

TransMi

*The evidence-based toolkit for
mitigating powerline-related avian
mortality*

GET
STARTED 

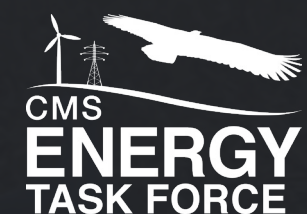
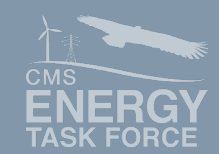


Photo © James Dwyer



INTRODUCTION

How to use the toolkit

Why mitigate?

Where and when to
mitigate

The mitigation hierarchy

INTRODUCTION

How to use the toolkit

Why mitigate?

Where and when to
mitigate

The mitigation hierarchy

Birds play an essential role in the functioning of the world's ecosystems. They act as pest controllers, pollinators, seed dispersers and waste disposers, as well as providing multiple cultural benefits. Many bird species are declining, therefore reducing human-caused mortality is crucial to help maintain healthy bird numbers and healthy ecosystems.

Globally, power transmission and distribution lines pose a threat to wildlife and birds in particular^{1,2}, chiefly through collision and electrocution. Many of the impacts can be avoided through careful routing and bird safe design of electricity infrastructure. Where impacts cannot be avoided, mitigation techniques can minimise impacts, preventing declines in bird populations while meeting the energy needs of the human population.

Mitigating bird collision and electrocution also benefits transmission system operators (TSOs). Collision and electrocution events often cause electrical faults³, power outages^{4,5}, fires⁶ and equipment damage⁷, which may lead to reputational and financial costs. Mitigation is therefore of mutual benefit to conservationists and TSOs.

**Mitigation is of mutual
benefit to conservationists
and transmission system
operators**



Photo © Grisha Bruev/Shutterstock

INTRODUCTION

How to use the toolkit

Why mitigate?

Where and when to
mitigate

The mitigation hierarchy

Where avoiding impacts altogether is not possible, mitigation measures should be used to minimise the impacts of powerlines on biodiversity. Incorporating mitigation measures into pre-construction planning is easier and less costly than retrofitting mitigation after powerline construction, therefore it should be considered as early as possible in the planning process.

In some cases, resources may be limited and so there will be a need to target mitigation at the highest risk sections of powerline. These may be identified proactively, using bird surveys and knowledge of factors increasing collision or electrocution risk, or reactively, using data on where collisions and/or electrocutions are already occurring. A combination of these methods was used to prioritise retrofitting of dangerous pylons in Catalonia, Spain, resulting in higher survival rates of Bonelli's Eagle¹.

If in doubt, a precautionary approach should be taken with mitigation used along as much of the powerline as possible.

Determine whether the powerline passes through any areas where it is likely to negatively impact biodiversity (e.g. using bird surveys, sensitivity mapping tools, consultation with ecologists)



Identify individual infrastructures in these areas that are likely to pose a high mortality risk



If the powerline is already constructed, use data on where mortalities are occurring to complete information on high-risk sites/infrastructures



Prioritise these sites/infrastructures for mitigation

INTRODUCTION

How to use the toolkit

Why mitigate?

Where and when to
mitigate

The mitigation hierarchy

The mitigation hierarchy is a stepwise framework to guide businesses in their mitigation of impacts from development and is widely considered best practice for the avoidance and management of biodiversity impacts. It recommends that impacts are first avoided, but if this is demonstrably unfeasible, then they should be minimised, before site restoration, or lastly offsets to compensate for any residual impacts.

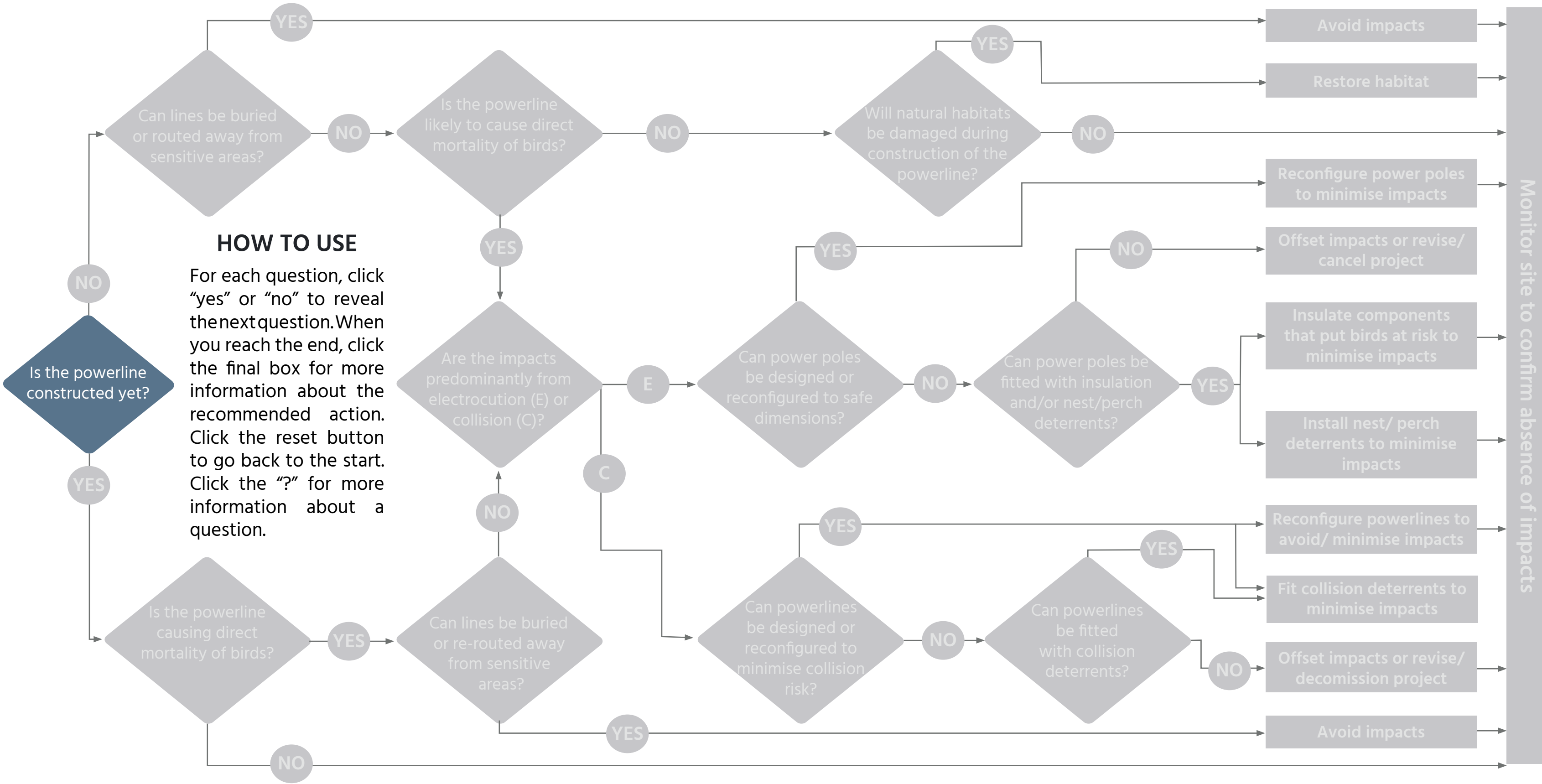


Click on each step of the diagram to learn more.



HOW TO USE

For each question, click "yes" or "no" to reveal the next question. When you reach the end, click the final box for more information about the recommended action. Click the reset button to go back to the start. Click the "?" for more information about a question.



AVOID

Where possible, impacts on biodiversity should be avoided. Burying powerlines underground is the most effective way to avoid avian mortality, particularly for species for which mitigation measures are less effective. Burying powerlines has been used to successfully avoid collisions of Great Bustards in Central Europe¹ and electrocution of Spanish Imperial Eagles in southwestern Spain². However, the high costs involved mean that it is unlikely to be feasible for long stretches or high voltage powerlines¹. The initial installation of underground powerlines may also have negative impacts on other wildlife, and should be avoided in wetlands as this may cause significant habitat degradation³.

If burial of powerlines is not feasible, avoidance may be achieved through (re-)routing the powerlines to avoid areas with large populations of birds that are likely to be susceptible to collision or electrocution. These areas are best identified through surveys of bird distribution and movements, but there are also various tools available to help developers avoid highly sensitive areas, such as the **Integrated Biodiversity Assessment Tool (IBAT)** and the **Soaring Bird Sensitivity Mapping Tool**.

Avoiding certain habitats may also help reduce the risk

of mortality. Powerlines on hill tops or in more open habitats tend to have a greater risk of both collision and electrocution, as birds tend to fly at lower heights and pylons are more likely to be used as hunting perches^{4,5}. For example, bustard collisions in southern Portugal are more likely to occur at powerlines with >20% of open farmland in the surrounding area⁶.

In some circumstances, instead of rerouting a powerline to avoid a sensitive area it may be possible to relocate the sensitive area. This is particularly the case with rubbish dumps which can be a significant attractant to scavenging birds. Moving a waste disposal site away from the route of an intended powerline can therefore be an effective method for avoiding bird fatalities.



Planning
tools help
developers
avoid highly
sensitive areas

MINIMISING IMPACTS TO BIRDS

Where impacts to birds can't be avoided, they should be minimised using mitigation technology. This should preferably be fitted during construction of the powerline; lines may also be retrofitted after construction, but this is usually a more expensive and technically challenging option. Consideration should be given to the inspection and maintenance required for different mitigation options. Some forms of mitigation may have a higher immediate cost, but will reliably reduce bird mortality in the long term, while others may be less expensive to implement, but may wear, deteriorate or fall off and without appropriate inspection, repair or replacement, may not achieve the goal of reducing bird mortality on the powerline over the long term.

Minimising electrocution

Mitigation against electrocution can be split into three categories – **separation** (reconfiguring the pole to increase the distance between energised components), **insulation** (covering energised or grounded components with insulating materials), and **redirection** (shifting birds away from energised equipment using nest or perch diversion)¹. Separation

is the most effective method, but is usually only practical for new poles, while redirection is the least effective and should be used in conjunction with one of the other two methods where possible.

Minimising collision

Mitigation against collision generally involves **reconfiguration of the powerlines** to make them less of an obstacle, or using **collision deterrents** to make lines more visible to birds. Certain species of bird such as bustards and cranes have low manoeuvrability and reduced visual fields, with limited sight in the direction of flight, therefore powerline reconfiguration may be more effective than using collision deterrents for these species.

POLE RECONFIGURATION

Overview

Jumper wires

Insulators

Crossarms

Poles with auxiliary
equipment

Electrocution occurs when a bird makes simultaneous contact with two conductors, or with a conductor and a grounded structure (e.g. a metal crossarm). Pole reconfiguration minimises (or in some cases eliminates) this risk by increasing the separation distance between these components to minimise the risk of simultaneous contact. This may involve moving jumper wires or insulators, or altering the configuration of crossarms. The distance required will depend on the largest species of bird at risk of electrocution – bigger birds such as storks and vultures require a larger separation distance than smaller birds.

Pole reconfiguration tends to be more effective than insulation at preventing electrocution, but retrofitting existing power poles in this way can be costly and normally requires an outage, therefore, where possible, separation should be considered in the initial pole design before construction.

