are also known to migrate at night.) The numbers of landbird migrants aloft in the daytime tend to decline in the latter part of the morning and through the afternoon.

The hourly pattern of landbird migration can be quite different when the birds have flown over a large body of water, desert, or other area unsuitable for landing prior to reaching the observation location. For example, landbirds crossing the Gulf of Mexico in spring may depart from the Yucatan Peninsula of Mexico at the usual time in the evening. However, given the width of the Gulf in relation to their flight speeds, they are still over water at dawn, and generally will not reach the north coast of the Gulf of Mexico until that afternoon or evening.

Almost all hawk, eagle and vulture migration is during daytime, with takeoff often delayed until mid-morning when thermal updrafts become stronger. Raptors such as falcons that are less dependent on soaring often take off earlier in the day than the soaring species.

Waterfowl migrate both by day and by night, as do shorebirds. Shorebirds often take off in late afternoon. The timing of takeoff by shorebirds can be modified by tidal cycles, with departures on long flights often occurring as the tide is rising and covering foraging or roosting areas.
Weather Effects on Numbers Aloft

At temperate latitudes, weather tends to fluctuate from day to day as High and Low pressure systems (anticyclones and cyclones in U.K. parlance) move across the region—generally from west to east. At temperate latitudes, numbers of birds aloft often vary 10-fold or even 100-fold from one day or night to the next, depending largely on weather. A given bird may migrate several hundred kilometers on a day or night with favorable weather, and then may not migrate (or may travel only short distances) during several subsequent days and nights. There are some exceptions, but most species are more likely to migrate at times with following or light winds than when winds are strongly opposing. Flight with light or following winds allows birds to travel a given distance more quickly and with less energy expenditure than would be necessary to cover the same distance while flying into a headwind. Flight with light or following winds may also reduce navigational problems (see below). In areas where following winds are uncommon, e.g. for birds that travel southwest or west in Europe during autumn, peak migration often occurs when opposing winds are light; in those areas, less migration occurs when opposing winds are strong.

In the Northern Hemisphere, winds blow clockwise around areas of high pressure and counterclockwise around areas of low pressure (Fig. 1). Thus, southerly winds are very likely when there is a High to the east and/or a Low to the west. In spring, those are the synoptic weather conditions during which the largest numbers of birds typically choose to fly. In contrast, northerly winds are very likely when there is a Low to the east and/or a High to the west, and in autumn those are the occasions when peak numbers of birds tend to fly. Other weather variables such as temperature, humidity and pressure also tend to vary in predictable ways as a function of pressure system locations (Fig. 1). Many weather variables are closely intercorrelated, and it is not well established which specific variables are the ones to which birds react in choosing when to migrate and when to remain on the ground (Richardson 1978, 1990a).

Species with different preferred flight directions (e.g. SW vs. SE) often fly preferentially with following winds relative to their own preferred directions. This has been demonstrated in both North America and Europe. For example, winds are often from the northwest on the first night after a cold front passes. On those nights, birds whose preferred heading is to the southeast are especially likely to migrate. On the next night, winds have often shifted to the N or NE, and birds whose preferred heading is S or SW are more likely to fly.

With seasonably unfavorable winds, small numbers of birds often engage in “reverse migration”, moving north in autumn at times with warm southerly winds, or south in spring at times with cold northerly winds. It is understandable why selection pressures would favor temporary southward retreat during cold weather in spring. It is not so obvious why northward reverse migration often occurs in autumn. Numerous possible explanations have been proposed for northward flights in autumn. Different species undoubtedly engage in northward reverse migrations for different reasons. Reverse migrations are often the dominant types of migration in progress on occasions with northerly winds in spring or southerly winds in autumn. However, the numbers of birds involved are usually very low relative to the numbers flying when the weather is favorable for migration in “seasonally appropriate” directions.

Altitudes

Altitudes of migration are highly variable and no doubt strongly influence the probability that migrating birds will collide with wind turbines. Most nocturnal migrants fly well above “turbine height”,...
Figure 1. Typical configurations of high (H) and low (L) pressure systems, fronts, precipitation, and winds at north temperate latitudes. Also shown is the normal direction of change (increasing or decreasing) of temperature, relative humidity, and barometric pressure in synoptic situations typically associated with strong spring migration (Low to west and High to east) and strong fall migration (High to west and Low to east). From Richardson (1990a).

e.g. at 50-1000 m above ground and sometimes higher. These birds are only at risk when taking off or descending to land, or if specifically attracted to some feature of the turbines. The same is true by day in many areas. However, migration altitudes are variable and are often strongly affected by the weather. Migrating birds tend to fly lower when moving into opposing winds than when flying with following winds. This is related to the fact that, due to ground friction, wind speeds are typically lower close to the ground than at higher altitudes. Birds flying into opposing winds can reduce their energy costs and the time needed to fly a given distance by flying low. There the wind speed is reduced and the birds’ ground speed will be higher for a given air speed.

