Turbine Shutdown Systems for Birds at Wind Farms: a Review and Application at the St. Nikola Wind Farm, Kaliakra, Bulgaria

D. Philip Whitfield

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Natural Research Ltd., Banchory Business Centre, Burn O'Bennie Road, Banchory,
Aberdeenshire, Scotland AB31 5ZU

CONTENTS

1. BACKGROUND

While broadly considered 'environmentally friendly', by being a clean source of renewable energy (Leung & Yang 2012), wind farms are not without potentially adverse effects on environmental features, notably birds (Abbasi *et al*. 2014). Such potentially adverse effects on birds primarily include fatalities through collision with rotating turbine blades, disturbance leading to the displacement of birds from feeding, drinking, roosting or breeding sites (effectively a form of habitat loss), and turbines presenting a barrier to flight movements, thereby preventing access to areas via those movements or increasing energy expenditure to fly around the turbine locations (Hötker *et al*. 2006, Madders & Whitfield 2006, Drewitt & Langston 2008, Masden *et al*. 2009, 2010, de Lucas *et al*. 2004, 2008, Ferrer *et al*. 2012, Grünkorn *et al*. 2016).

Of these putative adverse effects of wind farms on birds, the role of collision with rotating wind turbine blades is potentially the most severe in impact so far as affecting the persistence of bird populations (e.g. Hunt 2002, Carrete *et al*. 2009, Bellebaum *et al*. 2013, Hunt *et al*. 2017). To offset or mitigate against such prospectively adverse collision mortality the rotation of wind turbine blades can be stopped in the anticipation of potential collision event(s). There is a management method which invokes this process – a Turbine Shutdown System.

The aims of this Report are to describe and review the reasons why, so far as potential adverse impacts of turbine collisions on birds, a Turbine Shutdown System may need to be deployed. The criteria which should underpin a Turbine Shutdown System are also considered, as are the practicalities behind such a System's enactment – via an Early Warning System.

A Turbine Shutdown System may need to be enacted as part of the wider management and monitoring of an operational wind farm. The necessary monitoring works which are also required to support and feedback on proper delivery of a functional Turbine Shutdown System are additionally considered in this report.

This report also describes case studies, with a particular emphasis on the long-running study at the St. Nikola Wind Farm in northeastern Bulgaria http://www.aesgeoenergy.com/site/Studies.html.

2. COLLISION RISK AT WIND TURBINES

Wind turbines can pose a threat to birds because they can collide with (are struck and killed by) the rotating blades (e.g. Madders & Whitfield 2006, de Lucas *et al*. 2004, 2008, Ferrer *et al*. 2012). Death through turbine blade(s) strike can, thereby, increase the mortality rates of populations to which the individuals belong. In extreme circumstances, without due consideration or proper planning of the risk of such fatalities, some bird populations' status may be adversely affected by the increased mortality (Hunt 2002, Carrete *et al*. 2009, Bellebaum *et al*. 2013, Hunt *et al*. 2017).

Such circumstances appear extreme because of the many examples where there are very low recorded fatality rates which could not possibly endanger birds' populations (e.g. Erickson *et al*.

2001). Even in situations where many strikes have been recorded and where there are localised (superficially severe) wind farm effects on bird numbers and other demographics, these may still not be sufficient to adversely affect the wider population (e.g. Dahl 2014, http://sciencenordic.com/five-kilometres-between-life-and-death-sea-eagle: *cf* Bevanger *et al*. 2009, Dahl *et al*. 2012, 2013).

Nonetheless, such collisions and consequent fatalities can be minimised by post-operational procedures, if necessary. As birds generally collide with moving rotor blades, shutting down wind turbines during high-risk situations or in response to the presence of particular birds can effectively reduce the number of fatalities[1]. Hence, Turbine Shutdown Systems or "Shutdown-on-Demand" systems (Birdlife International 2015) can provide an important tool in minimising collision fatalities (e.g. de Lucas *et al*. 2012a, STRIX 2013, Birdlife International 2015, Hunt & Watson 2016). "Turbine Shutdown System" and "Shutdown-on-Demand" are alternative terms for the same process: hereafter "Turbine Shutdown System" (TSS) is used in this report.

3. JUSTIFICATION FOR TURBINE SHUTDOWN SYSTEMS

TSS is one tool among others (e.g. Hunt & Watson 2016) that is actively being used to alleviate the impacts of wind farms on birds. It is of particular value in areas where the impact of collision mortality upon birds cannot be or has not been reliably predicted at the assessment stage; or where through post-construction monitoring additional impacts become evident; or where it is anticipated the impacts could vary greatly depending on specific weather and birds' pattern of movements, at locations with high concentrations of birds during passage or where collision-vulnerable or demographically sensitive species occur (Birdlife International 2015).

The use of TSS therefore can be part of a wind farm management plan which may be required due to:

- mitigation for periodic high risk of collision fatalities;
- a precautionary safeguard against unpredictable or non-assessed levels of collision mortality;
- a precautionary safeguard because of the presence of species whose population may be demographically sensitive to additive collision mortality, and/or as reflected by 'high'

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[1] Recent research has indicated that it is not necessary for the turbines to be stopped completely, but their rotation can be slowed down to a minimal level for equal efficacy so far as preventing blade strikes (Manuela de Lucas, pers. comm.). This is sufficient for birds to be able to react to, and avoid, the spinning blade tips, but also avoids potential damage which relatively sudden and complete stops can have on the gearings and mechanics of the turbines.

Slowly moving blades offer birds a greater chance of perceiving the motion of blade tips and/or reacting to (avoiding) their changing presence in space. Through the physics of rotating blades revolving around a central hub, turbine blades move at increasing speed along their length (i.e. increasing with distance away from the hub), so that the tips move fastest. The speed at which blade tips move through the air is deceptively fast; especially in more modern turbine designs with longer blades. While direct observations of birds being stuck by turbine blades are few, they frequently record strikes at or close to the blade tip (Luis Barrios, pers. comm. Manuela de Lucas, pers. comm.; see https://www.youtube.com/watch?v=Dqs7fz-_Q0c as an example involving a griffon vulture *Gyps fulvus*).

conservation status (through classifications at several spatial levels and various legislative instruments);
- a response to unanticipated collision mortality which could be problematic demographically for the species or population concerned.

The factors involved as criteria underlying the need for and application of a TSS are the focus for the next sections (4 to 7) of this report.

4. FACTORS INVOLVED IN CRITERIA UNDERPINNING TSS

The justification or need for a TSS at a wind farm may involve several criteria which incorporate several underlying factors either alone or in combination:

1. Species vulnerability to collision (capacity to avoid collision);
2. Species sensitivity to collision mortality, including demographic capacity of populations to tolerate additional collision mortality, and/or protective regional/national/international conservation status;
3. Spatial (e.g. site-specific), temporal (e.g. time of day or year) differences in vulnerable and/or sensitive species' presence;
4. Spatial-temporal differences in weather conditions which may affect collision likelihood, and so, vulnerability of some species' individuals to collision strikes.

If a TSS is deemed necessary (see section 3), then it should be the presence of particular species at a wind farm which primarily dictates consideration of necessity. Hence, the first two factors (above) should be the primary drivers behind any potential need of a TSS; with the second two factors (above) providing additional spatial and temporal context as to if and when a TSS may need to be invoked. These factors are considered in more detail, next (sections 5 -7).

5. VULNERABILITY TO COLLISION

5.1 CAPACITY TO AVOID COLLISION WITH A TURBINE

All else being equal, birds apparently differ in behavioural traits which can facilitate avoidance of collision with wind turbines. Such differences can relate to the propensity to avoid wind farms entirely (displacement or macro-avoidance) and/or to avoid collision with a wind turbine once a wind farm has been entered (turbine avoidance or micro-avoidance) (e.g. Chamberlain *et al*. 2006, Whitfield & Madders 2006a, Band *et al*. 2007, Whitfield 2009, Scottish Natural Heritage 2010, 2013, 2016, Dahl *et al*. 2013, Hull & Muir 2013, Hunt & Watson 2016, Urquhart & Whitfield 2016). Differences between birds in capacity to avoid collision may be at several taxonomic levels: species; or within a species: population (location), age class or phase of annual cycle (e.g. on migration or settled at a breeding or wintering site; or even if just temporary during juvenile dispersal).

Several raptors and Old World vultures appear to be especially vulnerable to collision with wind turbines (e.g. Erickson *et al*. 2001, Madders & Whitfield 2006, Whitfield & Madders 2006a, de Lucas *et al*. 2008, 2012a, b, Whitfield 2010, Ferrer *et al*. 2012, Dahl *et al*. 2013, Hunt & Watson 2016, Thaxer *et al*. 2017). While this may be because wind farms may be placed in locations which these species use for feeding (Hunt & Watson 2016), it is also probably equally if not more relevant for 'soaring' raptors and Old World vultures, that both the birds and wind farm developers select locations which are rich in wind energy (e.g. Madders & Whitfield 2006, Katzner *et al*. 2012, Watson *et al*. 2014, Reid *et al*. 2015, Hunt & Watson 2016, Vasilakis *et al*. 2016). This selection for the same wind energy resource often creates a potential conflict (e.g. Katzner *et al*. 2012, Reid *et al*. 2015, Vasilakis *et al*. 2016, 2017).

At least some other 'soaring bird' species do not appear to be similarly vulnerable, however. For example, while Old World vultures and their taxonomic relatives may have some difficulty in avoiding collision (e.g. Barrios & Rodríguez 2004, Whitfield & Madders 2006a, Lekuona & Ursúa 2007, de Lucas *et al*. 2004, 2008, 2012a, b, Ferrer *et al*. 2012, Dahl *et al*. 2013, Dürr 2017, Thaxter *et al*. 2017) this difficulty does not seem to apply to New World vultures as they are disproportionately unlikely to be killed at wind farms despite their frequent occurrence (e.g. Erickson *et al*. 2001, Smallwood & Thelander 2008, Loss *et al*. 2013, Whitfield & Urquhart 2015, Thaxter *et al*. 2017). Another unrelated but predominantly scavenging species, the raven *Corvus corax*, is frequently recorded at wind farms but is rarely found as a victim of turbine collision (e.g. Smallwood & Thelander 2008, Loss *et al*. 2013, Hunt & Watson 2016).

