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Modelling the spatial concentrations of bird migration to assess conflicts with wind turbines

Felix Liechti *, Jérôme Guélat, Susanna Komenda-Zehnder

Swiss Ornithological Institute, 6204 Sempach, Switzerland

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ABSTRACT

Bird migration and wind energy production exploit a similar airspace. There is a well-founded claim that conservation should aim at facilitating both activities. Negative effects can be mitigated either by avoiding a spatial concurrence or by accounting for the temporal course of migration and stopping wind turbines during peak flight activities. In this study we promote a new methodological approach to reduce potential conflicts in the planning as well as during the operation phase of a wind energy project. The basis is a new spatially explicit model for broad front migration. It allows to quantify the collision risk with respect to topography. We simulated migration of non-soaring birds across Switzerland. Model parameters were tuned to achieve results in accordance with current expert knowledge based on many years of visual observations and radar measurements. The resulting maps were used to define areas with different collision risks. For medium and high risk areas, we propose a permanent monitoring system, which is able to shut down the local turbines during peak migration. We evaluated the impact of such a shutdown regime in five specific sites with quantitative radar data for at least one migration season. The model presented here is a simple preliminary, but robust, approach. The main weakness of the model is the use of large-scale rather than local wind conditions. Within the Alps, local wind fields can differ considerably from the general pattern, and accordingly also the distribution of flight directions. We hope to provide a basis for similar models in other geographic areas. In addition, we call for the use of large scale monitoring data, as hopefully will soon be available from weather radar networks, to validate any kind of spatially explicit migration models.

1. Introduction

Both bird migration and wind energy production exploit the airspace in their own specific spatial and temporal pattern. Bird migration is a worldwide phenomenon across land and sea (Alerstam, 1990; Newton, 2008). More than 20 billion birds regularly move twice a year between their breeding and non-breeding ranges. Distances covered can be tens to thousands of kilometres and flight altitudes range from a few metres above ground to thousands of metres in the free airspace. Wind is widely considered as a sustainable source of energy, and hence, wind farms are initiated rapidly worldwide (Global Wind Report, 2011). Apart from the positive effect of renewable energy production, wind turbines can also have negative effects on the natural environment. One of them is the collision risk of migrant birds with wind turbines reaching up to 200 m above ground (e.g. Drewitt and Langston, 2006; Hüppop et al., 2006).

The best way to mitigate conflicts between birds and wind turbines is to avoid their spatial concurrence (Bright et al., 2008). The distribution of breeding birds is often well known or can be established with an environmental impact assessment in due time. In contrast, the movement patterns of migratory birds are still poorly known, and because of the strong influence of weather, the temporal and spatial patterns may differ considerably across seasons and years. Only very few bird species migrate within a relatively narrow corridor (e.g. cranes *Grus grus*), but even the flight routes of such species vary substantially between years. Most migratory bird species move between breeding and non-breeding grounds in a broad front affected only by wind and topography. Migratory birds usually focus along topographical features like coastlines, straits, mountain ranges and passes (e.g. Kerlinger, 1989; Bruderer and Jenni, 1990; Bruderer and Liechti, 1999). In addition, bird migration is not only concentrated in space, but also in time. Weather conditions have a strong influence on the timing and can cause mass migration restricted to a few days within a much longer migratory season (e.g. Erni et al., 2002; Van Belle et al., 2007). Therefore, measures to reduce the impact of wind energy production on migratory birds include avoiding high concentration areas by wind farms or closing down wind turbines when migration occurs at a high intensity. To apply such measures, the spatial and temporal distribution of migratory birds needs to be known.

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* Corresponding author. Tel.: +41 414629782; fax: +41 414629710.
E-mail address: felix.liechti@vogelwarte.ch (F. Liechti).

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The overarching goal of this study was to develop a novel methodology. We present a new approach to model the general movement and local concentration of broad front bird migration in a strongly structured topography. The aim was to quantify the spatial distribution of the potential collision risk for migratory birds by modelling the spatial pattern of broad front bird migration for the whole of Switzerland. The main challenge was to predict the intensity of bird migration within 200 m above ground level (agl).

There are two distinctly different flight behaviours for migratory birds (Pennycuick, 1975). To save energy, large species mainly soar and glide. Since updrafts are site and weather specific, this flight type is restricted in space and time. Small birds, such as passerines, use powered flight, which, in principle, allows them to travel across any terrain at any time. About two thirds of these species migrate at night across Switzerland (Winkler, 1999). We restricted the model to species using powered flight, which make up the vast majority of migratory birds. From the results, we derived a sensitivity map for the potential collision rates of migrating birds with wind turbines. We also evaluated the mitigating effect of a stop and go regime for wind turbines driven by the intensity of bird migration based on real radar observations. We designate where a stop and go regime would be essential to keep the annual potential collision rate below a given threshold. Since bird strikes can never be ruled out completely, a maximum number of acceptable fatalities is discussed.