**Greater separation
distances are needed
for larger birds**



POLE RECONFIGURATION

Overview

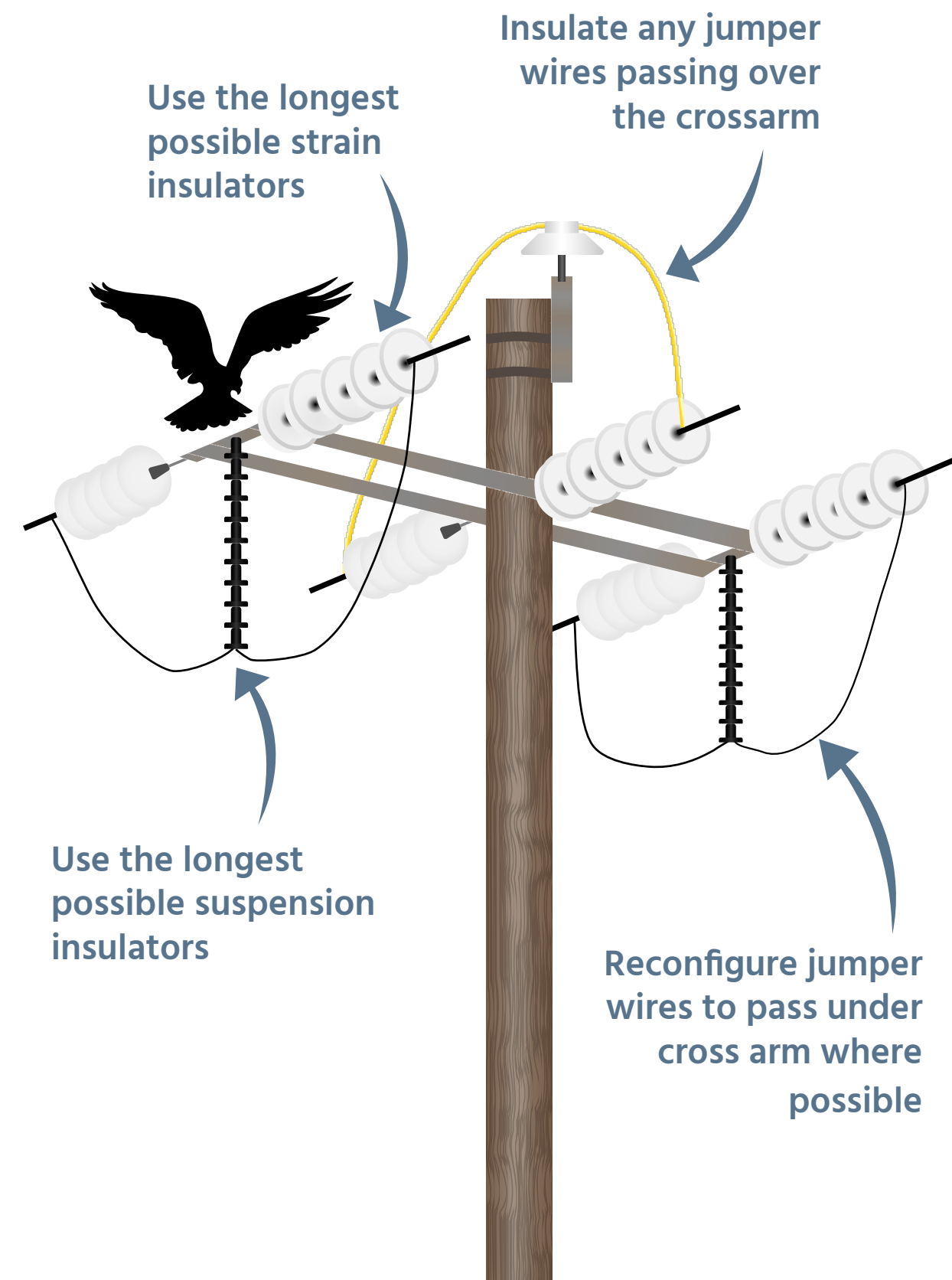
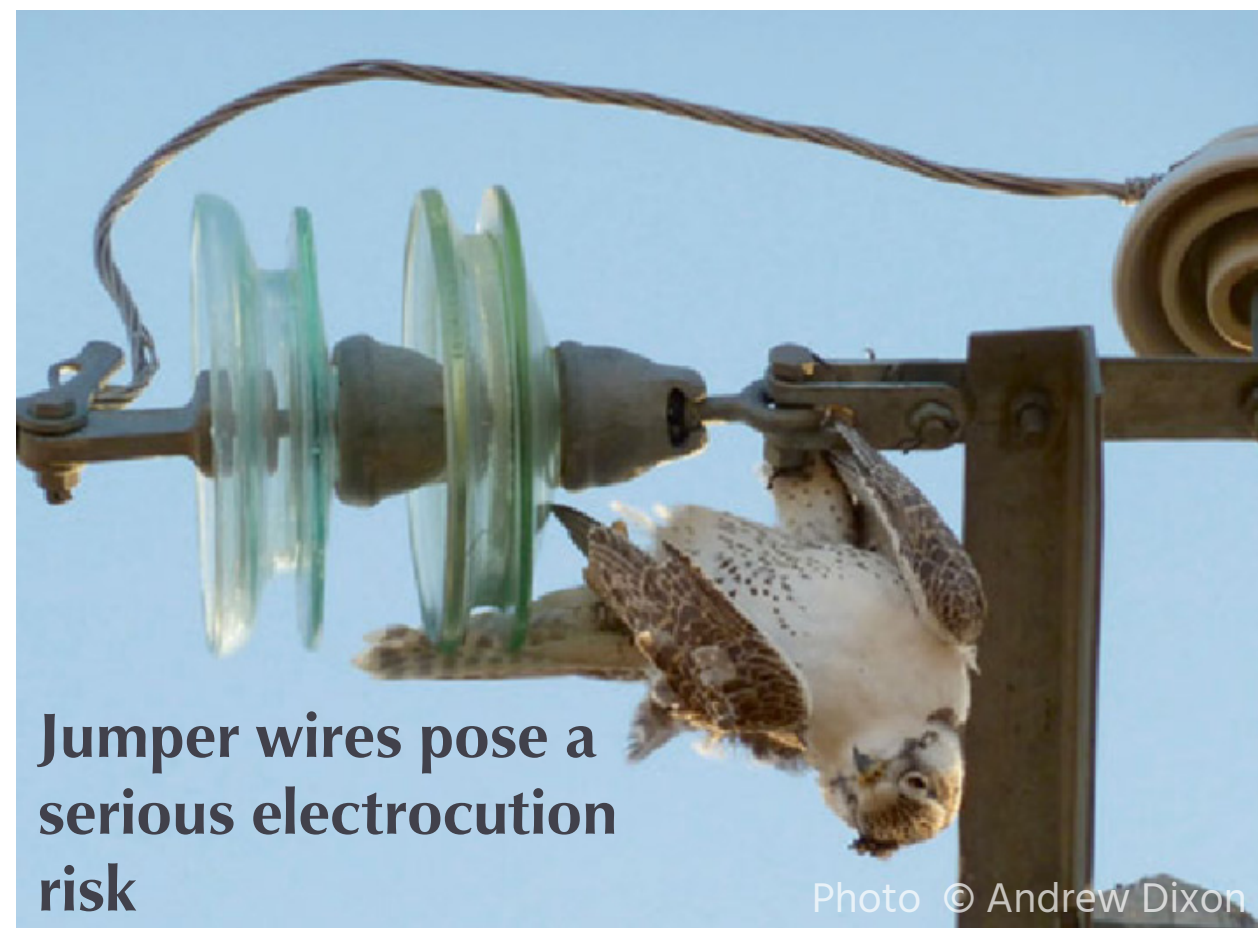
Jumper wires

Insulators

Crossarms

Poles with auxiliary
equipment

Jumper wires passing over the crossarm pose a serious electrocution risk to birds¹. Studies in Mongolia have found that reconfiguration of jumper wires at two phases, so that they pass under the cross arm via suspension insulators rather than over the top, resulted in a 16-fold reduction in electrocution². Any jumper wires still passing over the crossarm should be **insulated**. The longest possible vertical and horizontal insulators must also be used. In the case of supports that are regularly used for nesting, it may also be necessary to insulate jumper wires passing under the crossarm, and/or to use **nest diverters**.



POLE RECONFIGURATION

Overview

Jumper wires

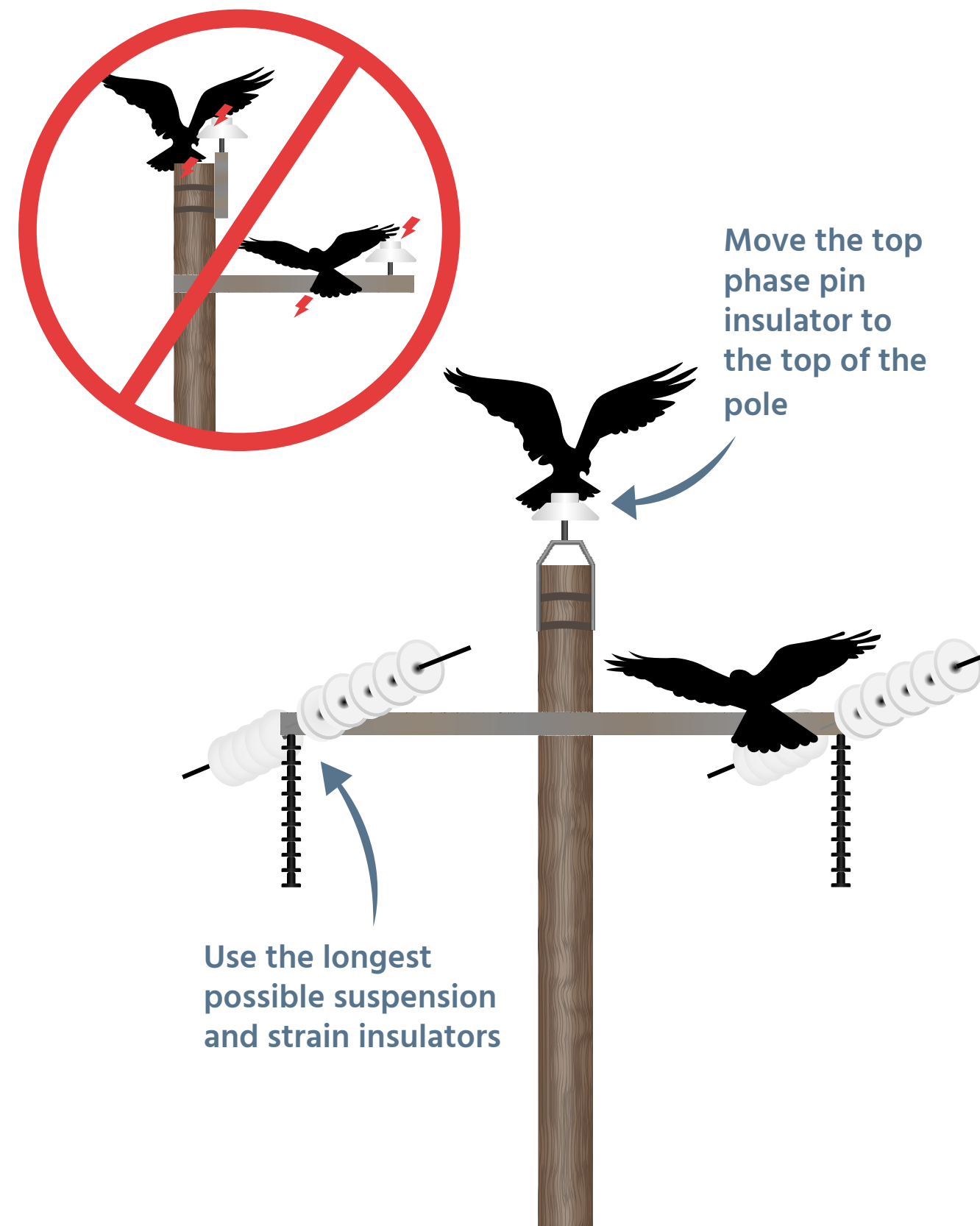
Insulators

Crossarms

Poles with auxiliary
equipment

Steel-reinforced concrete or metal poles with steel crossarms and upright pin insulators or short strain insulators pose an electrocution risk to birds if they touch a conductor cable while perched on the crossarm¹. Moving the insulators or choosing insulators that minimise the likelihood of contact occurring can therefore reduce electrocution risk. There are several ways to achieve this:

- ▶ Move the top phase pin insulator from the side of the pole to the top of the pole. When trialled in Mongolia, this reduced electrocution mortality by up to 85%^{2,3}, and was more effective than insulating the top phase³.
- ▶ Use suspension insulators. Several studies have found that poles with suspension insulators have a significantly lower electrocution rate than poles with upright pin insulators^{4,5,6}.
- ▶ Use the longest possible insulators. Longer insulators increase the distance between the crossarm and conductor cables, therefore reducing the likelihood of simultaneous contact. When six different strain insulators were tested in flight enclosures in Spain, those with the longest insulating section posed the lowest electrocution risk to raptors⁷.



POLE RECONFIGURATION

Overview

Jumper wires

Insulators

Crossarms

Poles with auxiliary
equipment

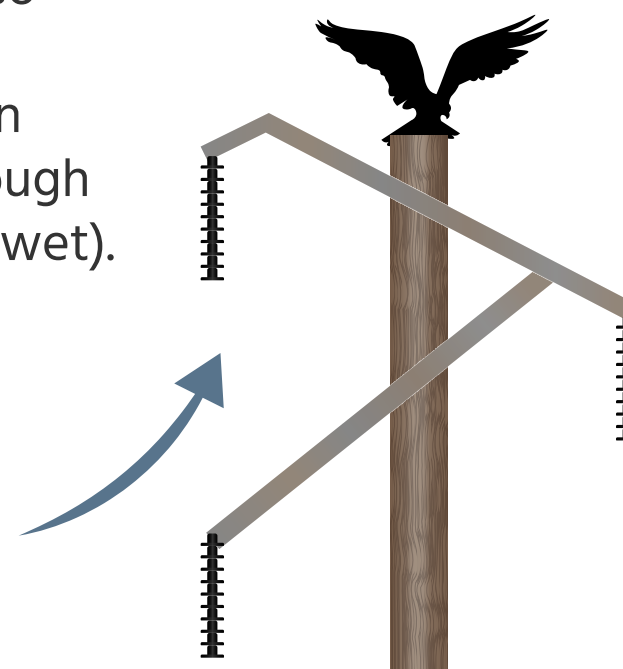
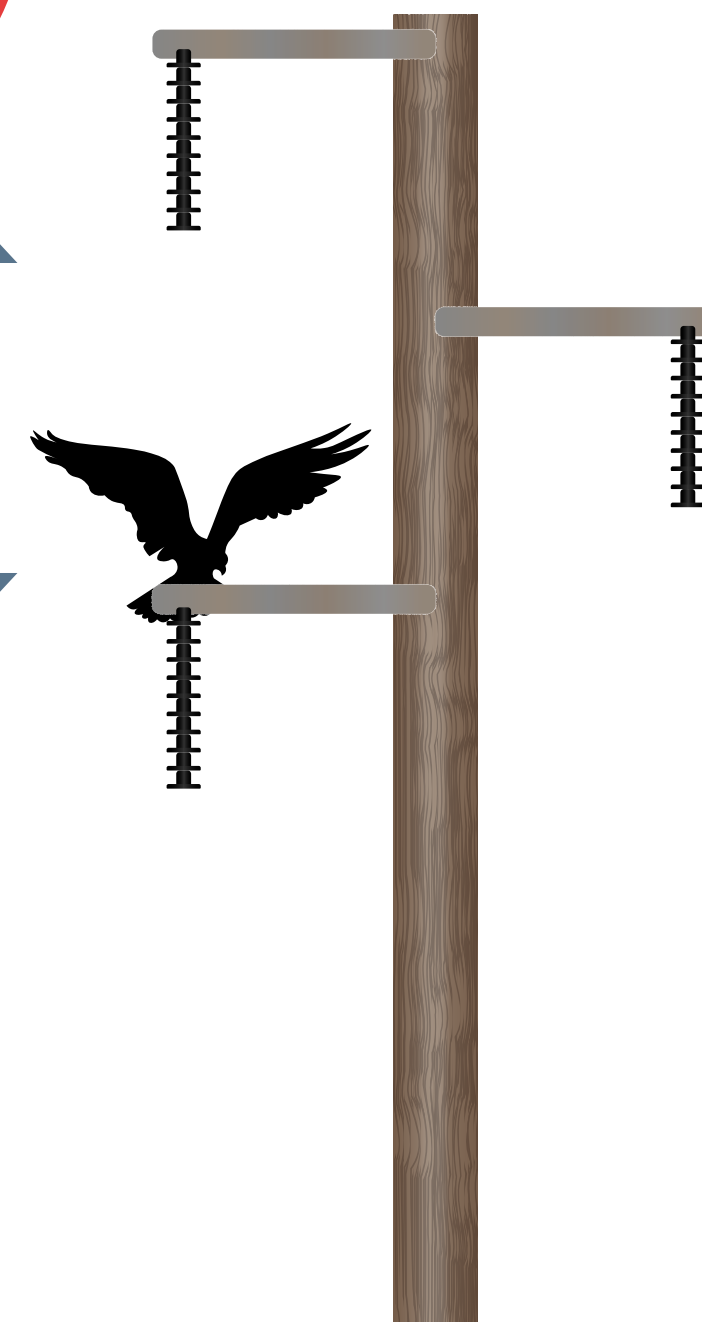
The number and distribution of crossarms may affect the risk of avian electrocution through influencing available perching positions. Any design that allows perching in a position where a bird can simultaneously touch a grounded and an energised component or two energised components poses a significant risk. In a survey of nearly 4,000 pylons with six different crossarm configurations in Barcelona, Tinto et al.¹ found that alternate crossarms were associated with the lowest electrocution rate. The distance between the crossarms and length of the suspension insulators must be large enough to ensure that no bird can simultaneously contact the crossarm and the phase conductor above or below.