Moreover, storks (*Ciconia* spp.) and their relatives are classic 'soaring' species on migration (Newton 2008). The white stork *Ciconia ciconia* is abundant at migration bottlenecks in Eurasia and is a common breeding species through much of temperate Eurasia. Yet this abundance is not reflected in records of wind turbine collision victims either on the breeding grounds (e.g. Grünkorn *et al*. 2016, Dürr 2017) or, more so, on migration when a soaring lifestyle is more apparent (e.g. Barrios & Rodríguez 2004, de Lucas *et al*. 2004). This material does not infer especial vulnerability to collision with turbine blades for white storks (although see a recent meta-analysis by Thaxter *et al*. 2017, which indicates vulnerability and so could infer precaution on consideration of Ciconidae vulnerability).

In several instances the comparative capacity to avoid collision with wind turbines has been quantified (e.g. Whitfield 2009, Dahl. *et al*. 2013, Hull & Muir 2013, Whitfield & Urquhart 2015, Scottish Natural Heritage 2010, 2013, 2016, Urquhart & Whitfield 2016). In other instances, when *inference* of vulnerability may be practically necessary, such inference should be based on material relevant to data from wind farms (e.g. Whitfield & Madders 2006a) and not transferred from vulnerability to other human-related sources of collision – of which there are many (Erickson *et al*. 2001, Hunt & Watson 2016). The next section cautions against using one such particular source of collision as an inferential factor: vulnerability to collide with power line wires.

5.2 VULNERABILITY TO COLLISION WITH POWER LINE WIRES IS NOT COMPARABLE

Some previous reviews have assumed that a species' vulnerability to collision with rotating wind turbine blades can be equated with vulnerability to collision with overhead power lines (e.g.

Langston & Pullan 2004, Drewitt & Langston 2008, Martin & Shaw 2010, Martin 2011). As knowledge has accumulated it has become apparent that such an assumption is false (e.g. Whitfield 2010, Whitfield & Urquhart 2015, Hunt & Watson 2016). Likely this is because the reasons why birds collide with such different objects differ, which is perhaps not surprising when considering thin, stationary static wires which may be near-invisible, as opposed to large mobile objects (turbine blades) that even to human eyes are clearly visible but which move through space with great rapidity, especially towards their extremity (as noted earlier).

Two examples can be highlighted in this regard:

- the adverse impact of "power lines" on raptors is more related to electrocution at power poles, than collision with overhead power line wires (e.g. Bevanger 1994, Lehman *et al*. 2007, Janss & Ferrer 2009, Janss 2000, Dahl 2014). Several raptors appear vulnerable to collision with turbine blades, but not vulnerable to collision with power lines (Janss 2000; and see section 5);
- geese and, especially, swans (*Cygnus* spp.) appear vulnerable to collision with power line wires but not vulnerable to collision with turbine blades (Janss 2000, Frost 2008, Whitfield 2010, Scottish Natural Heritage 2013, Whitfield & Urquhart 2015).

Forward visual capacity (through binocular vision) has been interpreted as playing a major role in the vulnerability of birds to collide with turbine blades (Martin & Shaw 2010, Martin 2011, Martin *et al*. 2012). A difficulty with this interpretation rests in how species differences in binocular vision capacity seem unlikely to transfer empirically to relative vulnerability in colliding with turbines.

It seems unlikely, for example, that Old World vultures (Martin *et al*. 2012) have vastly inferior binocular vision than New World vultures, or that ravens are better able to see turbines than raptors (see above, section 5). Burrowing owls *Athene cunicularia*, with excellent binocular vision typical of owls, are also relatively more likely to collide with turbines than other more aerial birds (Smallwood & Thelander 2008, Smallwood & Karas 2009) with poorer binocular vision (Martin 2011). Other factors (de Lucas *et al*. 2012a, b, Hunt & Watson 2016) seem more important in determining vulnerability to collision. In addition, whereas there are many examples when increasing the visual conspicuousness of power line wires through markers has demonstrably reduced collision (Bevanger 1994, Janss & Ferrer 1998, Alonso & Alonso 1999, Frost 2008) there are no such clear-cut examples from marking turbine blades, despite efforts (see for example citations in: Whitfield 2010, Hunt & Watson 2016).

5.3 VARIATION BETWEEN AND WITHIN WIND FARMS

There are many publications which document that there is variation between and within wind farms in the vulnerability of birds to collision, with some wind farms being unduly prone to kill birds (e.g. Erickson *et al*. 2001, de Lucas *et al*. 2008, Ferrer *et al*. 2012) and some turbines within wind farms being more likely to lead to fatal strikes (e.g. de Lucas *et al*. 2008, 2012a, b). Perhaps the best set of studies is that which has been conducted and is ongoing at wind farms in the region of Tarifa, in southern Spain (e.g. Barrios & Rodríguez 2004, Ferrer *et al*. 2012, de Lucas *et al*. 2004, 2008, 2012a, b). These studies are particularly informative because of the intensity of research (including focus on particular species) and its long-term nature. That they have also been conducted at the predominant migratory bottleneck in western Europe at the Strait of Gibraltar provides yet more value, and context.

Effectively, variation between and within wind farms may be considered to represent differences in spatial vulnerability to collision risk. Differences in temporal vulnerability to collision risk may also occur as these spatial scales (as has been documented by the cited studies); these differences are covered in a later section (7: Periodic Elevation of Collision Risk).

6. SENSITIVITY TO COLLISION

6.1 POPULATION DEMOGRAPHIC SENSITIVITY

Different species have broadly different life history traits, so far as the balance between individuals' inherent survival and fecundity capacities, such that they have been broadly classified into r-selected species (including low post-fledging survival rates, high reproductive output potential, and rapid maturity) and k-selected species (including high post-fledging survival rates, low reproductive output potential, and deferred maturity). While turbine collision may indirectly affect reproductive output (Dahl *et al*. 2012) it primarily and directly affects survival (mortality) rates. Species broadly classed as k-selected are therefore far more sensitive demographically to the addition of collision fatalities to baseline mortality rates (e.g. Drewitt & Langston 2008, Desholm 2009, Thaxter *et al*. 2017).

Larger birds are more likely to be classed as k-selected and so larger birds tend to be more demographically sensitive to collision mortality because the population impact of collision fatalities is in general more severe. Population abundance, trajectories and conservation status are consequently intrinsically more likely to be threatened in large k-selected birds; such as several raptors and Old World vultures. As k-selected species are also often vulnerable to collision (see section 5.1, above) and are also often classed as having special conservation status (see section 6.2, below) it is no surprise that particular concern over turbine collision impacts on bird populations mostly involves such species (see section 2).

6.2 CONSERVATION STATUS SENSITIVITY

There are many regional, national and international classifications of species' conservation status which in general reflect the species' risk of extinction (and/or rarity) at the relevant administrative level. Such classifications are often enshrined in national or international legislation; agreed in regional, national or international guidance documents; or treated as binding through Member-State signatory on, and membership of, international treaties.

Conservation status is thereby a key legislative requirement, or convention, in determining a species' (or a population's) sensitivity to collision mortality (or, even, the risk of collision mortality) at a wind farm. It is therefore also a critical factor in determining whether a TSS may be required. Notably, as it may often have legislative support or requirement.

In general k-selected birds are more likely to have an elevated conservation status (especially if endemic species or species with localised distributions are excluded) because intrinsically they are often of low abundance and demographically sensitive to several environmental perturbations (Newton 1998). For example, considering the avifauna of Europe there is a disproportionate representation of raptors and vultures, and other 'large birds' in the listing of Annex 1 species ("deserving of special protection measures") in the EC Birds Directive (2009/147/EC).

7. PERIODIC ELEVATION OF COLLISION RISK

7.1 FREQUENCY OF FLIGHT OCCURRENCE

It is axiomatic that if a bird does not enter a wind farm then it is not at risk of being killed by turbine collision whereas a bird is vulnerable to collision if it does. Hence, there is mutual exclusivity between the potentially adverse wind farm effects of displacement (macro-avoidance) and collision (Madders & Whitfield 2006). It would logically follow that the more often a bird flies through a wind farm then the more likely is the risk of collision. This equates to a temporal or spatial change in vulnerability to collision (section 5) rather than in sensitivity (section 6).

Higher flight occurrence may not necessarily result in higher collision mortality, however, because other factors leading to collision can be specifically involved within and/or between wind farms (de Lucas *et al*. 2008). At a gross level, nevertheless, whether spatially or temporally, there will be a background of greater potential collision risk when there are more birds exposed to this fundamental risk (Carrete *et al*. 2012).

The most obvious gross changes in frequency of occurrence relate to seasonal shifts between birds' breeding and wintering grounds; and migratory passage routes between them (section 7.2). Weather and diurnal changes therein may affect vulnerability to collision at any stage of birds' annual cycle (section 7.3).

7.2 SEASONAL CHANGES AND VULNERABILITY OF RESIDENT VS. MIGRATING INDIVIDUALS

Obviously, for migratory species (or populations) vulnerability to collision at a particular wind farm will have an overriding seasonal element. Species which are present year-round may also have seasonal shifts in vulnerability and this may be due to either gross changes in abundance or changes in the age structure of the population if, say, young birds are more susceptible to collide (see section 5.1.) (Hunt 2002, de Lucas *et al*. 2008, 2012a).

Several reviews emphasise the dangers of wind farms placed on migration routes because of a sudden seasonal 'pulse' in large numbers of birds (e.g. Langston & Pullan 2004, Birdlife International 2015). However, the vulnerability of an individual bird to collision is far higher for a local resident which may have to fly through a wind farm many hundreds of times in a year than for a passage migrant which may have to fly through only once or twice.

Masden *et al*. (2009, 2010) quantified the relative impacts of displacement on breeding birds (so were ‘resident’ for several months) against those for birds on migration and found far higher potential impacts on ‘resident’ birds. Displacement and collision risk are antagonistic processes (section 7.1), and the impact ‘currency’ differs, but the principles revealed by Masden *et al*.’s (2009, 2010) analyses in terms of the relative risks to ‘resident’ birds vs. birds on migration also apply to collision.

Therefore, a small sensitive bird population which resides near a wind farm is potentially far more vulnerable than a small sensitive bird population which only encounters wind farms on migration, even if such encounters are several. Impact assessments for wind farms which are situated on or near migration flyways, therefore, may objectively not highlight the potential impact on the migrants but the impact on local scarce resident (or breeding and/or wintering) birds, especially if the local birds are vulnerable to collision, as well as sensitive.

The need for a TSS may often be more to protect a sensitive local population which is present for many months than a large population of migrants on periodic passage.

