Considerations for Blade Patterning as a Mitigation Measure to Reduce Avifaunal Collisions with Wind Turbines in South Africa

Morkel, D[1]., Cervantes, F[2]., Clarke, C[2]., Ralston-Paton, S[4]., Scott-Shaw, L[5]., Simmons, R. E[6]., and Taylor, S[7*s].

*Corresponding author: Shaun.Taylor@mainstreamrp.com

Author affiliations:

1. SAWEA – Wind Energy & Birds Sub-committee
2. Centre for Statistics in Ecology, the Environment and Conservation, University of Cape Town
3. G7 Renewable Energies
4. Birdlife South Africa
5. SLR Consulting
6. Birds & Bats Unlimited
7. Mainstream Renewable Power South Africa

Current considerations for blade patterning as of August 2023

Problem statement

Wind generated power has many positive benefits for the economy and the environment compared to fossil-fuel power generation methods. However, it also presents some environmental challenges. One of which includes the collision of avifauna with wind turbine blades. In particular, fatalities of threatened raptor species are of considerable concern because raptors play an important ecological function, and many species are already threatened due to other sources of anthropogenic pressure. The risk wind turbines pose to birds can negatively affect conservation efforts and limit areas available for development. Currently, most measures available to minimise turbine collisions are expensive and rarely completely effective. Simpler and more cost-effective solutions are needed. As such, various stakeholders in the wind industry and avifaunal conservation sector seek to address and minimise this impact using innovative methods to avoid and prevent possible fatalities of all avifaunal species of conservation concern, especially raptors and vultures. Our experience in decades of monitoring the impacts of wind farms on birds suggests that no one measure will completely eliminate fatalities in every situation. At this point, we rather strive to accumulate a set of tools that allows us to adapt to different situations to reduce fatalities to sustainable levels.

Why do birds collide with turbines?

Avifaunal vision has primarily evolved for food finding and detection of predators (Martin 2017). The vision of birds has not evolved with large, moving structures that extend into their airspace. A common misconception is that birds see the world around them in the same way we do (Martin and Banks, 2023). This is not true, as some birds perceive their world in the ultraviolet (UV) spectrum while others have evolved high visual acuity at the expense of low contrast abilities. Some species have evolved binocular vision to assist with foraging techniques, while others (such as cranes and bustards) can only see either side of their skull, giving them a blind region directly ahead due to their skull morphology (Martin and Shaw 2010). In other scavenging species, despite their excellent vision for detecting prey below them, they spend little time focusing on the flight path directly ahead. The main physiological reason strikes with turbine blades are thought to occur is as a result of motion smear (Hodos, 2003), wherein the retina no longer perceives the motion of a blade, and the bird continues on its flight as if there are no obstacles ahead. A similar effect is apparent for humans when viewing a propellor on a plane or a helicopter's spinning rotors. This is exacerbated for raptors because their ability to see contrast, especially in low light, is 10-fold poorer than humans (Potier *et al*. 2018). This is despite, or probably because of, their eye's high-density fovea adaptations for high visual acuity. Indeed, lab experiments on the ability of both raptors and humans to perceive moving white turbine blades indicate that both groups find the white blades less conspicuous than blades with any form of patterning (McIsaac 2001). It is the flickering effect, produced by the contrast of a moving object against a background, that the avian eye is adept at detecting (Martin and Banks 2023). Thus the lack of contrast within wind turbine blades, their fast motion and the constraints inherent in the avian eye probably all contribute to avian impacts with turbine blades.

A potential solution

One potential method of preventing bird collisions or "strikes" is to pattern a single blade in a high contrast colour (preferably black) to make it more visible to birds, with the end goal that these species would be able to see and thus avoid the turbine and its moving blade altogether. There are several ways of achieving increased visibility:

- High contrast achromatic colours (e.g., black and white) are always best (Potier et al. 2018; Martin and Banks 2023), especially in low light.
- Painting about two-thirds of a single blade completely black and leaving the other two blades white (May et al. 2020).
- Patterning one blade with two broad stripes across the blade (i.e., the first quarter and the third quarter, with the second and fourth quarter left white (McIsaac 2001) and
- patterning all three blades with broad black stripes but alternating the relative position of the marking on the blade such that the last third is black on blade 1, followed by the next blade in which the last third is white, and back to black for blade 3 (Martin and Banks 2023). These authors also suggest that the tower is striped in black and white, so the flicker effect is enhanced as the blades pass before it.

