POST-CONSTRUCTION BIRD AND BAT FATALITY MONITORING FOR ONSHORE WIND ENERGY FACILITIES IN EMERGING MARKET COUNTRIES

Good Practice Handbook and Decision Support Tool

European Bank for Reconstruction and Development

KFW

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Cover photo, top left: European Honey Buzzard (*Pernis apivorus*). Photo: Getty Images
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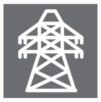

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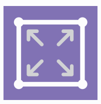

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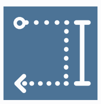

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GLOSSARY OF ACRONYMS AND TERMS

a	Mathematical symbol for Area Correction
ACCURACY	The degree to which an estimate matches the truth.
AICC	Akaike Information Criterion corrected for finite sample size
AREA CORRECTION	An adjustment to a carcass count to correct for the proportion of carcasses that may have fallen where searchers did not or could not search.
ARTIFICIAL DECOY	A fake version of a bird or bat, for example, plastic or fiberglass hunting pigeon or duck or a rubber toy bat that serves as a surrogate for searcher efficiency trials.
BAYESIAN MODEL	A statistical model that relies on the branch of statistics informed by Bayesian theory. Bayesian models are alternatives to the more familiar frequentist models.
BLADE FEATHERING	A method for slowing or stopping turbine blades to minimize collision risk (mainly used as collision mitigation for bats) achieved by adjusting the angle of the rotor blades so that wind resistance is minimized.
BIAS	With respect to PCFM, the extent to which a fatality estimate differs from true fatality. Carcass counts tend to be underestimates of true fatality, principally because of such things as imperfect searcher efficiency and carcass removal by scavengers and when portions of the carcass "fall zone" are unsearched.
BIAS CORRECTION	Mathematical adjustments to carcass counts that a statistical fatality estimator performs to produce an unbiased estimate of fatality. Some bias correction factors are calculated based on observed or known data. Others are calculated based on experimental data gathered especially for that purpose.
BIAS CORRECTION FIELD TRIAL	An experiment in which a single trial carcass or decoy is used to test searcher efficiency, or a trial carcass is used to measure carcass persistence. Results from multiple trials are used to estimate searcher efficiency and carcass persistence at the WEF. These estimates are required to calculate unbiased estimates of fatality using the GenEst fatality estimator.
BMP	Biodiversity Management Plan
CARCASS DENSITY	Relative frequency of carcasses beneath a turbine or OHL. Density tends to be higher closer to the turbine or nearer the centerline of the OHL than further away.
CARCASS DENSITY DISTRIBUTION	A statistical model that describes the carcass fall zone in terms of relative number of carcasses that occur at different distances and directions from turbines.
CARCASS PERSISTENCE	Average probability that scavengers (or other processes) will not remove a carcass that arrives at the WEF between two searches.
CI	Confidence Interval
CLEARING SEARCH	The first carcass search visit conducted by the search team, the purpose of which is to clear search plots of carcasses that were present before the study began so that a fatality estimate can be obtained for the study period only. Carcasses found during a clearing search will not be included in the fatality estimate.

COMMAND LINE INTERFACE	A way to access computing software (e.g., R statistical computing platform that GenEst uses) by typing computer language commands directly into the software. Compare with graphical user interface.
COLLECTOR SYSTEM	Medium-voltage power lines connecting turbines to the onsite substation which are typically underground cables unless geotechnical constraints or permitting conditions require parts of the system to be above-ground.
CONFIDENCE INTERVAL	A statistically estimated range of values within which one is X% confident that the truth occurs. X is the confidence level; the CI becomes wider as X increases. 90% is a common confidence level to use when reporting fatality estimates.
CRIPPLING BIAS	A process that causes carcass counts to be less than the true number of fatalities when injured animals travel beyond the bounds of a search plot before dying.
CURTAILMENT	Method that prevents turbine blades from rotating at low wind speeds: a principal collision mitigation measure for bats.
DENSITY WEIGHTED PROPORTION	An estimate of the fraction of carcasses that occur within the searched areas beneath turbines.
DESIGN TRADEOFFS	The concept that PCFM design in the context of limited resources requires decisions that balance effort and outcomes. For example, very narrow transect widths will result in high searcher efficiency but require a great deal of labor to execute, which may mean that fewer turbines are searched.
DETECTION PROBABILITY	The probability that a fatality that occurs at the turbine or OHL and is deposited in a search plot will be found by searchers.
DETECTION PROBABILITY INDEX	In the DST, an approximate prediction of the fraction of carcasses at the WEF that searchers will find. Includes detection probability (g) and density weighted proportion and is intended to be used to compare alternative PCFM designs rather than predict absolute detection probabilities.
DEVELOPER	The wind energy company that owns the WEF. It is not intended to reference early-stage project development only but is used generically to refer to the entity (company) ultimately responsible for the wind power project, including during the entirety of operations or any part of it.
DPI	Detection Probability Index
DST	Decision Support Tool
DWP	Density Weighted Proportion
EBRD	European Bank for Reconstruction and Development
EMERGING MARKET COUNTRIES	For the purposes of this Handbook, economies considered to be low income, lower middle income, and upper middle-income, per World Bank country classifications.
ENVIRONMENTAL MANAGER	Also referred to as the environmental and social manager; health, safety, and environmental manager; health safety environmental quality manager or other titles, this individual is responsible for overseeing implementation of project environmental and social management commitments, including for biodiversity.
EOA	Evidence of Absence Estimator
ESIA	Environmental and Social Impact Assessment

f	Mathematical symbol for Sampling Fraction
FALL ZONE	The area below the wind turbine or OHL in which a carcass will land.
FATALITY	Death at the individual level.
FIRST YEAR DESIGN	A generalized PCFM design for implementation in the first year(s) of WEF operation that accounts for all size classes of birds and bats and could be implemented in all types of environments.
g	Mathematical symbol for Detection Probability
GENERALIZED ESTIMATOR OF MORTALITY	The statistical models and software recommended in this Handbook, developed specifically to analyze PCFM data.
GENEST	Generalized Estimator of Mortality
GIIP	Good International Industry Practice
GLOBAL SOUTH	A term used to broadly refer to the regions of Latin America, Africa, Oceania, and parts of Asia.
GPS	Global Positioning System
GRAPHICAL USER INTERFACE	A "point and click" way to interact with computer software such as the GenEst fatality estimator. Compare with command line interface.
IFC	International Finance Corporation
IUCN	International Union for Conservation of Nature
k	Mathematical symbol for the factor by which searcher efficiency decreases with each successive search
KFW	The German development bank, *Kreditanstalt Für Wiederaufbau*
LE	Lead Ecologist
LEAD ECOLOGIST	A regionally experienced, knowledgeable field ecologist with a bachelor's or higher degree in ecology or related science from an accredited college or university with adequate postgraduate ecological experience in the wind-wildlife sector.
LENDERS	Collective term for international finance institutions and other development and commercial financiers.
M	Mathematical symbol for estimated total number of fatalities
MEASURABLE ADVERSE IMPACTS	Negative impacts on biodiversity that can be measured.
MITIGATION HIERARCHY	Actions taken to anticipate and avoid or, when avoidance is not possible, minimize and, when residual impacts remain, offset for risks and impacts on the environment. The mitigation hierarchy is a central tenet to IFC, EBRD, and KfW environmental and social standards.
MORTALITY	Death at the population level.
n	Mathematical symbol for turbine sample size
N	Mathematical symbol for total number of turbines
OFF-PLOT DISCOVERIES	Bird and bat carcasses found outside the search plot.

OHL	Overhead power line
p	Mathematical symbol for the probability of detection on the first search — See Searcher Efficiency
PBR	Potential Biological Removal
PCFM	Post-Construction Fatality Monitoring. In this Handbook refers to a systematic search program conducted along walked transects around turbines and along OHLs and associated bias correction trials.
PRECISION	Ability to specify an estimate within a narrow range of values, usually expressed as a CI. For example, an estimate of 4 with a 90% CI of (3, 5) is more precise than an estimate of 4 with a 90% CI of (2, 6).
PRIORITY BIODIVERSITY VALUES	Biodiversity values used to implement a lender's biodiversity standards (e.g., IFC Performance Standard 6). These may include species that are a) listed as Vulnerable, Endangered, or Critically Endangered on the IUCN Red List or that are nationally or regionally listed; b) restricted-range, migratory, or congregatory species; or c) Least Concern on the IUCN Red List but may be especially prone to collision with turbines or WEF-associated OHLs. Priority biodiversity values may also include species of importance to stakeholders for other reasons, such as those that have cultural value, and that might be at risk from cumulative impacts.
PVA	Population Viability Analysis
r	Mathematical symbol for the probability that a carcass arriving during a specified interval persists to the end of the interval — See Carcass Persistence
RAP	Road and Pad Plot
ROAD AND PAD PLOT	Area around a turbine that is maintained free of vegetation during the operational life of a wind farm for the purpose of vehicular access (e.g., turbine pad, crane pad, access roads).
SAC	Stakeholder Advisory Committee
SCADA	Supervisory Control And Data Acquisition. Computer system that controls turbines at a WEF.
SAMPLE	A representative group selected from a larger population. For PCFM, searchers will search a sample of the total number of turbines at the WEF.
SAMPLING FRACTION	The proportion of wind turbines at a WEF or the proportion of segments at a WEF-associated OHL that are searched.
SEARCH AREA CORRECTION	A correction to the counts of fatalities to account for areas under turbines or OHLs that could not be searched but within which carcasses might fall. See also density weighted proportion.
SEARCH INTERVAL	The length of time between searches.
SEARCH PLOT	The area in which carcass searching occurs.
SEARCH TEAM	The team of searchers who will search for carcasses at turbines or WEF-associated OHLs. Also referred to as the 'field team'.
SEARCH VISIT	A single search of all sample turbines.
SEARCHER	The person conducting fatality searches and participating in bias correction trials for a PCFM program.

SEARCHER EFFICIENCY	The probability that a searcher will detect a carcass that is present within the search plot during the search.
SHUTDOWN ON-DEMAND	Bird collision mitigation measure where one or more turbines are temporarily stopped from rotating. Shutdown may be observer or machine initiated in response an increased likelihood of bird collisions at a WEF.
SIZE CLASS	An experimental group used in bias correction field trials. Searcher efficiency and carcass persistence are likely to differ according to size of the fatality. Trials to test these two sources of bias are conducted using different size groups of carcass or decoy; typically, bat, small bird, medium bird, large bird.
SUBSEQUENT YEARS DESIGN	A PCFM design informed by first year(s) PCFM results and optimized to monitor fatalities of PCFM target species.
SURROGATE	In bias correction field trials, a carcass or decoy used as a substitute when there are insufficient WEF fatalities available to use in these trials. For searcher efficiency bias trials artificial decoys may be used.
TRIAL ADMINISTRATOR	In searcher efficiency bias correction field trials, an individual (often the LE) who places trial carcasses or decoys in the search plot before a search day begins, and checks whether they are still present if searchers do not find them.
VISIBILITY CLASS	Categories describing the extent and height of vegetation in search plots. Used to assess how difficult it is for searchers to detect carcasses (e.g., Easy — bare ground 90% or greater, all ground cover sparse and 15 cm or less in height; Very Difficult - little or no bare ground, more than 25% of ground cover over 30 cm in height). Visibility classes are mapped for each search plot and used to answer questions in the DST relating to transect width and inform the DPI.
WBG	World Bank Group
WEF	Wind Energy Facility. Comprising turbines infrastructure and WEF-associated OHLs, including any above-ground sections of the medium-voltage collector system which connects the turbines to the onsite substation, and the high-voltage interconnection line which evacuates power from the onsite substation to the grid.
X	Mathematical symbol for the count of fatalities detected through monitoring

Wind Energy Facility, Castile and León, northern Spain. Photo: Alvaro Camiña

FOREWORD

Scaling up the deployment of renewable energy projects is vital to achieve the 2030 targets of the Paris Agreement on climate change. The recent World Energy Transitions Outlook found that current annual investment in renewable energy technology must more than quadruple if we are to keep global temperature rise to 1.5°C over pre-industrial levels. Yet, if poorly planned, sited or designed, the additional infrastructure needed to meet these targets will have considerable adverse impacts on wildlife, including migratory bird and bat species.

Birds and bats are especially susceptible to adverse impacts from wind farms, with high risk of collision with infrastructure and displacement from favored habitats. Identifying the key areas and migratory pathways for these species, coupled with siting and mitigation measures to avoid such impacts, is essential for preventing negative impacts.

Post-construction fatality monitoring (PCFM) of such infrastructure is a critical component for ensuring that negative impacts to birds and bats are understood and minimized. Data from such monitoring efforts will provide valuable information to further reduce fatalities across species, sites, landscapes, and regions.

As the only global convention focused on the conservation of migratory species and their habitats, the Convention on the Conservation of Migratory Species of Wild Animals (CMS) addresses these and other issues, working with national governments, scientific experts, international organizations and stakeholders.

The CMS Energy Task Force, established in 2015 in accordance with CMS Resolution 11.27 (Rev.COP13), has become one of the world´s leading multi-stakeholder initiatives aimed at reconciling energy developments and wildlife. The CMS Energy Task Force provides a platform where governments, multilateral environmental agreements, private companies, investors, academia, and non-governmental organizations work together to promote and develop guidance for the sustainable deployment of renewable energy. *The Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Projects in Emerging Market Countries Good Practice Handbook* and *Decision Support Tool* is a result of such cooperation.

This Handbook is founded on robust science and provides a user-friendly Decision Support Tool, which will inform adaptive management measures throughout the life of a project. I would like to express our gratitude to the International Finance Corporation, European Bank for Reconstruction and Development, *Kreditanstalt für Wiederaufbau* who have undertaken the development of this valuable work, and I am keen to see it adopted by all relevant actors.