7.3 DIURNAL CHANGES AND WEATHER RELATED CHANGES

As well as seasonal shifts in gross vulnerability there are also obvious gross changes throughout the 24-hour day, when many birds are routinely (or periodically, during migration, for example: Newton 2008) restricted to diurnal or nocturnal flight activity. Several birds may not be so restrictive in their activity, or are active at all times of the day (e.g. many waders or shorebirds Charadrii) and in such species there may be assumptions that as visibility declines during darkness then vulnerability to collision may consequently increase for such birds.

There may be a strong element of anthropocentricity in such assumptions, and so they could well be erroneous. Simply because human eyes may seriously struggle to see clearly during the night time does not necessarily mean that some birds, which have been shaped by natural selection to be active at all times of the day, will struggle similarly (and so become more vulnerable to turbine collision). Apart from having eyesight adapted to low light, birds may also behave differently during the night in response to reduced visibility and so reduce vulnerability to collision (e.g. Dirksen *et al*. 1998, 2000, Tulp *et al*. 1999, Desholm & Kahlert 2005).

Periods when there is a perceived higher vulnerability to turbine collision can also include ‘bad’ weather, as well as darkness – once more, as arguments go, through impaired visibility (e.g. Langston & Pullan 2004, Hüppop *et al*. 2006). Again, however, the anthropocentric assumption is that birds are unable to react to such a change, such that despite natural selection they have not become innately attuned to such change; and so their behaviour does not change responsively or reactively.

Speculation for a link with poor weather and turbine collision may have come about because collisions with other man-made structures, such as communication towers, do appear to be greater when weather is poor (e.g. Erickson *et al*. 2001, Hüppop *et al*. 2006). However, mass bird mortality events which have been recorded at several communication towers during bird migration have not, apparently, been recorded at wind farms (e.g. Erickson *et al*. 2001, Hötker *et al*. 2006, Loss *et al*. 2013).

Once more, there has been an assumption, which appears mistaken, that what makes a bird vulnerable to collision with one man-made object can apply across all man-made objects (see also section 5.2). Bad weather which may impede visibility, such as fog, heavy rain or high winds, may not necessarily be associated with an increased risk of turbine collision (*cf* Madders & Whitfield 2006), however. Empirically the opposite may be the case (Hull & Muir 2013) or no obvious link may be found (Johnson *et al*. 2000, Anderson *et al*. 2005). Flight activity may decline. Other behavioural features change in response to poor weather e.g. birds may fly lower to the ground and slower (Moyle & Heppner 1998, Richardson 2000, Piersma *et al*. 2002) which may actually reduce the vulnerability to collision during poor weather.

Field research can also reveal that *other* weather variables may be more likely to lead to a collision, such as wind direction or strength affecting the capacity for soaring birds to avoid rotor swept volumes (Barrios & Rodríguez 2004, de Lucas *et al*. 2012a, b). Wind direction and strength can also influence birds' directional flight patterns (such as when on migration) affecting their capacity to avoid wind farms or result in them being 'blown off course' and be carried into wind farms away from the typical flight path (Skov & Heinänen 2015, Zehtindjiev & Whitfield 2016). On the other hand, prior assumptions on wind direction and strength as contributors to greater vulnerability to collision risk may be revealed as irrelevant as a result of monitoring (Sims *et al*. 2015).

8. EARLY WARNING SYSTEM WITHIN A TSS

An Early Warning System (EWS) can be defined as the practical mechanism(s) within a TSS which is responsible to enact the primary objectives of the TSS, so far as detecting the need to shut down turbines (according to TSS management criteria), and then shutting down turbines. It is then also the means for reinstating turbine operation once the event of elevated collision risk triggering shutdown (under the baseline criteria for TSS) has passed.

Component features of EWSs, their advantages and limitations have been reviewed by Birdlife International (2015). They are also the subject of evaluations through a European Commission (EC) LIFE Project[2] which is due to be completed in autumn 2018.

Broadly there are three basic potential components to EWSs, which are covered in sections 8.1 to 8.3; below.

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[2] LIFE12 BIO/GR/000554 Demonstration of good practices to minimize impacts of wind farms on biodiversity in Greece http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4726. Project website: http://windfarms-wildlife.gr/english/index.html

8.1 FIELD OBSERVERS

Field observers can be used to assess situations when incoming birds (deemed as target species or in more particular situations; according to the baseline TSS criteria) necessitate the shutdown of turbines. Depending on the size of the wind farm, visibility, and any directional expectations of target birds' movements, a number of observers are typically required to ensure complete coverage of the wind farm and surrounding area. Observers are usually situated in locations appropriate to best visibility around the periphery of the wind farm and according to any directional expectations of where potential ingress of target species into the wind farm will originate.

The observers must be experienced with the detection, identification and counting of birds as well as assessing their behaviour. Optical equipment such as binoculars and telescopes are necessary to aid observation.

To initiate shutdown (and restarting) direct contact between individual observers and the turbine(s) operation is preferable, because it is quicker. This contact may be to an engineer tasked on stand-by to respond; but, far preferably, via a system where direct control of individual turbine operation is literally in the hands of field observers. Birdlife International (2015) advocates two-way radio communication via a central field co-ordinator; but this increases delay between detection of a potential imminent threat of collision and turbine shutdown. It can also distract the observer from keeping track of the detected collision threat through the target bird(s) movement. If possible, this proposed system is not to be recommended. Practical experience deploying TSS at wind farms in southern Spain found a marked improvement in EWS efficacy when control of shutdown was given in hand, directly to field observers (de Lucas *et al*. 2012a, Manuela de Lucas pers. comm.: see also section 10).

An observer-based TSS at two Australian wind farms in Tasmania was abandoned, even though "*technology allowed observers to shutdown a turbine rapidly*", because "*it was impossible to conduct a shutdown faster than an eagle can move at top speed through the sites*" (Sims *et al*. 2015). Sims *et al*. (2015) do not describe the exact process of turbine shut down which was deployed. Birdlife International (2015) also refers to this case study but the cited documents are no longer available on the developer's website: reference is made to observers being at "*randomly selected locations around the wind farms*" which may not have been appropriate.

Field observers can be used in conjunction with other EWS tools, such as radar. Birdlife International (2015: pp. 15 -16) gives a breakdown of the advantages and limitations. Key advantages are that observers can accumulate knowledge on bird flight behaviours that feed back into shut down criteria and that observers may be more adaptable to some wind farm locations than radar (for example). Key limitations may involve the distance of detection and, especially, observer fatigue or boredom.

8.2 RADAR

Radars can be used to assess the numbers, densities and movements of flying birds at large spatial scales around or approaching wind farms. They can be used alone or in conjunction with field observers, or other detection tools if deemed necessary. Surveillance radar models are most often used in TSSs but vary in power and format which affects their range. The type of radar and the wind farm's location influences field setup and how many units may be required; although typically one is deployed (Birdlife International 2015).

Dedicated expertise in the interpretation and analysis of radar data is required to deal with the potentially vast amounts of data gathered through this method, particularly in relation to the interpretation of extraneous false return signals (or echoes) known as clutter. Avoiding confusing ground clutter may lead to scanned areas having to be above the flight heights which may present most risk of turbine strike. Other drawbacks can involve the need to screen out other false-positive records so far as aerial signals which are irrelevant to TSS criteria (e.g. non-target species). Such screening typically involves a period of expert intervention through 'training' the radar, via algorithmic software after visual 'truthing', to 'recognise' and so distinguish between species (at best) or taxonomic groups (at worst). Meeting this critical requirement may be the practical downfall of a useful contribution from radar in some circumstances.

The potential benefits of radars involve long-range detection beyond human observers' visual capacity, and that they are not encumbered by daylight hours and can work around-the-clock. Radar records of incoming bird signals can be directly linked to an automated shut down of turbines, or to alert field observers to an incoming 'wave' of potential target birds. If the records received via radar do not require much discrimination so far as the TSS criteria for shutdown – so that the TSS criteria for shut down are broad on target species and circumstance – then the prospect of false-positive records is reduced.

The merits of using radar as a EWS (or part of a EWS) will depend on the wind farm where the TSS needs to be deployed and the TSS criteria for triggering shut down. For example, if TSS criteria are very specific so far as particular target species, then radar may struggle to be useful – especially if the radar signals for the target species cannot be algorithmically distinguished from signals of other non-target species which are also likely to be more common. Conversely if the TSS criteria are broad then the capacity to train radar to species-specific signal-traits is not so much of an issue and so radar becomes a more valuable tool.

This potential utility of a TSS as designed with radar in combination with field observers is illustrated by the EWS at the Barão de São João Wind Farm in Portugal (STRIX 2013 and http://www.strix.pt/index.php/en/projects/projects-birdtrack/barao-sao-joao-bird-mortality-mitigation). Here, apparently, the TSS criteria are broad-based, including several soaring species which pass through the wind farm site during autumn migration. The BirdTrack® radar allows a range of species to be detected at long-range and this information can then be fed to field observers (thereby raising alertness: see earlier on potential fatigue/boredom of field observers: section 8.1) who are then prepared to be aware to triggering turbine shut down. This system is apparently highly effective, with no collision victims recorded over several years of monitoring although (see section 11) the publication of the relevant data is not available, other than commercial claims on the STRIX website.

Other advantages and limitations of radar systems, in general, are given by Birdlife International (2015). The various pros and cons of several specific radar models can also be found in the review by Birdlife International (2015). There are many such models, and variants (e.g. MERLIN, Robin 3D, STRIX BirdTrack, BirdScan, Swiss Birdradar, Deltatrack) and many have apparently been deployed at many wind farms (Birdlife International 2015) although objective available reports on their efficacy and utility are few in the extreme (beyond in-house commercial literature from manufacturers). Evaluation of the efficacy of marine surveillance radars is currently part of an EC LIFE Project: http://windfarms-wildlife.gr/english/index.html.

8.3 REMOTE IMAGERY

Other detection tools to support a EWS and to implement a TSS have been proposed, are available and/or have been used, which deploy image-based technology (Birdlife International 2015). Image-based (or "video surveillance") systems work by visual imagery, in one form or another, to identify target species which may be approaching a wind farm and so present a risk of collision (Birdlife International 2015). (Thermal-based imagery has also been scoped as a potential detection system: Desholm 2003).

Software 'training' for recognition by the basic hardware is necessary to distinguish, for example, between target and non-target species (or other situations in the TSS criteria) on visual traits. These video surveillance systems are effectively a substitute (or supplement) to field observers but being automated are not prone to fatigue and are, potentially, more sophisticated as camera imagery may allow nocturnal surveillance to come close to rivalling radar in this regard. Their range is limited and cannot be as great as radar; and for thorough coverage of a wind farm many units are required.

