Measures for mitigating avian collision rates with wind turbines

Determining an effective technique regarding effort and effect

*Alexander Hoge**

Münster University of Applied Sciences, Stegerwaldstraße 39, 48565 Steinfurt, Germany

Abstract

Because of the rapid expansion and widespread application of wind energy the overall environmental impacts of wind power plants have increased as well. For the further development of wind power, methods to lessen the adverse effects wind power has on avian populations have to be implemented. This review aims to find effective methods to reduce avian collision rates with wind turbines and that therefore can reduce bird fatality rates.

For the assessment the different mitigation methods, for which concrete data was found, are compared with each other regarding the hypothetical effort of implementation and effectiveness in reducing avian collision rates with wind turbines.

These methods are:

- Coloring of rotor blades
- Coloring of the tower base
- Ultraviolet/violet lightning
- Temporary shut-down of wind turbines
- Auditory warning signals
- Repowering

All of the mentioned methods report influence on reducing avian collision rates or at least the behavior of birds in flight.

This review found the following three methods to be most effective:

- Coloring of rotor blades
- Temporary shut-downs of wind turbines
- Repowering

The most effective method to reduce avian collision rates at horizontal axis wind turbines is to paint one of the rotor blades black and consequently increasing the visibility of the rotor blades. The presented study [1] reports 71,9 percent reduction of found carcasses of birds at the treated turbines. For this method the effort of implementation is low while the effectiveness is high.

The effectiveness of the found mitigation methods has been proven and they are suited for application. The method of using lightning or sound fields require more testing to determine their effectiveness. Another topic for research could be how different mitigation methods interact with each other. Is there a significant advantage to be had if multiple mitigation methods are applied at the same wind power plant or turbine? Furthermore the environmental impacts of wind turbines are not limited to birds. Other animals like bats are affected too and might require different methods of mitigation.

Keywords: wind turbine, wind energy, birds, collisions, mitigation

1 Preliminary note

The following chapter gives an introduction to the subject and explains the purpose of this review. In addition the methods that were used to gather the information as well as the criteria for choosing literature are acknowledged.

1.1 Introduction

Wind energy has undergone an rapid development in order to combat global warming. But with the numbers of wind turbines increasing, so does the severity of environmental impacts. Prominent among these impacts is the influence wind turbines have on avian population. All kind of different types of birds get affected. Soaring raptors might collide with the rotor

*Corresponding author: alexander.hoge@fh-muenster.de.

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blades. So do migratory bird. The same risk consist for residential birds who also might suffer from habitat loss.

The fear of severe avian population decline leads to financial burden, causes delays and can restrict the further development of wind power. Hence it becomes obvious, that bird-strikes are costly for both the wildlife and the expansion of wind power production.Therefore, measures to reduce avian collision rates with wind power turbines have to be developed and applied.

The aim of this review is to determine the state of scientific knowledge on reducing avian collision rates with wind turbines and to develop a recommendation for the implementation in practice through evaluation of the different methods.

An ideal method would be highly effective in reducing collision rates while also not be detrimental to the power production of the affected wind turbine and have a low effort of application.

1.2 Methodology

The contents of this review were acquired through a literature research using the internet. The search engines Google and Google Scholar were used to obtain sources. In addition the search for literature was expanded onto the library of the University of Applied Sciences Muenster using their own search engine FINDEX.

For the search different keywords where used. Both in German and English language. Among others, searches were started with the following terms:

- Innovative mitigation tools for avian conflicts with wind turbines
- Bird protection at wind turbines
- Ecological risks of onshore wind power
- Methods to reduce bird strikes on wind turbines
- Mitigation of avian impacts with wind turbines

The focus during the search for articles was to find those, that not only enumerate mitigation options, but also give concrete figures for a certain method. Preferably numbers about bird mortality before and after a certain method was applied.

2 Measures of mitigation

In the following subsections the different measures that have been found will be presented. No evaluation of the individual methods will be given yet.