Amy Fraenkel
Executive Secretary
Convention on the Conservation of
Migratory Species of Wild Animals (CMS)

CMS

PREFACE

A transition to clean energy is at the heart of the climate change mitigation objectives of the Paris Agreement. Energy consumption is a key driver of global greenhouse gas emissions, contributing three-quarters of worldwide emissions. Global action is urgently needed to decarbonize our energy supply. To do so, expanding the role of renewable energy globally will be essential for shifting to a low-carbon economy and ensuring access to sustainable, affordable clean energy for millions of people who are currently unconnected.

Wind energy has a role to play in filling the energy access gap. It is the second-fastest-growing renewable energy source globally, after hydropower, with an annual growth of over 10 percent in 2021, yet it is still a vastly underused resource. If we harness an increased share of that potential, wind energy will help achieve affordable, reliable, sustainable, and modern energy for all (SDG7) needed to tackle poverty reduction and climate change.

Against the backdrop of such enormous resource potential, the global wind industry is on the cusp of unparalleled expansion, and it is imperative that biodiversity be protected while such growth is achieved. Onshore wind energy facilities (WEFs) have potentially significant impacts on wildlife, particularly birds and bats. In the face of an unprecedented rate of global biodiversity loss and to further the commitment of multilateral development banks to support investments that are compatible with nature, we look to approaches and tools that will help ensure that the shift to a decarbonized future integrates biodiversity considerations. The only way to understand the collision impacts of WEFs on birds and bats is to design and implement post-construction fatality monitoring (PCFM).

Three development finance institutions — International Finance Corporation (IFC), European Bank for Reconstruction and Development (EBRD), *Kreditanstalt für Wiederaufbau* (KfW) — have developed this Handbook and its Decision Support Tool to promote a consistent, systematic approach to designing and implementing PCFM programs. The Handbook enables the private sector, governments, conservation organizations, and other experts in emerging market countries to better understand the actual impacts of wind energy on wildlife and to take concrete steps to mitigate them. We hope it will set a new global benchmark for biodiversity data collection and impact mitigation for the sector.

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The PCFM Handbook and Decision Support Tool have been developed by an international team of specialists guided by the experiences and advice from ecologists and wind wildlife practitioners from many parts of the world. This expertise has been essential and invaluable in realizing our core aim of providing a resource that develops and consolidates PCFM good practice for use in emerging market countries and elsewhere.

This initiative was led by Lori Anna Conzo (Global Biodiversity Lead, IFC), Daniel Skambracks (Senior Environmental Adviser, KfW) and Robert Adamczyk (Sector Lead Power and Heavy Industry, EBRD) who contracted the following consultancies to co-develop this work:

Western EcoSystems Technology (WEST)

A US-based consulting company that provides environmental and statistical consulting services and contract research nationally and internationally for industry, government, and private organizations.

Natural Power

An international consultancy and service provider working to create a world powered by renewable energy.

The core technical and drafting team consisted of Lori Anna Conzo and Simon Hulka from IFC, Paul Rabie and Kate MacEwan from WEST, and David Tidhar and Zoe Howell from Natural Power. In collaboration with other members of the team, Paul Rabie was the main developer of the Decision Support Tool and helped ensure its compatibility with the Generalized Estimator tool, and Simon Hulka was the main developer of the Density Weighted Proportion tool. IFC, KfW and EBRD are extremely grateful to WEST and Natural Power for their trusted technical guidance, their patience and tenacity, which have been a tremendous asset throughout the evolution of this work.

We are grateful for the guidance provided by our Stakeholder Advisory Committee, which was created at the inception of this work, and consisted of Tris Allison (BirdLife International), Jon Aronson (Camissa Sustainability Consulting), Alvaro Camiña Cardenal (ACRENASL consulting) and Cris Hein (National Renewable Energy Laboratory). In addition to the Stakeholder Advisory Committee, key contributions were provided by our Expert Review Committee, which was selected to incorporate global lessons learned on the topic of wind wildlife science and Post-construction Fatality Monitoring. They include Pablo Brandolin (*Universidad Nacional de Río Cuarto* - Argentina), Jan Blew (BioConsult SH Germany), Sherif Baha El Din (Nature Conservation Egypt), Laith El Moghrabi (Fieldfare Ecology - Jordan), Branko Karapandža (Fauna C&M consultancy; Wildlife Conservation Society Mustela - Serbia), Sujit Narwade (Bombay Natural History Society - India) and Christian Voigt (Leibniz Institute for Zoo and Wildlife Research - Germany).

The lead organizers of the Convention of Migratory Species Energy Task Force also deserve special recognition — Rhiannon Niven (BirdLife International) and Iván Ramírez (Convention of Migratory Species) were instrumental in continuing to promote this Handbook throughout its development. We also thank those members of the Energy Task Force who provided comments on this document during the external review period, and we thank Ashton Berry and Harvey Rich who were formerly leading the Energy Task Force in the initial stages of development of this Handbook and its conception.

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UNDERSTANDING POST-CONSTRUCTION FATALITY MONITORING

1

1. UNDERSTANDING POST-CONSTRUCTION FATALITY MONITORING

Impacts on wildlife caused by onshore wind energy facilities (WEFs) have been well documented for decades and include collision, habitat modification, displacement, and barrier effects (Allison et al. 2019; Drewitt and Langston 2006; Gove et al. 2013; Katzner et al. 2019; Perrow 2017; Schuster, Bulling, and Köppel 2015). Of these, collisions of birds and bats with turbines is the most universal, resulting in fatalities and requiring the most attention (Arnett et al. 2016; Marques et al. 2014; Thaxter et al. 2017). Overhead power lines (OHLs) associated with WEFs[1] exacerbate risks to birds through collision and electrocution (Jenkins, Smallie, and Diamond 2010; Lehman, Kennedy and Savidge 2017; Martín Martín et al. 2021 Prinsen et al. 2011). OHL collision risk to bats is poorly understood but studies indicate that most bat species are unlikely to regularly collide with these types of structures (e.g., Mogdans, Ostwald, and Schnitzler 1988; Vanderelst, Holderied, and Peremans 2015). The risk of OHL electrocution to larger bat species has been demonstrated (Chouhan and Shrivastava 2019; Rajeshkumar, Raghunathan, and Venkataraman 2013; Tella et al. 2020).

As the wind energy sector expands globally, the potential for site-specific and cumulative impacts on birds and bats will continue to increase. In developed markets, the risks and impacts from WEFs and the efficacy of associated mitigation measures are generally well understood, and regulations for biodiversity protection are often in place. In many emerging market countries,[2] the industry is typically at an earlier stage of development, and regulatory processes may not require adequate biodiversity safeguards at project sites. In these situations, the potential for adverse impacts on susceptible wildlife populations to go unchecked is significant. This concern is amplified as species data in emerging market countries are typically scarcer than in developed markets, and the extent of threatened biodiversity is comparatively higher.[3,4]

The impacts associated with WEFs are highly unpredictable, even when robust pre-construction baseline survey results are available (Ferrer et al. 2012; Hein, Gruver, and Arnett 2013; Solick et al. 2020). Although rigorous pre-construction baseline studies are necessary to characterize risks, post-construction fatality monitoring (PCFM) is the only way to understand the actual collision impacts of WEFs on birds and bats. Implementing a robust PCFM program during the operational phase of a WEF is therefore critical for effective management and mitigation of biodiversity impacts.

1.1 What is PCFM?

PCFM generally comprises:

- Searches conducted during the operations phase of a project to search for evidence of bird and bat fatalities at a WEF
- Field trials to estimate the number of fatalities missed during searches either because they were removed before the next carcass search (e.g., by scavenging animals) or because they were overlooked by searchers
- Analyses to quantify bird and bat fatality rates at the WEF using fatality estimation software

[1] OHLs associated with WEFs are referred to as WEF-associated OHLs in this Handbook.
[2] For the purposes of this Handbook, "emerging market" countries are those considered to be low-income, lower-middle income, and upper-middle-income economies, according to the World Bank Country Classifications.
[3] For example, of the 100 globally threatened bird and bat species predicted to be at the highest risk of collision with wind turbines, 82 and 88 percent, respectively, are in the Global South, based on data in Thaxter et al. (2017).
[4] See also, Schmeller et al. (2017) which highlights the relative scarcity of data from biodiversity-rich regions compared to North America and Europe, and Frick, Kingston and Flanders (2020), which highlights this disparity for bat populations specifically.

Despite the focus on fieldwork and analysis, PCFM is not meant to be an exercise in data collection for its own sake; it is intended to inform implementation of a Biodiversity Management Plan (BMP) during the operations phase of a WEF, namely the effectiveness of mitigation, as prescribed in the relevant Environmental and Social Impact Assessment (ESIA) or by government consenting or licensing authorities. During the operations phase of a WEF, PCFM data serve as the backbone for adaptive management (see Section 6), decision making, and demonstration of compliance with environmental requirements of governments or financiers (see Section 1.5).

A well-designed PCFM program will document the range of species occurring as fatalities, the scale of mortality, and reveal spatial and temporal fatality patterns all of which will allow the WEF developer[5] to effectively manage bird and bat collision and electrocution risk.

1.2 Why Focus on PCFM?

A unique aspect of biodiversity management at a WEF is that the focus of monitoring and mitigation is during the *operations phase*, rather than the *construction phase*, and the impacts are primarily in the *air space*. This combination of factors could make the screening of biodiversity risk for this sector difficult for financial institutions with large portfolios. For the wind energy sector, the condition of the terrestrial environment, no matter how modified, is not an appropriate indicator of risk. PCFM results provide the only quantitative basis for measuring the actual impacts of WEFs on birds and bats, and although practical advice is available on avoiding and minimizing impacts following the mitigation hierarchy[6] (e.g., Bennun et al. 2021; Rodrigues et al. 2015), there remains a need for a globally informed practitioners handbook to guide the process for monitoring and evaluating the scale of those impacts in a credible, robust manner during the operations phase of a project.

PCFM practice varies considerably between regions, especially in emerging market countries, where guidance may be limited or non-existent. Although PCFM is essential to understanding the impacts of operational WEFs, if not conducted following good international industry practice (GIIP), it could lead to impacts being underestimated or overestimated. As wind energy development is expanding rapidly, implications for entire landscapes are considerable. Although wind energy is regarded as green energy, impacts can be significant (e.g., Frick 2017), and without a GIIP-aligned

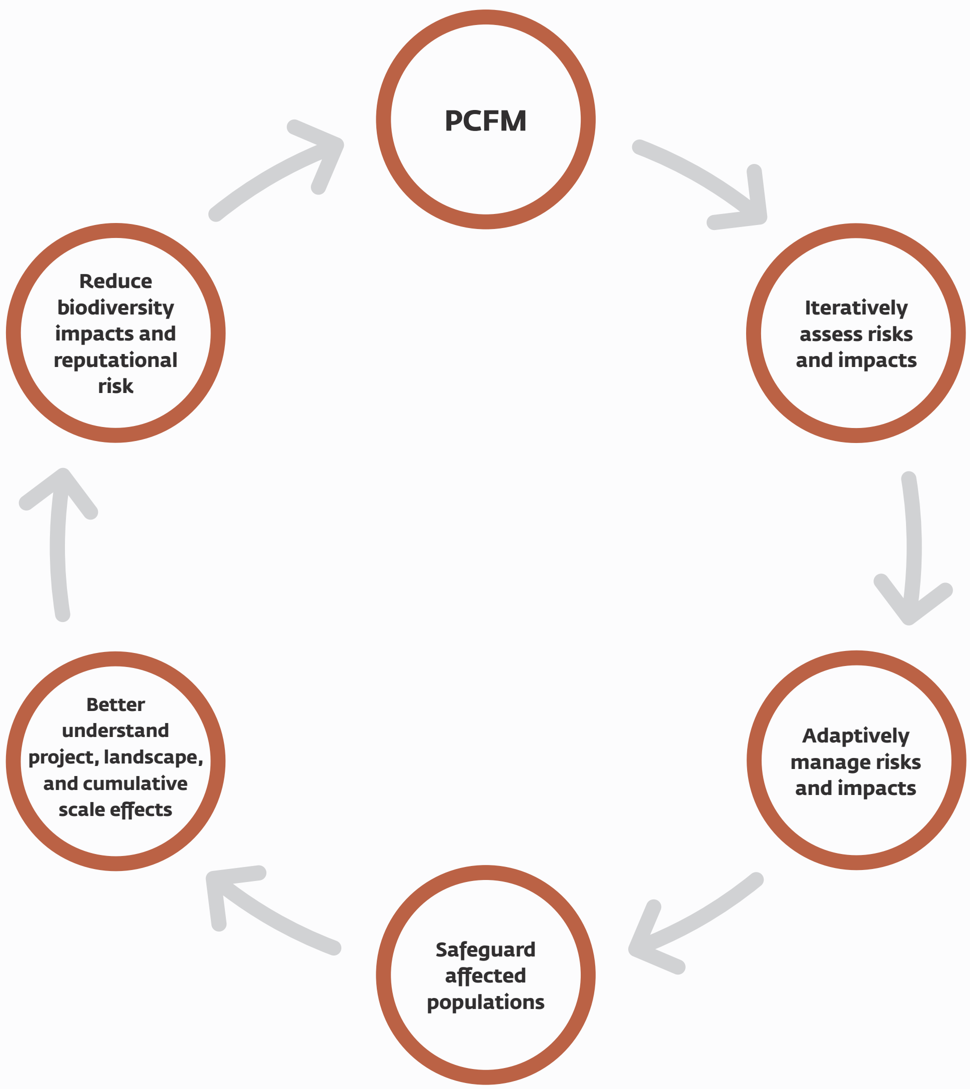
Black Harrier (*Circus maurus*). Photo: Chris Van Rooyen

5 The term "developer" is used to refer to the wind energy company that owns the WEF. It is not only intended to reference early-stage project development but is used generically to refer to the entity (company) ultimately responsible for the wind power project, including during the entirety of operations or any part of them.