Therefore, numbers of migrating birds flying at low altitudes (“turbine height”) may be as high or higher when winds are opposing as when they are following, even though total numbers of birds aloft are usually much reduced with opposing winds. The usual guidelines regarding weather conditions when maximum numbers of birds migrate may not apply in predicting when maximum numbers of migrating birds will be at risk of collisions with wind turbines. Forecasts of total numbers aloft, or numbers aloft at
altitudes high enough to pose a risk to low-flying aircraft, may not be suitable for predicting numbers of birds at risk of collisions with wind turbines. In order to use weather forecasts as a basis for predicting (a few hours in advance) the occasions when collision risk is high, specific data on numbers of birds migrating at low altitudes under different weather conditions would be needed.

Altitudes of migration can also be lower than usual when birds are crossing a ridge or pass, either by night or by day. In mountainous areas, large numbers of migrants can be funneled along valleys and may cross a ridge or pass at the end of the valley at a very low height above the terrain. This phenomenon has been studied in particular detail in the Swiss Alps. Even in lower passes, such as San Gorgonio Pass in California, where there is a major wind plant, nocturnal migration can be funneled along the valley.

**Inclement Weather**

Numbers of migrating birds aloft usually are reduced when visibility is impaired by fog or rain. However, some birds do fly under these conditions. This often occurs when birds have taken off under more favorable conditions but have moved into inclement weather during the course of their flight. With poor visibility, birds sometimes may have too few visual cues to allow a safe landing, and may continue flying for that reason. Birds flying under these conditions often seem to fly lower than normal, and thus are more at risk of collision with wind turbines. Also, under poor visibility conditions, nocturnal migrants tend to be strongly attracted by lights, especially steady lights that continuously illuminate the fog and/or precipitation in the airspace around the light. Maximum collision rates with tall structures are usually on nights of poor visibility when, although total numbers of birds aloft may be low, those birds that are aloft tend to be attracted to lights. There is a large literature on collisions of birds with tall structures, illuminated and otherwise. This literature provides considerable information relevant to bird-wind turbine issues. It shows that, when obstruction lights are required, these should be flashing, not steady. Floodlighting of tall structures should be avoided, at least on nights with inclement weather.

**Concentrations Along Linear Topographic Features**

During daytime, migrating birds often concentrate in rather narrow streams along linear topographic features such as coastlines, rivers, and ridges. This is especially true where the linear features are oriented within about 45º of the preferred flight direction. Birds will often divert as much as ~45º from their “preferred” course in order to fly along such a “leading line”.

Concentrations of migrants along linear features are less common and often less sharply defined at night than by day. For many years, it was widely stated that nighttime migration, especially of passerines, is on a broad front with little local variation. However, concentrations of night migrants have been documented in some areas of North America and Europe. As more high-resolution observations of night migrants are obtained by radar, acoustic, and electro-optical methods, more cases of concentrated nocturnal migration along coastlines, rivers, valleys, and passes are likely to be documented. As noted by W. Evans (these Proceedings), individual species of night-migrating birds may concentrate in particular migration corridors even when the overall migration (all species combined) is on a broad front.

Wind direction strongly affects both the propensity to concentrate along linear features and the precise location of the stream of migrants relative to the linear feature. At least in the daytime, concentrations along linear features are often strongest when there is a crosswind relative to that feature. When birds migrating over land or water encounter a coastline, they often turn along that coastline and form a concentrated stream of migration along the coast.
Lateral Wind Drift

Concentrations of migrating birds along linear features are in part related to the phenomenon of lateral drift by crosswinds. In some cases, the flight paths of birds over the ground (or water) are diverted to the left by a crosswind from the right, and to the right by a crosswind from the left (Fig. 2A). This is called wind drift. In other cases, the birds adjust their headings through the air in order to compensate partly or even fully for crosswinds (Fig. 2B). The situations in which birds do and do not detect and compensate for lateral drift have been studied and debated for decades (Richardson 1990b), and are still not fully resolved. When lateral drift does occur, as often seems to be the case for hawks over land and for various birds at sea, there is a particular tendency for these birds to concentrate along linear features such as coastlines and ridges that intersect their flight paths.

