Prepared by:

Guidance on avian post construction monitoring techniques for wind and solar energy facilities with specific reference to Migrating Soaring Birds (MSB) in the Rift Valley/Red Sea Flyway

Appendix I – Auxiliary Information

March 2014

Prepared for:

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FIGURES

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APPENDIX I – AUXILIARY INFORMATION

A. MONITORING SAMPLING DESIGN AUXILIARY INFORMATION

Before-After/ Control-Impact design – BACI

The occurrence of an impact can be properly assessed through the implementation of a Before-After/ Control (Reference)-Impact (BACI) approach. This method aims to estimate a variable's value before and after the impact, comparing its changes against a control site without impact (Figure 1). It allows taking into account the stochastic variables that cannot be controlled during the monitoring programme.

This sampling design implies that the parameter to evaluate is sampled:

- Before the impact occurs (before the construction of the wind/ solar energy facility);
- After the impact occurs (after the construction of the wind/ solar energy facility);
- At project site area;
- At one or more control area that have similar environmental conditions to the wind facility area (studies with two or more control areas produce more powerful results).

To produce comparable data the surveys of the pre-construction phase must be equivalent (locations, field collection data, sampling effort, etc.) of those implemented during the post-construction, both control and impact areas.

Control sites selection is also a key step. Control site should be located further away from the impact area. However, this approach may not be adequate as the community in a distant control site can be different to the bird community in the impact area. A possible practical (and economically advantageous) approach is to consider that the area of influence of the wind turbines is the area of impact (authors recommend approximately 500m for most raptor species (Whitfield & Madders 2006; Drewitt & Langston 2006; Pearce-Higgins *et al.* 2009) and the surrounding area is the control area.

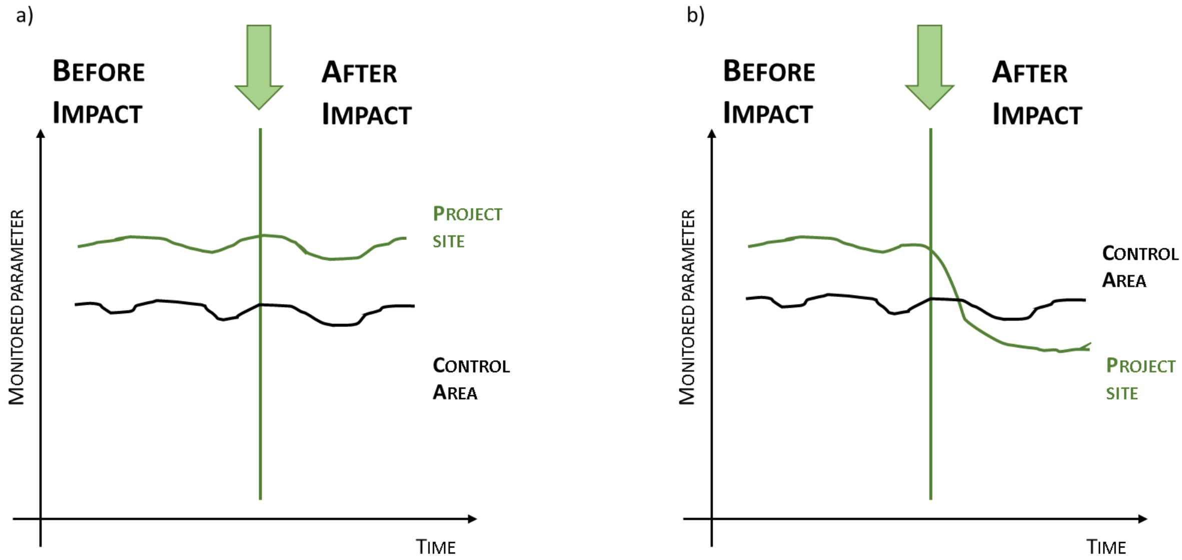

Figure 1 –The Before-After/ Control-Impact (BACI) design for estimating impacts (a) no wind/ solar energy facility effect; b) apparent wind/ solar energy facility effect) (adapted from(Strickland *et al.* 2007)**).**

Impact-Control design – CI

When baseline data is missing impact identification may be achieved through an impact-control design. In this method, the quantification of an impact is achieved by comparing the measurements of a parameter on the affected area after the impact as occurred with one or more control areas (Figure 2). This is a less robust method when compared to BACI and should not be a primer choice.

This sampling design implies that the parameter to evaluate is sampled:

- At wind facility area;
- At one or more control area that have similar environmental conditions to the wind facility area (studies with two or more control areas produce more powerful results).