6 In alignment with the International Finance Corporation's Performance Standard 1, the mitigation hierarchy is defined as actions taken to anticipate and avoid risks and impacts on the environment or, when avoidance is not possible, minimize and, when residual impacts remain, offset these risks and impacts. The mitigation hierarchy is a central tenet to the environmental and social standards followed by the International Finance Corporation, the European Bank of Reconstruction and Development and *Kreditanstalt für Wiederaufbau*.

PCFM program, the impacts of the sector on bird and bat populations, including at landscape and cumulative scales, cannot be properly understood or effectively managed. Furthermore, once a WEF is operational, impacts may persist throughout its approximately 20-year operational life. Potentially this represents substantive biodiversity and reputational risks for the wind energy developer and its financiers if decisive measures are not taken to understand and curb the impact. Figure 1.1 illustrates the role of PCFM within the adaptive management process

Figure 1.1 PCFM and the adaptive management process



1.3 This Good Practice Handbook and Its Decision Support Tool

This Good Practice Handbook (hereafter referred to as the "Handbook") provides guidance on the design of PCFM following GIIP, underpinned by the scientific method and based on decades of evolution of field and analytical methodologies. The accompanying Decision Support Tool (DST, presented in Appendix A) functions in tandem with the Handbook and is designed to assist in selecting an appropriate PCFM study design, based on WEF characteristics. The primary objective of the Handbook and the DST is to provide practical guidance for the design and implementation of GIIP-aligned PCFM methodology at WEFs in emerging market countries. A secondary objective is to promote global standardization in methodologies for monitoring bird and bat fatalities at WEFs so that fatality rates can be compared across sites, landscapes, countries, and regions, promoting more uniform, more effective management of site-specific and cumulative impacts. Although this Handbook is principally designed to account for collision risks, the methods were developed also to assess impacts of electrocution on birds and bats at WEF-associated OHLs.

1.4 Who Should Use This Handbook?

Four main user groups are expected to benefit from the Handbook and the DST.

> **Wind energy developers and the ecologists working with them are the primary targeted end users.** The Handbook and DST will enable them to characterize the impacts of the WEF, inform the type and scale of mitigation, help safeguard bird and bat populations within and around the WEF, and conform to environmental standards of international financiers.

> **International development financiers, commercial financiers, institutional investors, and asset managers** are encouraged to promote use of the Handbook and the DST among the wind energy developers in their portfolio to ensure that green energy investments are not having undue or unsustainable impacts on biodiversity.

> **Governments** are encouraged to use this material as a resource to inform the permitting and licensing of WEFs to regulate the impacts of WEFs on biodiversity in a sustainable, sector-specific manner.

> **Conservation organizations and academic institutions** may use this guidance to inform development of databases to track landscape-scale impacts of WEFs on birds and bats and to understand regional trends.

This Handbook uses the terms "reader" and "user" to refer to all of these types of stakeholders. The Handbook also frequently references "practitioner" and "Lead Ecologist (LE),"[7] which refers to the individual(s) working for the wind energy developer who will put this guidance into practice. LE and other terms are defined in the Glossary of Acronyms and Terms.

1.5 Applying Relevant Lenders' Environmental and Social Standards

This Handbook accompanies the environmental and social standards, guidance documents, and guidelines of the International Finance Corporation (IFC), the European Bank for Reconstruction and Development (EBRD), and the German development bank *Kreditanstalt für Wiederaufbau* (KfW). (These and other development and commercial financiers are collectively referred to as "lenders.") Relevant standards and guidelines include:

> IFC Performance Standard 6 on *Biodiversity Conservation and Sustainable Management of Living Natural Resources* and its accompanying Guidance Note 6 (IFC 2012, 2019)

[7] For further information about this role, see Appendix B.

- EBRD Performance Requirement 6 on *Biodiversity Conservation and Sustainable Management of Living Natural Resources* and its accompanying Guidance Note (EBRD 2019, 2022)
- As applicable to *Kreditanstalt für Wiederaufbau*'s public sector lending, the World Bank's Environmental and Social Standard 6 on *Biodiversity Conservation and Sustainable Management of Living Natural Resources* and its accompanying Guidance Note (World Bank 2017, 2018)
- The World Bank Group Environmental, Health, and Safety Guidelines for Wind Energy (WBG 2015)
- The World Bank Group Environmental, Health, and Safety Guidelines on Electricity Transmission and Distribution (WBG 2007)

PCFM results are relevant to the application of; a) Natural Habitat requirements of IFC Performance Standard 6 and World Bank Environmental and Social Standard 6 on *Biodiversity Conservation and Sustainable Management of Living Natural Resources*; b) Priority Biodiversity Features requirements of EBRD's Performance Requirement 6; and c) Critical Habitat requirements of all three[8]. They are particularly applicable to the no net loss[9,10,11] principle relevant to Natural Habitats and Priority Biodiversity Features requirements and the no measurable adverse impacts[12,13] goal associated with Critical Habitat requirements. PCFM, together with an operations-phase Adaptive Management Plan, represent a specific management tool to respond to these lender standards when applied to WEFs.

Pipistrelle Bat (*Pipistrellus pipistrellus*). Photo: Getty Images

[8] It should be noted that many bird and bat populations use the air space above degraded or converted habitats. In these instances, no net loss and no measurable impacts requirements may be applied to the species using the air space itself rather than the habitat below.

[9] As defined in footnote 9 of IFC's PS6 *"No net loss is defined as the point at which project-related impacts on biodiversity are balanced by measures taken to avoid and minimize the project's impacts, to undertake on-site restoration and finally to offset significant residual impacts, if any, on an appropriate geographic scale (e.g., local, landscape-level, national, regional)."*

[10] As defined in footnote 8 of the World Bank's ESS6 *"No net loss is defined as the point at which project-related biodiversity losses are balanced by gains resulting from measures taken to avoid and minimize these impacts, to undertake on-site restoration and finally to offset significant residual impacts, if any, on an appropriate geographic scale."*

[11] As defined in footnote 77 of EBRD's PR6 *"No net loss is defined as the point at which project-related biodiversity losses are balanced by gains resulting from measures taken to avoid and minimize these impacts, to undertake on-site restoration and finally to offset significant residual impacts, if any, on an appropriate geographic scale."*

[12] As defined in paragraph GN86 of IFC's Guidance Note 6 *"…[no measurable adverse impacts] means that project-related direct and indirect impacts will not jeopardize the long-term persistence of the biodiversity value(s) for which the critical habitat was designated, considering the range of mitigation measures implemented by the client throughout the life of the project and in alignment with the mitigation hierarchy."* It should be noted that this is referred to as "measurable net reduction" in the WB's ESS6 [see paragraph 24(c)].

[13] As defined in footnote 79 of EBRD's PR6 *"Measurable adverse impacts mean the project's direct and indirect impacts will jeopardize the persistence within the study area of any biodiversity value that triggers a critical habitat designation."*

OVERVIEW

2

2. OVERVIEW

This section provides a brief overview of the Handbook and an introduction to the DST.

2.1 Outline

This Handbook is developed for those who are new to the topic of PCFM, as well as for more experienced practitioners. The content is organized into the following six sections.

1 UNDERSTANDING POST CONSTRUCTION FATALITY MONITORING

- Defines PCFM and its importance for understanding impacts at a WEF
- Introduces the Handbook and DST
- Explains who is to benefit from the Handbook and DST
- Explains the relevance of PCFM to Lenders' environment and social standards

2 OVERVIEW

- Provides an overview of the key content in each of the sections of the Handbook
- Provides details of the resources that are provided to help users implement PCFM
- Introduces the Generalized "First Year" Design
- Outlines the compatability of the DST with the GenEst fatality estimation software
- Introduces PCFM guidelines for WEF-related OHLs

3 PCFM: CONCEPTS AND PRINCIPLES

- Outlines the "must know" core concepts and underlying principles needed to develop a PCFM design
- Outlines core concepts and underlying principles needed to develop a PCFM design
- Explains how monitoring objectives may influence PCFM design trade-offs
- Focuses on PCFM for turbines and highlights how concepts apply to WEF-associated OHLs

4 PCFM DESIGNS AND USING THE DST

- Provides guidance on developing PCFM designs for turbines and WEF-associated OHLs
- Provides guidance on using the DST to develop a generalized First Year design
- Provides guidance on using the DST to develop a "Subsequent Years" PCFM design
- Provides guidance on developing WEF-associated OHL PCFM designs

5 DATA ANALYSIS

- Focuses on the analysis of PCFM data
- Provides a brief overview of available fatality rate estimation tools
- Recommends approaches for reporting PCFM data

6 ADAPTIVE MANAGEMENT

- Describes how PCFM results are used to adaptively manage impacts
- Provides insights for developing an adaptive management plan
- Addresses adaptive management thresholds
- Outlines roles and responsibilities of an adaptive management program
- Provides an outline for reporting and disclosure

To support the Handbook, several resources are provided to help users design and implement PCFM programs effectively and efficiently. These are found in the appendices at the end of the document and summarized in Table 2.1.

Table 2.1 Resources to help practitioners design and implement PCFM programs effectively

APPENDIX	RESOURCE	DESCRIPTION
A	**Decision Support Tool (DST) Workbook**	**Tool for generating and evaluating PCFM designs**
B	**PCFM fieldwork guidance toolkit**	**Practical advice on planning and implementing PCFM fieldwork at turbines and WEF-associated OHLs**
C	**'GenEst' fatality software-worked example**	**Step-by-step guidance on using the GenEst software**
D	**Density Weighted Proportion (DWP) Tool**	**Tool for calculating DWP for use when generating fatality estimates in GenEst**
	Searcher Efficiency Trial Placement Tool	**Tool for generating random locations for carcasses and decoys for searcher efficiency bias trials**
E-J	**PCFM data collection forms**	**Printable fieldwork recording forms**
K	**PCFM equipment checklist**	**Printable checklist of equipment and other resources needed for PCFM fieldwork**

2.2 Generalized First Year Design

Turbine collision susceptibility is unknown for many species of birds and bats in emerging market countries, and impacts are often site-specific and not always accurately predicted from pre-construction baseline studies. For this reason, this Handbook and the DST provide a generalized PCFM design for implementation in the first year(s) of WEF operation that accounts for all size classes of birds and bats and could be implemented in any environment (see Section 4.1.2).

Although PCFM monitoring objectives may have been preliminarily established in the ESIA or as part of national permitting and licensing conditions, implementing the First Year PCFM design will enable the developer to determine accurate fatality estimates for a broad range of species size classes so that PCFM target species (see Section 3.2.1) can be identified, and an optimized PCFM program can be designed and implemented for subsequent years. Identifying an accurate set of PCFM target species is key to informing the WEF's monitoring objectives, which may change once fatality results become known (see Section 3.2.1 for further information on this topic). Although the study is referred to as the First Year design, it may need to be implemented over multiple years if the first year of monitoring does not accurately identify a set of PCFM target species (see Section 4.1.3). For more information on study duration, which is a separate concept, see Section 3.3.1.

2.3 The DST and Compatibility with the Generalized Estimator of Mortality

The DST (see Appendix A) is a spreadsheet-based support tool accompanying this Handbook that enables the user to begin designing a PCFM program. As described in detail in Section 4.1.1 of this Handbook, the DST asks the user a series of site-specific questions relevant to monitoring and estimating fatalities at the WEF (and based on the answers, outputs a recommended PCFM design). The DST is equipped with separate tabs (worksheets) for determining the First Year design (see Section 4.1.2) and the 'Subsequent Years' design, which is an optimized design focused on PCFM target species derived from the output of the first year(s) results (see Section 4.1.3).

The DST and this Handbook facilitate collection of PCFM data that are compatible with the Generalized Estimator of Mortality (GenEst) modeling tool[14] (Dalthorp et al. 2018), which is currently the best method for estimating bird and bat mortality at WEFs (Rabie et al. 2021). GenEst is a free, publicly available, user-friendly software that enables PCFM results from various projects and landscapes to be standardized (see Section 5.1.4.1 and Appendix C for further information).

The DST and GenEst are complementary and together support the wider objective of the Handbook; to promote a standard global PCFM method. A key benefit of improving standardization between WEFs is that it creates the opportunity to develop regional PCFM databases that will allow a better understanding of the cumulative effects that a rapidly expanding global wind energy industry may have on bird and bat populations.

2.4 Consideration of WEF-Associated OHLs

Although this Handbook focuses on PCFM at turbines, WEF-associated OHLs are also covered. This includes any above-ground sections of the medium-voltage collector system that connect the turbines to the onsite substation[15] and the high-voltage interconnection line that transfers power from the onsite substation to the grid. Practices recommended in this Handbook may be applicable to other OHLs, regardless of their association with wind energy generation, if implemented through the guidance of a qualified expert and with respect to any existing country- or region-specific guidelines.

[14] See https://www.usgs.gov/centers/forest-and-rangeland-ecosystem-science-center/science/a-generalized-estimator-estimating

[15] Although the collector system is usually buried (see also Section 4.2.1.1 of this Handbook), it is included in the definition of OHLs because there may be some exposed overhead lines due to geotechnical constraints or permitting conditions. The collector system is sometimes referred to as "cabling."