A blade patterning experiment at the Smøla wind-power plant in Norway showed a significant reduction in annual fatality rates. In this experiment, approximately two-thirds of a single wind turbine blade was painted black. 70% fewer fatalities of all bird species were recorded at the four turbines with a painted blade relative to the neighbouring (unpainted) control turbines. A 100% reduction in White-tailed Eagles (*Haliaeetus albicilla*) fatalities was recorded at marked turbines. (May *et al*., 2020). The Smøla experiment has continued for > 7 years, and the experimental turbines continue to show no eagle fatalities, while the white-bladed controls continue to kill, on average, six eagles per year (R. May and B. Iuell in litt). At the time of writing, May et al. 2020, was the only published paper showing results from an operational windfarm, but similar tests are currently known to be being undertaken across the world, including in Denmark United States of America and the Netherlands (Salkanović, 2023; van Gessel, 2022; Hodos, 2002).

Progress in South Africa

A first-of-its-kind pilot project has been initiated relatively recently in South Africa at the Umoya Energy Wind Farm (UEWF), Western Cape Province. Four problematic turbines were initially painted (*in situ*) with two broad signal-red stripes on a single blade in January-March 2023, and the 16 nearest remaining turbines will act as controls (i.e. no patterning). Dr Rob Simmons of Birds & Bats

Unlimited, consultant ornithologist, recommended that a total of ten turbines be painted, whilst ten turbines were used as controls. Due to financial constraints, the painting of the remaining turbines and the blades will take a phased approach over time (likely next year). The selection of "signal red" was taken forward in consultation with the South African Civil Aviation Authority (SA CAA) as it falls within the permissible colours for structures as contained in the technical standards. Theoretically, black is the best colour (see section 3 below), but SA CAA rejected this. Red is, however, perceived well by raptorial birds in good light conditions (Potier *et al.* 2018) and is seen as the second-best option. Painting blades at UEWF is a proactive measure to reduce fatalities because, despite the low fatality rates recorded at the facility, fatalities included the Endangered Black Harrier (*Circus maurus*). This species cannot afford additional anthropogenic fatalities (Cervantes *et al.* 2022).

A few other operational wind farms in South Africa are considering implementing this approach as part of their adaptative management strategies and have begun the process of obtaining the necessary approvals. Marking blades is also now often included as a potential mitigation measure in environmental impact assessments for proposed wind farms in South Africa.

Aim

In this document, we provide an overview of some of the key issues and recommendations developers, decision-makers, avifaunal specialists, environmental assessment practitioners and policymakers should take into account when considering marking turbines as a mitigation measure against bird strikes in South Africa. This is intended as a living document and will be updated as new information becomes available.

Challenges and factors to consider

1. South African Civil Aviation considerations

The South African Civil Aviation Technical Standards (SACATS) have been formulated for the safe operation of civil aviation within South Africa. Wind turbines can present a risk to aircraft safety, and the SACATS, therefore, includes standards for the configuration and marking of turbines. The latest SACAT outlining the Obstacle Limitations and Markings outside Aerodromes or Heliports, dated 2012, provides the regulations for marking obstacles/structures as well as wind turbines. It states, "*Turbines shall be painted bright white to provide the maximum daytime conspicuousness. The colours grey, blue and darker shades of white should be avoided altogether. If such colours have been used, the wind turbines shall be supplemented with daytime lighting, as required*". These SACATS were revised years before the Smøla black-blade patterning experiment was published and do not make provision for black blades.

Interestingly, the experiment at Smøla wind farm did manage to obtain the necessary permits to undertake such a study for the black blades, which included consent from the Norway CAA. Nonetheless, there is no provision for painting obstacles or the blades of turbines black in the SACATS, which will remain a challenge until motivation for deviation is successful.

Provision for the use of signal red (S1580-Y90R) does exist within the SACATS and provides an alternative to test the blade patterning experiment in South Africa. This can be achieved by submitting an Application for Recognition of Alternative Means of Compliance (Form Number: CA 11-10) with the SA CAA, as was done for the UEWF. This can be undertaken at a relatively low cost of R3 500.00, with a decision-making timeframe of up to 30 days. Supporting documentation will need to be included as motivation for the application, including *inter alia* avifaunal monitoring reports, supporting research, technical details surrounding how the blade will be painted, and what colour. A successful outcome to the application is likely to have conditional requirements for submission of results of the experiment to support further continuation of the experiment to assess its effectiveness.