2.1 Coloring of rotor blades

One method for reducing avian collisions with wind turbines is to increase the visibility of the rotor blades.

One study carried out by the Norwegian Institute for Nature Research from the 19th of February 2020 examined the effect of painting one of the three rotor blades black to reduce motion smear and therefor increase visibility. The painting was done during August of 2013 at four wind turbines in the Smøla wind-power plant in Norway (Fig.1). Four neighboring wind turbines where used as a control group. To assess the effect of the measures, searches for bird carcasses were performed at regular intervals in a radius of 100 meters around the wind turbines. These numbers were than compared to numbers of found carcasses determined before treatment. The experiment and the searches ran for seven and a half years pre- and three and a half years post-treatment. During the study the number of carcasses that have been found at the control turbines increased. From 7 before treatment to 18 after. At the treated turbines these numbers decreased from 11 to 6. The authors report that there has been an average 71.9 percent reduction in the annual fatality rate after the painting was conducted [1].

Fig. 1: Wind turbine in the Smøla wind-power plant with painted rotor blade (c) Roel May [1]

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2.2 Effect of tower base painting

Besides from colliding with the rotor blades, birds do also collide with the tower base of wind turbines.

In a study from the Norwegian Institute for Nature Research the effect of tower base painting on the collision rates of willow ptarmigan with the tower base is examined. The study was carried out in a very similar manner to the previous mentioned study done by the same institute. The study itself is from the 23rd of November 2019. Four wind turbines had the lower 10 meters of their tower base painted black in mid-August 2014. Unaltered, adjacent turbines were used as an control group. In mid-July 2015 another six wind turbines had their tower bases painted in the same pattern. To determine the effect of the painting, the carcasses found before and after treatment were compared. The study includes the findings of the searches for carcasses from 2006 to 2017. During this time 474 carcasses were found with the species willow ptarmigan being recorded 194 times. For the 10 control turbines the number of carcasses increased from 11 pre-treatment to 19 post-treatment. While at the treated turbines the numbers decreased from 25 to 14. The authors report an 48 percent reduction of recorded ptarmigan carcasses per search at the painted turbines relative to the control turbines [2].

2.3 Avian response to (ultra)violet lighting

Another method to increase visibility besides painting is to illuminate the wind turbines. Which is especially useful during periods of low natural lightning like during the night or bad weather. Normal paint-jobs are not sufficient then.

A study conducted by the Norwegian Institute for Nature Research from 2017 tested if birds in flight respond to violet and ultraviolet lighting. The basic idea for this experiments is, that especially many birds that collide with off-shore wind turbines are sensitive to ultraviolet light. The experiments were conducted outside with wild birds near a wind power plant. Two UV LED lights were placed vertically on top of a 2.5 meter high mast. One light emitted violet light with a wavelength of 400 *nm* (nanometer) and the other light emitted ultraviolet light with a wavelength of 365 *nm*. Over the duration of an week, the lighting was alternated between the two lights. Ultraviolet lightning was used during Tuesdays and Saturdays, while violet lightning was used on Wednesdays and Fridays. The days in between were used as control-days without any lighting. The experiment was run from March to May during 2014. The movement of the birds were recorded 24/7 using a special modulated radar. The author reports that relative to the control nights, the flight activity of the birds was reduced by both types of lighting. There was a 27 percent reduction when the ultraviolet light was on and a 12 percent reduction with the violet light on. In addition, a vertical displacement was present, with the birds increasing their average flight altitude by seven meters [3].

2.4 Temporary shut-down of wind turbines

Many birds that collide with wind turbines, do collide with the moving rotor blades. The most obviously method to reduce, if not completely prevent any collisions, is to shut down the wind turbine when birds are in the immediate proximity. Naturally, this would also lead to a decline in total power produced for a wind turbine.