As mentioned in Section 1, fatalities at WEF-associated OHLs can account for a substantial proportion of total fatalities at a project (Brenninkmeijer and Klop 2017) and, unlike turbines, OHLs may present collision and electrocution risks to birds and bats. An overview of these risks is provided in Section 3.4.1 of this Handbook, and recommended PCFM practices are introduced in Section 3.4 and presented in 4.2. There is no DST for WEF-associated OHLs, because the key components necessary to run the logic in the tool (e.g., carcass fall zone at OHLs) have not been sufficiently researched. Nonetheless, the guidance in this Handbook provides a reasonable approach for designing a PCFM study.

White Storks (*Ciconia ciconia*). Egypt. Photo: Emad Abd Allah

PCFM: CONCEPTS AND PRINCIPLES

3

3. PCFM: CONCEPTS AND PRINCIPLES

This section provides the conceptual background and building blocks for designing a PCFM study. The focus is on turbine searches, with differences in the design for WEF-associated OHLs presented in Section 3.4. One of the aims of this section is to explain how decision making throughout the design process may affect the precision[16] of PCFM results.

3.1 CORE CONCEPTS

As highlighted in Section 1 of this Handbook, PCFM principally involves:

- Designing, planning, and conducting searches for bird and bat fatalities
- Conducting bias correction field trials
- Calculating fatality rate estimates from the data collected during the previous two activities

The first two activities are covered in this section, and fatality rate estimation is described in Section 5.

Designing and planning a PCFM search program will require the practitioner to be familiar with the following design components:

STUDY DURATION is the number of years that PCFM should be conducted.

TURBINE SAMPLE is the number or proportion of turbines searched for bird and bat fatalities.

SEARCH PLOT SHAPE AND SIZE is the shape and size of the search area at each individual turbine. The search plot may be circular or square and centered on the turbine, or it may consist only of the gravel pad around a turbine, adjacent crane pad, and the road(s) leading up to it.

TRANSECT WIDTH is the spacing between transects walked by searchers within the search plots at each turbine when searching for fatalities.

SEARCH INTERVAL is the time between consecutive fatality searches (sometimes referred to as "search frequency").

[16] Precision refers to the repeatability of a statistical estimate and is usually indicated with a confidence interval (CI). See Section 5 of this Handbook.

Additionally, to derive unbiased fatality rate estimates, the results from a PCFM search program must be corrected to account for the main biases that arise when conducting PCFM fieldwork. To do this the practitioner will need to understand the following bias correction design components:

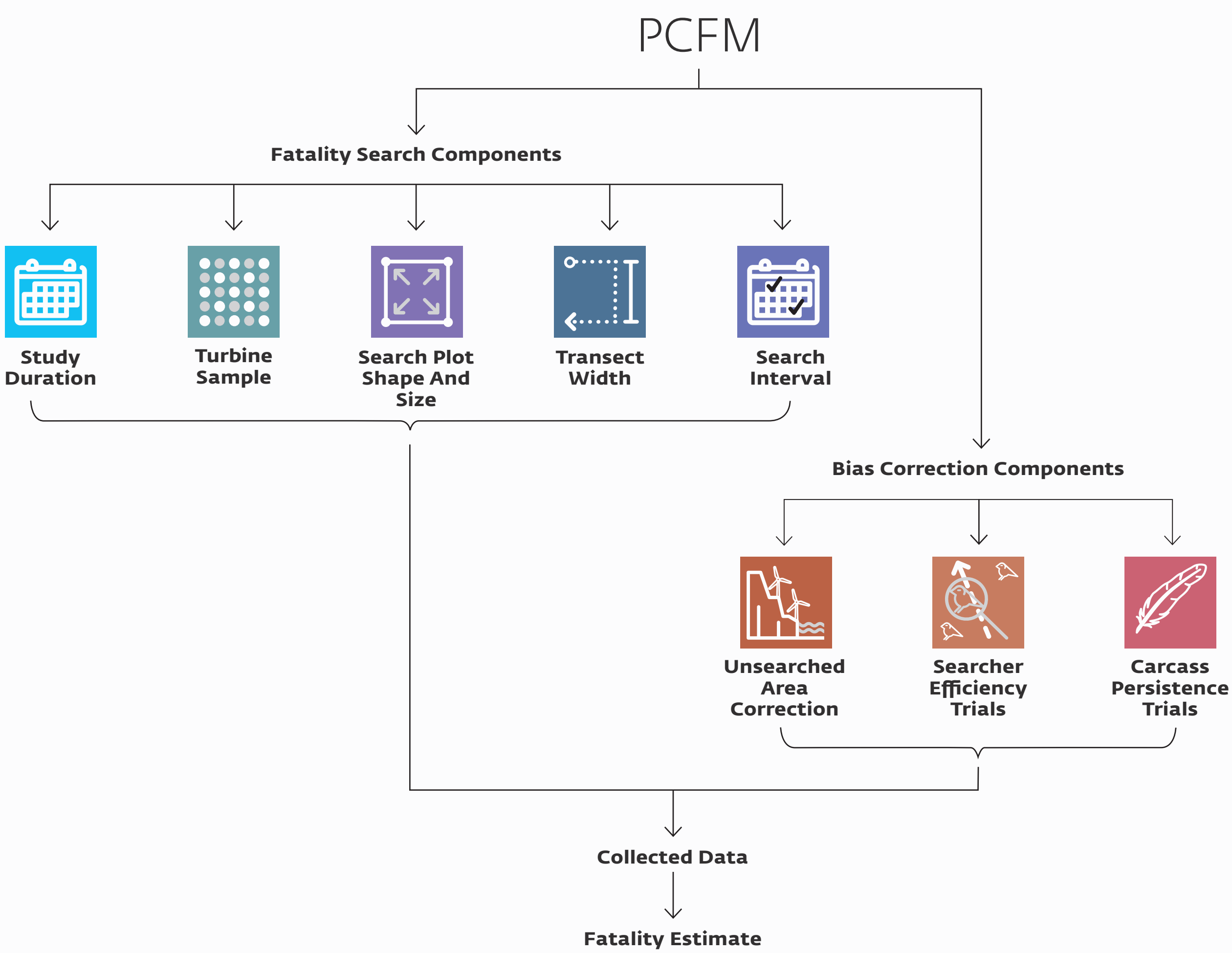
UNSEARCHED AND UNSEARCHABLE AREA refers to the areas within the fatality fall zone at a sample turbine that are unsearched for some reason, such as being beyond the search plot boundary, or within the search plot but unsafe to search (e.g., steep terrain) or having such complex ground cover that detection would be nearly impossible (e.g., forested areas).

SEARCHER EFFICIENCY TRIALS are field trials used to measure the probability that a searcher will detect a carcass on the ground at the time of a search.

CARCASS PERSISTENCE TRIALS are field trials used to measure the typical amount of time bird and bat carcasses persist on the ground before being removed by scavengers or becoming undetectable because of environmental factors (e.g., flooding, decomposition).

Figure 3.1 illustrates the PCFM design components for fatality searches and bias correction.

Figure 3.1 WEF PCFM design components



3.2 CROSS-CUTTING CONCEPTS

Four main cross-cutting concepts underpin all aspects of PCFM design:

- PCFM target species
- Monitoring objectives
- Sources of bias
- Detection probability

An understanding of these cross-cutting concepts will help the LE to evaluate the PCFM components (see Section 3.1) and build a robust, appropriate design.

3.2.1 PCFM Target Species

Lender biodiversity standards are often implemented with respect to a defined set of priority biodiversity values.[17, 18] Depending on the context, these priority values may be determined as part of an ESIA, BMP, or other biodiversity-related assessment (e.g., Critical Habitat Assessment, Biodiversity Monitoring and Evaluation Plan, Adaptive Management Plan). At a WEF, priority biodiversity values may include:

- Species listed as Vulnerable, Endangered or Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List[19] or are nationally or regionally listed
- Restricted-range, migratory, or congregatory species
- Non-threatened species on the IUCN Red List but especially prone to collision with turbines[20]

Priority biodiversity values may also include species of importance to stakeholders for other reasons, such as those that have cultural value, and species that might be at risk from cumulative impacts.

This Handbook uses the term *PCFM target species* which are bird or bat priority biodiversity values that occur in the WEF area of influence and that are being impacted, or have the potential to be impacted, through collision with turbines or collision or electrocution at WEF-associated OHLs. It is likely that PCFM target species will be a subset of the priority biodiversity values.

Although PCFM target species may be preliminarily defined in the ESIA or BMP, not all will be known before implementation of PCFM. Accurately identifying PCFM target species is key to defining the monitoring objectives for a WEF. It is also essential to *optimizing* the PCFM design over the study period and as part of adaptive management (see Section 6).

Cape Vulture (*Gyps coprotheres*). South Africa.
Photo: Chris Van Rooyen

[17] For example, see paragraphs GN12 and GN13 of IFC's Guidance Note 6.

[18] This concept is related to but separate from the concept of critical habitat species, which are those of highest biodiversity value. See Performance Standard 6 (IFC 2012), Environmental and Social Standard 6 (World Bank 2017), and Performance Requirement 6 (EBRD 2019) and related guidance notes.

[19] See https://www.iucnredlist.org/.

[20] For more information on collision susceptible bats see Arnett et al. 2016 and for collision susceptible birds see Thaxter et al. 2017

3.2.2 Monitoring Objectives

The main objective of any PCFM study is to characterize wildlife collision impacts to inform potential mitigation and adaptive management during the operational phase of the project. Other objectives may include:

- Determining the number of fatalities with respect to defined fatality thresholds[21] in the project's Biodiversity or Adaptive Management Plan or with respect to national or regional thresholds
- Determining temporal and spatial patterns of impact to inform and optimize mitigation strategies
- Meeting project-specific lender or regulatory policy requirements or achieving other management or scientific goals
- Contributing to an understanding of the cumulative or landscape-scale effects on PCFM target species and informing wind energy sector spatial planning

This Handbook assumes that the objective of characterizing wildlife collision impacts will initially be achieved by implementing and reviewing the results of the First Year PCFM design (see Section 4.1.2). However, some PCFM target species may not appear as fatalities in PCFM monitoring in the first year(s) (e.g., because of their rarity in the landscape, inter-annual variation) and yet might remain a focus of the project's monitoring objectives. Determining which species to retain as PCFM target species, and therefore as monitoring objectives, will consider both stakeholder values and the efficient use of resources. The monitoring objectives should be revisited after implementing the First Year PCFM design and routinely throughout the life of the project (see Section 6). PCFM study duration is covered in Section 3.3.1.

Rüppell's Vultures (*Gyps rueppelli*). Ethiopia. Photo: Alvaro Camiña

[21] See Section 6.2 for further information on thresholds.

3.2.3 Sources of Bias in PCFM Study Design

Generating scientifically robust estimates of fatality rates means accounting for and addressing sources of bias that are inherent to carcass counts from PCFM searches. The term "bias" with respect to PCFM means that counts of carcasses are lower than the true number of fatalities. Bias in PCFM studies is generated in three principal ways:

- Searchers do not find all carcasses (searcher efficiency bias).
- Not all carcasses persist long enough to be found (carcass persistence bias).
- Not all carcasses fall within searched areas (unsearched and unsearchable area bias).

Understanding the principles that underpin each PCFM component (Section 3.3) will help minimize these sources of bias when designing a PCFM program.

Bias may also be generated as a result of "crippling bias". See Box 3.1 for more information.

Box 3.1 Crippling bias

Crippling bias occurs when birds and bats are not detected during searches because, despite colliding or being electrocuted, they are able to move away from the search plot before dying (e.g., Murphy et al. 2016; Rioux, Savard and Gerick 2013; Travers 2021). As with the other types of bias described in this Handbook, crippling bias results in fatality estimates that are below the true number of fatalities. This bias is however impractical to quantify at the project scale, because it requires real-time monitoring of non-fatal collisions and electrocutions, which are likely to be rare and unpredictable. There is a gap in research on the extent to which crippling bias occurs as a result of collisions with turbines while for OHLs the option of using values from dedicated crippling bias research is not considered reliable because of the large variance in reported values (APLIC 2012; Birdlife International 2015). Recognizing these problems, approaches for assessing crippling bias are not included in the Handbook or the DST. The most appropriate approach when reporting fatality estimates is to highlight that crippling bias is not accounted for and that estimated mortality may therefore be lower than actual mortality. When there is evidence that injured birds or bats have moved outside the search plot, increasing the search plot distance from the turbine or OHL is a viable option for reducing the effects of this type of bias.

3.2.4 Detection Probability

Imperfect ability to detect carcasses can be accounted for through the detection probability, which is defined as the probability or likelihood that a fatality that is caused by the WEF will be found by searchers. Detection probability is also a convenient measure to use when comparing PCFM designs.