Figure 2. Lateral wind drift (A) vs. compensation for wind drift (B). A bird’s track velocity $T$ (speed and direction relative to the ground) is the vector sum of its heading velocity $H$ (speed and direction relative to air) and wind velocity $W$. (A) Tracks of birds flying on a constant heading will be drifted by winds with a cross component. (B) To maintain a constant track direction in varying winds, birds must adjust their headings into the wind. From Alerstam (1981).
Concentrations Near Favored Stopover Habitat

Some types of migrants, e.g. shorebirds and waterfowl, often concentrate in restricted areas of suitable habitat while resting and feeding between migratory flights. These can be interior lakes or marshes, coastal embayments and mud flats, or other areas that can provide food and/or shelter for many birds. Migration can be concentrated into corridors when the birds are either taking off on migration from one of these concentration points, or approaching it to land at the end of a flight. Furthermore, shortly after takeoff and shortly before landing, the altitudes of the migrants will usually be lower than those at which the birds “cruise”. The distance from the stopover area within which flight altitudes will be low enough to be at risk of collisions with turbines will depend on the type of bird and other factors. Some birds, like swans, typically climb only very gradually, and may remain low for a considerable distance after takeoff from the stopover area. Other birds climb (or descend) more rapidly. Concentrated streams of migrants departing from or approaching favored stopover habitats can occur both by day and by night. The occurrence of favored stopover habitats depends on site-specific features, and needs to be evaluated on a site-specific basis during siting studies for wind plants.

The flight behavior of migrants in any particular area will depend in part on local factors, and site-specific studies are needed to assess these. However, much is known about the general features of migration, especially in North America and Europe. This large body of knowledge should be taken into account when assessing potential collision hazards at a proposed wind plant, and when planning site-specific migration studies.

Bibliography

The following is a list of general reviews and Proceedings volumes concerning bird migration and flight behavior of migrating birds. Most of these were published in the past 20 years, but a few of the many earlier references of continuing relevance are included. Most of these publications are not specifically cited in the preceding text.

General Discussion

Migration specialist Dr. Paul Kerlinger emphasized that the grayest area of knowledge concerning migration/wind-turbine interactions is the question of flight altitudes relative to turbine heights. More
research is needed on this, including site-specific research in areas where wind plants are planned. He also noted that there is a need for standardized procedures and units in studies of migration. What low-altitude migration rate is sufficiently high to indicate that there is a concern about collisions between migrating birds and wind turbines?

Another participant noted that information about staging areas for migrating birds would also be a high priority in planning wind developments.

One attendee asked about the weather conditions that cause “fallouts” of migrants, i.e. unusual concentrations of grounded birds. These most often occur in two situations: (1) When weather conditions deteriorate suddenly at a given point along the migration route, inducing many birds to land there; this can occur when birds encounter a cold front extending across their path. (2) When birds that have been migrating over inhospitable terrain, e.g. landbirds traveling over the sea, finally encounter an area with suitable habitat where they can land, many may land in the same area.

In response to a question as to how well species differences in migration are known, Dr. Richardson noted that these were poorly known for night migrants, given the observation difficulties. He noted that acoustical methods are showing promise as a method for identifying migrating birds at night (see later paper by Evans, in these Proceedings).

An attendee commented on the wide and variable range of altitudes at which birds migrate, and suggested that little may be gained by attempts to discriminate flights at different heights. Richardson and others indicated that, on the contrary, the wide variability in altitudes (to some extent related to weather, topography, and other known factors) means that there is good reason to study and understand the altitudinal characteristics of migration at planned and operating wind plants.

There was a question as to whether lighted cities affect flight lines at night. Richardson indicated that this had not been studied in detail insofar as he knew, but there was little evidence of such an effect, at least on clear nights. A pilot study specifically designed to compare flight orientation and numbers aloft over a city vs. the surrounding countryside on clear nights found little difference (W.J. Richardson, unpubl. data.).

Why do normally-diurnal passerine birds usually migrate at night? Participants noted that there are different theories, including the following: (1) By flying at night, birds can feed during daylight. (2) Atmospheric and thermal conditions may be better for flight at night. (3) Predation risk is much lower at night.