2. Technical challenges

Several technical challenges exist with painting blades. These include whether a particular turbine supplier is willing to allow the painting of blades when considering warranties and working on the turbine blades for operational turbines. However, several well-known turbine suppliers do undertake the painting of blades at the factory, as some countries (e.g. India) have a mandatory requirement to paint the blades with red tips for civil aviation safety.

In addition, the extra weight of the paint (approximately 60 kg for a 40m blade that had roughly 75% of its area painted) may also have a physical impact on the blades. The rotational balancing of all three blades needs to be achieved to prevent strain on the drivetrain and associated operational and energy production issues. However, this can be overcome by counterbalancing the other two blades by painting the same additional quantity of white paint. At UEWF, the Vestas-manufactured blades were not counter-balanced in this way because the addition of 60kg is a fraction of the weight of a blade that weighs up to 10 tonnes. This saved time and costs.

In investigating the potential for painting blades black and the willingness of turbine suppliers to undertake this for blades in South Africa, concerns about possible blade deformation and aerodynamic performance were communicated. This presents a challenge which will need to be tested by players in the industry in conjunction with their turbine suppliers. In Smøla, Norway, regular inspection of the blades and potential differential heating or blistering were not found to be an issue (Iuell pers comm).

The actual painting of the blades can also present a technical and somewhat costly challenge for operational wind farms. At UEWF, the blades were stopped and physically painted using a rope pulley system, with workers painting the turbines under low or no wind conditions. Painting under windy conditions can be challenging and present health and safety risks to workers. Moreover, this can have cost implications for the wind farm if they need to fund and procure the necessary professional services to paint the blades. There will also be operational costs and losses if the turbines need to be stopped for any amount of time when energy production is required. These costs are, however, likely to be minimal compared to alternative measures to prevent avifaunal collision impacts (such as shutdown-on-demand using manual observers, radar, or cameras). If the blades can be painted at the factory before erection at the wind farms, the cost should be negligible.

3. Colour and pattern

Colour and pattern are important considerations, should blade patterning be considered for the purposes of avian blade collision reduction. These include the following key points:

- Paints that provide maximal contrast (i.e., absorbent black and reflective white or signal red-8% and pure white - 84%) are regarded as ideal for marking blades (Martin and Banks 2023). Theoretically, black is the best colour to use as it provides the greatest contrast on a white blade, but as discussed above, South African farms are currently constrained to signal red(S1580-Y90R) by SACATS 139.01.30.
- Ultra-violet (UV) paints are not encouraged as all birds do not see UV and thus would only be effective for those that do. Martin 2022 provides a good overview.
- The pattern used should enhance the flicker effect to increase conspicuousness. The single, black-painted blade at Smøla WEF was effective in reducing avian collisions, but it is not the only pattern that could be considered. Lab tests using two broad black stripes were well perceived by raptors and human subjects alike (McIsaac 2001). Recent recommendations for marine birds in low light conditions suggest all three blades can be patterned as long as they are marked alternately (black on the outer third, followed by white on the outer third), and the tower itself is patterned (Martin and Banks 2023). Interestingly, some helicopter rotors are also patterned alternately to enhance conspicuousness for pilots.
- Both sides of a blade (front and back) require marking, as birds can approach a blade from any angle. The tower itself is also best patterned as birds are known to collide with these too (Martin and Banks, 2023).

4. Robustness of available evidence and design of new experiments

The research results are promising, but the in situ effectiveness of marking turbine blades black has only been demonstrated at one wind farm (i.e. Smøla). Further research is required to test if the results from this study will be generalisable to other environments and to assess the effectiveness for different species or groups of species. This limitation must be considered when considering whether it is appropriate to implement blade marking as a mitigation strategy. Additional safeguards may be necessary to address significant impacts at some wind farms.

Wind energy facilities planning on implementing blade marking are encouraged to engage with statisticians and conduct a power-analysis to determine whether the experimental design and data collection methods are robust enough to yield statistically meaningful results. A power analysis considers factors like sample size, the size of the effect, and variability in data to estimate the probability of detecting an existing effect or relationship. By conducting a power analysis, researchers can plan their studies and ensure they have enough data to draw meaningful conclusions.

Even studies with a low probability of detecting an effect can be valuable if data and results are shared. Combining data from multiple projects would provide a variety of conditions that could facilitate the generalisation of findings to other conditions not explicitly tested. Whether a power analysis for a single project is needed will depend on the purposes of the study and on whether the blade marking is expected to mitigate severe impacts at that specific project.