2. Material and methods

2.1. The model

The study area included the Swiss territory and some regions nearby (Fig. 1). The topography is characterised by three basic areas: the Alps in the south, the Jura in the northwest and the plateau lying in between. Many mountain tops of the Alps are around 4000 m above sea level (asl), the peaks of the Jura are around 1700 m asl. The plateau lies between 400 and 700 m asl.

We used a two-dimensional cellular automaton with absorbing edges to simulate broad front migration across Switzerland (Packard and Wolfram, 1985). The area for simulation ranged from 48.0°N to 45.6°N and 5.2°E to 12.9°E. The grid consisted of 260 rows and 592 columns, with a 1 km resolution. To simulate autumn migration, we used an east–west starting line 20 km north of the study area, extending 60 km westwards and 185 km eastwards of the Swiss territory. For spring migration, the starting line was set on an east–west line, 20 km south of the study area and on a north–south line 60 km to the west. The simulation started with an equal number of birds in the cells of the starting lines, except for those cells in the south, within the main mountain range of the Alps (cells 60–200). These grid cells were filled with half as many birds as the other cells to account for the expected lower number of migrants stopping over within the Alps and thus entering the study area from this region. Iteratively, a density probability was calculated for each cell based on the densities in the eight surrounding cells. Each surrounding cell contributed a certain probability and a flight altitude, which then for the focal cell was summarized, or averaged, respectively. The density probabilities to move from one cell to a neighbouring cell were calculated step by step, according to the preferred flight directions of the birds, and according to the height differences between the elevation of the surrounding cells and the mean flight altitude within the cell of origin (see below and Supplementary material Figs. A1 and A2).

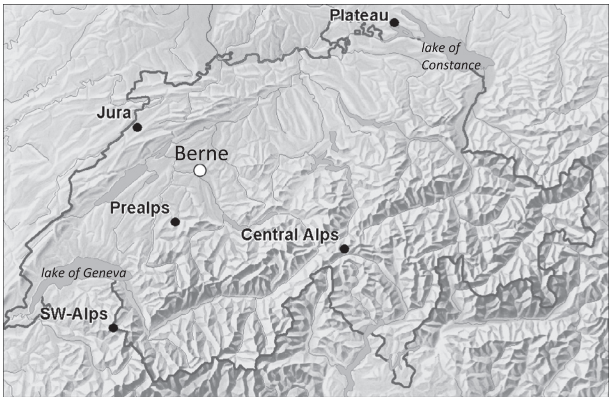

Fig. 1. Topography of Switzerland and nearby regions. The Swiss lowland extends from the Lake of Constance in the NE to the Lake of Geneva in the SW. The mountain ranges of the Alps cover the southern half of Switzerland, and the lower mountains of the Jura arise along the north-western border. Indicated are the capital (Berne) and the five sites, where radar observations were carried out (copyright institute of cartography and geoinformation, ETH).

2.2. Flight directions

The flight directions were implemented as the probability of moving from the cell of origin to one of the eight neighbouring grid-cells. We used the results from radar observations in southern Germany and Switzerland (Bruderer and Liechti, 1990) to define a mean and scatter of preferred flight directions under various wind conditions. In Central Europe, migrant birds show a directional preference according to the season, i.e. 225° in autumn and 45° in spring. Weak winds (<5 m s^{-1}) alter the distribution only marginally and indifferently of wind directions (Liechti, 1993). Tail winds narrow the range of flight directions, whereas head winds increase the scatter (Bruderer and Liechti, 1990). The particular Swiss topography dominated by the Jura and the Alps and the broader European weather systems result in a bimodal distribution of wind directions, mostly from south-west or from north-east. Based on studies relating weather conditions and migratory intensities (Erni et al., 2002; Zehnder et al., 2001a, 2001b), we estimated that within the study area 50% of the migrants selected weak wind conditions (<5 m s^{-1}), 30% moderate tail-winds (5–10 m s^{-1}) and 20% migrate under moderate head-winds (5–10 m/s). Because unfavourable headwinds predominate during migration across Switzerland, there are always some movements into light headwinds. Due to low migration intensities, rare conditions like strong winds (>10 m s^{-1}) and winds from directions other than south-west or north-east were disregarded. For each of the three wind scenarios, the birds' flight directions were implemented as probabilities for flying into one of the neighbouring cells (detailed probabilities in the Supplementary material Table A2).

2.3. Effect of topography

Hills and mountains exceeding a bird's flight altitude force it either to gain height or to change direction. It is unknown at what distances flying birds are taking note of obstacles ahead and initiate an adequate response. In our model the effect of topography depends on the range we expect a bird is taking into account to react to obstacles ahead. Our assumptions are based on single birds tracked in radar studies (Liechti and Bruderer, 1986). We used a moving window to calculate the altitude in the expected flight direction, which might be relevant for the reaction of a bird. The size of the moving window represents the range a bird might consider. We tested different measures to represent the altitude within this range (e.g. mean, max, quartiles) and simulated various ranges for the moving window (1–400 km^2). Based on the magnitude of the difference between the bird's flight altitude in the cell of origin and the height of the neighbouring landscape, respectively (range of the moving window), we applied a weight factor