The materials used for the crossarms and pole also influence electrocution risk - highly conductive materials such as steel pose a far greater risk than those made from wood or composite fibre (although wooden supports increase in conductivity when wet).

Sloping alternate
crossarm design -
prevents perching
on crossarms



Ensure
sufficient
distance
between
crossarm and
next phase
conductor



POLE RECONFIGURATION

Overview

Jumper wires

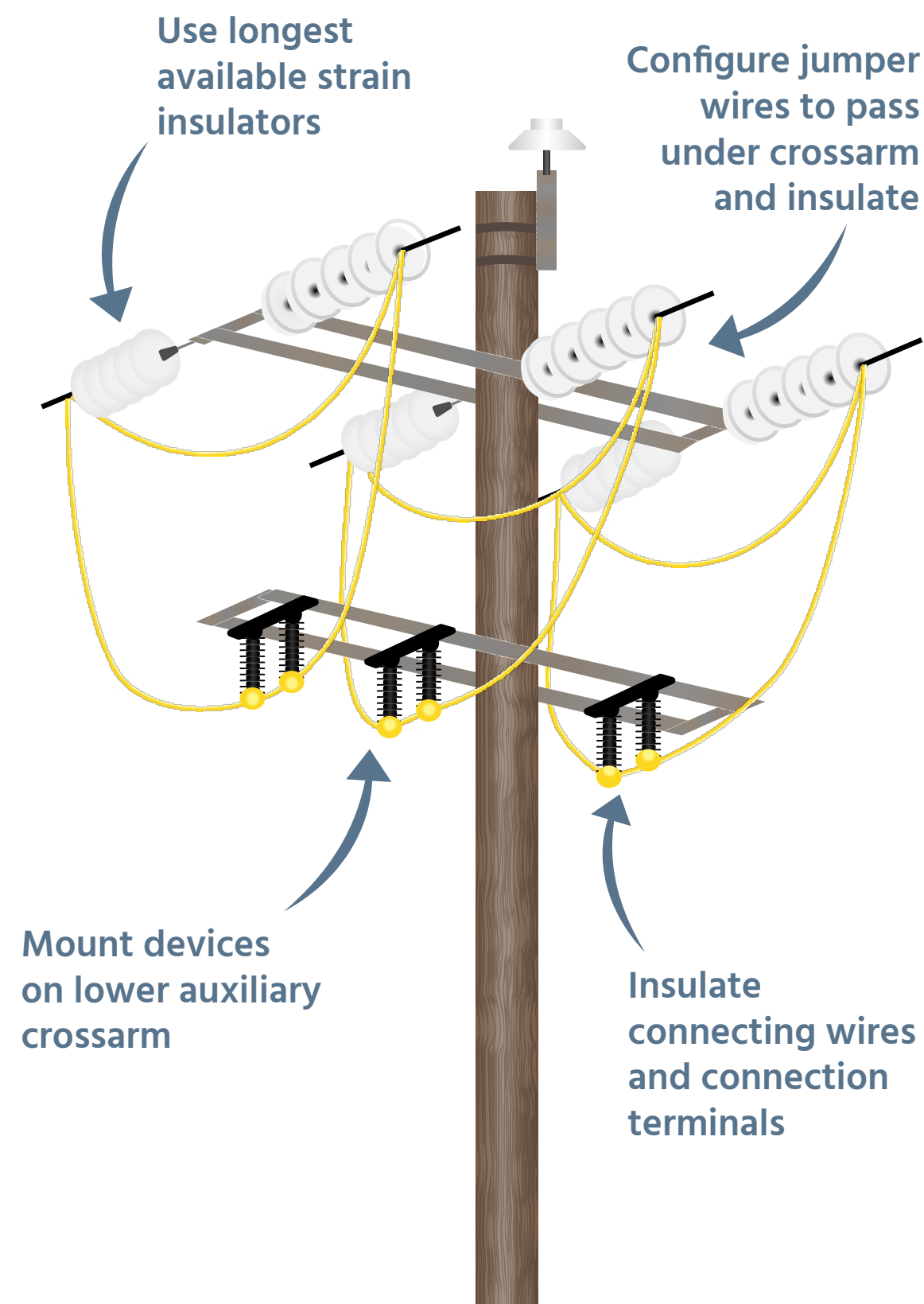
Insulators

Crossarms

Poles with auxiliary
equipment

Although poles carrying auxiliary equipment (e.g. transformers, disconnectors, surge arresters) only form a relatively small part of the powerline network, they are responsible for a significant number of bird electrocutions due to the presence of multiple closely-spaced energised components. Several measures are needed to minimise the risk of electrocution on these types of infrastructure¹:

- ▶ Avoid having live elements above the main crossarm by mounting devices on an auxiliary crossarm below the main crossarm or suspending them from the main crossarm
- ▶ Configure jumper wires to pass under the main crossarm
- ▶ Use the longest available insulators
- ▶ Use **insulation** (preferably in the form of preformed parts and insulated cables) to cover connecting wires, connection terminals and other exposed live elements



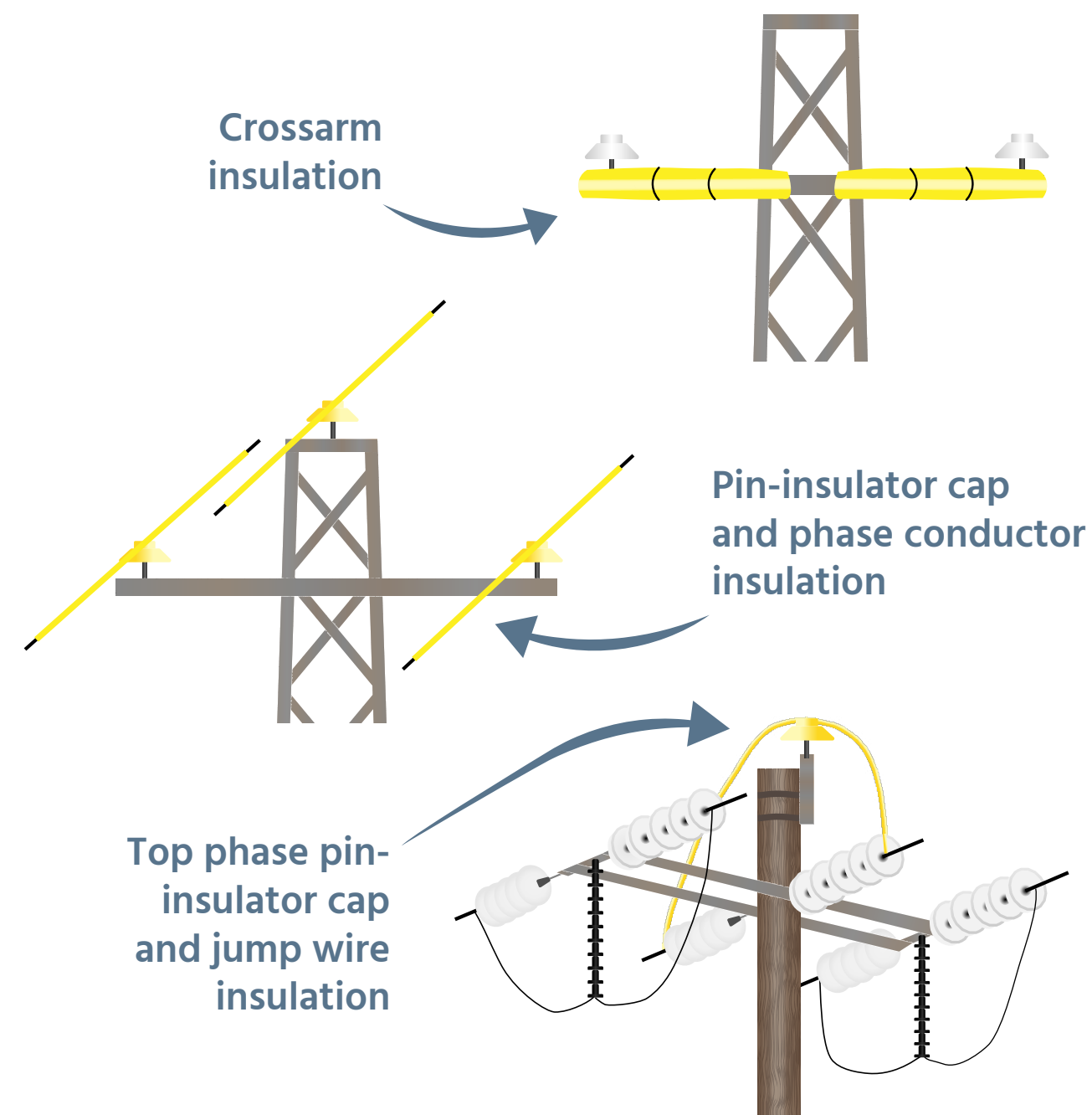
INSULATION

If it is not possible to **change the base configuration** of the pole to reduce the risk of electrocution, or in the case of structures **supporting auxiliary equipment** (such as transformers, switch-disconnectors etc.), insulation should be used to provide a barrier between the bird and any energised components which it may contact when landing or sitting on the structure. Insulation may be installed over energised cables (e.g. phase conductors or jumper wires) or over grounded perching sites (e.g. metal crossarms). Insulation is generally more effective at reducing mortality than using **perch diversion** to redirect birds away from energised equipment, although both methods used together can be highly effective^{1,2}.

Insulation has been shown to successfully reduce electrocution of Bonelli's Eagle in southern France³ and Golden Eagles in Colorado². A study in Mongolia found that insulation of the topmost phase using a pin-insulator cap and insulation around the cable reduced electrocution mortality by 59%, while insulation of the two lower phases reduced mortality by 66%⁴.

The effectiveness of insulation may be undermined if there is a failure to identify potential points of contact during the planning stage, or through incorrect application or deterioration of insulating products^{5,6}. This can be avoided through improved training and careful

planning, which will prevent the need for corrective measures later on and therefore minimise budget spend. Wherever possible, preformed pieces manufactured with approved materials should be used to insulate the various elements rather than insulating tapes.



NEST & PERCH DIVERSION

Overview

Perch diversion

Nest diversion

If power poles can't be designed or reconfigured to safe dimensions, birds may be discouraged from perching or nesting in potentially dangerous positions. This can be achieved through two methods:

- ▶ Installation of deterrent devices on crossarms, insulators or other parts of the powerline that pose an electrocution risk to discourage use
- ▶ Providing supplementary perches/nest sites to encourage birds to utilise these instead

Redirection (shifting birds away from energised equipment) is generally less effective than **insulation** or separation via **pole reconfiguration**, and should therefore be used alongside other mitigation measures or only in situations where no other mitigation option is feasible.

Some bird species
routinely nest on
pylons



NEST & PERCH DIVERSION

Overview

Perch diversion

Nest diversion

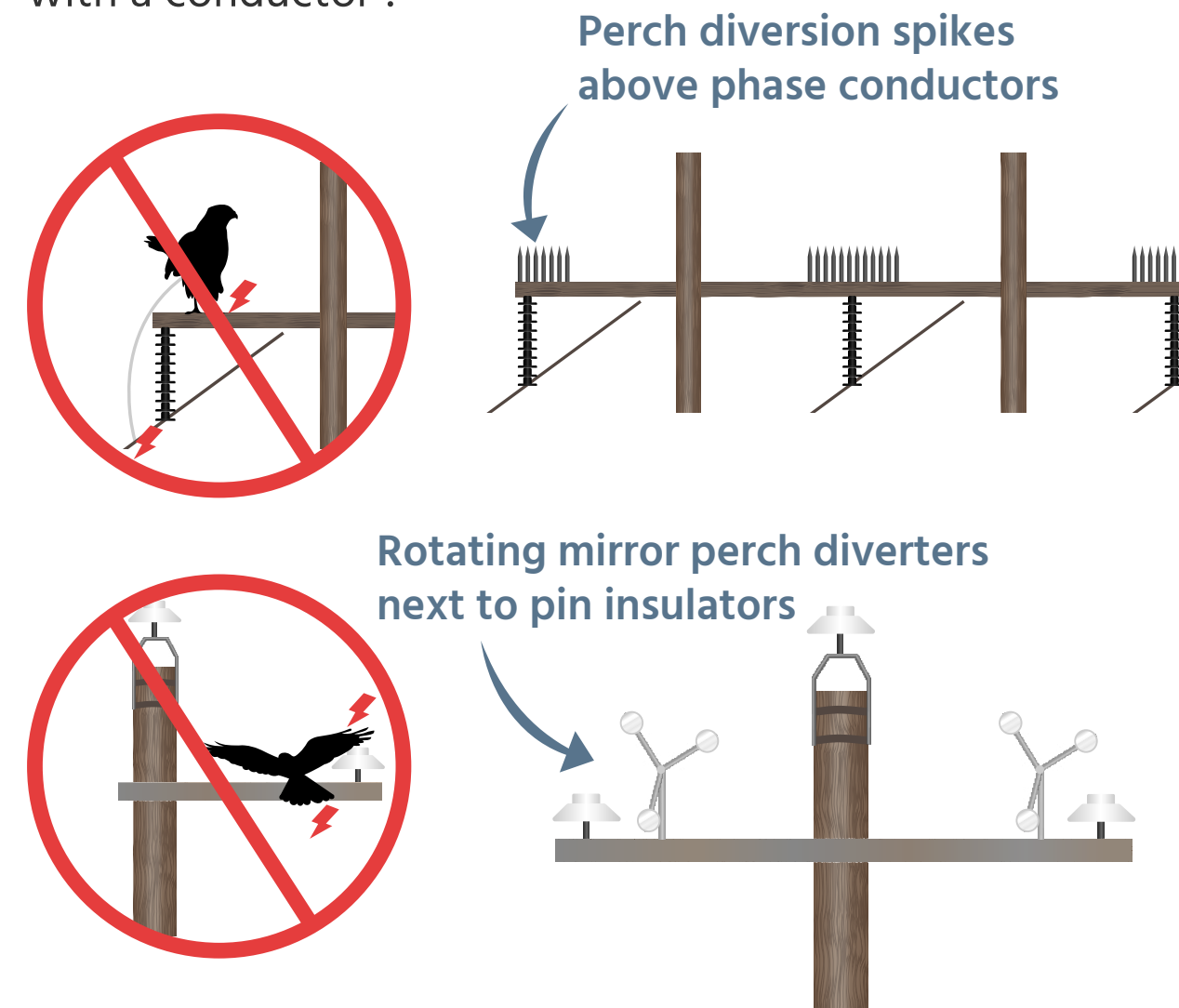
Perch diversion may take the form of alternative perches, designed to encourage perching in a safer location, or perch deterrents, designed to prevent perching in unsafe locations. There is very little evidence to suggest that supplementary perches alone are effective at reducing electrocution risk – at least two studies have found no effect^{1,2}, while another found them to be effective for some species but not others³.