Choosing the control area is also a key step, and the same assumptions for BACI design should be followed.

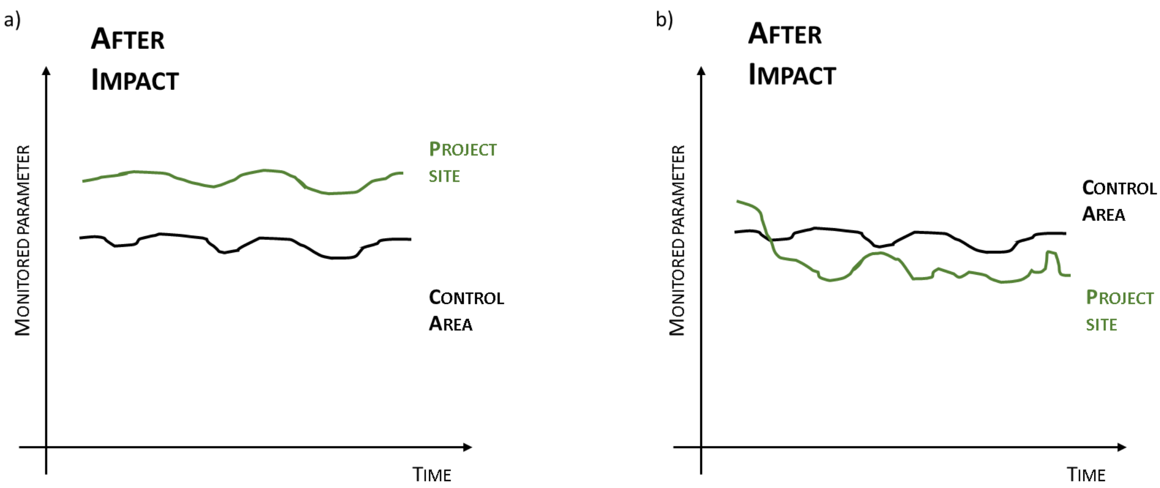

Figure 2 –The Control-Impact (CI) design for estimating impacts (a) no wind facility effect; b) apparent wind facility effect) (adapted from(Strickland *et al.* 2007)**).**

Impact-Gradient design

When baseline data is missing the impact identification may be achieved through an impact-gradient design. This method is based on an analysis of the relationship between the impact indicator and the distance from the hypothesized impact source, e.g. wind turbines (Figure 3). This is a less robust method when compared to BACI and should not be a primer choice.

This sampling design implies that the parameter to evaluate is sampled:

- At different distances from the wind turbines, from the wind facility area to areas over no influence of the wind facility.

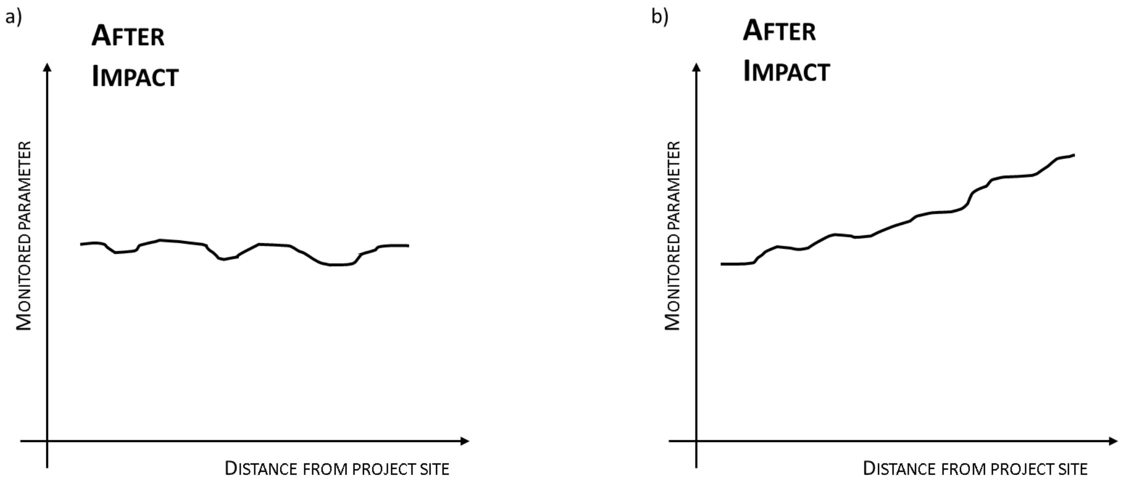

Figure 3 –The Impact-Gradient design for estimating impacts (a) no wind facility effect; b) apparent wind facility effect) (adapted from(Strickland *et al.* 2007)**).**