This technology can be a self-contained system (completely remote) and/or a supplementary to other EWS components. While other imagery-based systems are available (Birdlife International 2015) and other simpler inexpensive systems are in development (Manuela de Lucas pers. comm., Birdlife International 2015) at the moment the leading system in terms of deployment and publicity appears to be DTBird® (Birdlife International 2015).

Each DTBird unit, and ongoing support from the manufacturer, is relatively expensive given the range of each unit: for modern wind farms with wide spacing between turbines, many units are required. If the criteria in a TSS involve bird flight ingress from particular directions, however, then fewer units could be required.

DTBird comes with several add-on options including automated shut-down and auditory 'dissuasion' or deterrence facilities (Birdlife International 2015, http://www.dtbird.com/), although any study on habituation to dissuasion – which could happen - has not been published. In general, there have been very few published independent studies of the utility of DTBird (e.g. May *et al*. 2012) despite its apparent deployment at several wind farms. (But, on critical balance, details of many TSSs involving several other EWS component-variants are similarly rare in the public domain.) Evaluation of the technical efficacy of DTBird is currently part of an EC LIFE Project due to report in autumn 2018: http://windfarms-wildlife.gr/english/index.html.

8.4 OTHER EWS CONSIDERATIONS

EWSs, especially those involving field observers, can exploit periodic elevations of collision vulnerability on a predictive basis by anticipating periods of high bird presence (section 7). Weather may affect the likelihood of birds' presence and activity. For example, weather can affect not only the likelihood of major movements of migratory birds through recognised flyway staging points (Bildstein 2006, Newton 2008) but also the likelihood of some birds being diverted away from flyways (Bildstein 2006, Newton 2008, Skov & Heinänen 2015, Zehtindjiev & Whitfield 2016). Weather severity may also broadly influence potential presence of species which may be itinerant within winter (Zehtindjiev & Whitfield 2017).

Time of year is also another obvious factor which can influence birds' presence or their flight activity. This can be, for example, via seasonal presence for migratory species (on breeding or wintering grounds; or at migration flyways or routes and stopovers) and/or for non-migratory species, with increased presence following enhanced population size soon after young birds have fledged or dispersed).

Features of the wind farm itself and its location should influence the component(s) of EWS; and the criteria for triggering turbine shutdown are also critical to the type of EWS which is used. One EWS set-up or underlying set of TSS criteria should not be universal: a TSS should be governed by the particular circumstances of the wind farm to which it applies. There should be no "one-size-fits-all" TSS between different wind farm management plans, not only on the criteria to trigger a TSS but also the practical mechanisms by which a TSS is enacted through the components of the underlying EWS. Moreover, like the TSS which it serves, the EWS should be adaptive and subject to review based on feedback from monitoring.

It should also not be forgotten that, away from TSSs and supporting EWSs, other post-operation mitigation or compensatory measures may also be available, if appropriate (e.g. Smallwood & Neher 2004, Dahl 2014, Sims *et al*. 2015).

9. MONITORING EFFECTIVENESS

Monitoring the effectiveness of a TSS is a vital element of a TSS and should be integral. Substantially this usually requires surveillance of turbine collision victims through searches around turbines (e.g. Morrison 1998, Smallwood 2007, Hull & Muir 2010, Huso 2011, Bispo *et al*. 2013, Urquhart & Whitfield 2016). Such searches may not be wholly reliable because carcasses may disappear (e.g. scavenged) before a search, or searches may not detect all carcasses (either because of vegetation and visibility, other aspects of searcher efficiency, the search area being too small or that some fatally injured birds may die away from the turbines). Surveillance of collision victims through searches should also, therefore, account for these potential biases, notably carcass persistence and efficiency during searches. There is now a large literature on this issue, not only for wind farms (e.g. Smallwood 2007, Bispo *et al*. 2013, Grünkorn *et al*. 2016) but for other fields of research where carcass searches need to be conducted (e.g. power line collisions: Ponce *et al*. 2010) which this Report will not comprehensively refer to.

Biases on carcass persistence and searcher efficiency can be calibrated through staged trials which attempt to simulate the presence of collision fatalities, and therefore account for these biases in estimated "true" fatality rates (e.g. Ponce *et al*. 2010). These trials should be specific to the wind farm and to the time of year to which the TSS refers (e.g. Ponce *et al*. 2010, Bispo *et al*. 2013, Urquhart *et al*. 2015), since both factors are liable to affect the relevant search biases (e.g. scavenger communities can vary by location and through the year at a location; as does vegetation affecting search efficiency: Grünkorn *et al*. 2016). The biases may also vary over years, and so periodically the trials should ideally be repeated to evaluate if their influence may have changed.

In some cases search biases may be minimal because, for instance, searches around turbines are undertaken daily and the main target species are large (and so visually obvious), their carcasses also tend to persist, and the vegetation around turbines is unlikely to obscure the visibility of searchers (de Lucas *et al*. 2008, 2012a, Ferrer *et al*. 2012). Such capacity for search effort (and likely chances of finding a carcass) and other associated wind farm features are unusual, however.

It appears that, in general, small bird carcasses persist for a shorter time than carcasses of large birds (small birds being more susceptible to rapid decomposition and a wider range of scavenging removal, from invertebrates through small and large mammals to avian scavengers), and leave fewer signs even after removal (e.g. Smallwood 2007, Grünkorn *et al*. 2016). The palatability of dead birds to the primary scavenging community can probably also affect carcass persistence: large raptors – often being target species for searches – appear less palatable than other species often used as "surrogates" during carcass persistence/searcher efficiency trials (Urquhart *et al*. 2015).

On searcher efficiency, small carcasses and associated remains are also obviously more difficult to find than large carcasses and associated remains (Smallwood 2007, Grünkorn *et al*. 2016). Vegetation and other habitat features (e.g. topography) can affect searcher efficiency – spotting a dead bird is more difficult in a heavily vegetated topographically complex area around a turbine than in an area which is flat and largely devoid of vegetation (such as in some agricultural habitats during winter: Zehtindjiev & Whitfield 2017).

Human searchers may become bored and drop attention if the search regime is more frequent than the expected rate of collision mortality. Related, there is also a cost-effective balance to be struck between the financial costs of searches (and the "find-nothing costs" such as boredom) and the benefits (in terms of finding a carcass so far as expectation) as regards the frequency of searches. Estimates of the strength of biases associated with varying search frequency options, informed by trials on carcass persistency and searcher efficiency, are an additional benefit of such trials: http://www.aesgeoenergy.com/site/Studies.html.

Trained dogs can be used to search for collision victims: these are more efficient because they avoid potential biases due to visibility and fatigue/boredom in human searchers (Bennett 2015; and references therein). They are, however, a specialised commodity which may not be available to all wind farm management programmes.

Feedback to the TSS from the collision victim monitoring programme is essential, through turbine searches and associated calibration trials to give (at least) broad confidence limits to the raw results from turbine searches. The monitoring of collision mortality, after accounting for the possible biases in the monitoring methods, is critical to ongoing scrutiny of the TSS and any revisions that may, or may not, be needed.

A key message is that Environmental Management Plans (which can include TSS) formulated before construction or before monitoring of actual impacts may need to be adapted through review as a result of monitoring and the gathering of more information (e.g. Sims *et al*. 2015). TSSs need to be flexible in response to unanticipated change, or previously unknown factors, because TSSs may be revealed to be practically unrealistic or unnecessary (in total or for some species or circumstances) or, conversely, may need to be upgraded so far as species targets in criteria for triggering shutdown. The value of monitoring and subsequent adaptive review with revision to TSS criteria based on monitoring is consequently critical. For example, if monitoring reveals too few species were included in the original criteria for TSS, then the TSS should be able to adapt.

A further consideration may also be any contribution of the wind farm at which the TSS applies, to other wind farms which may have a similar TSS (or not have a TSS, but the vulnerabilities and sensitivities are the same or similar). In other words, cumulative impacts (e.g. Sansom *et al*. 2016), and the role of TSS criteria in managing this potential impact, may also require consideration.

10. PUBLISHED STUDIES ON EFFECTIVENESS OF TSSs

Unfortunately, there are few accessible studies on the role of the TSSs in wind farm Environmental Management Programmes. Three studies were given as case examples by the review of Birdlife International (2015). These involved studies at: 1) many wind farms near Tarifa in southern Spain, 2) a single wind farm in southern Portugal, and 3) two windfarms in Tasmania, Australia. A fourth set of studies is available, not referred to by Birdlife International (2015), but see section 11 (The TSS at the St. Nikola Wind Farm) and at http://www.aesgeoenergy.com/site/Studies.html.

10.1 FINANCIAL EFFECTIVENESS

Accepting that TSSs can and should be variable in nature in so far as how often turbines may need to be shut down, it is apparent nevertheless, so far as can be determined, that documented TSSs appear to result in low financial cost in returns from lost wind energy ‘capture’ due to temporary shutdown, as the shutdown periods are minimal in time (de Lucas *et al*. 2012a, May *et al*. 2012, Birdlife International 2015, Zehtindjiev & Whitfield 2016, 2017) and can improve through experience (Birdlife International 2015: Appendix 6.1, prepared by STRIX).

A loss of only 0.07 % energy production from several wind farms near Tarifa in southern Spain (244 turbines) was estimated due to TSS by de Lucas *et al*. (2012a), when there were many shut-down events. At the Barão de São João Wind Farm in southern Portugal available data (STRIX 2013, Birdlife International 2015) suggest that the TSS led to 0.96 % reduction in available operational hours for the wind farm, which latterly improved to 0.5 %.

Additional financial cost is liable in the set-up and deployment of the EWS, the implementation of the TSS and associated monitoring. Automated EWSs such as involving radar and/or visual-imagery set-ups are usually more expensive; at least initially. Considering the potential financial gains from wind farms’ outputs, even such larger costs may be minimal in the grand scheme of a wind farm’s operational financial budget.

10.2 EFFECTIVENESS IN REDUCING COLLISION FATALITIES

This is fundamentally critical, as it is the basis for TSS deployment in the first place, and it relies on a monitoring programme to record and thereby estimate the number of collision victims at the wind farm (section 9). De Lucas *et al*. (2012a) concluded that the observer-only TSS reduced collision mortality (mostly griffon vultures) by about 50 %. The bird community was a mixture of resident species, species present seasonally (breeding or non-breeding) swelled by migrants during spring and autumn.