Of the perch deterrents that have been tested experimentally, spikes^{2,4,5,6,7} and rotating mirrors⁸ tend to be the most effective, while brush deterrents have been shown to be ineffective^{8,9}. Due to their moving parts, rotating mirrors may have a higher failure rate than static deterrents⁸. Preliminary results suggest that X-type perch deterrents installed above strain insulators may also reduce electrocution risk¹⁰. When installing perch deterrents on crossarms with pin insulators, it is important to place them directly next to the pin insulator for optimum performance^{4,5}. Perch deterrents may also be placed on crossarms directly above phase conductors to prevent electrocution of a bird defecating while perched above the conductor.

Perch deterrents should not be made from a metallic material, to prevent electrocution of a bird touching a conductor as it tries to perch, should be securely

attached to the support, and should preferably have a blunt tip and some flexibility to minimise the risk of damage to the bird.

Perch deterrents should only be used to prevent perching in unsafe locations – installing deterrents at safe perching locations may encourage perching at less safe locations, or cause birds to undertake broad wing-flaps while trying to balance on deterrents, increasing the risk of contact with a conductor⁶.



NEST & PERCH DIVERSION

Overview

Perch diversion

Nest diversion

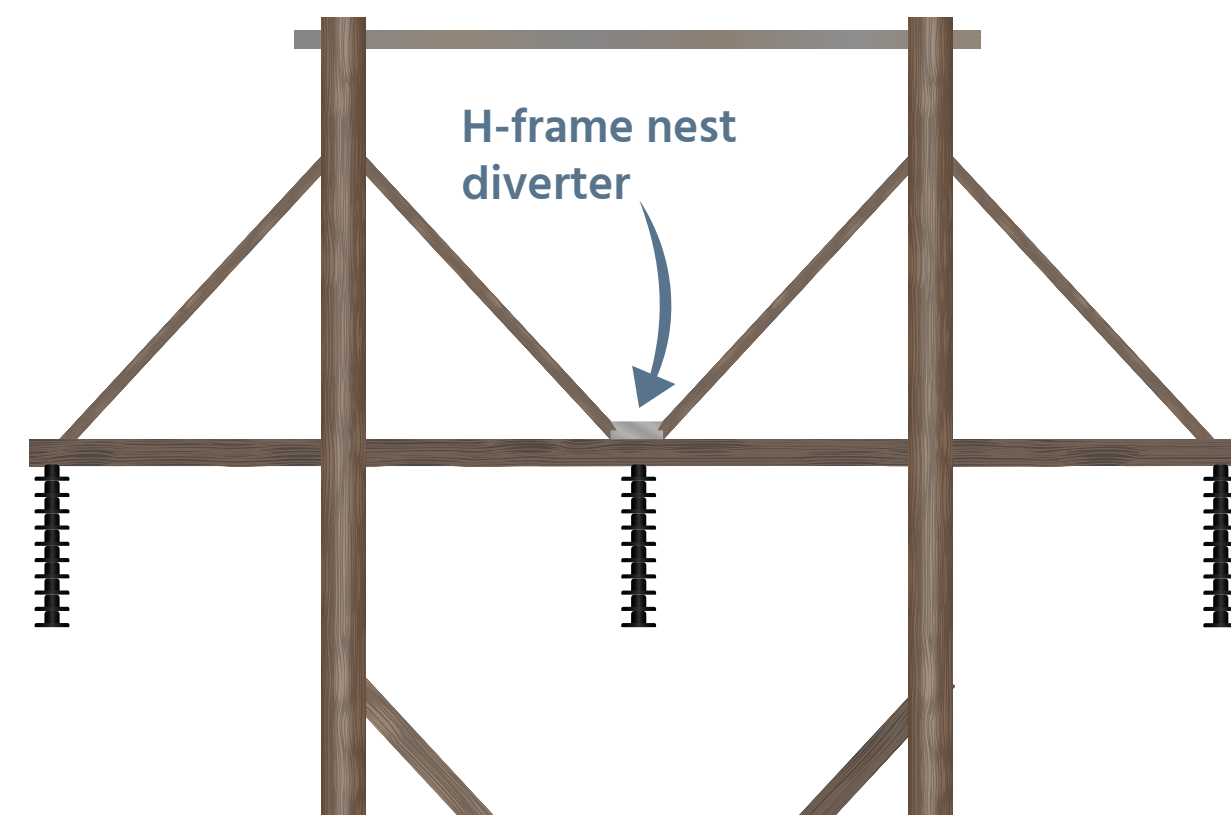
Some bird species routinely nest on electricity pylons, particularly in heavily human-modified habitats where few natural nest sites remain. This may be beneficial for some species, allowing them to persist in areas where they otherwise could not, however it may also increase the risk of avian electrocution, power outages and fires. Some utility companies remove nests during the non-breeding season to minimise these risks, however this requires annual investment¹.

Nest deterrent devices may be installed to prevent any nesting on pylons, or to prevent nesting in particularly dangerous locations. If designed correctly, these devices can be highly effective. For example, Dwyer & Leiker¹ designed a nest deterrent device to prevent Chihuahuan Ravens from nesting over the centerphase of H-frame transmission structures in North America. The ravens nested on 34% of structures that hadn't been fitted with the deterrent, but didn't nest on any structure fitted with the device.

In areas where natural nest sites are limited, supplementary nest sites may be installed to encourage nesting in a safer location. These may take the form of nesting platforms for open-nesting species such as storks, or nest boxes for cavity-nesting species such as kestrels. Nest platforms have been used to successfully redirect

nesting of White Storks in Portugal² and Ferruginous Hawks in Canada³, while nest boxes installed on top of pylons in Iran for Eurasian Kestrels reduced the rate of electrocution per nest and the number of electrical faults⁴. Supplementary nest sites may additionally provide positive communication opportunities, for example through live streamed nest cameras and social media campaigns.

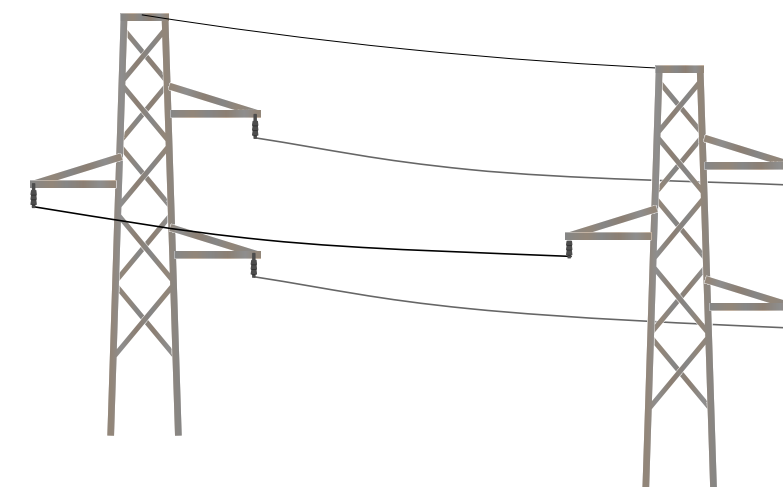
However, careful monitoring is necessary to ensure that an ecological trap is not formed, in which more birds are attracted to the area by the increased nesting opportunities but subsequently suffer a high rate of mortality⁴.



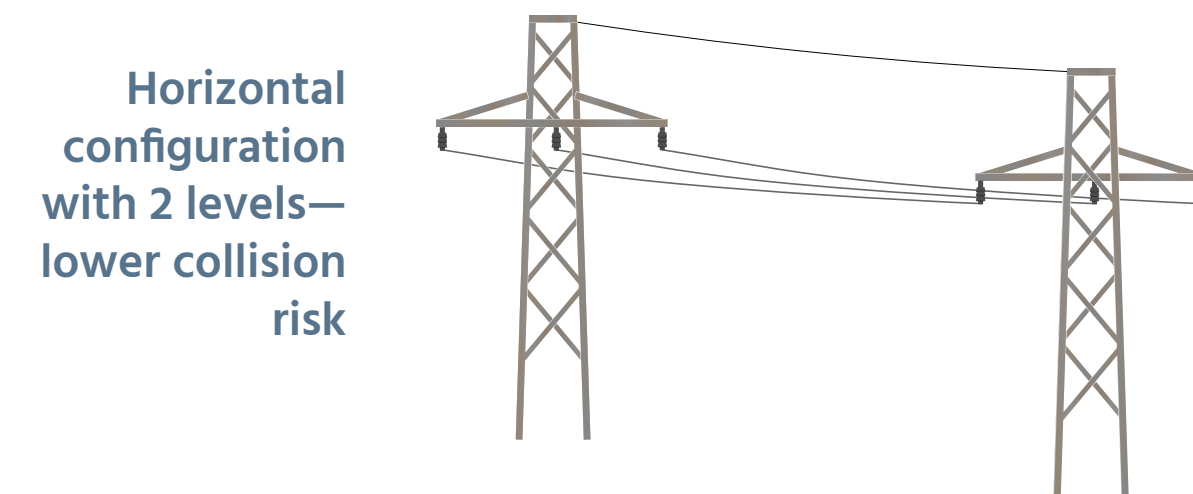
LINE RECONFIGURATION

Powerlines with more wire levels tend to pose a greater collision risk¹. The design and configuration of the phase conductors and earth wire should therefore be carefully considered, preferably before construction. Horizontal configurations, with cables at only one or two levels, or insulated, twisted conductors should be used where possible. Grouping sets of powerlines together with staggered support structures², and/or placing them alongside other linear infrastructure (e.g. roads or railways) may also minimise negative impacts on birds by reducing cumulative effects³. As some collisions may still occur, it is usually necessary to install collision deterrent devices as well.

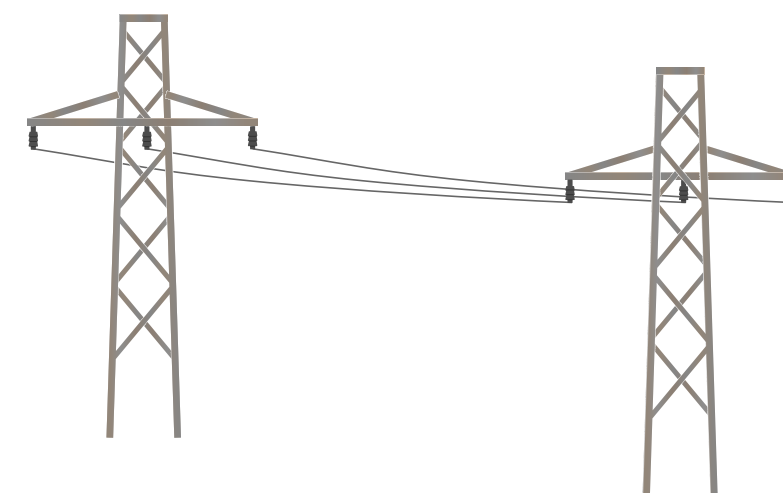
Whether located above or below the phase conductors, earth wires increase the vertical distribution of wires, therefore increasing the collision risk¹. In addition, earth wires tend to be thinner and less visible than phase conductors, further increasing collision risk. Removing earth wires where possible is therefore a highly effective mitigation method, which has been shown to reduce collision rate by 51% for grouse⁴ and 80% for cranes⁵. Thickening the earth wire to make it more visible has been suggested as an alternative to removing it, however when tested on 3.2 km of transmission line in North America this had no effect on crane collision mortality⁵.



Vertical
configuration
with 4 levels—
high collision
risk



Horizontal
configuration
with 2 levels—
lower collision
risk



Horizontal
configuration
with earth wire
removed—
lowest collision
risk

COLLISION DETERRENTS

Overview

Flappers

Spirals

Illumination

Maximising line marker
efficiency

Line markers and other collision deterrents make powerlines more detectable to birds, therefore minimising the risk of collision. There is a wide array of line marking technologies available, which vary in their effectiveness and durability in different contexts (See the **Evidence Library** for summaries of research assessing line marker effectiveness). Overall, a recent meta-analysis showed line marking to have an average effectiveness of 50%¹, although this is likely to be an overestimate due to a reticence to publish negative data. However, in some situations line marking can be extremely effective.

Flappers, spirals and aviation balls are the most commonly used devices for line marking. All have been shown to reduce collisions but contrasting flappers generally outperform static spirals and aviation balls^{1,2}. Certain species, including bustards, cranes and many raptors have visual blind areas in the direction of flight that limit their ability to detect even the most well-designed line markers³.