B. Vantage point datasheet

Project reference:					**Survey** (e.g. Winter I)**:**					**Observer(s):**										**Vantage points**	
Date	**Sampling location**	**Start time**	**End time**	**Duration**	**Species**	**Number of individuals**	**Distance to project (m)**	**Sex**	**Age**	**Flight height (m)**	**Flight type**	**Time of use (sec.)**	**Grid ref.**	**Route ref.**	**Wind speed**	**Wind direction**	**Cloud Cover**	**Precipi-tation**	**Visibility**	**Tempera-ture**	**Observations**

Notes:

To ease and speed up the process of data recording in the field and further analysis it is recommended to abbreviate the species names using notation. It can be done in arbitrary way as long as they were understood by fieldworkers and during data processing. In cases where correct identification of soaring birds is impossible at species level, the genus must be recorded and if the identification of genus is also impossible then bird should be recorded as unidentified, but still counted.

Table 1 – Parameters to be collected in the vantage points.

Parameter	Objective
Date and start/end times of observation and Duration	Date is an important parameter for data organization and quality control. Start/End Time and Duration allow the standardization of the observation effort by the number of sampling hours.
Identification of the observers	The identification of the observers will allow checking for observer bias, being considered as a quality measure.
Sampling location	The definition of a sampling location and notation in the field sheet allows to organize data by location and to control the quality of surveys. This data can also be used to infer for temporal and spatial variations between locations.
Species (total and per observing unit – minutes or hour)	The identification of the species is fundamental to produce any analysis regarding bird community. By identifying the species observed, species richness and abundances per species can be calculated (as long as the remaining parameters are also collected per species observed).
Number of individuals (total and per observing unit – minutes or hour) for each observed species	The collection of the number of individuals of each species is fundamental to calculate abundance indexes, which will enable to assess the presence of impacts or the existence of risk areas. This is also an essential parameter to calculate collision risk models.
Age, sex and morphology (if possible) of each individual observed	The collection of this type of information is many times difficult and considered as complementary. However if possible, this type of data may help evaluate impacts regarding disturbance or displacement effects, such as breeding success.
Flight behaviour (direction and height of flight, distance to observer) or additional information about behaviour (soaring, gliding, hunting flight, etc.)	The collection of information regarding type of flight will allow to evaluate both the risk of collision (as some flights represent more danger than others), but also the existence of impacts such as disturbance or avoidance impacts.
Flight height	By noting the estimated altitude of the migrant birds observed, can be assessed the risk of collision with infrastructures, such as wind turbines, solar collectors, weather masts, among others. The estimated altitude may also provide information regarding non-fatal

Parameter	Objective
	impacts such as avoidance impacts, and is an essential parameter to calculate collision risk models.
Time of use	This parameter indicates the amount of time the observer saw or followed a soaring bird using the proposed site. The estimation of the time of use of a certain area or within a certain flight height may help answer questions regarding areas of collision risk, or disturbance/displacement effects.
Route reference	This parameter allows to do a correspondence between the drawing of the birds path on the topographic map and the flight characteristics that are noted in the field sheet. This route reference must be a unique code for each individual line with singular characteristics drawn in the map.
Grid reference	For ease of reference should be overlaid over the topographic maps a regular grid with a unique code for each grid cell. This grid has a dual function: it may help to calculate distances and help doing the correspondence between the drawn routes and its relevant information written in the field sheet.
Distance to the Project features (wind turbines, solar panels)	The notation of the distance of migrant soaring birds to the project infrastructures will help determine risk areas and detect barrier effect impacts, once bird movements are to abundant to be drawn on map.
Weather conditions (including temperature in the beginning and end of survey, wind speed and direction, precipitation, cloud cover, visibility). Local weather conditions should be recorded in the beginning of observation every observation and then at the beginning of every hour	Weather conditions may help predict migration fronts and condition the movements/behaviour of soaring birds. Therefore, by collecting this information, data analysis can be performed linking the existence of risk of collision periods with the environmental variables.