The TSS deployed at the Barão de São João Wind Farm in Portugal (STRIX 2013 and http://www.strix.pt/index.php/en/projects/projects-birdtrack/barao-sao-joao-bird-mortality-mitigation) was mostly concerned with large soaring migrants although other birds were target species too. The EWS was a system involving a radar and field observers and was reportedly 100 % successful, in so far as results from monitoring of collision victims.

Sims *et al*. (2015) record an observer-only EWS was part of an Environmental Management Plan and TSS at two Australian wind farms in NW Tasmania. It was abandoned because it was not successful. This case study is referred to by Birdlife International (2015) which notes: "*Turbine shutdown in response to the perceived increased collision risk for wedge-tailed eagles proved unsuccessful in preventing collisions and the programme was later suspended in order to focus on other areas of mitigation…Difficulties in observing wedge-tailed eagles were noted for birds greater than 1500 m from the observer and after one hour of continuous observation due to fatigue. This situation was specific to local birds…*".

The Australian TSS study appears somewhat different to those in other available case studies as the principal criterion involved a local resident population of a particular target species, the wedge-tailed eagle *Aquila audax fleayi* (Birdlife International 2015, Sims *et al*. 2015). Detecting relatively small numbers of individual birds intermittently (and rapidly?) accessing a wind farm will be far harder to detect and predict (at least for field observers) than when large groups of birds, for example, soar towards a wind farm on a more predictable basis.

Details of a further case study involving TSS deployed at a wind farm in NE Bulgaria are given special attention in the following section.

11. THE TSS AT THE ST. NIKOLA WIND FARM

11.1 BACKGROUND

The principles behind TSS implementation described above are well-illustrated by the specific details of the TSS which are applied at the St. Nikola Wind Farm (SNWF), situated on the Kaliakra Cape in northeastern Bulgaria, a peninsula within the Dobrudzha region in the western Black Sea (43° 27' N, 28° 26' E). SNWF consists of 52 Vestas V90 3.0 MW turbines, a hub height of 100 m and three 50 m rotor blades. Mean inter-turbine distance is 562 m (SD = 143 m), median 520 m (range 380 – 985 m).

The large majority of turbines (83 %) are close to (within 100 m of) thin shelterbelts of trees. An area of hard standing surrounding each turbine (devoid of vegetation) is typically about 65 x 40 m. SNWF connection to the power grid was in October 2009. During the 2009 - 2010 winter turbines were operational in pre-commissioning tests: 20 at a time and in up to 10-day periods per turbine, as a prelude to the project becoming 'live' commercially in March 2010. A permanent meteorological station is set up at SNWF

The core study area around the wind farm is a flat landscape c. 50 – 100 m asl dominated by arable agriculture, fringed by remnants of near-natural steppe to the south and east, and vineyards and conurbations of Balgarevo and Kaliakra to the southwest. The principle arable crops involve wheat, rape, and sunflower. Many fields are bordered by shelterbelts: long dense rows of small trees (< 15 m tall); and a network of tracks. Within fields, crop cultivation is often within smaller plots reflecting adherence to a traditional 'strip' cultivation system involving several farmers. A tendency towards larger cultivation plots and fewer more discontinuous shelterbelts is apparent in the eastern parts of SNWF, and in the southern and eastern parts of the core study area. These habitats within the core study area, dominated by agricultural crop cultivation, are common and widespread throughout the region.

The Environmental Management and Monitoring Plan (EMMP) for SNWF (termed the Kavarna Wind Farm in the EMMP) outlined (P. 16) the development and implementation of a TSS to ensure operations at SNWF do not result in population impacts or incremental bird mortality for any given species that exceeds thresholds pursuant to an assessment on Collision Risk (based on Band *et al*. 2007): a "Collision Risk Assessment") and/or not exceeding more than a 1 % increase over the existing baseline mortality for any given bird species as set forth in the EMMP. The target species within the TSS vary according to season. They were selected on the basis of previous knowledge of the bird community of the area and pre-construction surveys and assessments (and deploying relevant criteria as noted in previous sections: notably national and international conservation status classifications). IUCN criteria have been used for evaluation of bird conservation status (and so, a key sensitivity metric) during monitoring in the autumn migration study period because of the unknown origin of migratory populations in autumn when the movements of birds found dead can cover different continents. National conservation status criteria are also considered in the event of any obvious national origin of the recorded birds' origins.

The Owners Monitoring Plan (OMP) gives additional details of adopted monitoring protocols, which have been further informed by feedback from the ongoing annual monitoring results. Monitoring of collision victims, informed by periodic staged trials on likely levels of biases in searches for collision victims, is aware of (and reports as such) any need on TSS revision under vulnerability or sensitivity criteria as regards the ethos of the EMMP. Over the several years of monitoring this feedback has added to conditional criteria by which the TSS is applied (see later: section 11.6). Initially stipulated commitments on criteria have not allowed for reduction of any of these commitments, despite monitoring results which may suggest or strongly indicate that initial commitments may have been over-precautionary.

11.2 ACCESS TO INFORMATION ON SNWF MONITORING

Numerous reports are available on the Environmental Management Plans (such as the EMMP and OMP), preconstruction studies and the considerable post-construction monitoring studies across many years and seasons, at a dedicated website: http://www.aesgeoenergy.com/site/Studies.html. Rather than repeatedly refer to these reports and the website where they can be found, subsequent text assumes that the reader can access them for any of the points made.

The environmental management and monitoring of SNWF provides much important knowledge and can serve as a successful role model to other wind farm developments. What is especially laudable about the management of SNWF is the open access to the results of the monitoring at the wind farm, including the TSS, through the posting of numerous monitoring reports at the dedicated AES website. An obvious critique of some other 'TSS case studies' whether deemed "successful" (Barão de São João Wind Farm, in Portugal) or "unsuccessful" (Bluff Point and Studland Bay Wind Farms, in Tasmania, Australia) is the shortage of relevant documentation. Although, many other aspects of studies at the Tasmanian wind farms have been published (e.g. Hull & Muir 2013, Hull *et al*. 2015 and references therein).

11.3 RADAR

A "BirdScan" fixed beam radar (developed by the Swiss Ornithological Institute: e.g. Schmaljohann *et al*. 2008), is deployed on the site. Typically the radar has been deployed to scan on an east-west axis to intercept the most frequently anticipated (and most often visually recorded) flight directions of 'incoming' birds. During daylight the radar has been run continuously in the study periods and for a 15 minute period during every hour of the night time. A typical scanning program which has been used is as follows:

Diurnal Radar Observations

1. Four minutes at 30 mills, or as low as ground clutter permits (equivalent to approximately 25-275 m elevation at 5 km distance);
2. Four minutes at 80 mills (equivalent to275-525 m at 5 km distance);
3. Four minutes at 130 mills (equivalent to 525-775 m at 5 km distance);
4. Four minutes at 180 mills (equivalent to 775-1025 m at 5 km distance);
5. The magnetron then rested for one minute, and then the cycle was recommenced.

Nocturnal Radar Observations

1. Four minutes at 30 mills; (equivalent to approximately 25-275 m elevation at 5 km distance);
2. Four minutes at 150 mills (equivalent to 675-825 m at 5 km distance);
3. Four minutes at 700 mills (equivalent to 3375-3625 m at 5 km distance);
4. The magnetron then rested for 48 minutes, and then the cycle was recommenced.

The radar has required 'training' for recognition of the received echoes insofar as the target species. This has proved problematic during the autumn migration period when many target and non-target species may be present and there was inadequate capacity to distinguish on echo metrics; even within ‘soaring species’. The radar has therefore not been used as an active EWS component within the TSS at this time of the year, and the EWS relies on field observers: which has proven to be effective (see later). Reporting on only visual observations also allows consistency between records gathered before the wind farm was constructed and in the years afterwards (since the radar was only deployed after construction).

The radar has provided greater potential utility during winter, when the species and circumstances generating echoes are fewer and so the radar is more easily ‘trained’ on recognition of traces. At this time of year, however, the TSS has much reduced thresholds for being triggered (see section 11.6) and the radar is consequently not directly involved in the EWS. It does prove useful, nevertheless, in generating independent records of birds’ flight activity which can be used to cross-check against those of the field observers. For example, in analysis of birds’ flight heights (a critical measure when modelling collision risk) the estimates of field observers can be contrasted with those derived from radar for geese during winter.

11.4 FIELD OBSERVERS

Field observers are the sole component in enacting the TSS through EWS at SNWF. In the EWS for SNWF field observers have direct individual control on instructing turbine shut down; and turbine re-start.

The field observers involved in the EWS are experienced and suitably qualified; and are named, together with their qualifications and experience, in each monitoring report. They are also specifically trained to estimate the height and distance of birds in flight by on-site exercises, and using local geographical features. Training is also undertaken in the methods for searching for collision victims under turbines.

Observers are stationed at a number of ‘permanent’ locations around the periphery of the wind farm, selected on the basis of providing best visibility and coverage. During study periods an observer is present at each permanent observation point each day throughout the day, weather and access to the points allowing. Additional ‘temporary’ observation points are also occupied at varying times and for varying durations (which may often include locations within the wind farm or in non-permanent peripheral positions). These temporary locations allow recording of birds which may settle or have settled within the wind farm and/or recording of birds entering the wind farm from atypical directions. “End-of-day” meetings of the team of observers allow cross-checking to remove any double-counting of records and to share experience.

Furthermore, surveys and observations are routinely conducted away from the wind farm in order to ascertain the regional presence of target species (several of which occur periodically even within dedicated study periods) and, consequently, their potential for subsequent use or fly-through or fly-over of the wind farm. Such surveys during winter include, for example, checking for the presence of wintering geese at more northern locations (including important ‘protected’ freshwater lakes used as roost sites) and roosting geese on the adjacent Black Sea (which seems to occur when the ‘protection’ of geese at the freshwater lakes fails, and so less preferred saltwater roosting sites are used).

This system of both fixed and flexible observation points, coupled with gathering information from areas further afield from the wind farm, allows consistent reporting of results as well as the capacity to react to unpredictable change, while also attempting to anticipate imminent change. It relies on a committed set of skilled observers with constant communication within the team and (of paramount importance) co-ordinated by an experienced and highly knowledgeable senior ornithologist, Dr Pavel Zehtindjiev. The value of such skilful and knowledgeable observers in field work is critical (Madders & Whitfield 2006) but is not often considered or described in other studies, never mind acknowledged.