When choosing which type of device to install, it is important to consider durability as well as effectiveness. There is often a trade-off between the initial cost of the device and device application, and the likely longevity and replacement schedule.

Line marking
has an average
effectiveness of
50%



Photo © WKS Global

COLLISION DETERRENTS

Overview

Flappers

Spirals

Illumination

Maximising line marker
efficiency

Flapper-type devices have parts that move in the wind, making them more detectable to birds. Flappers tend to outperform aviation balls or spiral bird flight diverters^{1,2,3,4}, and may reduce collision frequency by over 90% in some situations^{5,6}. However, their moving parts may make them more likely to malfunction than static devices^{7,8}, and they may not be effective for some species, such as bustards^{1,6,9}.



Hover over/click a device to read more

COLLISION DETERRENTS

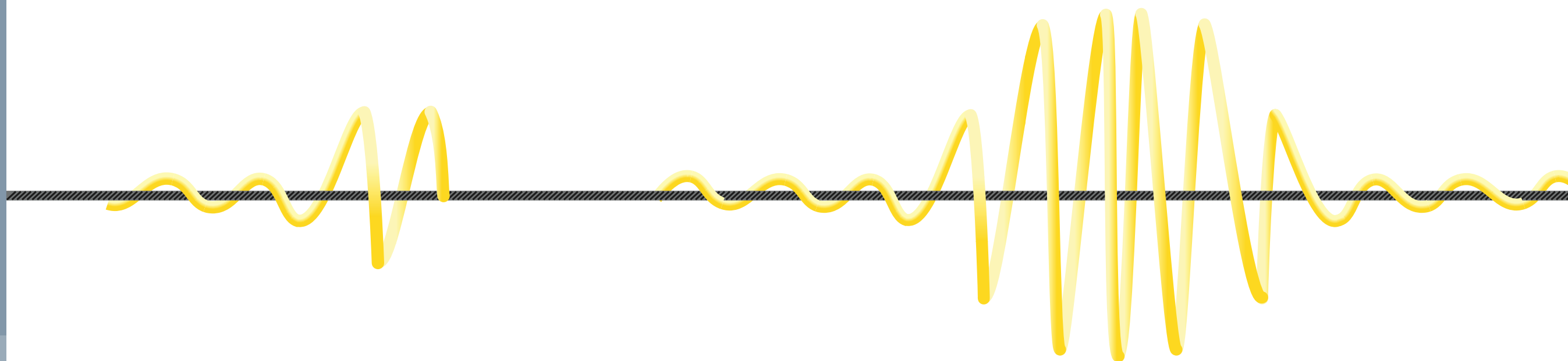
Overview

Flappers

Spirals

Illumination

Maximising line marker
efficiency



PVC spirals are one of the most popular devices for mitigation due to their ease of application, durability and lack of corona, or electrical discharge. Although static spirals tend to be outperformed by flappers in terms of collision prevention^{1,2,3}, their lack of moving parts makes them less prone to failure^{4,5}.

The effectiveness of spiral diverters varies depending on the species present, with most studies finding a reduction in collision mortality of c.30-80%^{1,2,5,6,7,8,9,10,11,12,13,14}, but some achieving reductions of over 90%^{15,16}, while another found no effect of spiral

markers on avoidance behaviour for most species on the north coast of Rio Grande do Sul, Brazil¹⁷. There is some evidence to suggest that spirals with a larger diameter placed at smaller intervals may achieve the greatest reductions in collision rate¹⁴.

COLLISION DETERRENTS

Overview

Flappers

Spirals

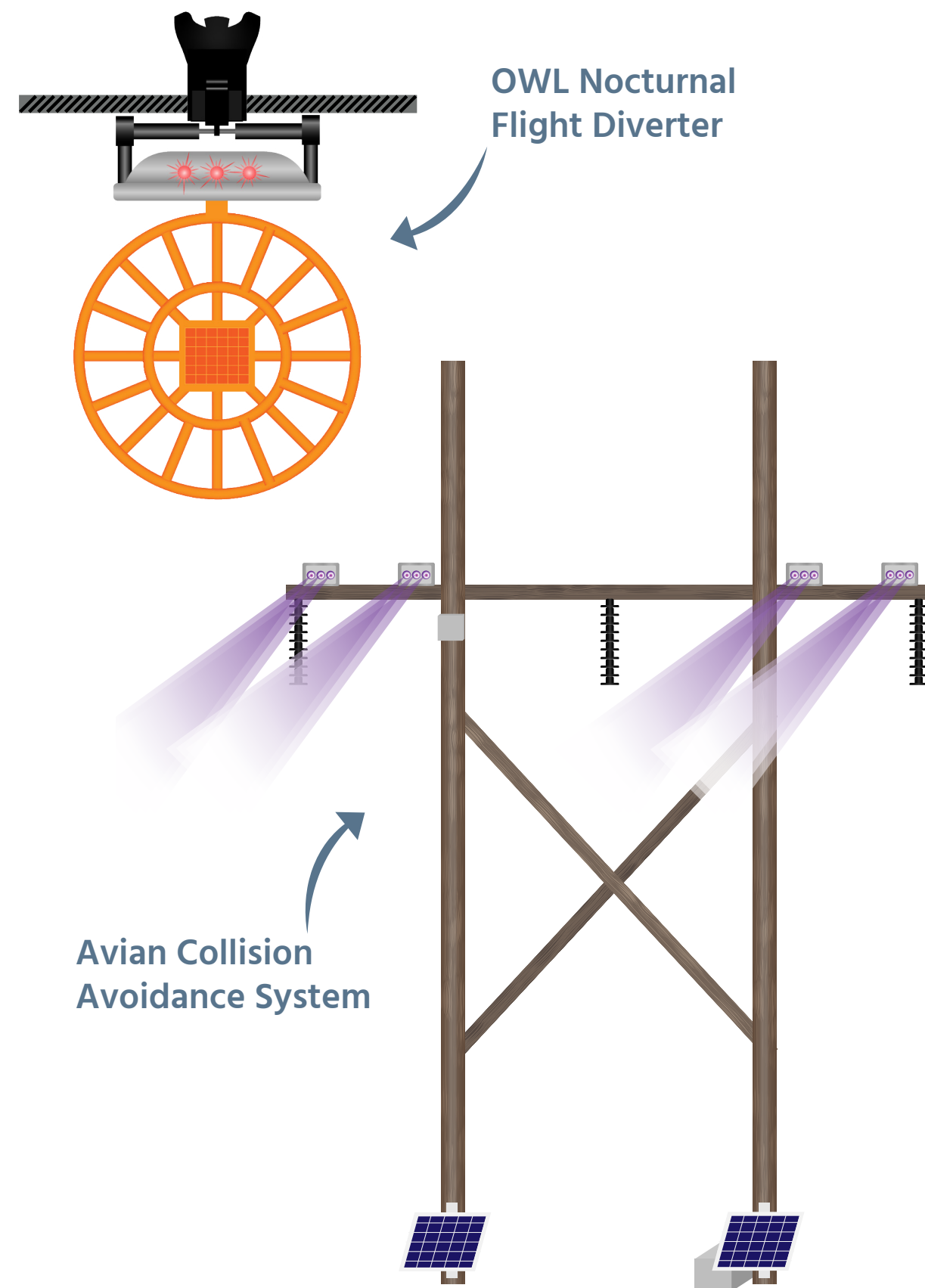
Illumination

Maximising line marker
efficiency

Although line markers appear to reduce collision risk in many situations, significant mortality may still occur, particularly in the case of species that fly at night or during other periods of low visibility. Murphy et al.^{1,2} recorded over 300 Sandhill Cranes colliding with a marked powerline crossing the Platte River in Nebraska, USA during a single spring migration. Further mitigation measures may be necessary in these situations.

Dwyer et al.³ designed and tested a new Avian Collision Avoidance System (ACAS) consisting of four solar-powered UV-A lights mounted on the crossarm of an H-frame support structure. Use of the ACAS on the span of powerline crossing the Platte River resulted in a 98% reduction in Sandhill Crane collisions and an 82% reduction in dangerous flight behaviour. The cost of using a system like this may make it infeasible for widespread use, however targeted use on high-risk spans (e.g. at migration bottlenecks) may be highly beneficial.

In South Africa, energy provider Eskom are trialling the 'OWL' Nocturnal Flight Diverter - a flapper equipped with solar-powered LEDs that flash to illuminate the lines at night. More research is needed to establish how effective they are, but Initial results are promising, with the devices appearing effective at reducing collisions of night-flying birds like Lesser and Greater Flamingos⁴.



COLLISION DETERRENTS

Overview

Flappers

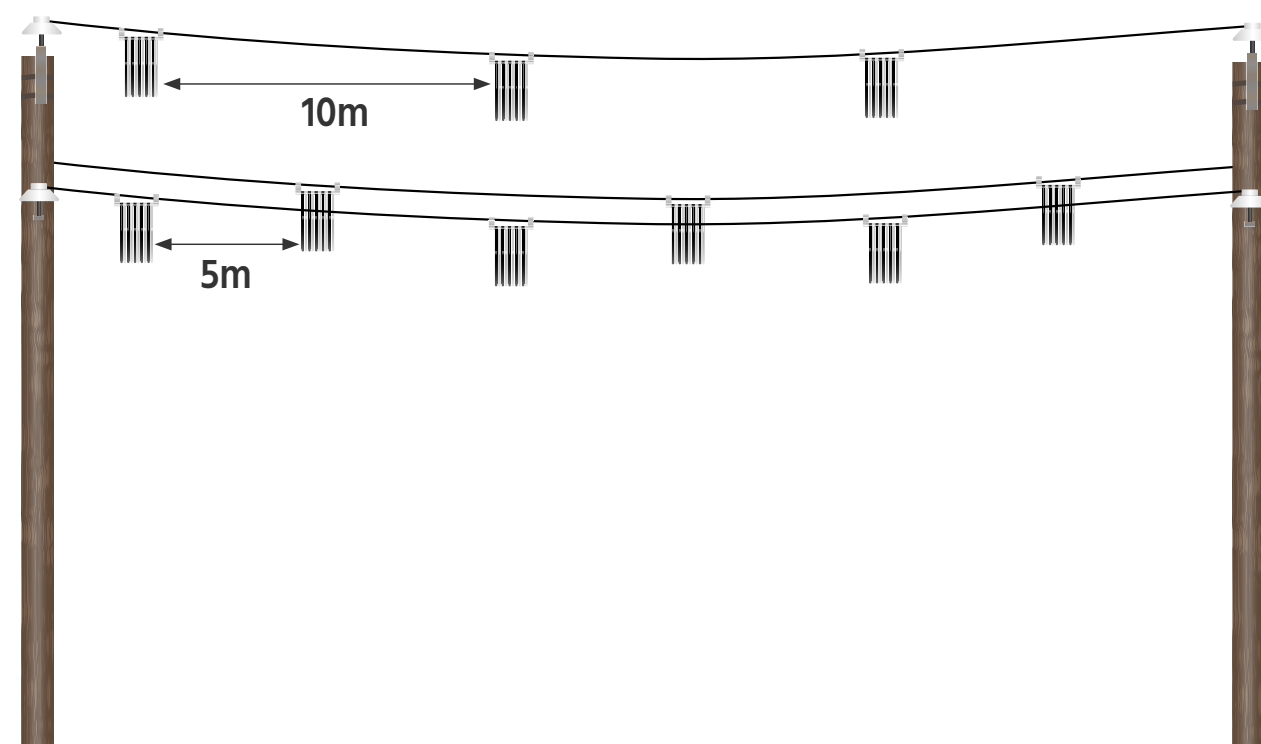
Spirals

Illumination

Maximising line marker
efficiency

There are a few simple rules to maximise efficiency of line marking.

1. Mark as many lines in a span as possible and **stagger line markers** with a maximum gap of 5-20 m between markers. If resources are limited, the upper most wire (usually the earth) should be prioritised for marking, as these are thinner and cause the majority of collisions



2. Use RIBE stripes (or similar design) on larger powerlines and the largest-available, most **mobile and contrasting flappers** on smaller distribution lines
3. When retrofitting, prioritise the **most dangerous spans** first
4. Use **durable devices**, able to withstand extreme weather conditions
5. Use **luminous devices** where possible
6. Trial **new technologies**, such as UV-A illumination, nocturnal flight diverters, Bird Strike Indicators and Bird Activity Monitors

RESTORE

Restoration of impacted ecosystems is often not feasible in the context of powerlines—as long as the powerline is present, it will pose a risk. However, work may be done to restore habitats damaged during construction of the powerline, or following the removal of an old powerline. The installation of powerlines in degraded landscapes with low ecological value, such as agricultural monocultures and brownfield sites, can also be used as an opportunity to restore these habitats, delivering significant positive biodiversity outcomes. Integrated Vegetation Management (IVM) can be used to create “green corridors” along powerline networks, providing connectivity within fragmented natural landscapes¹.

However, whilst habitat restoration can benefit sensitive bird species, it is important to avoid creating ecological traps in which collision- or electrocution-prone bird species are attracted to the area due to the high quality habitat but then suffer increased mortality due to the powerlines. For instance, if restoring natural habitat beneath powerlines increases raptor prey species this could ultimately result in increased raptor fatalities due to electrocution. To avoid this, restoration measures should always be combined with mitigation measures.