Consideration should be given to the following:

- How many turbines should be marked? It is important to replicate treatments, so one needs to have multiple turbines marked and several unmarked. The number of turbines needed in each group depends on the expected number of fatalities per turbine, the variation in this number and the effect produced by the treatment (change in number of fatalities) we are willing to accept as being significant.

- How should turbines be selected for marking? In principle, turbines should be selected randomly. However, defining areas or blocks with similar characteristics (in terms of propensity to collision – to be defined) and selecting turbines randomly within each block can increase the power of an analysis.
- When should turbines be marked? The availability of pre-treatment data for both marked and unmarked turbines allows one to establish base-level mortality for both groups before any treatment. Otherwise, it is more difficult to determine whether observed differences in mortality levels are produced by the treatment or by other factors affecting the turbines. These studies are more robust and should be preferred. However, marking blades before or during construction may be more cost-effective. If this is the case, ensuring that differences between turbines are equally represented in both treatment groups (marked and unmarked) will be necessary. Working with large samples and adhering to randomisation procedures when selecting turbines for each group (point 2) both help.
- How will effectiveness be measured?
    - A change in fatality rates is the obvious metric to use. Fatality rates can be estimated through carcass searching around the turbines with the blades painted and those that have not been painted (i.e., control sites) (see Jenkins et al. 2015 for detailed survey methods). Consider if fatality rates will be aggregated for all species or if changes in particular species' fatality rates are a priority. Is the frequency and extent of fatality surveys suitable to accurately estimate fatalities?
    - What alternative methods could be used to measure impact? Measuring fatality rates will not provide much insight in terms of the movements of the birds and whether the painted blades are more conspicuous to the birds or not. Therefore, a further measure to be considered could be to tag (by means of a GPS tracker) individuals of certain priority species known to inhabit the area and track their movements in fine detail relative to the painted blades. This could help to show whether the birds are exhibiting any avoidance behaviour around the turbines with painted blades. However, there are ethical considerations to tag priority species, and approvals will be required from the relevant authorities or institutions before implementation.
- The duration of the experiment. How long is it likely to take to show statistically significant results? Are there limitations to how long turbines can be marked (e.g. CAA requirements)? Are there any circumstances when the experiment should be called off?
- Are there opportunities to pool data from other wind farms? (see "Next Steps").

5. Visual Impact on Humans

For operational wind farms, existing Environmental Authorisations (EAs) may refer to the colour that the turbines will need to be (e.g. white), in which case, prior to implementing blade patterning, an amendment to the EA will be necessary. Where EAs do not refer to the colour, consideration must be given to how the wind turbines were assessed and if any change to the visual impact assessment will be required. In such instances, this could also necessitate the need for amendment of the EA.

For new projects applying for EA and that wish to include blade patterning as a mitigation option, it will be important to ensure that this is brought to the attention of the specialist undertaking the visual impact assessment. The public participation component will be an interesting space to keep an eye on to understand the public's perception towards this measure. Details in this regard are yet to come to the fore, and the industry should be mindful of this aspect.

Next steps:

1. Operational facilities

Operational wind energy facilities are well placed to conduct Before-After-Control Impact studies. They are encouraged to implement well-designed experiments to assess the effectiveness of marking turbine blades under different environmental conditions (including possibly novel colours and designs). By doing so, these facilities can play a valuable role in advancing research on this cost-effective potential solution. However, it must be emphasised that further research is essential before we can confidently rely on this as a mitigation measure. If a facility is recording significant impacts on birds, implementation of blade patterning should be complemented by additional mitigation (e.g. shutdown-on-demand) until there is robust statistical evidence to confirm that marking blades alone is effective in that context.

2. New facilities

Considering the relatively low cost of painting turbines before construction, and potential benefits, developers may wish to mark some or all of their turbines proactively. This could be to a) reduce the collision risk on site or b) contribute data and conduct research on the effectiveness of this as a mitigation measure (or both). If the aim is purely risk reduction, there may be little harm in implementing blade marking, provided the uncertainty related to its effectiveness is taken into account in the environmental impact assessment (along with the other considerations discussed above).

Where the objective is to contribute to research on the effectiveness of blade marking as mitigation, ensuring enough data to draw meaningful conclusions will be a challenge at wind farms with low fatality rates. If turbines are marked from the outset of operation, the lack of pre-treatment data will exacerbate this problem.