11.5 COLLISION FATALITY MONITORING

As noted earlier (section 9, and see also section 10.2) monitoring of collision victims is essential to determine the effectiveness of a TSS and any need that its terms may require to be adapted (or, even, abandoned: Sims *et al*. 2015). Throughout the year, searches for collision victims under fully operational turbines have been conducted at SNWF. The basic nature of these searches was informed by existing protocols (notably Morrison 1998). Searchers are trained, and a consistent set of recording the details of any remains found is followed. Hand-held GPS units have been introduced in recent years to provide spatially accurate records of areas searched. In the several years of monitoring studies at SNWF, searches under turbines have amounted to several thousands in total.

Searches under turbines do not always find every collision fatality. Staged trials using randomly placed ‘surrogate’ carcasses can help to inform (and so calibrate) the results of turbine searches by documenting carcass persistence and searcher efficiency (section 9). Such trials have been conducted at SNWF for both of the periods (autumn migration and winter) when the TSS is applied, with initial trials being staged at the outset of the programme for turbine searches.

As well as informing the rates of carcass persistence and the efficiency of searchers, the initial trials also allowed a cost-benefit analysis of how frequently the area under turbines should be searched. The applied search frequency estimated that about 50 % of any collision victims of target species would be detected under a regime of searches every seven days. More frequent searches would have gained little additional benefit in carcass detection and disproportionately higher costs, whereas less frequent searches would have seen carcasses being undetected at a rate that was disproportionate to the cost-savings from a higher inter-search frequency.

Searcher efficiency/carcass persistence trials have been repeated since the initial trials (in both of the main study periods) to check for any radical changes in the main metrics affecting the calibration of the results of turbine searches, and any need to revise the search frequency (section 9: see also, for example on autumn migration study period: Zehtindjiev & Whitfield 2014). The repeat trials have largely confirmed the initial trials. This potential need for re-evaluation through further trials, nevertheless, will continue through the lifespan of the wind farm.

As noted earlier in this section 11, the collision fatality monitoring also informs any need to add species or ‘circumstance of species occurrence’ to the triggering of TSS (on vulnerability and/or sensitivity criteria according to the EMMP) to be implemented via the EWS, and potential acting revision of the OMP.

11.6 SEASONAL ENACTMENT OF TSS AT SNWF

The requirement for a TSS at SNWF through the EMMP and OMP refers to two periods of the year: 1) during autumn migration, and 2) during winter 'migration' when the main species of concern is the red-breasted goose *Branta ruficollis* (RBG), which periodically uses SNWF (as indicated by pre-construction surveys) along with much larger numbers of greater white-fronted goose *Anser albifrons* (GWFG).

Breeding season

The breeding bird community has been thoroughly studied at SNWF (before and after wind farm operation) and is unremarkable so far as species' or population sensitivity to collision, both on demography (section 6.1) and species conservation status (section 6.2). A TSS is not applied during this time of the year, therefore, although searches for collision victims are conducted around the turbines regularly – albeit less frequently than during other times of the year.

Autumn migration

The vast majority of migratory bird activity at the Kaliakra Cape and SNWF is during the autumn. The TSS accordingly was restricted to the autumn passage period. Initially (2009 – 2012) this period was deemed to be 15 August to 30 September but was extended to 15 August to 31 October in 2013 and in later years. Relatively little migratory activity occurs during October but the extended period was introduced on a precautionary basis.

Estimates of the numbers of birds and a number of associated metrics (e.g. flight height) recorded by observers in and around the core study area of SNWF are reported on annually. Reporting also includes descriptions and analyses to facilitate understanding of the weather factors which may influence birds' presence or proximity to SNWF.

It is highly apparent from several years of study at SNWF that autumn migrants are most often recorded during times when westerly winds occur. Westerly winds do not prevail during autumn, but when they do occur they can result in an influx of soaring and other migrants. Not every day when a westerly wind occurs results in an influx of migrants, but the vast majority of influxes are associated with westerly winds.

The most obvious explanation of these results is that the main migratory flyway (Via Pontica: e.g. Bildstein 2006) is to the west of SNWF and the Kaliakra Cape which hosts the wind farm. The migratory flux of birds on this flyway depends on several factors (as on any such flyway e.g. Bildstein 2006, Newton 2008) which may not always occur when winds are from the west. (Indeed, the presence of a westerly wind is not beneficial to a bird using the Via Pontica at this spatial juncture in northeastern Bulgaria.) When other factors influence airborne behaviour of migrants on the Via Pontica, however, if these coincide with a westerly wind then these migrants will be pushed to the east and towards SNWF.

That SNWF does not lie on the autumn migratory flyway (Via Pontica route) through eastern Europe is also shown by other independent research, confirming the studies at SNWF, such as the satellite tracking of several species where individuals were tagged on the breeding grounds (notably white stork *Ciconia ciconia*: see material in Zehtindjiev & Whitfield 2010) and independent counts of birds across the main flyway route, and beyond it, in Bulgaria (e.g. Laine 1978, Milchev *et al*. 2012, http://natura2000.moew.government.bg/PublicDownloads/Auto/OtherDoc/276299/276299_Birds_120.pdf: pages 151 – 171, and references therein). This is also shown by a web-based tool for mapping migratory soaring bird 'sensitivity' on locations for (explicitly, wind farm proposals) developed by BirdLife International and collaborators (https://maps.birdlife.org/MSBtool/). As well as the empirical data showing that SNWF and the Kaliakra Cape does not lie on the Via Pontica flyway route (see also: Bildstein 2006), then by way of its geography, notably its proximity to a large waterbody, the Black Sea, this also confirms and is consistent with theoretical expectations (van Loon *et al*. 2010).

The five most commonly recorded 'soaring' birds during pre- and post-construction surveys (2008 to 2017) at SNWF involve the white stork (N = 50579), white pelican *Pelecanus onocrotalus* (N = 14347), common buzzard *Buteo buteo* (7716), honey buzzard *Pernis apivorus* (N = 6947) and red-footed falcon *Falco vespertinus* (N = 4251). Several species have been also recorded with a total count of around 3000 over the 10 years of observation associated with the SNWF development: common (great) cormorant *Phalacrocorax carbo*, Levant sparrowhawk *Accipiter brevipes*, marsh harrier *Circus aeruginous*, and lesser spotted eagle *Clanga pomarina*. Hirundines (notably barn swallow *Hirundo rustica*), and European bee-eaters *Merops apiaster* have also been recorded in comparable numbers in the day time, but their migratory flight behaviour does not lend itself to consistent records due to their high flight altitude as regards observer acuity.

Target species initially invoking TSS involve 'soaring' birds, notably black stork *Ciconia nigra*, white stork, white pelican, and Dalmatian pelican *Pelecanus crispus*.

A total of 4585 searches under the 52 individual turbines have been conducted over eight autumn seasons. **None of the target species have been recorded as collision victims, despite the substantial number of searches**.

Through both the turbine search programme and field observations, potentially adverse impacts on other species have been kept under constant review within a process to add species to the TSS criteria, if needed. During the autumn study period over eight years between 2010 and 2017 a total of 49 birds have been recorded by searches as having been struck by turbine blades. The most commonly recorded species is yellow-legged gull *Larus michahellis* (N = 9, a species too common to record by field observers). Hirundines, as a group, have been recorded as victims 12 times: common swift *Apus apus* (N = 7), house martin *Delicon urbicum* (N = 3), barn swallow *Hirundo rustica* (N = 2). Passerine species contribute the majority of recorded collision victims. Only four diurnal raptors have been recorded in searches across all seasons: common buzzard (N = 1), common kestrel *Falco tinnunculus* (N = 2) and red-footed falcon (N = 1).

Of the recorded casualties only the red-footed falcon is not classed as "Least Concern" by IUCN international conservation status classifications. The red-footed falcon is classed as "Near Threatened" by IUCN and over 4000 red-footed falcons have been recorded at SNWF in post-construction monitoring to date. A single collision victim (and after accounting for biases associated with searches) does not constitute a demographic threat to the species or population, and this species has not been added to the TSS triggering criteria; although it will be kept under review by future monitoring/feedback studies.

Griffon vulture *Gyps fulvus* has been added to the TSS criteria (and therefore the EWS) on regional conservation sensitivity after a lone individual collided with a SNWF turbine at the extremity of the array in 2013 (only the third griffon vulture seen near or over the wind farm to that date: previous records were at high altitude, and none were recorded in pre-operational surveys). White-tailed eagle *Haliaaetus albicilla* is also not often recorded but was also added as a trigger to the TSS due to its similarly high vulnerability to collision as documented in studies elsewhere (e.g. Dahl 2014). Other rarely-recorded raptors which would trigger TSS under a perceived threat of collision include eastern imperial eagle *Aquila heliaca*. Egyptian vulture *Neophron percnopterus* is also very rarely seen but has also triggered TSS due to its global and national conservation status.

Common crane *Grus grus* is uncommon in occurrence, but has increased somewhat in recent years through small groups' presence (total count to 2017 = 260), and is now also a feature for triggering TSS. As noted previously, other species will be kept under review and if monitoring data indicate inclusion, then the TSS will be further expanded on criteria for shut down.

Winter season

The winter season refers to the period from 1 December to 15 March in the studies at SNWF and the operation of the TSS. The primary TSS target species is the red-breasted goose (RBG), although as it often associates with the more common greater white-fronted goose (GWFG) the TSS criteria for shut down do not distinguish. In winter, SNWF's TSS has only been deployed according to geese during "bad weather" when snow storm, fog or very high winds may lead to reduced capacity for geese to avoid collision with turbines (and field observers are unable to track goose flights). Following on from recognition of the white-tailed eagle's vulnerability to collision (see earlier) the presence of this species – which, while infrequent, seems to be through attempted predation of geese – has also recently triggered TSS (e.g. all turbine shut-downs in the 2016 – 2017 winter were due to this raptor: Zehtindjiev & Whitfield 2017).

Prior to the construction of SNWF there was ample evidence that its location was not critical nationally or regionally for RBG and that the concentrated geographical importance lay to the north at the freshwater lakes of Durankulak and Shabla (hence Natura 2000 designations there) and the surrounding areas as primary feeding areas (Dereliev 200a, b, 2006, Dereliev *et al*. 2000). Subsequent investigations, both at SNWF and, independently and elsewhere, confirm this conclusion (European Commission 2015, Zehtindjiev & Whitfield 2017; and references therein). The number of wintering geese observed in SNWF during winter broadly corresponds to the total number of wintering geese in the larger region of coastal Dobroudzha region on the western Black Sea; but is lower, in keeping with SNWF being a fundamentally less-preferred area (grossly and intrinsically, irrespective of the wind farm's presence).