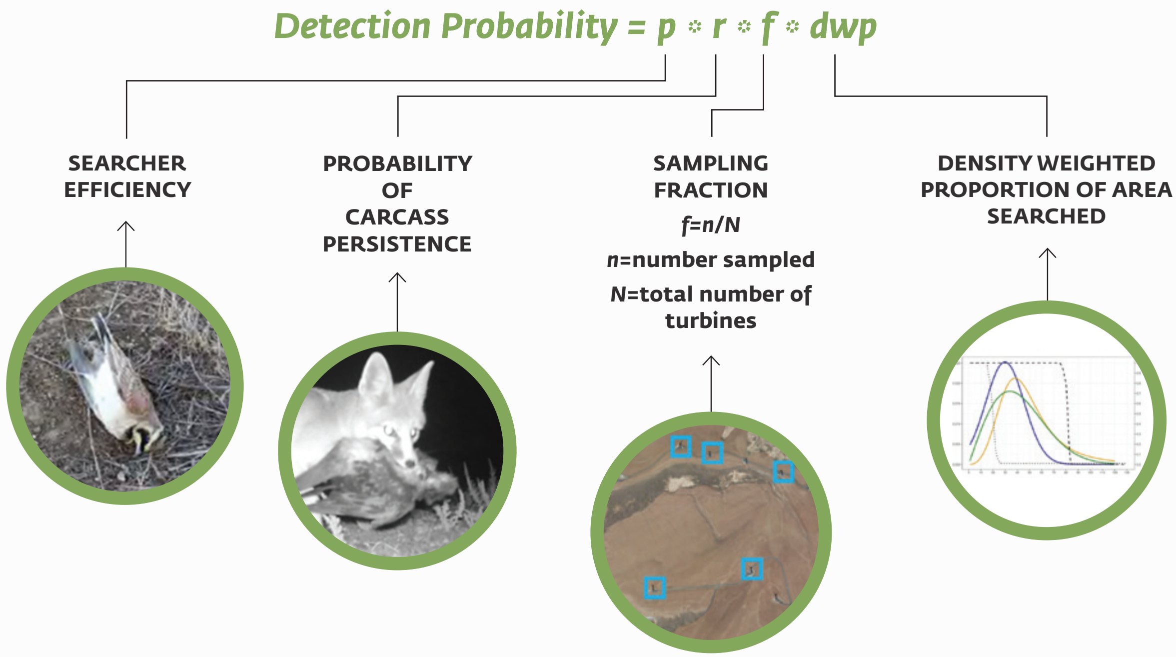
In a perfect world, in which searchers detected 100 percent of fatalities caused by a WEF, the detection probability would be 1, and no bias corrections would be necessary. In the real world, detection probability is always less than 1 due to the combined effects of factors that can prevent searchers from detecting fatalities. However, the primary benefit of the bias correction methods discussed in this Handbook is that, as long as biases can be characterized and the detection probability can be estimated, it is possible to estimate the "true" or unbiased bird and bat fatality rates generated by a WEF.

As shown in Figure 3.2 detection probability incorporates:

- The effectiveness of searchers in detecting carcasses [searcher efficiency (p)]
- The probability a carcass is not removed by scavengers or other factors [carcass persistence (r)]
- The proportion of turbines sampled [sampling fraction (f=n/N)]
- The proportion of fatalities that occur within searched areas [area correction (DWP)]

The result will be a number between 0 and 1. For example, a PCFM design with a detection probability of 0.1 means that on average, 10% of carcasses that are killed by WEF infrastructure will be found by searchers, whereas a design with a probability of 0.45 means that searchers will find an average of 45% of WEF-caused carcasses.

Figure 3.2 General representation of detection probability as the product of searcher efficiency, carcass persistence probability, sampling fraction, and area correction



Box 3.2 Detection probability and meeting lender requirements

At each WEF, geographical, environmental and ecological conditions will differ. These differences will result in varying levels of bias and affect the detection probabilities within PCFM programs. For example, a WEF in a sandy desert will generally have a higher searcher efficiency, less unsearched area, and possibly lower scavenger pressure, resulting in higher detection probability, compared with a WEF in a tropical forest, where these biases are likely to be higher. These differences between WEFs and the limitations that they impose mean that it is not feasible to set a single detection probability that each project should attain to meet lender standards.

In general, lenders will expect more monitoring effort at WEFs where there are PCFM target species with higher risk profiles, and greater monitoring effort should lead to higher detection probability. For example, a higher risk profile may include collision susceptible species that are a) listed as Vulnerable, Endangered, or Critically Endangered on the IUCN Red List; b) restricted-range, migratory, or congregatory species; or c) non-threatened species on the IUCN Red List but for which there are demonstrated high numbers of fatalities, also considering cumulative impacts. In these cases, the developer should expect to expend more monitoring effort (e.g., sampling more turbines, decreasing search interval) to increase detection probability. This determination should be made on a project-by-project basis in consultation with the developers and financiers.

To develop a PCFM design that is likely to meet lender requirements, the developer should have a clear understanding of the PCFM components and principles outlined in this Handbook and use the DST to develop an initial recommended PCFM design and, where applicable,[a] use the Design Explorer tool in the DST (see Section 4.1.3.3) to test alternative designs. The developer should also use the detection probability index results in the DST to evaluate and compare the recommended and alternative design and consult with lenders to agree on the PCFM design that will best meet lender requirements.

a The DST outputs a generalized First Year design. The Design Explorer tool is developed to be used when developing a Subsequent Years PCFM design (see Section 4.1.3)

Differing ground cover search conditions. Left: Algarve region, Portugal. Right: Tafila region, Jordan. Photos: Alvaro Camiña (left), Simon Hulka (right)

3.3 PCFM COMPONENTS—TURBINE SEARCHES

In this section, each PCFM component for turbine searches is described in detail, and the key underlying principles supporting design decisions are presented and highlighted in blue boxes. By the end of this section, the reader should understand:

> The individual contribution of each component to detection probability

> The basic principles important to making decisions about each component

> How the components interact with each other

Each component is connected to activities in the field. Appendix B provides guidance on how to collect high-quality field data, which will directly influence the accuracy and precision of fatality estimates.

3.3.1 Study Duration

Key Concept

Longer study duration increases confidence that the species impacted by the WEF are documented and reduces the chances of missing rare events such as collision fatalities of scarce species with high biodiversity value.

With respect to study duration (number of years of monitoring), a minimum of three years after commercial operation of the WEF has begun, covering all relevant seasons[22, 23, 24] is recommended. Study duration should be extended when there are PCFM target species with higher risk profiles or the effectiveness of adaptive management warrants longer-term monitoring. Longer studies have advantages, including establishing potential spatial and temporal trends in fatality data, and certain PCFM target species may only be detected after multiple years of PCFM. Ultimately, the study duration should be determined by the level of risk and impact to PCFM target species.

22 Seasons are defined based on climate (e.g., summer, autumn, winter, spring; rainy (monsoon), dry) and according to ecological and/or biological factors (e.g., migration periods, breeding and non-breeding seasons of the PCFM target species).

23 At some WEFs, turbines may begin operating before reinstatement of the ground surface around turbines is completed. During this period, the WEF may implement a protocol that requires fatalities and injured animals to be documented as "chance finds," following the guidance in Section 3.5.

24 For very large WEFs, commercial operations may be staged, with groups of turbines scheduled to become operational sequentially over an extended period. In these cases, PCFM should start at each turbine group when it becomes operational and not be delayed until the WEF is fully operational.

3.3.2 Turbine Sample

3.3.2.1 How Many Turbines to Sample?

Key Concept

Sampling more turbines leads to higher detection probabilities and more precise fatality estimates.

How many turbines are searched (what proportion of the WEF is searched) is a basic and important decision for any PCFM study design. To maximize detection probability, the preference is to search all turbines at a WEF. If that is not feasible, a representative sample should be selected. The DST will recommend the number of turbines, although the decision will ultimately depend on the risk to PCFM target species.

When increased effort is necessary to maximize detection probability during a particular season, it may be appropriate to search more turbines during that season. The number of turbines searched should be the same throughout a season, unless, for example, one or more of the turbine search plots become unsearchable (e.g., the land around the turbine becomes flooded, maintenance activities prohibit searching). The turbines searched should only be changed at the beginning of a new season. For example, if constraints on a PCFM design mean that only a fraction of turbines can be searched for very large WEFs, then an option could be to search a different sample of turbines in the next season. Although searching a different set of turbines in each season will not increase the sampling fraction, it will reduce the possibility that fatality hotspots are missed.[25]

3.3.2.2 Which Turbines to Search?

Key Concept

To obtain unbiased fatality rate estimates, the selection of sample turbines should be random.

When only a sample of turbines is selected for a PCFM design (i.e., fewer than 100% of turbines are searched), they should be selected *randomly* so that unbiased fatality rate estimates for the WEF can be obtained. Using non-random factors to guide selection of search turbines, such as characterizing

[25] Altering the sample completely can also lead to questions about whether differences in seasonal or annual fatality patterns may be related to the turbines sampled. Some practitioners prefer to maintain a consistent portion of the turbine sample over seasons and years. For example, of 40 turbines included in the first PCFM season, 10 are maintained and 30 new turbines are selected for the second PCFM season.

certain spatial fatality patterns or experimental aims (e.g., characterizing the effectiveness of operational phase mitigation), requires advanced statistical techniques to produce unbiased fatality rate estimates and are outside the scope of this Handbook.

3.3.3 Search Plot Shape and Size

3.3.3.1 Why are Plot Shape and Plot Size Important?

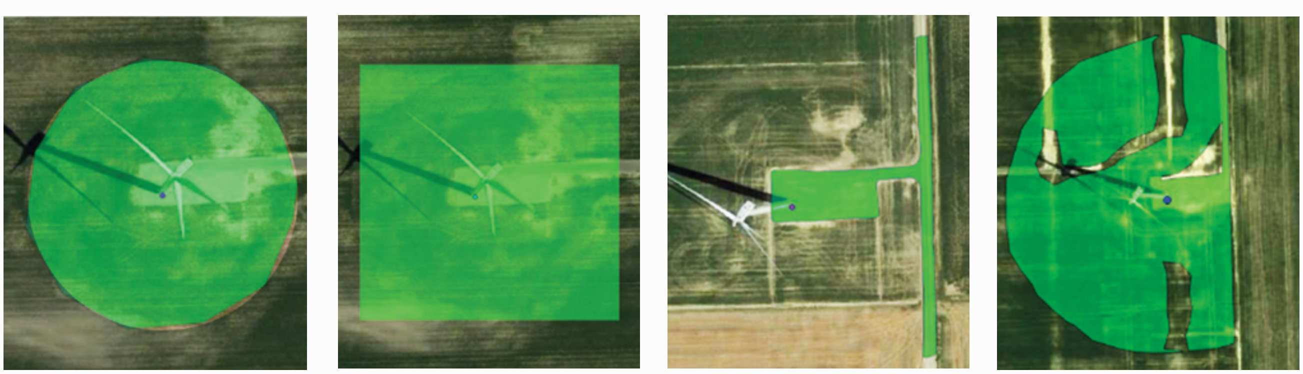
Key Concept

Bigger plots contain more of the carcasses that fall below turbines, resulting in higher detection probability and more precise fatality estimates, but they require a greater level of effort per search.

Plots can vary in shape but are typically circular or square[26] with the base of the turbine tower located in the center (see Figure 3.3). Circular plot size is described in terms of its maximum radius, and square plot size by the length of the sides. Optimum selection of search plot size is generally defined in terms of the search plot radius in relation to the maximum installed blade tip height of the turbines, which is equivalent to the hub height plus the rotor radius. This is because bigger turbines will generally cause bird and bat carcasses to fall over wider, more dispersed areas (Choi, Wittig, and Kluever 2020). Regardless of size or shape, plots will require an area correction to account for carcasses that may fall beyond the edge of the plot. For more information on accounting for the unsearched and unsearchable area, see Section 3.3.7.1.

Figure 3.3 Examples of search plot types (light green polygons): (A) circular plot, (B) square plot, (C) road and pad plot, (D) partial circular plot because of flooding and crop land

A B C D



[26] They could also be a rectangle, for example, if there are limitations in the terrain.

3.3.3.2 Road and Pad Plots

A road and pad (RAP) plot is a search plot restricted to ground surfaces or substrates that will be maintained free of vegetation during the operations phase of the WEF out to a fixed, pre-defined radius. Such cleared areas generally include the gravel area around the turbine base, the area maintained clear for crane access (crane pad), and portions of turbine access roads (Figure 3.3 C).

In many environments, such as croplands, forests, shrublands, and moist or wet climate zones, RAP search plots may be the only option because areas outside of the RAP areas are likely to be unsearchable,[27] but in environments such as steppes, deserts, and other areas that are more readily searchable, full search plots are recommended.

RAP plots have the benefit of being rapid and relatively easy to search and generally lead to higher searcher efficiency than the areas off the RAP. However, there is a tradeoff, because the proportion of the carcass fall area around a turbine that is covered by RAP surfaces is smaller than a full plot. Consequently, only a small proportion of the potential carcasses available for searchers to find will land within a RAP plot. This will result in low detection probability and fatality estimates with wide confidence intervals, resulting in a level of precision that may limit the ability to identify PCFM target species. For RAP designs, the fatality estimate is therefore very sensitive to the unsearched area correction.

Road and pad plots. Photos: Inkululeko Wildlife Services

[27] This is because vegetation growth impedes detection unless it is managed by mowing or other means, which is generally not recommended practice in emerging market countries given the potential impacts on local communities (e.g., croplands) and on biodiversity.

3.3.4 Transect Width

3.3.4.1 What Determines Transect Width?

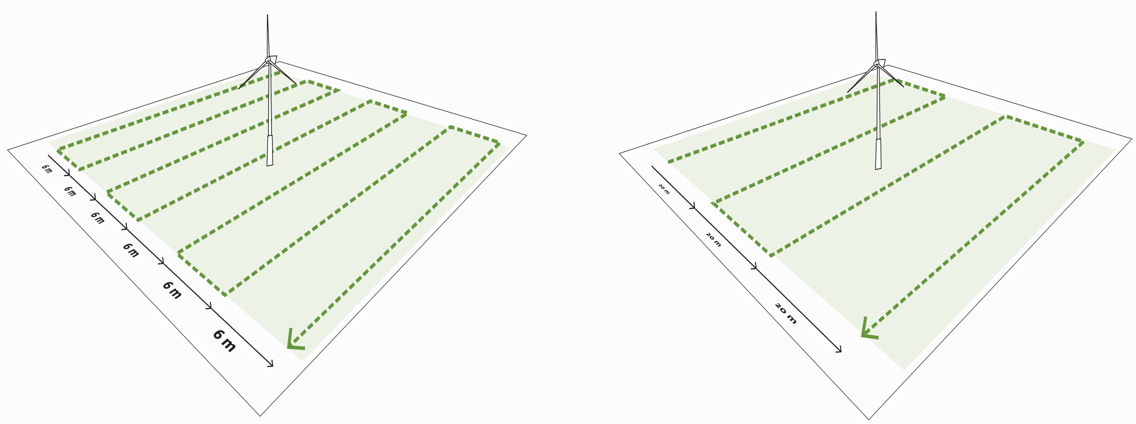
Key Concept

Narrower transects will increase detection probability but will increase effort. Optimum transect width should be determined based on the size class of the PCFM target species.