C. GENERAL POINT SURVEYS DATASHEET

Project reference:				**Survey** (e.g. Winter I)**:**				**Observer(s):**						**GENERAL POINT SURVEYS**
Date	**Sampling location**	**Start time**	**End time**	**Duration**	**Species**	**Number of individuals**	**Distance to the observer (m)**	**Wind speed**	**Wind direction**	**Cloud Cover**	**Precipitation**	**Visibility**	**Temperature**	**Observations**

Table 2 - Parameters that should be collected during general point surveys.

Parameter	Purpose/Objective
Date and start/end times of observation and Duration	Date is an important parameter for data organization and quality control. Start/End Time and Duration allow the standardization of the observation effort by the number of sampling hours.
Identification of the observers	The identification of the observers will allow to checking for observer bias, being considered as a quality measure.
Sampling location	The definition of a sampling location and notation in the field sheet allows to organize data by location and to control the quality of surveys. This data can also be used to infer for temporal and spatial variations between locations.
Species (if not possible to identify the species, it should be registered the genus or a higher identified category)	The identification of the species is fundamental to produce any analysis regarding bird community. By identifying the species observed, species richness and abundances per species can be calculated (as long as the remaining parameters are also collected per species observed).
Number of individuals of each observed (and/or heard) species	The collection of the number of individuals of each species is fundamental to calculate abundance indexes, which will enable to assess the presence of impacts or the existence of risk areas.
Distance to the observer (absolute distance to the transect in case of no distance limit or the distance belt in which the species was observed, in case of distance limit)	By collecting the information regarding the perpendicular distance of the bird observed to the observer, relative density estimated may be generated to produce population estimates.
Weather conditions (including temperature in, wind direction and its speed, precipitation, cloud cover, visibility). Local weather conditions should be recorded in the beginning of every survey and then at the beginning of every hour	Weather conditions may help predict migration fronts and condition the national and even local movements/behaviour of soaring birds. Therefore, by collecting this information, data analysis can be performed linking the existence of risk of collision periods with the environmental variables.

D. Line Surveys datasheet

Project reference:					**Survey** (e.g. Winter I)**:**						**Observer(s):**								**LINE SURVEYS**
Date	**Sampling location**	**Start time**	**End time**	**Duration**	**Species**	**Number of individuals**	**Age**	**Sex**	**Distance to the observer (m)**	**Distance to the project (m)**	**Flight behaviour**	**Flight height**	**Wind speed**	**Wind direction**	**Cloud Cover**	**Precipitation**	**Visibility**	**Temperature**	**Observations**

Table 3 – Parameters that should be collected during line surveys.

Parameter	Purpose/Objective
Date and start/end times of observation and Duration	Date is an important parameter for data organization and quality control. Start/End Time and Duration allow the standardization of the observation effort by the number of sampling hours.
Identification of the observers	The identification of the observers will allow checking for observer bias, being considered as quality measure.
Sampling location	The definition of a sampling location and notation in the field sheet allows to organize data by location and to control the quality of surveys. This data can also be used to infer for temporal and spatial variations between locations.
Species, or at least to genus (total and per observing unit – minutes or hour)	The identification of the species is fundamental to produce any analysis regarding bird community. By identifying the species observed, species richness and abundances per species can be calculated (as long as the remaining parameters are also collected per species observed).
Number of individuals (total and per observing unit – minutes or hour) or each observed species	The collection of the number of individuals of each species in fundamental to calculate abundance indexes which will enable to assess the presence of impacts or the existence of risk areas. This is an essential parameter to calculate collision risk models.
Age, sex and morphology (if possible) of each individual observed	The collection of this type of information is many times difficult and considered as complementary. However if possible, this type of data may help evaluate impacts regarding disturbance or displacement effects, such as breeding success.
Flight behaviour (direction and height of flight, distance to observer) or additional information about flight style, feeding behaviour (for resident species)	The collection of information regarding type of flight will allow to evaluate both the risk of collision (as some flights represent more danger than others), but also the existence of non-fatal impacts such as disturbance or avoidance impacts.
Flight height	By noting the estimated altitude of the migrant birds observed, can be assessed the risk of collision with infrastructures, such as wind turbines, solar collectors, weather masts, among others. The estimated altitude may also provide information regarding non-fatal impacts such as avoidance impacts, and is an essential parameter to calculate collision risk models.
Distance to the Project features (wind turbines, solar panels)	The notation of the distance of migrant soaring birds to the project infrastructures will help determine risk areas and detect barrier effect impacts, once bird movements are to abundant to be drawn on map.
Distance to the transect (absolute distance to the transect in case of no distance limit or the distance belt in which the species was observed, in case of distance limit)	By collecting the information regarding the perpendicular distance of the bird observed to transect, relative density estimated may be generated to produce population estimates.
Weather conditions (including temperature in the beginning and end of survey, wind speed and direction, precipitation, cloud cover, visibility). Local weather conditions should be recorded in the beginning of observation every	Weather conditions may help predict migration fronts and condition the movements/behaviour of soaring birds. Therefore, by collecting this information, data analysis can be performed linking the existence of risk of collision periods with the environmental variables.