The Department of Ethology and Biodiversity Conservation from Seville in Spain, among others, conducted a study at 13 wind farms in Tarifa, Cadiz, Spain before and after when selective turbine stopping programs were implemented. These programs would stop wind turbines when vultures were observed nearby. To determine the effectiveness of these programs in reducing avian collisions, the number of dead griffon vultures that were found near the wind turbines were recorded. The searches for carcasses were performed before the stopping programs were implemented from 2006 to 2007 and after implementation from 2008 to 2009. In total 244 wind turbines of 10 wind parks were equipped with the stopping programs. The authors recorded a reduction in the vulture mortality rate by 50 percent with a consequent reduction in total energy production by 0.07 percent per year [4].

2.5 Auditory warning signals

Another method to reduce bird-strikes on wind turbines or buildings in general is to alert the bird to the presence of an obstacle by means of an auditory signal.

A study by the Biology Department of the Institute for Integrative Bird Behavior Studies of the College of William and Mary in Williamsburg, USA, examined the impact of a warning signal on birds in flight. The authors suggested that one reason for avian collisions with man-made structures is, that birds in cruising flight do not pay adequate attention to the area directly in front of them. When the body and head of birds are aligned to reduce drag during flight, their visual gaze is directed downwards. The authors tested captive zebra finches that were trained to fly down a corridor and through an opening in an wooden frame. A net with large enough gaps for the bird to be able to fly through was installed in the opening. The birds now had to fly through the corridor once without a warning signal and once while being exposed to an sound field projected in front of the net up to a distance of 1.5 meters. The experiment showed that the birds reduced their flight speed approximately 20 percent more when the sound field was present. In addition the only time where the birds avoided the net occurred when the sound field was active. The authors concluded that, the birds where only able to completely avoid the net when they got a acoustic warning signal, but they also reduced their flight speed significantly. Translated to free-roaming birds, this would mean that even when the birds would not be able to avoid the obstacle, the force of the collision would be reduced and so the severity of an potential injury. Furthermore the authors recommend that, when using this method on large buildings such as wind turbines, the warning signal should be audible more than 30 meters from the strike surface [5].

2.6 Repowering

Replacing old wind turbines with newer, more efficient and often larger models, is common practice. These projects are also met with concerns, that new-generation wind turbines on taller towers and with an larger rotor diameter would result in a higher fatality rate for birds. But one study suggested that increasing the tower high might actually reduce the bird mortality by over 70 percent [6].

K.S. Smallwood et al. [7] published a study, in which the authors examined the effect that repowering of wind turbines had on the fatality rates of birds. In the study they compared estimates of fatality rates from between 1998-2003 and 2005-2007 and between a repowered wind project and old-generation wind turbines. The wind turbines were part of the Altamont Pass Wind Resource Area (APWRA) in California, USA. The authors found that, although the fatality rates caused by the repowered wind turbines where not lower than the replaced turbines, they were 66 percent lower for all birds compared to the old-generation wind turbines. The authors concluded that lowering the mean annual fatality rates by 65 percent for all birds could be possible at APWRA by repowering the old-generation wind turbines while also more than doubling the annual energy production.

It should be mentioned, that in the repowering project vertical axis turbines were replaced by horizontal axis turbines (Tab.1). Which lead to an insignificant rise in fatalities for specific bird species [7].

3 Assessment

In the following table (Tab.2) the different mitigation methods that where introduced in chapter two are compared with each other regarding the hypothetical effort of implementation and effectiveness in reducing avian fatalities. An reduction in bird fatalities equal or greater than 50 percent is considered to be of high effectiveness.

The coloring of one rotor blade is a simple and highly effective method. The study [1] proves that this method is universally applicable for horizontal axis turbines and should lead to similar results no matter the location of the wind power plant.

Painting the tower base of a wind turbine is a reasonable effective method considering it only affects specific bird species [2]. But at locations where those bird species are present, it can be applied with low effort.

Although lightning is easy to install and the study [3] reports an respond of the birds to the lightning, its exact effect on bird collisions at wind turbines still has to be determined. In addition, illuminating wind turbines with violet-lightning could lead to conflict with local residents if the wind turbines are close to human settlements.