Restoring degraded habitats around powerlines can deliver positive biodiversity outcomes

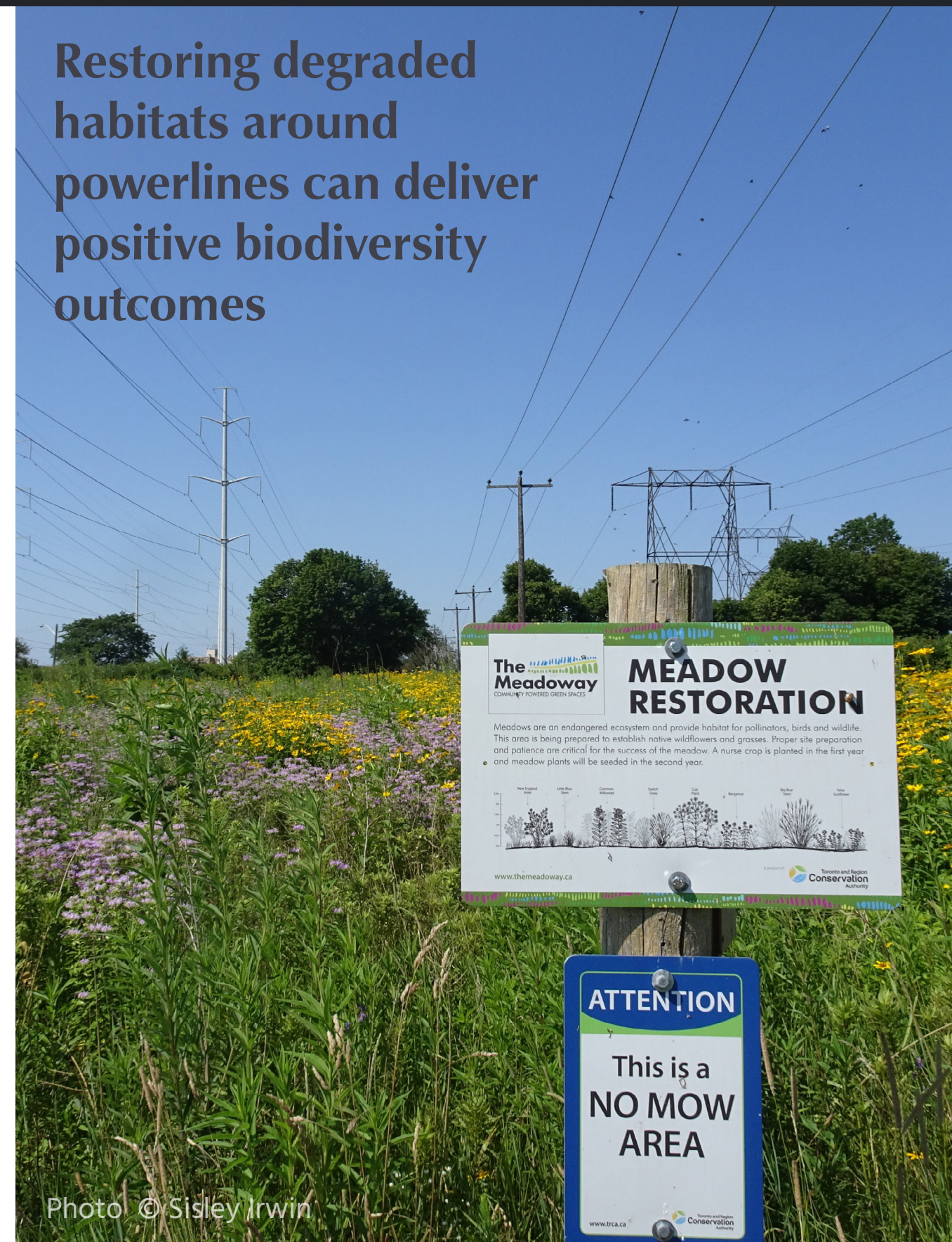


Photo © Sisley Irwin

OFFSET

Wherever possible, **avoidance** and **minimisation** options should be used to prevent significant impacts to biodiversity from powerlines. However, where this is not possible, biodiversity offsets may be necessary. Offsets aim to minimise the overall environmental impact of a project by compensating for the damage done to a species and/or habitat at the project site with conservation actions elsewhere. Offsets are often expensive and complex, and there is very limited evidence of their success¹, so they should be considered a last resort.

Offsets are generally divided into two types:

- ▶ **Restoration offsets** aim to remediate past damage to biodiversity at the offset site.
- ▶ **Avoided (or averted) loss offsets** generate biodiversity gains by protecting or maintaining existing biodiversity features that would otherwise be degraded.

To the best of our knowledge, there are currently no published assessments on the effectiveness of offsets for the impacts of powerlines on birds. A review of the overall effectiveness of biodiversity offsets found that

only one-third of offset schemes resulted in no net loss of biodiversity (but many used widely criticised methods to measure the impacts on biodiversity), and there was no evidence for the success of avoided loss offsets¹.

**Biodiversity offsets
should be considered
a last resort**



MONITORING

In order to progress our understanding of the relative effectiveness of mitigation measures, robust scientific studies need to be conducted to demonstrate superior methods. To reach a stage where we can provide evidence-based suggestions for the single-best mitigation option for a particular species in a particular environment, the testing of mitigation interventions will need to improve. Suggestions for monitoring can be found in Bernardino et al.¹

Some key recommendations to maximise the benefit of powerline monitoring are:

1. Monitor bird mortality with a systematic method before and after applying a range of mitigation devices, along with a control site (Before-After-Control-Impact approaches) e.g. Barrientos et al.²
2. Inform studies with an estimate of carcass persistence and searcher efficiency (see Barrientos et al.³)
3. Estimate bird-crossing rates along the powerline
4. Follow a standard survey schedule across seasons

5. Carry out monitoring at times of year when birds are most likely to use the area - e.g. during the breeding season or migration
6. Extrapolate results to un-surveyed spans
7. Contribute monitoring data to apps like **IUCN e-faunaalert**
8. Publish findings, for example in the open access **Conservation Evidence journal**, which will add to the knowledge pool and assist other practitioners implementing powerline mitigation
9. Continue long-term monitoring

**Robust scientific studies
are needed to identify
superior methods**



EVIDENCE LIBRARY

Welcome to the Evidence Library! Research has been carried out around the globe to test the effectiveness of different mitigation measures. Browse the Evidence Library to read short summaries of these studies. Click a summary to follow the web link to the full publication.



Click to browse the library by mitigation type, bird type, or region



**BROWSE BY
MITIGATION
TYPE**



**BROWSE BY
BIRD TYPE**



**BROWSE BY
REGION**

BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Demerdzhiev 2014</u>	Suspension insulators	Various, including storks, raptors & corvids	Bulgaria	Pole configurations with suspension insulators posed the lowest threat and rarely caused electrocution
<u>Dixon et al. 2013</u>	Jump wire configuration	Raptors	Mongolia	Significantly fewer electrocutions at poles with jump wires passing under the crossarm than those with jump wires passing over the crossarm
<u>Dixon et al. 2017</u>	Reconfiguration of jump wires to pass under crossarm at two phases	Raptors & corvids	Mongolia	16-fold reduction in electrocution mortality
<u>Dixon et al. 2018</u>	Top phase pin insulator moved to top of pole. Unconnected pin insulators placed on crossarm next to connected insulators	Raptors & corvids	Mongolia	85% reduction in electrocution mortality
<u>Dixon et al. 2019</u>	Top phase pin insulator moved to top of pole	Various, including raptors & corvids	Mongolia	73% reduction in electrocution mortality

BROWSE BY:
MITIGATION
METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
Guil et al. 2021	Type of strain insulator	Raptors	Spain	Differences in strain insulator configuration increased estimated electrocution risk up to 12-fold. Strain insulators with the longest insulating section pose the lowest risk
Kaługa et al. 2011	Fitting of isolators and disconnectors	White Stork	Poland	100% reduction in electrocution mortality
López-López et al. 2011	Suspension insulators and jump wires below crossarm	Spanish Imperial Eagle	Spain	97% reduction in electrocution mortality in Doñana population. 62% reduction in electrocution mortality in Andalusian population
Tintó et al. 2010	Substitution of dangerous pylons with new design - alternate crossarms, suspended jump wires and insulators, isolation of conductive parts	Various, including raptors & corvids	Spain	Significant fall in electrocution mortality (from 29 birds to 0 birds)

BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Chevallier et al. 2015</u>	Insulation	Bonelli's Eagle	France	Reduction in electrocution mortality from 56% to 14% in juveniles, 52% to 27% in immature individuals and 13% to 0% in adults
<u>Dixon et al. 2019</u>	1. Insulation of top phase conductor and pin-insulator cap 2. Insulation of lower two phase conductors	Various	Mongolia	1. 59% reduction in electrocution mortality 2. 66% reduction in electrocution mortality
<u>Dwyer & Mannan 2007</u>	All differentially energised hardware <60cm apart insulated	Harris Hawk	USA	Number of electrocutions per nest decreased from 1.4 to 0.2
<u>Janss & Ferrer 1999</u>	Crossarm insulation, pin insulator cap, jump wire insulation	Raptors	Spain	All insulation types reduced electrocution mortality significantly. Combination of perch guard over pin insulator and insulation of jump wire reduced mortality by 95%
<u>Lehman et al. 2010</u>	Jump wire insulation, bushing covers	Raptors, including Golden Eagle	USA	47% reduction in electrocution mortality (perch deterrents used alongside insulation)
<u>Matsyna et al. 2010</u>	Phase conductor insulation	Various	Russia	Reduction in electrocution mortality from 58 birds of 17 species to 1 bird.

BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Dixon et al. 2013</u>	Perch deterrent spikes	Raptors	Mongolia & China	Significantly fewer electrocution mortalities at poles fitted with functional spikes
<u>Dixon et al. 2017</u>	Perch deterrent spikes	Raptors & corvids	Mongolia	50% reduction in electrocution at poles with 3 or 4 spikes
<u>Dixon et al. 2019</u>	1. Rotating mirror perch deterrent 2. Brush perch deterrent	Various	Mongolia	1. 91% reduction in electrocution mortality 2. No significant effect on electrocution mortality
<u>Dwyer & Doloughan 2014</u>	Pole cap, insulator deterrent, shroud, perch deterrent spikes	Raptors & corvids	USA	Perch deterrent spikes were most effective at preventing perching
<u>Dwyer & Leiker 2012</u>	H-frame nest diverter	Chihuahuan Raven	USA	Less nest material placed and no nesting on structures with nest diverters
<u>Ferrer & Hiraldo 1991</u>	Supplementary perch	Spanish Imperial Eagle	Spain	No significant effect on electrocution mortality

BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Janss & Ferrer</u> <u>1999</u>	Perch deterrent spikes, double curved steel bar perch deterrent, insulator deterrent, supplementary perch	Raptors	Spain	In flight enclosure: on poles with suspension insulators, unsafe perching was reduced from 43% to 10% using the double curved steel bar perch deterrent, and 55% to 15% using perch-deterrent spikes. Supplementary peches had no significant effect on unsafe perching. In field: combination of perch guard over pin insulator and insulation of jump wire reduced mortality by 95%
<u>Kolnegari et al.</u> <u>2020</u>	Nest boxes	Eurasian Kestrel	Iran	Rate of electrocution per kestrel nest decreased from 0.33 to 0.19 (although total number of kestrel electrocutions increased). Electrocution mortality for all birds declined by 58%. Number of electrical faults also decreased.
<u>Lammers & Collopy</u> 2010	Inverted Y perch deterrent + steel plate perch deterrent	Raptors & corvids	USA	Small decline in perching frequency and reduction in perch duration on structures with deterrents

◀ Previous

Next ▶

BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

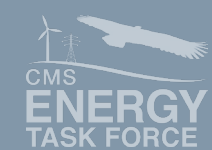
Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Lehman et al. 2010</u>	Triangle perch deterrent + perch deterrent spikes	Raptors, including Golden Eagle	USA	47% reduction in electrocution mortality (perch deterrents used alongside jump wire insulation and bushing covers)
<u>Orihuela-Torres et al. 2021</u>	Brush perch deterrent	Raptors & corvids	Mongolia	No significant effect on electrocution mortality
<u>Prather & Messmer 2010</u>	FireFly hazing deterrent, cones, triangles, perch deterrent spikes	Raptors & corvids	USA	Perch deterrents did not affect perching frequency on the structure overall , but birds did avoid the deterrents and instead perched on other parts of the structure
<u>Sanchez et al. 2020</u>	Supplementary perch	Raptors	Portugal	For most species perceived risk was lower for poles with supplementary perches, but use of perches varied between species.
<u>Slater & Smith 2010</u>	Perch deterrent spikes	Raptors & Common Raven	USA	Raptor activity significantly lower at the line fitted with deterrents than the control line (42 perching events on pylons seen on deterrent line, 551 on control line)
<u>Tincher et al. 2020</u>	X-shaped perch deterrent	Great Horned Owl & Red-tailed Hawk	USA	Preliminary results suggest perch deterrents were effective at preventing perching directly below the deterrent

◀ Previous



BROWSE BY:
MITIGATION
METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

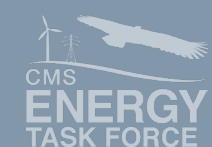
Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Bevanger & Brøseth 2001</u>	Removal of earth wire	Rock Ptarmigan & Willow Ptarmigan	Norway	51% reduction in collision mortality
<u>Brown et al. 1985</u>	Removal of earth wire + thickening of earth wire	Cranes & waterfowl, including Sandhill Crane & Whooping Crane	USA	>80% reduction in crane collision mortality after removal of earth wire. Thickening the earth wire had no effect on collision rate.
<u>Marques et al. 2020</u>	Number of wire levels	Great Bustard & Little Bustard	Portugal	Taller pylons and those with more wire levels posed a higher risk for both species



BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Alonso et al.</u> <u>1994</u>	Spiral	Various, including cranes, storks & bustards	Spain	60% reduction in collision mortality
Anderson 2002	Spiral + flapper	Various, including Ludwig's Bustard & Blue Crane	South Africa	67% reduction in collision mortality after marking with spirals (although fewer cranes & bustards in area during post-marking period due to dry weather). Adding flappers alongside spirals further reduced bird mortality by 52%. Flappers were more effective than spirals at preventing collision, particularly for Blue Crane
<u>Barrientos et al.</u> <u>2011</u> (Meta-analysis)	Various collision deterrents	Various	Global	Mortality rate 78% lower at marked lines
<u>Barrientos et al.</u> <u>2012</u>	Spiral	Various, including bustards & sandgrouse	Spain	47% reduction in carcasses found after marking. After taking into account detection bias, 9.6% reduction in estimated mortality
<u>Bernandino et al.</u> <u>2019</u> (Meta-analysis)	Various collision deterrents	Various	Global	Line marking reduced collisions by 50.4%

Next ►

BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Biasotto et al. 2017</u>	Spiral	Various	Brazil	No significant change in flight behaviour at marked sections, except for Hirundines
<u>Brown & Drewien 1995</u>	1. Spiral 2. Flapper	Various, including cranes & waterfowl	USA	1. 61% reduction in mortality rate at marked sections (but considerable seasonal variation) 2. 63% reduction in mortality rate at marked sections (but considerable seasonal variation)
Crowder 2000	Spiral	Various	USA	'Pigtail' spiral reduced casualty rate by 73%. Swan-flight diverter reduced casualty rate by 37.5%
<u>De la Zerda & Roselli 2003</u>	Spiral	Various, including nightflying rallids, herons & ducks	Colombia	50% reduction in collision mortality at marked lines
<u>Deutschova et al. 2020</u>	Spiral + flapper	Various, including raptors & waterfowl	Slovakia	94% reduction in mortality and increased reaction distance after marking
<u>Dwyer et al. 2019</u>	UV illumination	Sandhill Crane	USA	98% reduction in collision, and 82% reduction in dangerous flights

◀ Previous

Next ▶

BROWSE BY:
MITIGATION
METHOD

- Pole reconfiguration
- Insulation
- Nest & perch diversion
- Power line reconfiguration
- Collision deterrents

Click an author to follow the web link to the full publication.