Parameter	Purpose/Objective
observation and then at the beginning of every hour	

E. Focal site surveys datasheet - Nests or Roosts

Project reference:					**Survey** (e.g. Winter I)**:**						**Observer(s):**									**Nests or Roosts**
Date	**Site code**	**Start time**	**End time**	**Duration**	**Species**	**Number of adults**	**Age**	**Sex**	**Type of nest/roost**	**Occupation**	**Breeding activity**	**Number of eggs**	**Number of juveniles**	**Wind speed**	**Wind direction**	**Cloud Cover**	**Precipitation**	**Visibility**	**Temperature**	**Observations**

F. Focal site surveys datasheet – Wetlands and/or stopover locations

Project reference:	**Survey** (e.g. Winter I):	**Observer(s):**	**Wetlands and Stopover**																
Date	**Site code**	**Start time**	**End time**	**Duration**	**Species**	**Number of individuals**	**Age**	**Sex**	**Direction of arrival**	**Direction of departure**	**Flight behaviour**	**Flight height**	**Wind speed**	**Wind direction**	**Cloud Cover**	**Precipit ation**	**Visibility**	**Tempera ture**	**Observations**

Table 4 - Parameters that should be collected during focal site surveys.

Parameter	Purpose/Objective
Date and start/end times of observation and Duration	Date is an important parameter for data organization and quality control. Start/End Time and Duration allow the standardization of the observation effort by the number of sampling hours.
Identification of the observers	The identification of the observers will allow to checking for observer bias, being considered as a quality measure.
Weather conditions (temperature, wind direction and its speed, precipitation, cloud cover, visibility). Local weather conditions should be recorded in the beginning of every survey and then at the beginning of every hour	Weather conditions may help predict migration fronts and condition the movements/behaviour of soaring birds. Therefore, by collecting this information, data analysis can be performed linking the existence of risk of collision periods with the environmental variables.
Site code	The definition of site code and notation in the field sheet allows to organize data by location and to control the quality of surveys. Using this information data can also be compared among locations to infer for temporal variations.
Species (if not possible to identify the species, it should be registered the genus or a higher identified category)	The identification of the species is fundamental to produce any analysis regarding bird community. By identifying the species observed, species richness and abundances per species can be calculated (as long as the remaining parameters are also collected per species observed).
For Nests or Roosting locations	
Type of nest/roost (*e.g*. cliff, tree, pylon, building, rock cavity)	The notation of the type of nest/roost, associated to the site code allows detecting referencing errors, and therefore quality control. Also, in situations when the species is unknown, the type of nest may give an indication of the species that may be using it.
Signs of occupation (*e.g*. fresh droppings, fresh food remains, freshly moulted feathers…)	The indication of signs of occupation will help determine the importance of the location to the species.
Signs of breeding activity (*e.g*. adults at nest, adult incubating or brooding, eggs or nestlings)	The indication of signs of breeding activity and of the number of individuals/nestlings/eggs/juveniles observed will allow determining breeding success.
Number of adults/eggs/nestlings/juveniles seen	
For Wetlands or other type of Stopover locations	
Number of individuals present of each observed species	The collection of the number of individuals of each species is fundamental to calculate abundance indexes which will enable to assess the presence of impacts.
Age (adult, juvenile/chicks), sex and morphology (if possible) of each individual observed	The collection of this type of information is many times difficult and considered as complementary. However if possible, this type of data may help evaluate impacts regarding disturbance or displacement effects.
Direction of arrival/departure from the water body	This type of information should help evaluate impacts regarding disturbance/ displacement effects, and possible avoidance behaviours.

G. Carcass searches datasheet

Project reference:			**Survey** (e.g. Winter I):					**Observer(s):**			**CARCASS SEARCHES**
Date	**Sampling location**	**Start time**	**End time**	**Weather conditions**						**Fatality recorded?** (Yes/ No) *	**Observations**
				Wind speed	**Wind direction**	**Cloud Cover**	**Precipi-tation**	**Visibility**	**Tempera-ture**		

* If a fatality is recorded, it is mandatory to fill in the "Fatality records" datasheet.