A potential solution could be for wind farms to agree to participate in national (or even international) experiments where standard treatments (colour(s), design and selection of turbines) are implemented in all participating wind farms. A coordinated approach to marking and monitoring turbines across could have far-reaching benefits for the industry as the effectiveness of this mitigation measure could be assessed in a relatively short time. This will require best practices and scientifically sound methodologies to be agreed on and resources made available to coordinate implementation, data management and analysis. Importantly, it will require buy-in from the wind energy industry.

Industry members are therefore encouraged to share ideas and suggestions in this regard to ensure that considerations across the board are taken into account and addressed collectively.

3. Further research

The need for further research on the effectiveness of blade patterning as mitigation against bird strikes has been emphasised throughout this document. However, there are some other research questions that would be helpful to have answered, including those related to the following:

- The effects of differential heating for red and black painted blades under different environmental conditions, and if necessary, potential solutions to negative effects.
- Public perceptions and acceptance of increased visibility due to painted blades.
- Movements/behaviour patterns of priority species around painted blades.

Conclusion

The authors hope that blade patterning will be demonstrated as effective in mitigating bird-strikes, and eventually become a standard practice in the industry. Until then, stakeholders interested in promoting or adopting blade patterning as mitigation are encouraged to carefully consider the risks, opportunities, and recommendations outlined above. We look forward to seeing the technical and legislative challenges resolved, and the body of evidence grow.

SAWEA - Wind Energy & Birds Sub-committee Group
Birdlife South Africa
Dr Rob Simmons
SLR Consulting
G7 Renewable Energies
Mainstream Renewable Power South Africa
Centre for Statistics in Ecology, the Environment and Conservation, University of Cape Town

References:

Cervantes Peralta F. Martins M. Simmons RE. 2022. Population viability assessment of an Endangered raptor using detection/non-detection data reveals susceptibility to wind farm impacts. Roy Society Open Science. https://royalsocietypublishing.org/doi/10.1098/rsos.220043

Hodos, W. 2002. Minimization of Motion Smear: Reducing Avian Collisions with Wind Turbines. National Renewable Energy Laboratory. NREL/SR-500-33249

Jenkins AR, van Rooyen CS, Smallie JJ, Harrison JA, Diamond M, Smit-Robinson HA, Ralston S. 2015. *Best Practice Guidelines for assessing and monitoring the impact of wind energy facilities on birds in southern Africa.* EWT and Birdlife South Africa

Martin GR. Banks AN. 2023 Marine birds: Vision-based wind turbine collision mitigation. Global Ecology and Conservation 42 (2023) e02386

May R. Nygård T. Falkdalen U. Åström J. Hamre Ø. Stokke B. 2020. Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. Ecology and Evolution. 10. 10.1002/ece3.6592.

McIsaac HP. 2001 .Raptor acuity and wind turbine blade conspicuity. Proceedings of National Avian-Wind Power Planning Meeting IV, 59-87. https://www.osti.gov/servlets/purl/822422

Potier S. Mitkus M. Kelber A. 2018 High resolution of colour vision, but low contrast sensitivity in a diurnal raptor. Proc. R. Soc. B 285: 20181036. http://dx.doi.org/10.1098/rspb.2018.1036

Salkanović E. 2023. Protecting avian wildlife for wind farm siting: The Screening Tool Proof of Concept. Energy for Sustainable Development. https://doi.org/10.1016/j.esd.2023.03.002

van Gessel, C. 2022. Research into the effect of black blade in wind turbine. Vattenfall. https://group.vattenfall.com/press-and-media/newsroom/2022/black-turbine-blades-reduce-bird-collisions#:~:text=Taking%20previous%20research%20to%20the%20Netherlands&text=That%20study%20showed%20that%20painting,Larsen%2C%20Environmental%20Expert%20at%20Vattenfall.

Acknowledgements

Thank you to UEWF (and particularly Sabri Abrahams) for sharing their experiences painting the blades of their turbines with the South African Wind Energy Association (SAWEA) / South Africa Photovoltaic Industry Association (SAPVIA) Environmental Working Group. UEWF shared the consultation process to paint the blades with the South African Wind Energy Association (SAWEA) / South Africa Photovoltaic Industry Association (SAPVIA) Environmental Working Group. SAWEA/SAPVIA hope to facilitate the sharing of this information with the industry to foster greater awareness and consideration should this measure be implemented at other wind farms in the future.

BirdLife South Africa's Birds and Renewable Energy Project is sponsored by the Lewis Foundation, Eskom and Investec Rhino Lifeline.

Lastly, thank you to Prof. Martins, Marlei Martins, Estibaliz Sorondo from Siemens Gamesa, for reviewing the briefing note and supporting it with their expertise.