[Back to evidence library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Ferrer et al. 2020</u>	Spiral + flapper	Various	Spain	Overall 52% reduction in collision mortality at marked lines. Flapper most effective (70% reduction in mortality), followed by orange spiral (44%) and yellow spiral (40%)
<u>Frost 2008</u>	Spiral	Mute Swan	UK	95% reduction in collision mortality
<u>Galis & Sevcik 2019</u>	Spiral + flapper	Various, including waterbirds	Slovakia	93.5% reduction in collision mortality. RIBE flight diverters associated with highest number of positive reactions
<u>Janss & Ferrer 1998</u>	Spiral, neoprene bands + thin black plastic stripes	Various, including cranes & bustards	Spain	Spiral most effective (81% reduction in collision mortality), followed by neoprene bands (76% reduction, but not effective for Great Bustard). Black plastic strips ineffective.
<u>Koops & de Jong 1982</u>	Spiral	Various	Netherlands	Small spirals at 5m intervals most effective (86-89% reduction in collision mortality), followed by large spirals at 15m intervals (65-74% reduction), then small spirals at 10m intervals (57-58% reduction)

BROWSE BY: MITIGATION METHOD

Pole reconfiguration

Insulation

Nest & perch diversion

Power line
reconfiguration

Collision deterrents

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Mitigation	Species	Country	Results
<u>Marques et al. 2020</u>	Spiral + flapper	Great Bustard & Little Bustard	Portugal	Line marking associated with a small but significant reduction in collision risk for Little Bustard. No effect for Great Bustard (possibly due to limited data)
<u>Morkill & Anderson 1991</u>	Aviation ball	Sandhill Crane	USA	54% reduction in collision mortality
<u>Murphy et al. 2016</u>	Spiral, flapper + aviation ball	Sandhill Crane	USA	Greater reaction distances and more gradual avoidance behaviour at lines marked with flappers and spirals compared to aviation balls
<u>Murphy et al. 2009</u>	Flapper	Sandhill Crane	USA	c. 50-66% reduction in collision mortality after installation of flappers
<u>Pavon-Jordan et al. 2020</u>	Spiral	Various	Norway	Higher flight altitude, greater reaction distance and fewer abrupt turns at marked sections of line
Pretorius, Leeuwner & Hoogstad 2017	OWL Nocturnal Bird Diverter	Various, including Lesser and Greater Flamingo and Blue Crane	South Africa	Mortality generally lower under spans marked with OWL devices than those marked with traditional line markers or unmarked, but insufficient data to confidently state effectiveness

◀ Previous

Next ▶

BROWSE BY:
MITIGATION
METHOD

- Pole reconfiguration
- Insulation
- Nest & perch diversion
- Power line reconfiguration
- Collision deterrents

Click an author to follow the web link to the full publication.



[Back to evidence library home](#)

Author & year	Mitigation	Species	Country	Results
Raab et al. 2012	Aviation ball + flapper	Various, including Great Bustard	Austria/Hungary	Bustard collisions significantly lower at marked line sections
Savereno et al. 1996	Aviation ball	Various	USA	53% reduction in collision mortality
Shaw et al. 2021	Spiral + flapper	Various, including Blue Crane & Ludwig’s Bustard	South Africa	51% reduction in collision mortality for all large birds, including 92% reduction for Blue Cranes. No effect on bustards
Sporer et al. 2013	Spiral + flapper	Waterbirds	USA	29% reduction in collision mortality. Birds with high-aspect-ratio wings (e.g. shorebirds and gulls) benefitted most
Ventana Wildlife Society 2009	Spiral	Waterbirds, including geese & Sandhill Crane	USA	‘Pigtail’ spiral reduced estimated collisions by 48%. Swan-flight diverters reduced estimated collisions by 38%. Both devices ineffective for American Coot
Yee 2008	Flapper	Various, including Sandhill Crane & large waterfowl	USA	60% reduction in collision mortality. Collision frequency also reduced on spans neighbouring marked spans

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

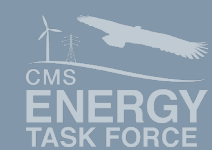
Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
Anderson 2002	Ludwig's Bustard & Blue Crane	South Africa	Line marking with spirals and flappers	67% reduction in collision mortality after marking with spirals (although fewer cranes & bustards in area during post-marking period due to dry weather). Adding flappers alongside spirals further reduced bird mortality by 52%. Flappers were more effective than spirals at preventing collision, particularly for Blue Crane
<u>Barrientos et al. 2012</u>	Various, including Great Bustard & Little Bustard	Spain	Line marking with spirals	47% reduction in carcasses found after marking. After taking into account detection bias, 9.6% reduction in estimated mortality. Large spirals more effective than smaller spirals for Great Bustard
<u>Janss & Ferrer 1998</u>	Various, including Great Bustard & Little Bustard	Spain	Line marking with spirals, neoprene bands or thin black plastic strips	Spiral most effective (81% reduction in collision mortality), followed by neoprene bands (76% reduction, but not effective for Great Bustard). Black plastic strips ineffective



BROWSE BY:
BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Marques et al. 2020</u>	Great Bustard & Little Bustard	Portugal	Line marking with spirals or flappers	Line marking associated with a small but significant reduction in collision risk for Little Bustard. No effect for Great Bustard (possibly due to limited data). Collisions more likely to occur at sections of powerline with taller pylons, more wire levels, and >20% (for Little Bustard) or 50% (for Great Bustard) of open farmland habitat in the surroundings
<u>Raab et al. 2012</u>	Various, including Great Bustard	Austria/Hungary	Line marking with aviation balls or flappers & burying powerlines	Bustard collisions significantly lower at marked line sections. Collision mortality declined significantly with increasing length of underground cabling
<u>Shaw et al 2021</u>	Various, including Ludwig’s Bustard	South Africa	Line marking with spirals or flappers	51% reduction in collision mortality for all large birds, but no effect on bustards

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
Anderson 2002	Blue Crane & Ludwig's Bustard	South Africa	Line marking with spirals and flappers	67% reduction in collision mortality after marking with spirals (although fewer cranes & bustards in area during post-marking period due to dry weather). Adding flappers alongside spirals further reduced bird mortality by 52%. Flappers were more effective than spirals at preventing collision, particularly for Blue Crane
<u>Brown & Drewien 1995</u>	Various, including Sandhill Crane	USA	Line marking with spirals or flappers	61% reduction in mortality rate at sections marked with spirals, 63% at sections marked with flappers, including reduction in crane collisions (but considerable seasonal variation)
<u>Brown et al. 1985</u>	Sandhill Crane and Whooping Crane	USA	Removal of earth wire and thickening of earth wire	>80% reduction in crane collision mortality after removal of earth wire. Thickening the earth wire had no effect on collision rate.
<u>Dwyer et al. 2019</u>	Sandhill Crane	USA	USA	98% reduction in collision, and 82% reduction in dangerous flights
<u>Janss & Ferrer 1998</u>	Various, including Common Crane	Spain	Line marking with spirals, neoprene bands or thin black plastic strips	Spiral most effective (81% reduction in collision mortality, including reduction in crane collisions), followed by neoprene bands (76% reduction). Black plastic strips ineffective

Next ►

BROWSE BY:
BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Morkill & Anderson 1991</u>	Sandhill Crane	USA	Line marking with aviation balls	54% reduction in collision mortality
<u>Murphy et al. 2009</u>	Sandhill Crane	USA	Line marking with flappers	c. 50-66% reduction in collision mortality after installation of flappers
<u>Murphy et al. 2016</u>	Sandhill Crane	USA	Line marking with spirals, flappers or aviation balls	Greater reaction distances and more gradual avoidance behaviour at lines marked with flappers and spirals compared to aviation balls
Pretorius, Leeuwner & Hoogstad 2017	Various, including Lesser and Greater Flamingo and Blue Crane	South Africa	OWL Nocturnal Bird Diverter	Mortality generally lower under spans marked with OWL devices than those marked with traditional line markers or unmarked, but insufficient data to confidently state effectiveness
<u>Shaw et al. 2021</u>	Various, including Blue Crane	South Africa	Line marking with spirals or flappers	51% reduction in collision mortality for all large birds, including 92% reduction for Blue Cranes.
<u>Yee 2008</u>	Various, including Sandhill Crane	USA	Line marking with flappers	60% reduction in collision mortality. Collision frequency also reduced on spans neighbouring marked spans

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

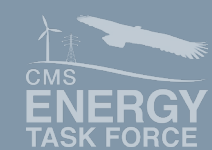
Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Brown & Drewien 1995</u>	Waterfowl and cranes	USA	Line marking with spirals or flappers	61% reduction in mortality rate at sections marked with spirals, 63% at sections marked with flappers (but considerable seasonal variation)
<u>De la Zerda & Roselli 2003</u>	Nightflying rallids, herons and ducks	Colombia	Line marking with spirals	50% reduction in collision mortality at marked lines
<u>Frost 2008</u>	Mute Swan	UK	Line marking with spirals	95% reduction in collision mortality
<u>Galis & Sevcik 2019</u>	Various, mostly waterbirds	Slovakia	Line marking with spirals or flappers	93.5% reduction in collision mortality. RIBE flight diverters associated with highest number of positive reactions
<u>Sporer et al. 2013</u>	Various waterbirds	USA	Line marking with spirals or flappers	29% reduction in collision mortality. Birds with high-aspect-ratio wings (e.g. shorebirds and gulls) benefitted most
<u>Ventena Wildlife Society 2009</u>	Various waterbirds	USA	Line marking with spirals	'Pigtail' spiral reduced estimated collisions by 48%. Swan-flight diverters reduced estimated collisions by 38%. Both devices ineffective for American Coot



BROWSE BY:
BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Barrientos et al.</u> <u>2012</u>	Various, including sandgrouse	Spain	Line marking with spirals	47% reduction in carcasses found after marking. After taking into account detection bias, 9.6% reduction in estimated mortality.
<u>Bevanger and Brøseth</u> 2001	Rock Ptarmigan & Willow Ptarmigan	Norway	Removal of earth wire	51% reduction in collision mortality

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Chevallier et al. 2015</u>	Bonelli's Eagle	France	Insulation	Reduction in electrocution mortality from 56% to 14% in juveniles, 52% to 27% in immature individuals and 13% to 0% in adults
<u>Demerdzhiev 2014</u>	Various, including raptors & corvids	Bulgaria	Pole reconfiguration - insulator configuration	Pole configurations with suspension insulators posed the lowest threat and rarely caused electrocution
<u>Dixon et al. 2013</u>	Raptors	Mongolia	Perch deterrents and jump wire reconfiguration	Significantly fewer electrocution mortalities at poles fitted with functional spikes and at poles with jump wires passing under the crossarm
<u>Dixon et al. 2017</u>	Raptors & corvids	Mongolia	Perch deterrents and jump wire reconfiguration	50% reduction in electrocution at poles with 3 or 4 spikes. Reconfiguration of jump wires associated with 16-fold reduction in electrocution mortality
<u>Dixon et al. 2018</u>	Raptors & corvids	Mongolia	Pole reconfiguration - insulator reconfiguration	85% reduction in electrocution mortality

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Dixon et al. 2019</u>	Various, including raptors & corvids	Mongolia	Insulation, perch deterrents & insulator reconfiguration	Reconfiguring the top insulator, insulating the top phase, insulating the bottom two phases, and using rotating mirror perch deterrents reduced mortality by 73%, 59%, 66% & 91% respectively. Brush perch deterrents had no significant effect.
<u>Dwyer & Doloughan 2014</u>	Raptors & corvids	USA	Perch deterrents	Perch deterrent spikes were most effective at preventing perching
<u>Dwyer & Leiker 2012</u>	Chihuahuan Raven	USA	H-frame nest diverter	Less nest material placed and no nesting on structures with nest diverters
<u>Dwyer & Mannan 2007</u>	Harris Hawk	USA	Insulation	Number of electrocutions per nest decreased from 1.4 to 0.2
<u>Ferrer & Hiraldo 1991</u>	Spanish Imperial Eagle	Spain	Line burial, insulation and supplementary perches	Survival of juveniles in their first 6 months increased from 17.6% to 80%. Supplementary perches had no significant effect.
<u>Guil et al. 2021</u>	Raptors	Spain	Pole reconfiguration - type of strain insulator	Differences in strain insulator configuration increased estimated electrocution risk up to 12-fold. Strain insulators with the longest insulating section pose the lowest risk

◀ Previous

Next ▶

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Janss & Ferrer 1999</u>	Various, including raptors	Spain	Insulation & perch diversion	<p>In flight enclosure: on poles with suspension insulators, unsafe perching was reduced from 43% to 10% using the double curved steel bar perch deterrent, and 55% to 15% using perch-deterrent spikes. Supplementary peches had no significant effect on unsafe perching.</p> <p>In field: All insulation types reduced electrocution mortality significantly. Combination of perch guard over pin insulator and insulation of jump wire reduced mortality by 95%</p>
<u>Kolnegari et al. 2020</u>	Eurasian Kestrel	Iran	Nest boxes	Rate of electrocution per kestrel nest decreased from 0.33 to 0.19 (although total number of kestrel electrocutions increased). Electrocution mortality for all birds declined by 58%. Number of electrical faults also decreased.
<u>Lammers & Collopy 2010</u>	Raptors & corvids	USA	Perch deterrents	Small decline in perching frequency and reduction in perch duration on structures with deterrents

◀ Previous

Next ▶

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.