Table 5 - Parameters that should be collected during carcass searches.

Parameter	Purpose/Objective
Date and start/end times of each search	Date is an important parameter for data organization and quality control. Start/End Time allow the standardization of the search effort by the number of sampling hours.
Sampling location (e.g. ID number of the turbine; ID of the area searched in the solar facilities)	Information about were the searches were conducted is important to later analyse the spatial distribution of the survey effort and fatalities.
Identification of the observers	The identification of the observers will later allow to checking for observer bias, being considered as a quality measure.
Weather conditions (including temperature, wind direction and its speed, precipitation, cloud cover, visibility). Local weather conditions should be recorded in the beginning of every search.	Weather conditions may help understanding possible differences in searcher efficiency between different visits or turbines/areas.

I. Fatality records datasheet

Project reference:			**Survey** (e.g. Winter I)**:**				**Observer(s):**			**FATALITY RECORDS**
Date	**Sampling location**	**Fatality reference code**	**Species**	**Age/ Sex**	**Condition of carcass**	**Estimated time of death**	**Estimated cause of death**	**GPS location**	**Distance to project feature**	**Observations**

Table 6 - Parameters that should be collected when a carcass, feathers or injury animal is found.

Parameter	Purpose/Objective
Fatality reference code	The attribution of a unique code number to each fatality record avoids confusion between different carcasses or feathers when collected for later identification.
Species (if not possible to identify the species, it should be registered the genus or a higher identified category)	The identification of the species is fundamental to produce any analysis regarding the impact of fatalities on bird community composition.
Sex and Age (when possible)	The collection of this type of information is many times difficult and considered as complementary. However if possible, this type of data may help evaluate species relative-sensibility for collision (when enough information is gathered).
Condition of carcass (entire, partial, scavenged, only feathers)	The carcass may be whole or only partial, exhibiting marks of scavenging or decomposing, leaving only small body parts (*e.g.* feathers).
Estimated time of death (*e.g.*, 1 day, 1 week)	Estimated time of death provides information regarding the persistency of the carcass on place, indicating if the fatality has occurred since last carcass search or if has not been detected in a previous conducted search.
Estimated cause of death	If possible, determine the cause of dead or injury (e.g. collision with wind turbine, solar panel or associated infrastructure; burn by heliostats; other cause of death: shooting, poisoning, etc.), in order to assess the cause of impact.
Distance to the wind turbine, solar panel or other associated infrastructures	The notation of the distance of the fatalities found to the project infrastructures will help determine possible cause of death.
GPS location	This information is intended to provide estimates of patterns of fatality according to the location where the carcass was found. This may indicate certain wind directions or bird movements that pose a higher risk.

J. Bird Monitoring Data Analysis Auxiliary information

i. Graphical analysis

To summarize the counting data, graphics that demonstrate changes in a species' total count over the course of the season can be performed hourly, daily, weekly, monthly, by sampling point, impact vs reference area, among others. The unit of choice will depend on the question asked. When examining seasonal or diurnal patterns of variation in flight magnitude within a given year, and in cases where variability in daily observation effort is significant within the period of interest, a more accurate picture may be derived by standardizing daily counts based on daily effort (*e.g.*, counts per hour of observation). Similarly, when analysing seasonal or daily variation across years in cases where inter-annual variation in observation effort is significant, a more accurate picture may be derived by standardizing daily, or time-interval, counts as the proportion of that year's total flight.

i. Measures

Migrant abundance (total number of migrating birds per day)

Migrant abundance is the total number of migrating individuals that crossed the study area per day. A measure of data variation (standard error, for instance) should be associated to the estimations.

Relative Abundance (number of bird individuals per sampling point)

Relative Abundance is expressed as the average number of individuals observed in each sampling point. A measure of data variation (standard error, for instance) should be associated to the estimations.

Species Richness (number of bird species per sampling point)

Species richness may is expressed as the average number of bird species observed per sampling points. A measure of data variation (standard error, for instance) should be associated to the estimations.

Density (number of bird individuals per area)

For point count surveys, density is calculated by considering that all individuals occurring at a minimum distance (50m for close habitats and up to 200m for open habitats) can be detected and that beyond that the detection probability decreases (Bibby *et al.* 2000). Density is then obtained by dividing the number of individuals of each species detected within the defined radius, by the area of a circumference with the same distance radius.