To standardize search effort and methodology, searches should be conducted by walking along regularly spaced transects that collectively provide comprehensive coverage of the search plot. The transect spacing directly influences the proportion of carcasses that searchers find, particularly for smaller fatalities (notably bats), and this can affect the determination of PCFM target species. Optimum spacing of transects generally ranges from 4 to 20 meters and should be determined based on the size class of the PCFM target species and density of vegetation within the search plot, noting that smaller PCFM target species and vegetation and other ground conditions that hamper visual detection will generally require more closely spaced transects (Figure 3.4). Transects can be oriented in a variety of ways but are usually parallel and face a consistent direction (e.g., north-south) in all search plots. In RAP search designs, access roads within search plots may require only one or two search transects (along the road edge), whereas crane pads will require several regularly spaced, parallel transects, similar to larger search plots. For information on conducting searches with dogs see Box 3.3 below.

Figure 3.4 Examples of transect spacing (not to scale): (A) 6 m spacing for a study intended to capture data on bats and small birds and (B) 20 m spacing for a raptor-focused PCFM study

A. 6 m spacing **B. 20 m spacing**



Note: Dotted lines indicate the walking path of a searcher. Transects should be no further than half the transect width from the edge of a plot.

Box 3.3 Fatality searches using dogs

In some more developed markets, where trained ecologists conduct all PCFM fieldwork, dogs have been used effectively to search for fatalities. Searches with dogs are particularly effective when PCFM target species are bats or small birds and where the search plot has dense vegetation or is otherwise difficult to search.

PCFM using dogs is a specialized technique that requires extensive dog and handler training, dog search protocols to ensure consistency of searches, resources to ensure animal welfare, and ongoing trials to assess dog search efficiency. This PCFM method should only be considered if trained ecologists conduct fieldwork and use dogs professionally trained for this purpose. At WEFs where both human and dog searches are conducted, each plot should be designated for search exclusively by a dog or a human search team. WEF environmental managers and LEs considering this approach are strongly encouraged to read published studies to fully understand the benefits, challenges, and limitations of using dogs in wildlife studies (e.g., Cablk and Heaton 2006; Wasser et. al. 2004) and, specifically, PCFM using dogs (e.g., Bennet 2015; Domínguez del Valle, Cervantes Peralta, and Jaquero Arjona 2020; Mathews et al 2013; Paula et al 2011).

3.3.5 Scanning Searches: An Alternative Approach to Transect-Based Searches for Large Birds

Where PCFM target species are large birds, and ground surface visibility allows searchers to see fatalities at long range, a systematic scanning search method, conducted from fixed locations around each turbine, is an alternative that can be used when it is impractical or unfeasible to conduct transect-based surveys.[28] Although scanning and transect search designs include the same PCFM components, aspects of the scanning search design and the analysis are more complex, and only advanced PCFM practitioners with assistance from a statistician should use this method. See Appendix B for further information.

[28] Transect-based and scanning searches should not be used together for a single turbine because it makes the analysis more complicated, although it would be acceptable to have transect-based searches at some turbines and scanning searches at other turbines in the same WEF. If combining scanning and transect-based searches at the same turbine is unavoidable, a statistician should be consulted.

3.3.6 Search Interval

3.3.6.1 What is the Search Interval?

Key Concept

Shorter search intervals result in fewer opportunities for carcasses to decompose or be removed by scavengers before searchers can find them, increasing detection probability and fatality estimate precision.

The search interval is the length of time between searches and is sometimes referred to as "search frequency." Every PCFM program should set a consistent search interval for each season.[29] The search interval directly influences the proportion of fatalities that searchers find and, in turn, the precision of the fatality rate estimate. There is an important relationship between the search interval and the average number of days that fatalities will remain on the ground before scavengers remove them, referred to as "carcass persistence" (see Section 3.3.7.3). With shorter search intervals, carcasses will be fresher when found, which will help with identification and reduce opportunities for carcass removal by scavengers or other means. As search interval decreases, the probability of a carcass remaining on the ground (or persisting) long enough to be found increases, which in turn increases the overall detection probability.

3.3.6.2 Factors Influencing Search Interval Selection and Carcass Size

Key Concept

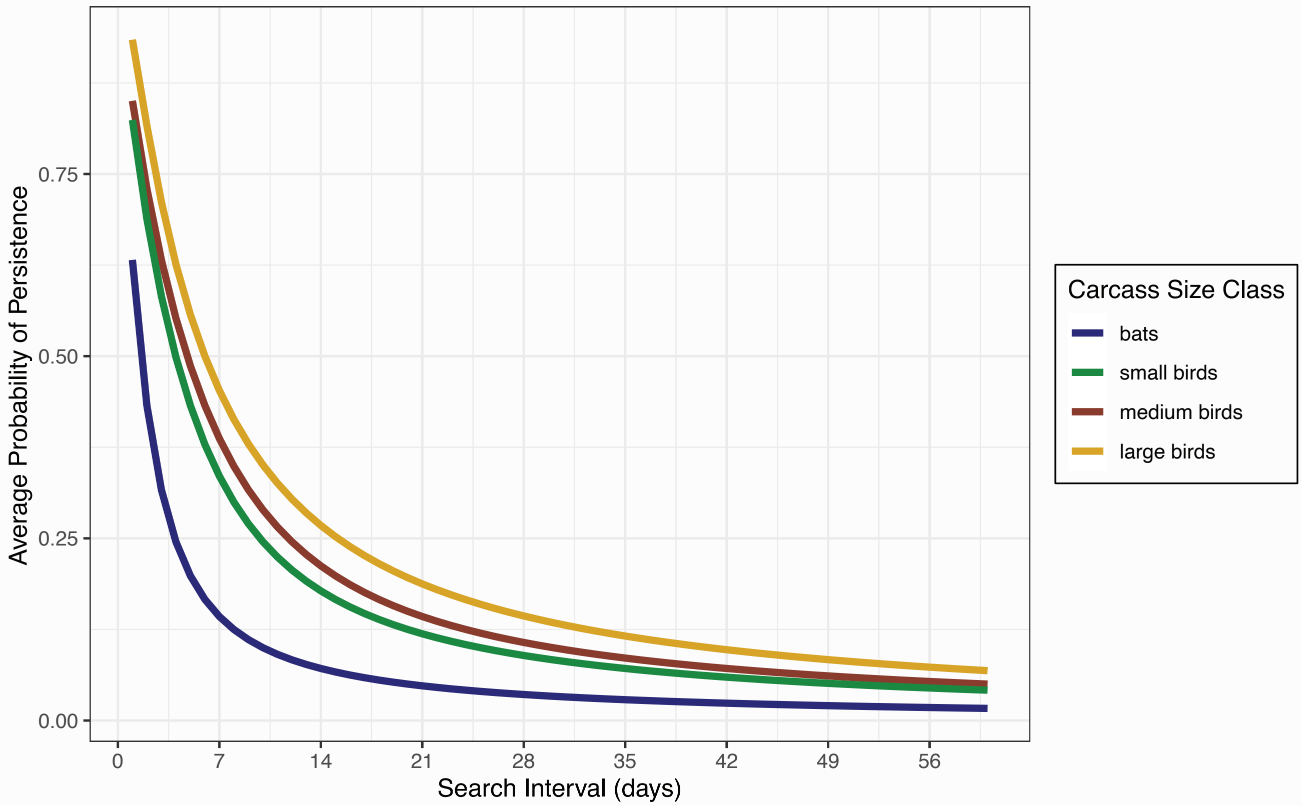
Smaller carcasses tend to be removed more quickly than larger carcasses and therefore require a shorter (more frequent) search interval.

Carcasses are generally classified into four size classes: a) bats[30] ,b) small birds (<30 cm body length), c) medium birds (30-55 cm body length), and d) large birds (>55 cm body length). Smaller carcasses, especially bats, tend to have shorter persistence times than large birds, such as large raptors (see also Section 3.3.7.3 and Figure 3.5), which means that scavengers are more likely to remove them between searches. Other factors also affect the amount of time the carcass will persist. For example, carcasses sometimes disappear faster in wetter and warmer climates than in drier and colder climates. Carcass persistence times are highly variable (and could vary seasonally), and it is unlikely that they will be known in advance of the PCFM study.

[29] Minor deviations from this search interval are inevitable, but statistical fatality estimators, including GenEst, can easily handle them.

[30] Most bats are classified as small (<30 cm body length with a wingspan of <100 cm), although some of the larger fruit bats, known as flying foxes, in Asia Pacific and off the east coast of Africa have a body length greater than 30 cm and a wingspan greater than 100 cm. There is little PCFM information on these larger bat species, but for practical purposes, they may be classified in the same size class as medium birds.

Figure 3.5 Schematic examples of typical carcass persistence probability for four size classes of carcasses relative to search interval



Source: Confidential pooled data.
Note: In all cases, persistence probability increases as search intervals decrease.

3.3.7 Bias Correction

Bias correction refers to mathematical adjustments to carcass counts that a statistical fatality estimator performs to produce an unbiased estimate of fatality. Some bias correction factors (e.g., unsearched area correction; Section 3.3.7.1) are calculated based on observed or known data. Others (e.g., searcher efficiency and carcass persistence corrections; Section 3.3.7.2 and 3.3.7.3, respectively) are calculated based on experimental data gathered especially for that purpose.

3.3.7.1 Unsearched and Unsearchable Area

What are unsearched and unsearchable areas?

Birds and bats fall at varying distances from the turbine base after colliding with a turbine blade; this is the "fall zone."[31] Within the fall zone, fatalities that land within the designated PCFM search plot and are not removed by scavengers, are available to be detected by searchers. The others are

[31] The size of the fall zone depends on turbine height, blade length, wind regime, and carcass size and varies from study to study but can easily have a radius that is larger than the maximum turbine blade tip height.

not detectable by searchers because they are in areas that are not searched or cannot be searched. For example:

- If the search plot does not cover the entire fall zone, fatalities that land ***beyond the search plot*** will not be detected (the unsearched area).

- Some areas within the search plot may be ***inaccessible to searchers*** because of, for example, land access restrictions, dense vegetation, or hazardous terrain (the unsearchable area).

To produce unbiased fatality estimates, **it is important to account for carcasses that land in these unsearched and unsearchable areas of the fall zone**, especially if such areas cover a large proportion of the fall zone (e.g., in RAP search plots). Unsearched and unsearchable areas are accounted for by calculating the density weighted proportion (DWP; Huso and Dalthorp 2014) of the fall zone that is searched. The DWP allows fatality estimates to be adjusted to account for carcasses falling in unsearched and unsearchable areas. See below and Box 3.4 for further description of DWP.

Accounting for unsearched and unsearchable areas

The total size of the fall zone can be estimated based on turbine size and carcass fall patterns that have been reported in the scientific literature. In principle, it would seem simple to apply an area correction factor equivalent to the proportion of the area of the fall zone that the search plot covers and is searched, but this simple method is not valid, because it does not account for well-documented carcass fall patterns. Carcass fall density is not uniform within the fall zone; it is generally concentrated toward the base of the tower (Figure 3.6). Furthermore, the spatial patterning of carcass fall is typically different for different types of carcasses. For example, bat carcasses often fall close to the tower,[32] whereas birds tend to fall in a more dispersed pattern (Figure 3.6). A number of statistical methodologies have been developed to account for this type of variation in carcass fall density within searched and unsearched areas (e.g., Dalthorp et al. 2020; 2022; Huso and Dalthorp 2014; Maurer et al. 2020; Studyvin et al. 2020), although most of these require proficiency with relatively advanced statistical methods and statistical software such as R (R Development Core Team 2018).

Users with the resources to explore such methods are encouraged to do so. To support users who may not have access to these statistical tools, the DWP tool in Appendix D of this Handbook presents a relatively simple method for estimating DWP, which is also outlined in Box. 3.4.

Unsearchable areas within search plots. Photos: Inkululeko Wildlife Services

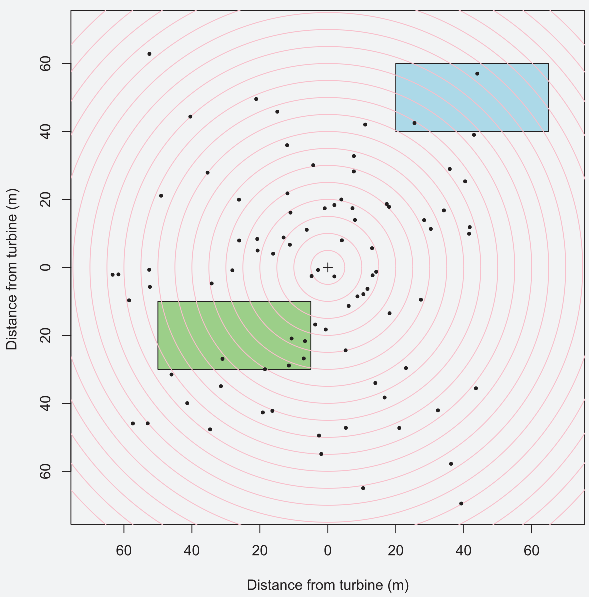
[32] Note that their fall pattern may be highly influenced by the local wind regime.