The study [4] chosen to represent the method of temporary shut-downs reports promising results: minimal loss of energy production while significant reduction in avian fatalities. The use of temporary shut-downs and also auditory warning signals requires additional effort, because a system to identify approaching birds has to be included. And the effectiveness of this system to correctly identify birds also influences the possible reductions of bird moralities.

The data presented to determine the effectiveness of auditory signals come from an controlled environment. In reality, the birds would move with an higher travel speed and could also be distracted by different kind of signals. But considering that in the study [5] the birds would completely avoid the obstacle only with the sound field present leads to the assumption that this method could also be of use in a realistic scenario. Similar to the installation of lightning, loud auditory signals might be unacceptable near human settlements.

In addition to the study by K.S. Smallwood et al., which reported a significant decrease in bird mortality after repowering [7], other studies came to different conclusions. One study found that replacing horizontal axis turbines with larger horizontal axis turbines lead to a similar collision risk [8].Another study even reported that taller turbines towers increase the mortality rates of birds and recommended that repowering of older wind farms with griffon vulture populations nearby, should avoid placing turbines on hills with gentle slopes [9]. This leads to the conclusion that in certain situations repowering can reduce the mortality rates or at least does not lead to an increase of fatalities. Although repowering can be considered to be the method with the highest effort and to be the most costly one, it also leads to a significant increase in power production. This might result in an indirect reduction in bird fatalities because the higher

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Tab. 1: Attributes of wind turbines involved in the Diablo Winds Energy Project, which repowered 21 megawatts (MW) of rated capacity in the Altamont Pass Wind Resource Area, California, USA, in February 2005 [7]

Attribute	Repowered| Flowind[a] vertical-axis turbines		New Vestas[b] horizontal axis turbines	
Model	F-17	F-19	V47	V47
No. turbines	105	21	24	7
Rated output/turbine (MW)	0.15	0.25	0.66	0.66
No. of blades	2	2	3	3
Rotor diam (m)	17.2	19.1	47	47
Rotor speed (revolutions/min)	66.3	59.7	28.5	28.5
Hub ht above ground (m)			50	55
Highest blade reach above ground (m)	29.5	32.3	73.5	78.5
Lowest blade reach above ground (m)	4	4	26.5	31.5
Inter-turbine spacing within rows (m)	51	51	104	104

[a] FloWind Corp., San Rafael, California, USA.
[b] Vestas Wind Systems A/S, Randers, Denmark.

Tab. 2: Comparison of mitigation methods

Method	Effort	Effectiveness
Coloring blades	Low	High
Tower painting	Low	Medium
UV/Violet-Lightning	Low	Low
Temp. shut-down	Medium	High
Auditory signals	Medium	Medium
Repowering	High	High

efficiency could make other, old-generation wind turbines obsolete.

4 Results

The three methods with the highest effectiveness are:

- Coloring of rotor blades
- Temporary shut-downs of wind turbines
- Repowering

The coloring of rotor blades can be considered to be the preferable method. The effort of implementation is low while the effectiveness is high. Because it is effective for different species of birds it can be implemented at wind power plants regardless of location.

5 Outlook

Minimising environmental impacts should be a part of wind energy projects. Application of mitigation methods can vary depending on the specific location of wind power plants and the occurrence of specific bird species. The effectiveness of the mentioned mitigation methods has been proven and they are suited for wide spread application. The method of using lightning or sound fields require more testing to determine their effectiveness. A further question could be, if the combination of different mitigation methods would result in an greater reduction of bird collision rates then the methods would achieve individually. Furthermore the environmental impacts of wind turbines are not limited to birds. Other animals like bats are affected too and might require different methods of mitigation.

There are also mitigation methods that were not included in this review. These reason for this is, that for these methods no concrete data could be found. These methods include:

- Micrositing of wind turbines
- Dummy wind turbines
- Noise to deter birds

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