Many materials show that the geese which may winter in the region are itinerant (Zehtindjiev & Whitfield 2017). The occurrence of geese within the wider region seems to be broadly governed by the severity of the winter (and availability of ice-free freshwater bodies), with geese apparently having an overarching 'strategy' of wintering as far north as winter temperatures allow, with proximity to freshwater bodies used for roosts and drinking water as further features of wintering site use. Disturbance (probably primarily by hunters) also appears to affect birds' distribution (e.g. the likely less-preferred use of the Black Sea as a roost site: which patently influences the presence of geese at SNWF due to birds leaving these roost sites). Preferences for large fields cultivated for wheat also play a role at a subordinate level (Zehtindjiev & Whitfield 2017; and references therein).

There are no indications of any gross displacement of geese due to the turbines at SNWF. Small scale avoidance of wind turbines in the region has been suggested as part of the LIFE Project (European Commission 2015) using a multi-variate analysis which included several other landscape features, and with the fine-scale distribution of feeding geese being sampled by recording of goose droppings (Harrison & Hilton 2014). This study concluded that current wind turbines in coastal Dobroudzha, notably those as part of SNWF, amounted to only a small loss of potential feeding areas through fine-scale displacement (to tens of metres of habitat loss around a turbine).

Zehtindjiev & Whitfield (2017) present several arguments, including information from other studies from the same LIFE Project, which propose that even this conclusion of minimal displacement impact is probably exaggerated. Zehtindjiev & Whitfield (2017) posit that any fine-scale displacement effect at SNWF, if it occurs, is likely of no material consequence, based on: a) other studies under the LIFE Project; b) prior suggested revisions and factors that should have been (but were not) considered by the ‘fine-scale displacement’ studies; c) earlier research such as those of Dereliev (*op. cit.*), and; d) previous AES monitoring studies at SNWF. Zehtindjiev & Whitfield (2017) also point to the indirect impact of hunting on feeding and roosting geese, not considered by the ‘fine-scale displacement’ study, as a far more serious problem, through gross displacement from preferred and critical resources.

Moreover, the area around a turbine where there is no or limited food for a goose is at or towards the limit at which the study of Harrison & Milton (2014) placed the fine-scale displacement distance of a turbine (e.g. the hard-standings around turbines, and proximity to shelterbelts and tracks). Therefore, arguably at least some, or most, of this displacement in response to a turbine as posited by Harrison & Milton (2014) was actually a reaction to the absence of any food for a goose to feed on around a turbine; rather than a reaction to the turbine *per se*.

The location of SNWF is not an important site for wintering geese, and the wind farm has not apparently made any discernible difference to the use by wintering geese of the agricultural habitat within its turbine arrays. Nevertheless, due to the very large numbers of RBG and GWFG which may winter in the wider Dobroudzha region beside the western Black Sea, even though SNWF is of peripheral importance, SNWF can still can experience many geese passing through its airspace and have many geese settling within it to feed. This use varies by year and by periods within the years.

Over the years of monitoring at SNWF, many hundreds of thousands of flights by geese have been recorded, through the wind farm or flying in and out to use the wind farm as a feeding area. A large proportion of these flights have been at heights which place the geese at risk of collision, given the volume swept by the blades of SNWF’s turbines. Despite this ostensibly and superficially high risk of collision, there has been no goose recorded as a collision victim despite the regular (every seven days, at most) searches under turbines in every of eight winters when the geese have been present during SNWF’s operation. These searches have amounted to several thousand over the years and involving all of the 52 turbines, in total, and search biases within the protocol have been estimated. Nonetheless, despite the potential superficially high risk of collision, and considerable efforts to detect evidence of collision, **there has been no evidence of collision fatalities**.

Earlier results, from SNWF monitoring studies up to winter 2010 – 2011 (i.e. over two winters), were used by Scottish Natural Heritage (2013) to produce guidance that under the "Band Collision Risk Model (CRM)" (Band *et al*. 2007) the collision avoidance rates for geese at SNWF should be very high under this CRM (> 99.9 %). Since this guidance was produced, subsequent monitoring at SNWF over six further winters, when there has been continued recording of an absence of any collision fatalities despite very large prospective risk of collision, indicates even higher capacity for geese to avoid collision with wind turbines. The capacity to avoid collision is consequently even greater than considered by Scottish Natural Heritage (2013).

This is despite previous claims of the 'vulnerability' of geese to turbine collision in earlier literature (e.g. Langston & Pullan 2004) and collision mortality being deemed a 'threat' to geese (specifically RBG: Cranswick *et al*. 2012). While the focus of concern on wintering geese at SNWF has been RBG, it is noteworthy that GWFG, which are far more abundant and usually flock with RBG, have also not been recorded as a collision victim.

These results from SNWF studies illustrate two key conclusions:

1. Geese, including RBG, are in no conceivable way threatened by potential collision fatality at SNWF; and
2. Wintering geese have a nigh-on perfect capacity to (micro-) avoid collision with wind turbines at SNWF.

11.7 EFFECTIVENESS

Shut down durations

Details of turbine shut downs, their duration and the observer-originator of the shut down and re-start are given in recent annual reports for both times of year (autumn migration and winter) when the TSS operates at SNWF. TSS is most often deployed in autumn when the triggering criteria are more numerous (see section 11.6 above; and examples which follow).

As an example, in autumn 2015 there were 15 'shut down events', for an average of 0.17 hours per event (i.e. about 10 minutes, each) involving on average 13 turbines per event, with a total of 38.31 'lost' turbine-hours of operation due to shut down. No figures are available on the actual operational time of the SNWF (i.e. accounting for other shut downs – whether natural because of no wind, or mechanical because of turbine hardware/parts depreciation and/or maintenance). No data are available on TSS implications for lost electricity generation at SNWF, either.

However, these absences of data are somewhat moot when considering that over the autumn study period (1872 hours) for a 52 turbine wind farm, the maximum potential for operation was 97344 turbine-hours. Hence, taking the example from autumn 2015, there was only a loss of 0.04 % of maximum potential operational time for SNWF's turbines due to TSS. This very low consequence of TSS for operational turbine functioning as generators is similar to, or better than, other estimates from TSS case studies in southern Spain and southern Portugal (see section 10.1).

Another recent example, from the 2016 – 2017 winter at SNWF, when shut downs were only deployed due to white-tailed eagle presence, there were only four shut down events, for an average of 0.16 hours per event (i.e. again, about 10 minutes, each) involving an average of nine turbines per event. With a total of 5.55 ‘lost’ turbine-hours of operation due to shut down, over a winter this refers to a study period of 2520 hours and a maximum potential for SNWF operation of 131040 turbine-hours. The TSS consequence therefore resulted in only a loss of 0.004 % of maximum potential operational time for SNWF’s turbines due to TSS (i.e. an order of magnitude less than for the autumn 2015 example).

In other words, these examples illustrate that the TSS at SNWF only results in miniscule loss of potential turbine operation and that all else being equal, this loss is lowest during the winter deployment of TSS.

No adverse impact after several years of operation and monitoring

Collision fatality monitoring has been conducted rigorously over many years (currently, as of this Report, after eight years for autumn migration and eight years for winter), with several thousands of searches per-turbine over the years and with an ability to reference any biases in the search protocol through several staged trials.

None of the target species within the TSS as originally constituted have suffered any recorded collision fatalities, in any season. The monitoring has also shown that no other species’ population (i.e. not deemed as a target species, but which may be deemed to be sensitive on demography or conservation status) could be threatened by the recorded collision fatalities[3].

This has been achieved despite relatively little time when turbines were shut down (see subsection above and also section 10.1). The demonstrable success for SNWF to avoid any additive collision mortality which could even remotely endanger any vulnerable and/or sensitive bird population(s) can be largely explained by three factors, which have been discussed in more detail by several previous reports on the monitoring of birds at SNWF. These three factors refer to:

1. Exaggerated pre-construction claims of collision impacts prompted by the Bulgarian Society for the Protection of Birds (BSPB);
2. Capacity for birds to avoid collision, and;
3. TSS deployment.

Exaggerated BSPB pre-construction claims

A substantial explanatory factor behind the “unexpected” but (subsequently) demonstrably low collision mortality at SNWF can be deemed to be due to exaggerated claims of higher potential impacts from the Bulgarian Society for the Protection of Birds (BSPB) pre-construction; but which nevertheless informed the management and monitoring systems deployed at SNWF.

These BSPB claims, cast in severe doubt by other on-site pre-construction observations but revealed conspicuously by post-construction monitoring as being exaggerated, refer broadly to two issues: 1) the location of SNWF as regards the Via Pontica autumn flyway, and 2) the importance of the area to wintering RBG.

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[3] Monitoring and analyses from SNWF studies have also dismissed as insignificant other potential adverse impacts on bird populations due to other potential effects, such as displacement or barriers to migratory movement or occurrence.

Autumn

Zehtindjiev & Whitfield (2014) document several BSPB exaggerations in detail as regards the autumn study period. Prior to SNWF construction, several sources of data were available on counts of birds at the (prospective) location of the wind farm.

Three years of counts (2004 – 2006) were conducted by the Bulgarian Academy of Science (BAS) representing total counts over the migratory season and were restricted to the (potential, at the time) SNWF wind farm location. In as much as effort and observation point locations, it is unclear if the BAS data are directly comparable with the data collected in 2008 as part of the proposal's assessment (RSK Environment Ltd 2008) and the later AES-sponsored monitoring data collected over many years post-construction at SNWF (http://www.aesgeoenergy.com/site/Studies.html). The BAS data, nevertheless, were similar in estimates to the data collected in 2008 as part of the proposal's assessment (RSK Environment Ltd 2008) and subsequent monitoring data at SNWF.

Data from BSPB (which were used to influence the assessment and subsequent management programmes of SNWF) were of uncertain provenance but probably referred to counts across the Via Pontica flyway for at least some species and reputedly referred to "peak counts" in the SNWF area "and its vicinity". It also has to be assumed (but without confirmation) that the BSPB "data" were also comparable in time with the BAS data (or at least were recent, at the time). But, there was uncertainty in time and space as to what they referred to. This did not, nevertheless, prevent their influence being pressed by BSPB and this influence being part of SNWF's impact assessment and consequent management programmes (notably the EMMP and OMP). BSPB peak counts invariably amounted to at least one or several orders of magnitude greater than total counts at SNWF across multiple species.