Box 3.4 Density Weighted Proportion and the DWP Tool

It is usually not feasible to search all areas beneath wind turbines where carcasses may fall; the carcass fall zone is large and may include areas that have impenetrable vegetation or other hazards that make it impractical to search. Adjusting fatality estimates to account for the proportion of carcasses that fall beyond the boundaries of plots (unsearched areas) or in areas that are impractical to search (unsearchable areas) is essential to production of an unbiased fatality estimate. This estimate is called the density weighted proportion of area searched to emphasize that the proportion of area searched is not the same as the proportion of carcasses in the search area. Wind wildlife ecologists in emerging market countries frequently mention the lack of a simple to understand method for estimating the DWP as a principal barrier to estimating fatality rates at WEFs. This is why the DWP tool provided in Appendix D has been developed.

Figure B3.4.1 shows the locations of simulated carcasses beneath a wind turbine. The green and blue areas represent unsearchable land. They are exactly the same size, but the green area includes about three times as much of the carcass fall density as the blue area. By accounting for unsearched area in rings (red circles) and considering carcass counts in rings, the DWP tool can estimate the area correction more accurately than if it simply used the proportion of area searched.

Figure B3.4.1 Carcass distribution within the fall zone around a turbine overlayed with rings used to calculate DWP

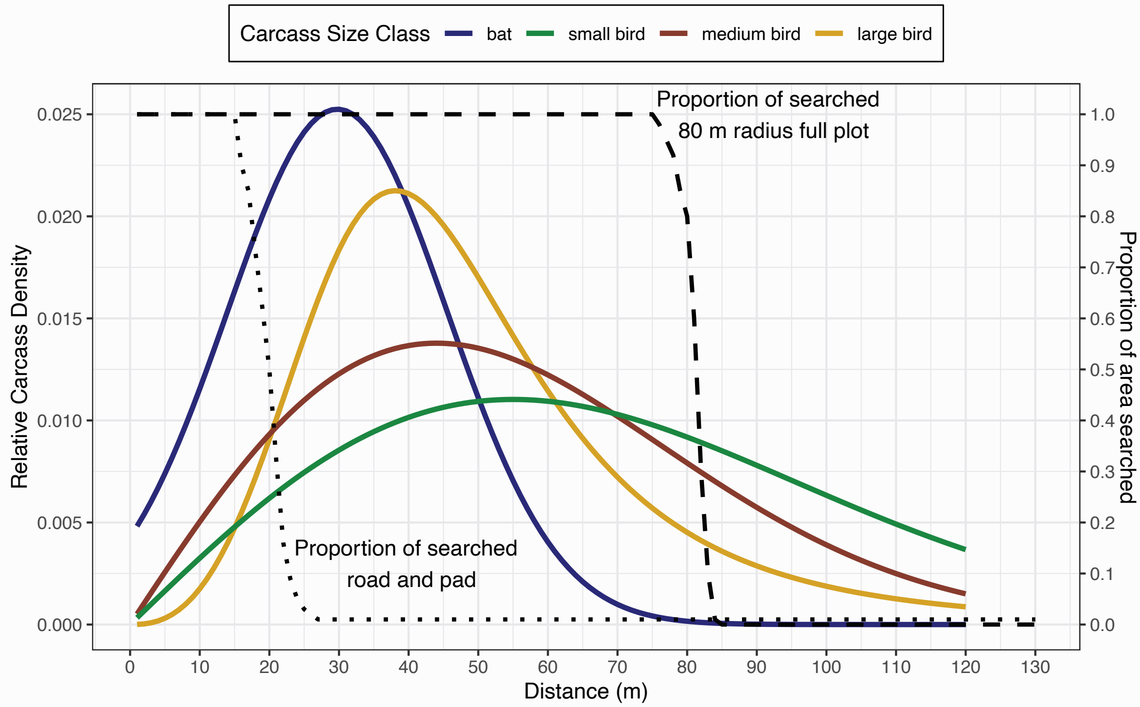


The DWP tool asks users to provide:

- The proportion of area searched within each 5 m ring extending to the limit of the searched area around each turbine at the WEF
- The carcass count (according to carcass size class) within each 5 m ring around all turbines at the facility

Then, rather than estimate the simple proportion of area searched, the tool uses the input data to estimate the proportion of carcasses occurring in each 5 m ring around the turbine and, together with the information about proportion of area searched, the tool estimates the DWP.

Figure 3.6 Schematic examples of carcass density distributions for four carcass size classes and proportion of areas searched on hypothetical 80 m radius full plots or road and pad plots



Source: Confidential pooled data.
Note: These density distributions are indicative of general carcass fall patterns; the distances of carcasses from the turbine base at other facilities may vary.

3.3.7.2 Searcher Efficiency

Searcher efficiency and why to measure it

Searcher efficiency is the probability that a searcher will detect a carcass on the ground at the time of a carcass search. Despite best efforts, searchers may not detect carcasses within search plots for a variety of reasons: size, cryptic coloration, carcasses that are no longer intact or have been reduced to feather piles, vegetation or other ground conditions that hamper visual detection. Thus, every PCFM study will need to conduct searcher efficiency trials to measure the proportion of carcasses missed by searchers and then apply the resulting searcher efficiency correction factor in the statistical estimates of total facility-generated fatality rates.

Measuring searcher efficiency for different carcass size classes

Carcasses of smaller animals are harder to detect than those of larger animals. Carcass coloration may also influence detectability, which is a possible explanation for why bat carcasses (typically brown) are generally less detectable than small bird carcasses, which are more variable in coloration. For these reasons, searcher efficiency is typically measured and characterized separately for each of four carcass size classes (bats, small birds, medium birds and large birds), with searcher efficiency trial carcasses in each size class reflecting as closely as possible the characteristics of the PCFM target species at the site. See Box 3.5 on obtaining carcasses for use in bias correction trials.

Box 3.5 Obtaining carcasses for bias correction trials: challenges and alternative approaches

Ideally, bias correction trials should use bird and bat collision fatalities found at the WEF that are kept fresh and stored in an on-site chest freezer at the project site, but at many WEFs, the number of bird and bat carcasses found is well below the sample size needed to run valid bias correction trials. In such cases, suitable surrogates and other approaches are needed.

Searcher efficiency and carcass persistence trials have different constraints and criteria governing the suitability of surrogates. For searcher efficiency trials, it is most important that surrogates visually resemble actual collision fatalities in the eyes of (human) searchers. They should therefore be of similar size, shape, and color as actual fatalities but smell is unimportant. For this reason, non-animal surrogates can be suitable for searcher efficiency trials.

For carcass persistence trials, in addition to being of similar size, shape, and color, surrogates should smell like the actual fatalities recorded so that the same scavengers detect them over similar timescales. Surrogate carcasses such as domesticated poultry and game birds are more palatable to carcass scavengers (and hence removed more quickly) than carcasses of the large birds that they could be used to surrogate for, specifically raptors. It is likely that using these types of surrogates for raptors will inflate fatality rate estimates for this group and therefore should be avoided (but see, e.g., Hallingstad et al. 2023). This is particularly important because raptors will often be PCFM target species at a WEF. Importantly, the LE must ensure that all carcasses acquired for bias correction trials regardless of their source must be legally obtained.

Surrogate carcasses that may be acceptable for searcher efficiency and carcass persistence trials and have been used in PCFM studies for this purpose:

- Farm-raised ducks and pigeons as surrogates for non-raptor bird fatalities
- Dark-colored adult mice as surrogates for bats
- Fresh road-killed birds and bats
- Freshly killed and frozen birds and bats that non-governmental organizations or government officials have confiscated from illegal possession (through hunting or trafficking)
- Freshly killed and frozen bird and bat carcasses available from lethal control undertaken at airports or elsewhere

Surrogate carcasses that should not be used in searcher efficiency or carcass persistence trials:

- Animals suspected of being poisoned
- Domestic poultry
- Game birds as raptor surrogates (see DeVault et al. 2017; Urquhart, Hulka, and Duffy 2015) unless it can be demonstrated that persistence rates can be reliably extrapolated (see, e.g., Hallingstad et al. 2023)
- Any bird or bat acquired by killing individuals from wild populations

When insufficient fatalities or suitable surrogates are available, alternate approaches for implementing bias correction trials may be needed. Examples include the following:

- For searcher efficiency trials, a variety of artificial decoys may be suitable, provided that they are of similar size and color to the carcasses likely to be found at the WEF. These include hunting bird decoys and toy bats. It is generally acceptable to re-use artificial decoys in multiple searcher efficiency trials if they remain reasonably intact.
- For carcass persistence trials, it may be possible to conduct joint trials with neighboring projects if located within the same habitat with a similar composition of scavengers. Data could be pooled for use at multiple projects. For certain species, especially raptors that persist for long periods, some organizations or regions are developing standardized carcass persistence rates that can be used in fatality estimation calculations (Hallingstad et al. 2023; Wilson, Hulka, and Bennun 2022).

When and where to measure searcher efficiency

Searcher efficiency should be measured throughout the study period and over the entire spatial extent of the WEF to capture possible variation over time and space, for example, as a result of seasonal vegetation growth. Searcher efficiency trials work best when they are spaced regularly throughout the season and widely across sampled areas so that estimated searcher efficiency does not depend on conditions during a single day or within a limited portion of the WEF. For practical information on conducting searcher efficiency trials, see Appendix B and then use the Searcher Efficiency Trial Placement Tool[33] in Appendix D to select random placement of carcasses.

Using visibility classes in searcher efficiency models

Searcher efficiency is sometimes measured separately for each visibility class present in the search plots (e.g., Easy — bare ground 90% or greater, all ground cover sparse and 15 cm or less in height; Very Difficult — little or no bare ground, more than 25% of ground cover over 30 cm in height), and doing so improves the accuracy of fatality estimates, albeit at the cost of increased field effort to map visibility classes and conduct searcher efficiency bias trials in each type of visibility class. Although this Handbook does not specifically suggest including visibility class in the GenEst analysis of searcher efficiency models to reduce fieldwork effort and the number of trial carcasses or decoys required, readers should be aware that it is a practice in some regions, and an option if desired.

[33] This tool generates a random distance and compass direction from a turbine for each searcher efficiency trial carcass. At the start of the trial, carcasses are placed in the locations generated by the tool.

Turbine collision fatalities of different carcass size classes. Left: Big free-tailed bat (*Nyctinomops macrotis*). Photo: Confidential source. Center: Eurasian Sparrowhawk (*Accipiter nisus*). Photo: Alvaro Camiña. Right: Booted Eagle (*Hieraaetus pennatus*) Photo: Photo: Alvaro Camiña

3.3.7.3 Carcass Persistence

What is carcass persistence and why measure it?

If a fatality occurs and the carcass is removed or disappears from the search plot before the next search visit,[34] searchers cannot detect it. If the proportion of carcasses that disappear (before searches are conducted) is not estimated and factored into total fatality rate estimates, fatality rates will be biased downward (underestimated). Carcasses may be removed or disappear from search plots for a variety of reasons, including scavenging, weathering, decomposition, and human-related activities (e.g., agricultural practices). "Carcass persistence" refers to how long a carcass remains or "persists" on the ground before one of these factors removes it. Because of the recognized importance of this bias factor, PCFM studies should incorporate specialized carcass persistence field trials to quantify carcass persistence rates at the site and then apply the resulting carcass persistence correction factors in the statistical estimation of total facility-generated fatality rates.

Why is carcass persistence important for determining search interval?

As explained in Section 3.3.6, carcass persistence is fundamentally linked to search interval. Because carcasses disappear over time, more frequent searches increase the chances that a collision-generated carcass will be present at the time of the next search.

When and where to measure carcass persistence

Similar to searcher efficiency trials, carcass persistence should be measured throughout the study period and over the entire spatial extent of the WEF to capture possible variation in carcass persistence over time and space, for example as a result of seasonal variation in scavenger activity. Carcass placement should be limited to a maximum of two trial carcasses at any one turbine at any one time to avoid undue attraction of scavengers. For additional information on obtaining carcasses for use in bias correction trials, see Box 3.5. For technical information on conducting carcass persistence trials, see Appendix B.

[34] In this Handbook, a "search visit" is a single search of all sample turbines.

Highly decomposed large bird carcass. Martial Eagle (*Polemaetus bellicosus*). Photo: Inkululeko Wildlife Services

3.4 PCFM COMPONENTS—WEF-ASSOCIATED OHL SEARCHES

WEFs typically require OHLs to transport energy that turbines generate to substations and electrical grids. This infrastructure presents a potential collision risk to birds and an electrocution risk to birds and bats and requires a dedicated PCFM design to quantify WEF-associated OHL fatalities and to assess the overall impact of a WEF. Collision and electrocution risk at OHLs is increasingly relevant to emerging market countries with high numbers of potentially susceptible species and a rapidly expanding infrastructure (Bernardino et al. 2018; Martín Martín et al. 2022; Shaw et al. 2021).

This section outlines risks to birds and bats associated with this infrastructure and highlights similarities and differences in the underlying principles determining turbine and OHL PCFM designs.

3.4.1 Risks from OHLs

The conductor wires that form part of WEF-associated OHLs present a potentially high collision risk to birds as they are difficult to detect and occupy low-altitude airspace where flight activity is often highest. OHLs may extend through considerable proportions of habitat used by collision susceptible species. Heavy-bodied birds with limited maneuverability such as bustards, cranes, waterbirds, and large raptors are particularly susceptible to collision with OHLs. Potential impacts are especially high when OHLs are constructed in areas used by species at risk of multiple collisions because they typically fly in flocks, and in areas where collision susceptible species congregate, such as wetlands, migratory corridors (especially bottleneck areas), colonial breeding, and roost sites (Bevanger 1998; De La Zerda and Rosselli 2002; Prinsen et al. 2011; WWI 2018).