Whenever possible is recommended that the distance of birds to the observer is determined in the field, in order to estimate detection probability (Buckland *et al.* 2001). When the monitoring programme design contemplates a sufficient number of sampling transects/ points and the appropriate methodology is implemented (e.g. recording absolute distances from the individuals to the transect line / point centre) it is also possible to use the Distance software (http://www.ruwpa.st-and.ac.uk/distance/) to calculate densities, with the estimation of detection curves. For more guidance regarding the assumptions for the utilization of this software refer to Buckland *et al.* (2001) and other studies

(Thomas *et al.* 2010). However even with small samples is recommended to estimate a detection function as it will make estimates less precise but protected against changes in detectability. This apparent loss in precision is however preferred than the otherwise underestimation bias (Marques, T., *pers. comm.*).

Activity Index (number of bird contacts per unit of time)

Activity Index (AI) is a measure that can be used for vantage points of resident and migratory soaring birds. For resident species it expresses the average number of contacts observed during the observed period (as one individual may be counted more than once) by the total period of observations implemented at each site. For migrant birds the number of passing individuals per species during the observed period is obtained. For the analysis of data collected through vantage points, and in order to be able to calculate abundance as a measure of contacts per unit of time, an analysis of the view shed of each vantage point should be conducted and a quantification of the amount of time each area was observed (number of hours of observation) should be made (for techniques and criteria see (Fielding & Haworth 2013) per example).

The AI is calculated as follows:

AI = number of contacts recorded/number of hours of observations

Thus the AI can be expressed in contacts per hour. A variation of this index can be useful to determine a more specific type of activity of interest to wind facilities: activity index spent at rotor height (by taking into account only the contacts obtained at rotor height). The outputs can be used for statistical analysis with standard packages, and can be compared for temporal and spatial variations, or for the assessment of higher activity areas.

Kilometric Abundance Index (number of individuals per unit of length)

Kilometric Abundance Index (KAI) is a common measure used in wildlife studies. This parameter allows a straightforward comparison of species abundance in different sites or at different times. KAI shows the ratio of the total number of individuals observed along transect by the total transect length covered at each site. The KAI is calculated as follows:

KAI = number of birds recorded /number of kilometres of transect

Rather recently the module v.transect.kia was developed for GRASS GIS (http://grass.osgeo.org/grass64/manuals/addons/v.transect.kia.html). The module is aimed at automating the evaluation of KAI, reducing the risk of manual errors especially when handling large datasets. It also has opportunities to split large transect according to a given environmental variable (typically habitat type is used for such cases). The module has an option to evaluate true 3D length of transect. For calculation of KAI the module is using a point map of sightings and saves the results in the attribute table of the file. The output can then be displayed in any GIS software or used for statistical analysis with standard packages.

Collision Risk (index of danger of collision with facility infrastructures or associated infrastructures)

The calculation of the collision risk can either be made through indexes or models. The chosen method can be adapted to the site and species characteristics.

For wind facilities the Collision Index can be calculated when its specifications are known and field characteristics of bird migration are recorded. One of the possible methods is calculation of a simple "relative" index to risk of turbine collisions by birds as a function of relative abundance (i.e., bird use/unit area/unit time), and flight behaviour. The index (I) is calculated using the following formula (Strickland *et al.* 2011):

$$CI = U \times P_f \times P_t \; CI = U \times P_f \times P_t$$, where:

- U = average use by species i adjusted for visibility bias;
- Pf = proportion of all observations of species i where activity was recorded as flying. Pf is used as an index to the approximate percentage of a time that species i spends flying during the daylight period;
- Pt = proportion of all flight height observations of species i within the height band swept by the turbines.

Another form of calculation is more complicated and takes into consideration the detailed construction of a wind turbine. To calculate the index the following parameters should be recorded: (1) avian species, (2) number of individuals of each species (abundance) flying in the study area, (3) whether the bird was flying in the risk zone, below it or above it, (4) total flight time of each species in minutes (flight activity) and (5) the flight activity of birds in the risk zone (risk activity). The risk zone for the wind turbine is defined as the region between the lowest and top most points swept by the rotor blades or the aerial height band swept by the rotor blades. The average flight speed for the species can be obtained from literature while type of flight (0 = Fl. – Flapping, 1 = Gl. – Gliding) should be observed in the field.