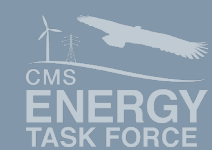


[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Lehman et al. 2010</u>	Raptors & corvids	USA	Perch diversion & insulation	47% decrease in electrocution mortality
<u>López-López et al., 2011</u>	Spanish Imperial Eagle	Spain	Pole reconfiguration - Suspension insulators and jump wires below crossarm	97% reduction in electrocution mortality in Doñana population. 62% reduction in electrocution mortality in Andalusian population
<u>Matsyna et al. 2010</u>	Various, including raptors & corvids	Russia	Insulation	Reduction in electrocution mortality from 58 birds of 17 species to 1 bird
<u>Orihuela-Torres et al. 2021</u>	Various, including raptors & corvids	Mongolia	Perch deterrent	Brush perch deterrent had no significant effect on electrocution mortality
<u>Prather & Messmer 2010</u>	Raptors & corvids	USA	Perch deterrent	Perch deterrents did not affect perching frequency on the structure overall , but birds did avoid the deterrents and instead perched on other parts of the structure
<u>Sanchez et al. 2020</u>	Raptors	Portugal	Supplementary perch	For most species perceived risk was lower for poles with supplementary perches, but use of perches varied between species

◀ Previous

Next ▶



BROWSE BY:
BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Slater & Smith 2010</u>	Raptors & Common Raven	USA	Perch deterrent spikes	Raptor activity significantly lower at the line fitted with deterrents than the control line (42 perching events on pylons seen on deterrent line, 551 on control line)
<u>Tincher et al. 2020</u>	Raptors	USA	Perch deterrent	Preliminary results suggest perch deterrents were effective at preventing perching directly below the deterrent
<u>Tinto et al. 2010</u>	Various, including raptors & corvids	Spain	Pole reconfiguration - crossarm, jump wire & insulator reconfiguration	Significant fall in electrocution mortality (from 29 birds to 0 birds)

BROWSE BY: BIRD TYPE

Bustards

Cranes

Waterfowl

Grouse

Raptors & corvids

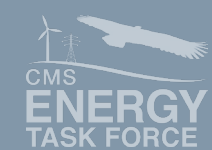
Storks

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Species	Country	Mitigation	Results
<u>Demerdzhiev</u> <u>2014</u>	Various, including White Stork & Black Stork	Bulgaria	Pole reconfiguration - insulator configuration	Pole configurations with suspension insulators posed the lowest threat and rarely caused electrocution
<u>Janss & Ferrer</u> <u>1999</u>	Various, including White Stork	Spain	Insulation & perch diversion	All insulation types reduced electrocution mortality significantly. Combination of perch guard over pin insulator and insulation of jump wire reduced mortality by 95%
<u>Kaługa et al. 2011</u>	White Stork	Poland	Fitting of isolators and disconnectors	100% reduction in electrocution mortality



BROWSE BY:
REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
Anderson 2002	South Africa	Ludwig’s Bustard & Blue Crane	Line marking with spirals & flappers	67% reduction in collision mortality after marking with spirals (although fewer cranes & bustards in area during post-marking period due to dry weather). Adding flappers alongside spirals further reduced bird mortality by 52%. Flappers were more effective than spirals at preventing collision, particularly for Blue Crane
Pretorius, Leeuwner & Hoogstad 2017	South Africa	Various, including Lesser and Greater Flamingo and Blue Crane	OWL Nocturnal Bird Diverter	Mortality generally lower under spans marked with OWL devices than those marked with traditional line markers or unmarked, but insufficient data to confidently state effectiveness
<u>Shaw et al. 2021</u>	South Africa	Ludwig’s Bustard & Blue Crane	Line marking with spirals or flappers	51% reduction in collision mortality for all large birds, including 92% reduction for Blue Cranes. No effect on bustards

BROWSE BY: REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Biasotto et al. 2017</u>	Brazil	Various	Line marking with spirals	No significant change in flight behaviour at marked sections, except for Hirundines
<u>Brown & Drewien 1995</u>	USA	Waterfowl and cranes	Line marking with spirals or flappers	61% reduction in mortality rate at sections marked with spirals, 63% at sections marked with flappers (but considerable seasonal variation)
<u>Brown et al. 1985</u>	USA	Sandhill Crane and Whooping Crane	Removal of earth wire and thickening of earth wire	>80% reduction in crane collision mortality after removal of earth wire. Thickening the earth wire had no effect on collision rate.
Crowder 2000	USA	Various	Line marking with spirals	'Pigtail' spiral reduced casualty rate by 73%. Swan-flight diverter reduced casualty rate by 37.5%
<u>De la Zerda & Roselli 2003</u>	Colombia	Nightflying rallids, herons & ducks	Line marking with spirals	50% reduction in collision mortality at marked lines
<u>Dywer & Doloughan 2014</u>	USA	Raptors & corvids	Perch deterrents	Perch deterrent spikes were most effective at preventing perching
<u>Dwyer & Leiker 2012</u>	USA	Chihuahuan Raven	H-frame nest diverter	Less nest material placed and no nesting on structures with nest diverters

Next ►

BROWSE BY: REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Dwyer & Mannan 2007</u>	USA	Harris Hawk	Insulation	Number of electrocutions per nest decreased from 1.4 to 0.2
<u>Dwyer et al. 2019</u>	USA	Sandhill Crane	UV illumination	98% reduction in collision, and 82% reduction in dangerous flights
<u>Lammers & Collopy 2010</u>	USA	Raptors & corvids	Perch deterrents	Small decline in perching frequency and reduction in perch duration on structures with deterrents
<u>Lehman et al 2010</u>	USA	Raptors & corvids	Perch diversion & insulation	47% decrease in electrocution mortality
<u>Morkill & Anderson 1991</u>	USA	Sandhill Crane	Line marking with aviation balls	54% reduction in collision mortality
<u>Murphy et al. 2009</u>	USA	Sandhill Crane	Line marking with flappers	c. 50-66% reduction in collision mortality after installation of flappers
<u>Murphy et al. 2016</u>	USA	Sandhill Crane	Line marking with spirals, flappers or aviation balls	Greater reaction distances and more gradual avoidance behaviour at lines marked with flappers and spirals compared to aviation balls
<u>Prather & Messmer 2010</u>	USA	Raptors & corvids	Perch deterrent	Perch deterrents did not affect perching frequency on the structure overall , but birds did avoid the deterrents and instead perched on other parts of the structure

◀ Previous

Next ▶

BROWSE BY: REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Savereno et al. 1996</u>	USA	Various	Line marking with aviation balls	53% reduction in collision mortality
<u>Slater & Smith 2010</u>	USA	Raptors & Common Raven	Perch deterrent spikes	Raptor activity significantly lower at the line fitted with deterrents than the control line (42 perching events on pylons seen on deterrent line, 551 on control line)
<u>Sporer et al. 2013</u>	USA	Various waterbirds	Line marking with spirals or flappers	29% reduction in collision mortality. Birds with high-aspect-ratio wings (e.g. shorebirds and gulls) benefitted most
<u>Tincher et al. 2020</u>	USA	Raptors	Perch deterrent	Preliminary results suggest perch deterrents were effective at preventing perching directly below the deterrent
<u>Ventena Wildlife Society 2009</u>	USA	Various waterbirds	Line marking with spirals	'Pigtail' spiral reduced estimated collisions by 48%. Swan-flight diverters reduced estimated collisions by 38%. Both devices ineffective for American Coot
<u>Yee 2008</u>	USA	Various, including Sandhill Crane	Line marking with flappers	60% reduction in collision mortality. Collision frequency also reduced on spans neighbouring marked spans

◀ Previous

BROWSE BY: REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Dixon et al. 2013</u>	Mongolia	Raptors	Perch deterrents and jump wire reconfiguration	Significantly fewer electrocution mortalities at poles fitted with functional spikes and at poles with jump wires passing under the crossarm
<u>Dixon et al. 2017</u>	Mongolia	Raptors & corvids	Perch deterrents and jump wire reconfiguration	50% reduction in electrocution at poles with 3 or 4 spikes. Reconfiguration of jump wires associated with 16-fold reduction in electrocution mortality
<u>Dixon et al. 2018</u>	Mongolia	Raptors & corvids	Pole reconfiguration - insulator reconfiguration	85% reduction in electrocution mortality
<u>Dixon et al. 2019</u>	Mongolia	Various, including raptors & corvids	Insulation, perch deterrents & insulator reconfiguration	Reconfiguring the top insulator, insulating the top phase, insulating the bottom two phases, and using rotating mirror perch deterrents reduced mortality by 73%, 59%, 66% & 91% respectively. Brush perch deterrents had no significant effect.
<u>Orihuela-Torres et al. 2021</u>	Mongolia	Various, including raptors & corvids	Perch deterrent	Brush perch deterrent had no significant effect on electrocution mortality

BROWSE BY: REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Alonso et al. 1994</u>	Spain	Various, including cranes, storks & bustards	Line marking with spirals	60% reduction in collision mortality
<u>Barrientos et al. 2012</u>	✓ Spain	Various, including bustards & sandgrouse	Line marking with spirals	47% reduction in carcasses found after marking. After taking into account detection bias, 9.6% reduction in estimated mortality
<u>Bevanger and Brøseth 2001</u>	Norway	Rock Ptarmigan & Willow Ptarmigan	Removal of earth wire	51% reduction in collision mortality
<u>Chevallier et al. 2015</u>	France	Bonelli's Eagle	Insulation	Reduction in electrocution mortality from 56% to 14% in juveniles, 52% to 27% in immature individuals and 13% to 0% in adults
<u>Demerdzhiev 2014</u>	Bulgaria	Various, including storks, raptors & corvids	Pole reconfiguration - suspension insulators	Pole configurations with suspension insulators posed the lowest threat and rarely caused electrocution
<u>Deutschova et al. 2020</u>	Slovakia	Various, including raptors & waterfowl	Line marking with spirals + flappers	94% reduction in mortality and increased reaction distance after marking

Next ►

BROWSE BY: REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Ferrer & Hiraldo</u> 1991	Spain	Spanish Imperial Eagle	Line burial, insulation and supplementary perches	Survival of juveniles in their first 6 months increased from 17.6% to 80%. Supplementary perches had no significant effect
<u>Ferrer et al. 2020</u>	Spain	Various	Line marking with spirals or flappers	Overall 52% reduction in collision mortality at marked lines. Flapper most effective (70% reduction in mortality), followed by orange spiral (44%) and yellow spiral (40%)
<u>Frost 2008</u>	UK	Mute Swan	Line marking with spirals	95% reduction in collision mortality
<u>Galis & Sevcik</u> 2019	Slovakia	Various, mostly waterbirds	Line marking with spirals or flappers	93.5% reduction in collision mortality. RIBE flight diverters associated with highest number of positive reactions
<u>Kaługa et al. 2011</u>	Poland	White Stork	Fitting of isolators and disconnectors	100% reduction in electrocution mortality
<u>Koops & de Jong</u> 1982	Netherlands	Various	Line marking with spirals	Small spirals at 5m intervals most effective (86-89% reduction in collision mortality), followed by large spirals at 15m intervals (65-74% reduction), then small spirals at 10m intervals (57-58% reduction)

◀ Previous

Next ▶

BROWSE BY: REGION

Africa

Americas

Asia

Europe

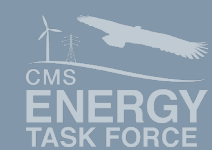
Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>López-López et al., 2011</u>	Spain	Spanish Imperial Eagle	Pole reconfiguration - Suspension insulators and jump wires below crossarm	97% reduction in electrocution mortality in Doñana population. 62% reduction in electrocution mortality in Andalusian population
<u>Marques et al. 2020</u>	Portugal	Great Bustard & Little Bustard	Line marking with spirals or flappers	Line marking associated with a small but significant reduction in collision risk for Little Bustard. No effect for Great Bustard (possibly due to limited data). Collisions more likely to occur at sections of powerline with taller pylons, more wire levels, and >20% (for Little Bustard) or 50% (for Great Bustard) of open farmland habitat in the surroundings
<u>Matsyna et al. 2010</u>	Russia	Various, including raptors & corvids	Insulation	Reduction in electrocution mortality from 58 birds of 17 species to 1 bird
<u>Pavon-Jordan et al. 2020</u>	Norway	Various	Line marking with spirals	Higher flight altitude, greater reaction distance and fewer abrupt turns at marked sections of line



BROWSE BY:
REGION

Africa

Americas

Asia

Europe

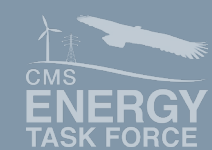
Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Raab et al. 2012</u>	Austria/ Hungary	Various, including Great Bustard	Line marking with aviation balls or flappers & burying powerlines	Bustard collisions significantly lower at marked line sections. Burying powerlines explained more of reduction in collision mortality than line marking
<u>Sanchez et al. 2020</u>	Portugal	Raptors	Supplementary perch	For most species perceived risk was lower for poles with supplementary perches, but use of perches varied between species
<u>Tinto et al. 2010</u>	Spain	Various, including raptors & corvids	Pole reconfiguration - crossarm, jump wire & insulator reconfiguration	Significant fall in electrocution mortality (from 29 birds to 0 birds)



BROWSE BY:
REGION

Africa

Americas

Asia

Europe

Middle East

Click an author to
follow the web
link to the full
publication.



[Back to evidence
library home](#)

Author & year	Country	Species	Mitigation	Results
<u>Kolnegari et al.</u> <u>2020</u>	Iran	Eurasian Kestrel	Nest boxes	Rate of electrocution per kestrel nest decreased from 0.33 to 0.19 (although total number of kestrel electrocutions increased). Electrocution mortality for all birds declined by 58%. Number of electrical faults also decreased.