The provenance of the BSPB 'count' data used to inform SNWF's management was not clear before SNWF's construction and is becoming even less clear as more data accumulate from monitoring at SNWF. However, it seems most likely that BSPB probably took from records collected on the Via Pontica and claimed that these applied to SNWF, across the whole temporal window of autumn migration. Ironically, in light of BSPB's partnership within BirdLife International, BirdLife International have promoted a useful web-based tool (https://maps.birdlife.org/MSBtool/) which clearly shows studies (aside from other empirical data, not least the many years of study at SNWF) illustrating that the Kaliakra Cape region where SNWF lies, is not on a major migratory flyway (i.e. not on the Via Pontica, in sharp contrast to BSPB's apparent claims prior to SNWF's construction). This joins with the many other sources of data in showing that the pre-construction claims of BSPB as regards the potential impact of SNWF were exaggerated, unduly pessimistic, and not even within the statistical realms of what could be reasonably considered as 'precautionary'. Whatever the source of the supposed BSPB "data" they were clearly and disturbingly fallacious as regards SNWF.

Using these data sources, predictions of collision mortality using the CRM of Band *et al.* (2007), before SNWF were modelled, and were reported by RSK Environment Ltd (2008). These assumed a 95 % avoidance rate under the Band *et al.* CRM, and the results depended on whether the count data provided by BSPB or collected by BAS were used. It was no surprise that estimates of collision mortality were substantially greater according to BSPB data.

Zehtindjiev & Whitfield (2014) reported on the disparities in collision mortality predictions, bringing in data from the collision fatality monitoring since SNWF's construction up to autumn 2014. These predictions of collision fatalities have been brought up to date, together with observed fatalities, for four 'key' species (Table 1).

Table 1. Predictions of collision mortality made pre-construction under the Band *et al*. (2007) model and assuming a 95 % avoidance rate for several 'key' species reported by RSK Environment Ltd (2008: Table 4.7) together with observed collision mortality derived from searches under operational turbines at SNWF.

Species	**Predicted annual collisions**		**Predicted total collisions 2010 - 2017**		**Observed collisions 2010 - 2017**
	BAS data	BSPB data	BAS data	BSPB data	AES SNWF data
White stork	14.6	86.1	117	689	0
White pelican	0.26	1.58	2	12.6	0
Honey buzzard	0.27	0.9	2.2	7.2	0
Lesser spotted eagle	0.09	0.15	0.7	1.2	0

It is obvious that the expectations from pre-construction count data and CRMs have not been realised by the monitoring of collision fatalities, most especially from predictions based on BSPB data. This is most striking for the white stork (Table 1). According to BSPB counts and the original mortality projections based on Band *et al*. (2007) CRMs using a 95 % avoidance rate, by the end of autumn 2017 689 white storks should have been killed. According to BAS counts comparable projected mortality should have been 117 storks. Clearly, both have been revealed to be too pessimistic but the disparity between BSPB and BAS projections are substantial.

Pre-construction BAS counts were similar to those collected in 2008 by dedicated counting efforts at the proposed wind farm site (i.e. also pre-construction) and in the eight years of monitoring at the operational SNWF (http://www.aesgeoenergy.com/site/Studies.html). Hence, the erroneous mortality projections based on BAS data are less likely to be construed as being due to erroneous count data, but to other factors (see later).

In contrast, BSPB claims on the numbers of autumn migrants at SNWF have not found any comparable independent confirmation, at the time, or subsequently. Despite this, the BSPB claims on migrant numbers influenced expectations on the pre-construction impact of SNWF as regards collision mortality. It seems highly likely, therefore, that the exaggerated claims of BSPB on the numbers of autumn migrants at SNWF have played a large part in the apparent success of SNWF's operational management. But this 'success' is in large part due to the inflated expectations which the flawed BSPB count data predicted, even though other factors may be involved (notably higher capacity for collision avoidance and TSS deployment).

Winter

Turning to the winter time; unfortunately there is a similar historical narrative of BSPB having exaggerated the importance of (and so risk posed by) SNWF prior to construction, as regards 'key species'; which at this time of year refers to RBG. This appears to have come about through BSPB claims which took the highest regional counts so far as the numbers of RBG which SNWF could have affected. Again, there was evidence at the time to dispute these claims, from several sources (e.g. studies of Dereliev *op. cit.* and dedicated pre-construction counts associated with the application for SNWF development: RSK Environment Ltd 2008).

Once more, however, the BSPB claims were taken into account in the management and monitoring of SNWF. These led to projections of RBG collision mortality which are well in excess of those predicted from other data sources, and as revealed by subsequent monitoring of both use of SNWF and goose fatalities at the wind farm (http://www.aesgeoenergy.com/site/Studies.html). The exaggerations of the pre-construction claims by BSPB are also illustrated (again, ironically) by the EC LIFE Project on RBG in which BSPB have been involved since SNWF has become operational (European Commission 2015).

Capacity for birds to avoid collision

In addition, original collision risk models (CRMs) conducted prior to SNWF operation were overly precautionary, in some instances at least, because they used avoidance rates which were not appropriate (see Zehtindjiev & Whitfield 2014, for example). Avoidance rates are critical to assumptions of CRMs and highly influential on predicted estimates of collision fatalities (Chamberlain *et al*. 2006). This has been revealed especially for geese, when it appears that at SNWF the capacity for geese to avoid collision with turbines, despite no evidence of displacement (macro-avoidance) from the wind farm itself, is nigh-on perfect (see also: Whitfield 2010, Scottish Natural Heritage 2013, Whitfield & Urquhart 2015). This finding is most apparent during winter because of the limited deployment of TSS at this time of the year as a potential confounding explanatory variable.

It is less obvious for the autumn study period as to how the capacity for birds of the target species to avoid collision has contributed to the absence of any recorded collision fatalities, since the TSS is more often deployed in this study period at SNWF. Nevertheless, overly precautionary collision avoidance rates pre-construction have probably been influential in overestimates of several raptor species' fatalities (e.g. Zehtindjiev & Whitfield 2014). This conclusion is likely because for several 'key' raptor species, as defined pre-construction (RSK Environment Ltd 2008), the TSS has not been applied in autumn (e.g. Zehtindjiev & Whitfield 2014) and so could not be a factor. This conclusion has also been affirmed elsewhere by estimates of collision avoidance being greater than assumed pre-construction (i.e. > 95 %) in similar 'soaring' raptor species under the Band *et al*. CRM (Whitfield 2009, Whitfield & Madders 2006a, b, Urquhart & Whitfield 2016; although see May *et al*. 2010, for white-tailed eagle).

More subjectively, a capacity for the main target species in autumn (*Ciconia* and *Pelecanus*: including the two commonest species, white stork and white pelican) to avoid collision has probably played a part, as several studies elsewhere at wind farms on the migratory routes of some of these birds have not documented mass casualties as would be expected in the absence of a TSS (e.g. de Lucas *et al*.

2008, 2012a), or have inferred a poor capacity to avoid collision (see several references *op. cit.*, despite Thaxter *et al*. 2017, which trawls several source data with inadequate discrimination).

This is particularly apparent for white stork when Band *et al*. CRMs based on a 95 % avoidance rate and empirical on-site counts of birds at SNWF (i.e. ignoring BSPB "data") still appear very high in the light of empirical evidence of recorded collision victims and not based on inflated BSPB data (Table 1; and see RSK Environment Ltd 2008) and even though the TSS is triggered by incipient presence of this species within SNWF. It is difficult to be sure, of course, but it does seem likely that an overly precautionary assumption was made pre-construction so far as the capacity for white stork to avoid collision (along with several other species).

TSS deployment

The only available study which was able to quantify the influence of a TSS on collision fatalities was at Tarifa in southern Spain because it involved "before and after TSS" research (de Lucas *et al*. 2012a). This study area involved a large number of turbines (244) and several vulnerable species – notably the griffon vulture. The TSS effectiveness (reduction of fatalities to about half) was primarily based on its capacity to reduce fatalities of griffon vultures, under a situation that was far more prone to unpredictable vulture behaviour than, say, the Barão de São João Wind Farm in southern Portugal (STRIX 2013, Birdlife International 2015). The Tarifa studies did not seem to involve the SNWF target species as TSS-trigger species even though white storks were abundantly present and black storks were local breeders (de Lucas *et al* 2012a, Manuela de Lucas pers. comm.).

Without any pre- and post-TSS deployment data on collision fatalities at SNWF it is difficult to ascertain objectively the role which TSS has played in SNWF's management plans achieving their success, so far as the clear absence for any adverse impacts through collision mortality on any target species (or on non-target species which are kept under constant review). It is most obvious that in winter the TSS has probably not played any substantive role in the absence of any recorded collisions of wintering geese at SNWF (and despite the searches not being able to detect all collision victims).

TSS is least likely to have played a role in winter at SNWF because its operation is restricted to periods of 'bad weather' when (see earlier) the target species (geese) are likely to use behaviours which may compensate for reduced visibility when TSS is deployed. In the rare periods of TSS during winter as applied for geese, then it <u>may</u> (at best) have prevented a small number of collisions. Away from SNWF, geese have been recorded as collision victims, albeit infrequently (e.g. Whitfield 2010, Rees 2012, Scottish Natural Heritage 2013, Whitfield & Urquhart 2015, Dürr 2017), and there are some few records elsewhere when bad weather has been attributed to atypical and minor collision fatalities. However on balance, in the absence of TSS, at worst, it seems unlikely that bad weather would have resulted in any mortality of geese which could have threatened the respective populations of geese at SNWF.

TSS at SNWF is more likely to have played a role in preventing collision fatalities during the autumn study period, since it is more frequently deployed then (see above). Even at this time of year, however, it seems to be a secondary or tertiary factor in explaining the 'success' of the wind farm in avoiding or minimising collision mortality of potentially sensitive species. There are no species which trigger TSS at SNWF which also appear to be vulnerable to collision and occur at SNWF in numbers during autumn sufficient to cause an intrinsic incipient problem of collision mortality on respective populations. This is in contrast to other case studies elsewhere where a TSS has been applied at wind farms when conspicuously vulnerable species have been present in large numbers (see section 10). (It is also in contrast to other case studies at other wind farms, where a TSS has not been applied, but where collision fatalities can be high: e.g. Smallwood & Thelander 2008, Dahl *et al*. 2012).

Nevertheless, as also noted earlier in this Report, TSS can also be used to militate against any collision mortality and if its deployment incurs minimal financial cost (as also, see earlier) then its deployment as a safety mechanism can be justified. Hence, TSS appears to be primarily a safety mechanism at SNWF, from all accounts, and as such it can be seen as a responsible management protocol which is based on a precautionary set of criteria for deployment.

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