Collision index for a species (CI) = Number of birds flying through rotor x Probability of bird flying through rotor being hit. Therefore (SNH 2013),

$$CI = \frac{n(Vr/Vw)}{v} \times 2\int_0^R p(r)\left(\frac{r}{R}\right)d\left(\frac{r}{R}\right) \; CI = \frac{n(Vr/Vw)}{v} \times 2\int_0^R p(r)\left(\frac{r}{R}\right)d\left(\frac{r}{R}\right)$$, where:

- n is a number of wind turbines;
- d is the depth of the rotor back to front
- l is the length of the bird,
- π is Pythagoras constant
- R is radius of rotor
- Vr (the combined volume swept out by the wind facility rotors) = N x π x 2 x R x (d + l) (in m^3);
- Vw is a flight risk volume which is the area of the wind facility multiplied by the risk height of the turbines.
- p(r) is the probability p of collision for a bird at a radius r from hub.

The above referred model assumes no bird avoidance of turbines behaviour, however it is known that birds may, and most times do avoid obstacles. Band Model (Band, Madders & Whitfield 2007) considers this avoidance behaviour as a factor of the collision risk assessment, but caution is recommended regarding the avoidance values used for each species (Chamberlain, Freeman & Rehfisch 2005; Whitfield 2009). Other models have also been developed considering factors regarding the species characteristics and its resilience in face of an impact (Noguera, Pérez & Mínguez 2010). More complex models include modelling of wind currents and local topography, which may be of particular use regarding MSB movements (De Lucas, Ferrer & Janss 2012; Liechti, Guélat & Komenda-Zehnder 2013).

K. Fatality Assessment Auxiliary Information

The following tables summarize the mathematical formulas required for the fatality estimation using Huso's and Korner-Nievergelt's estimators (Huso 2011; Korner-Nievergelt *et al.* 2011). The notation presented is the one used by the original authors.

Table 7 - Mathematical formulas to estimate carcass persistence correction parameters.

Bias Correction Parameter	Formula	Notation	Notes
Mean persistence time (Erickson 2004)	$\bar{t} = \frac{\sum_{i=1}^{s} ti}{s - s_C}$	$\bar{t}$ is the estimated mean persistence time (days) t_i is the time (days) a carcass remains in the study area before it is removed ***s*** is the number of carcasses used in removal trials s_c is the number of carcasses in removal trials that remain in the study area at the end of the trials	The mean persistence time (in days) is the removal correction factor required by Huso's estimator (Huso 2011)
Daily persistence probability (Bispo *et al.* 2013)	$s = r_{vk} = \frac{1}{I}\int_0^I S_k(t)dt$	***s*** is the daily persistence probability of a carcass, i.e. proportion of killed bats/birds which do not disappear (e.g. due to decay or scavengers) in 24 hours r_{vk} expresses the average carcass persistence probability at the v-th search for the k-th condition defined by the covariates levels (or combination of levels) ***I*** is the time interval between two consecutive searches $S_k(t)$ is the parametric survivor function for the k-th condition	The daily persistence probability is the removal correction factor required by Korner-Nievergelt's estimator (Korner-Nievergelt *et al.* 2011)

Table 8 - Mathematical formulas to estimate fatality of wildlife.

Estimator	Formula	Notation
Huso 2011	$\hat{F} = \sum_{i=1}^{n} \frac{1}{\pi_i} \sum_{j=1}^{S_i} \sum_{k=1}^{K_{ij}} \frac{c_{ijk}}{g_{ijk}}$	***i*** is any arbitrary turbine; g_{ijk} is the probability of detection of a carcass; y_{ijk} is the number of fatalities in the kth group with probability of detection, g_{ijk}

Estimator	Formula	Notation
		c_{ijk} is the number of the y_{ijk} actually observed ***π_i*** is the product of the proportion of the actual fatality at turbine i that is contained in the searchable area of the plot and the probability of including turbine ***i*** in the sample
Korner-Nievergelt *et al.* 2011	$\hat{p} = \frac{1}{nd} Af \left[n + \sum_{x=2}^{n} \sum_{j=1}^{x-1} k^{x-j} s^{(x-j)d} \prod_{i=0}^{x-j-1} (1 - fk^i \right]$	***A*** is calculated by $s(1 - s^d / 1 - s)$ ***d*** is the search interval, i.e. number of days between two searches ***n*** is the number of searches in the study ***s*** is the daily persistence probability of a carcass, i.e. proportion of killed bats/birds which do not disappear (e.g. due to decay or scavengers) in 24 hours ***k*** is the factor by which the searcher efficiency decreases with each search ***f*** is the searcher efficiency, i.e. the proportion of bats/birds killed and not removed that are found during one search ***p*** is the probability that a bat/bird, which is killed during the study period, is found

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