Birds and large bats are electrocuted on OHLs, particularly medium-voltage distribution lines, where they come into simultaneous contact with energized and grounded components (e.g., Biasotto et al. 2022 Dixon et al. 2015; Tella et al. 2020). Any above-ground collector lines are likely to present this risk, particularly for raptors, including vultures, owls, falcons, and eagles). These birds are attracted to pylons and distribution line poles because they provide nest locations and perches for resting or to use during hunting. For bats, the principal known threat is to flying foxes (*Pteropus spp.*), which are known to hang from OHLs and are electrocuted when their wings touch the wires (Chouhan and Shrivastava 2019; Rajeshkumar, Raghunathan, and Venkataraman 2013).

American Kestrel (*Falco sparverius*). Brazil. Photo: Alvaro Camiña

3.4.2 Comparing PCFM Designs for Turbines and OHLs

A PCFM program conducted along a WEF-associated OHL has the same components as a turbine search (e.g., plot size and shape, transect width, search interval, bias correction trials) and the same overarching objective of characterizing wildlife impacts to inform potential mitigation and adaptive management during the operational phase of the project. There are two key differences:

- Some of the underlying principles supporting design decisions differ because OHLs are static linear structures rather than a collection of separate structures rotating from fixed locations.
- PCFM for OHLs will reveal fatalities caused not only by collision, but also by electrocution.

Table 3.1 lists the components used to design PCFM programs for turbines and highlights some of the key differences from designs for OHLs. The topic of above-ground collector lines and electrocution risk is further discussed in Section 4.2.1.1.

3.5 CHANCE FINDS

During a PCFM program, search teams and other personnel (e.g., operations, maintenance personnel, WEF contractors) may discover bird and bat fatalities that are not part of the systematic

Table 3.1 Comparison of turbine and OHL PCFM design components

	PCFM COMPONENT	TURBINE DESIGN	OHL DESIGN	RELATED INFORMATION
FATALITY SEARCHES	**STUDY DURATION**	Turbine and OHL designs based on the scale and duration of effects on PCFM target species.		See Section 3.3.1.
FATALITY SEARCHES	**TURBINE SAMPLE**	Sample turbines randomly selected	The OHL sample is not random: sample section location and sampling rate depend on expected level of risk to susceptible species within landscape along OHL.	See Section 4.2.1 for more details about defining OHL sample.
FATALITY SEARCHES	**SEARCH PLOT SHAPE AND SIZE**	Square or circular plot centered on turbine informed by fatality fall zone and determined by adequate detection probability value.	Corridor on either side of OHL center line defined according to length of each OHL sample search plot and extent of fall zone scaled according to maximum height of OHL.	See Section 3.3.7.1 for underlying principles relating to fall zone. See Section 4.2.2 for more details about defining OHL search plot size.
FATALITY SEARCHES	**TRANSECT WIDTH**	Turbine and OHL transect width based on estimated detection probability for species and size class(es) of interest.		See Section 3.3.4 for underlying principles involved in selecting transect width. See Section 4.2.3 for more details about defining OHL transect width.
FATALITY SEARCHES	**SEARCH INTERVAL**	Turbine and OHL search interval based on estimated carcass persistence time for species and size class(es) of interest.		See Section 3.3.6. for underlying principles involved in selecting search intervals. See Section 4.2.4 for more details about defining OHL search interval.
BIAS CORRECTION	**UNSEARCHED AND UNSEARCHABLE AREA**	Includes area beyond search plot to edge of fall zone; typically search plots will not extend to edge of fall zone.	Limited to difficult to search areas within each search plot; typically, entire fall zone assumed to be included within search plot.	See Section 3.3.7.1 for underlying principles involved in determining unsearched and unsearchable areas and why they are important in calculating fatality estimates. See Section 4.2.5.1 for more details about defining OHL unsearched areas.
BIAS CORRECTION	**SEARCHER EFFICIENCY TRIALS**	OHL searcher efficiency trials based on same underlying principles as for PCFM for turbines.		See Section 3.3.7.2 for underlying principles relevant to designing searcher efficiency trials. See Section 4.2.5.2 for more details about designing OHL searcher efficiency trials.
BIAS CORRECTION	**CARCASS PERSISTENCE TRIALS**	OHL carcass persistence trials based on same underlying principles as for PFCM for turbines.		See Section 3.3.7.3 for underlying principles relevant to designing carcass persistence trials. See Section 4.2.5.3 for more details about designing OHL carcass persistence trials.

PCFM plot searches for turbines or WEF-associated OHLs. Fatalities may be found within plots but between search visits or in areas outside defined search plots (referred to as off-plot discoveries).

3.5.1 Chance Find Fatalities Found Within Search Plots

Collision fatalities discovered within search plots *that are not found* as part of systematic PCFM searches are typically *included* in the sample of fatalities used to derive total, bias-corrected fatality rate estimates for the WEF. The assumption is that these fatalities would have been discovered within that search plot during the next search. It is important that these fatalities be included in the sample used to derive fatality estimates only if they resulted from collision with turbines or collision or electrocution at WEF-associated OHLs during the study period. If the fatality resulted from another source (e.g., poisoning) or occurred outside of the study period, it should be recorded and reported but not included in the fatality rate estimate sample.[35]

3.5.2 Chance Find Fatalities Found Outside Search Plots

Fatalities discovered at any time outside of search plots (off-plot discoveries) are not included in the sample of fatalities to derive total bias-corrected fatality rate estimates for the WEF. Although off-plot carcass discoveries do not influence estimation of bias-corrected total fatality rates, they provide valuable information regarding the species composition of fatalities at the WEF and are important for understanding impacts especially with respect to thresholds for PCFM target species. (for more information on threshold-setting see Section 6.2).

All chance find fatalities at a WEF or associated OHL (including non-collision, non-electrocution fatalities) should be recorded on a fatality record form (Appendix E), and the carcass should be removed and stored in the same way as PCFM carcasses so that it is not found a second time. There is a section on the fatality record form to indicate whether the fatality was a within-plot or off-plot chance find and the likely cause of death (turbine collision, WEF-associated OHL collision or electrocution, other).

Red Kite (*Milvus milvus*). Photo: Alvaro Camiña

[35] At times, accurately determining cause of death or estimating time of death is difficult in the field. Consulting with a specialist to perform a necropsy may be necessary, particularly for globally threatened and PCFM target species.

PCFM DESIGNS AND USING THE DST

4

4. PCFM DESIGNS AND USING THE DST

Section 4 builds on the core concepts and principles of PCFM design described in Section 3 and provides guidance to develop real-world PCFM designs for WEFs in emerging market countries. For turbine searches, the DST (Appendix A) is key to that process, and this section outlines in detail how to use it. Standardized PCFM designs for OHLs are still evolving, so the DST does not attempt to automate this process, but recommended design approaches based on GIIP are included for WEF-associated OHLs in Section 4.2.

4.1 TURBINE PCFM DESIGNS

This Handbook and its DST recommend two PCFM design approaches for turbine searches:

- A generalized **First Year** design for use during the first year(s) of operations.
- An optimized **Subsequent Years** design informed by the first year(s) of PCFM data and the project's monitoring objectives.

Section 4.1.2 explains the purpose of the First Year design, provides advice on using the DST to generate a Year 1 design and then explains the DST First Year design output. Section 4.1.3 follows the same format and provides equivalent information for the Subsequent Years design.

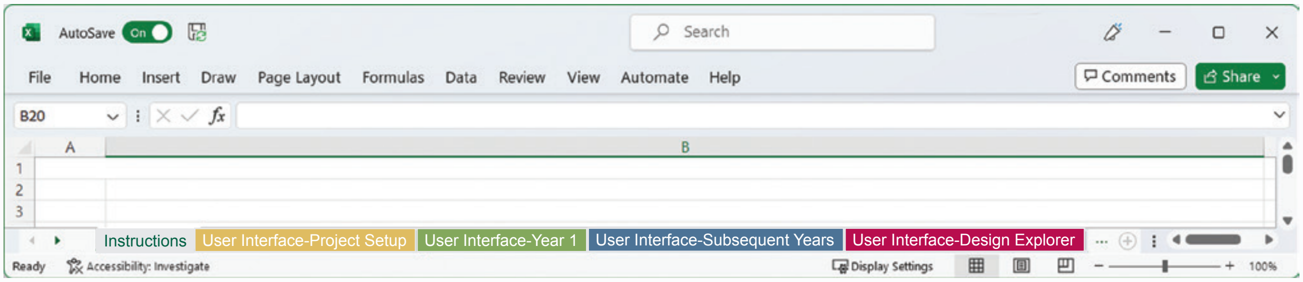
Importantly, it should be noted that **all fatalities found during PCFM surveys are recorded regardless of whether a First Year or a Subsequent Years design is being implemented and regardless of the PCFM target species.** For example, a Subsequent Years design that is optimized for large birds with a relatively wide transect width and long search intervals will not be optimized for bats or smaller birds, but carcasses in these size classes will be found during searches and should always be recorded.

4.1.1 Using the DST

The DST is operated using a single Microsoft Excel spreadsheet. The reader is encouraged to open the DST (Appendix A) when reading this section to trial its content. Within the spreadsheet, the user will find 11 worksheet tabs. The first tab is labeled "Instructions," and users are expected to interact with the DST through the four tabs labelled "User interface..." (Figure 4.1). The remaining seven tabs run DST logic and calculations. Users cannot interact with these, but they are visible to allow users to understand the tool's mechanics.

The content and purpose of the 'User Interface...' tabs are summarized below.

Figure 4.1 DST User Interface tabs



User Interface — Project Setup

Asks three questions about WEF specification relevant to both the First Year and to the Subsequent Years design.

User Interface — First Year

Asks three questions about practical constraints related to the PCFM during the first year. These are used to adjust the First Year design so that it is applicable to the specific WEF. This tab generates a generalized design for the first year(s) customized to specifications and practical constraints at the WEF.

User Interface — Subsequent Years

Asks 14 questions about the First Year design PCFM results, project monitoring objectives and practical constraints on PCFM to build a profile of the WEF. Based on answers to these questions, the tab generates a recommended design optimized for PCFM target species.

User Interface — Design Explorer

Allows the user to input two alternative PCFM designs and compare these with the recommended design that the Subsequent Years tab generates. The Design Explorer is provided to allow flexibility to test and evaluate the validity of alternatives to the recommended Subsequent Years PCFM design. This flexibility may be needed if the project has specific constraints, and the Design Explorer will help ensure that these constraints result in a PCFM design that can fulfill the principal objective of providing robust, reasonably precise fatality rate estimates for PCFM target species.

Lead Ecologist explaining PCFM. Photo: Caleb Gordon

4.1.2 First Year Design

At the start of the first year of monitoring, no prior knowledge of fatality rates at the WEF is assumed. The generalized First Year PCFM design provides information about any species and size classes occurring as fatalities at turbines. The objective is to adequately characterize wildlife collision impacts for the first year(s) and determine PCFM target species so that optimized, targeted monitoring can progress in subsequent years. Although this generalized First Year design is recommended, the LE may need to consider additional site-specific habitat and ecological factors, as well as priority biodiversity values of particular importance to stakeholders when making the final First Year design decisions. All deviations from the DST First Year design should be justified and documented. Lastly, although intended for one year, the generalized PCFM design might need to be used for multiple years, as explained in Section 4.1.3.

4.1.2.1 DST Input — First Year Design

For ease of use, most PCFM components for the generalized First Year design are predetermined, and user input is limited to some basic information about the WEF. These predetermined values have been carefully selected so that, collectively, the results will achieve optimal detection probability for a generalized First Year design given the characteristics of the WEF. To generate a recommended PCFM design for the first year(s) for a specific WEF, the LE needs to input the following details into the DST.

User Interface-Project Setup

Open the **User Interface — Project Setup tab** and answer questions 1 to 3 about the WEF (Table 4.1).

Table 4.1 DST Project Set-up tab: Questions 1-3

QUESTION	USER INPUT
1. How many turbines are at the facility (1-999)?	WEF-specific answer
2. What is the hub height of the turbine (m)?	WEF-specific answer
3. What is the blade length of the turbines (m)?	WEF-specific answer

User Interface-Year 1

Open the **User Interface — First Year tab** and answer questions 4 to 6 about the area beyond the RAP (Table 4.2).

Table 4.2 DST First Year tab: Questions 4-6

QUESTION	USER INPUT
4. Is it legal to access areas not on the RAP *Legality of access extending to maximum radius of full plot searches should be clarified with WEF management.*	**1. Yes/No**
5. Is it safe to access areas not on the RAP ? *Hazards such as ruggedness of terrain and risks from animals will determine whether full plot searches are possible. Health and safety risks and protocols should be discussed with WEF management.*	**2. Yes/No**
6. Is vegetation beyond the RAP conducive to searching? *The LE should (qualitatively) assess for the WEF overall how difficult it is to walk transects off the RAP. This should be assessed during the pre-PCFM visit to each turbine (see Appendix B 'Tasks to be completed by the Lead Ecologist before the start of PCFM fieldwork').*	> **Yes** (no more than 75% of the surface has vegetation exceeding 30 cm in height) > **No** (at least 75% of the surface has vegetation exceeding 30 cm in height)

4.1.2.2 DST Output — First Year Design

As mentioned in 4.1.2.1 most of the DST First Year design output values are predetermined and will be the same regardless of the project for which the design is being developed. For example, the recommended transect width will always be 6m, search interval will always be 7 days and every design will recommend searching all turbine RAPs. Other values such as number and size of full plots will differ between projects depending on the size of the WEF and the turbine specifications. The DST is used to generate only the project-specific values with respect to the First Year design.

Once answers to the six questions above are entered into the DST, the generalized First Year PCFM design is generated with respect to the project site on the right-hand side of the User Interface — First Year tab.

This provides:

- Number of turbines to search with RAP and full plots
- Full plot search radius
- Transect width
- Length of access roads to search when conducting RAP searches
- Search interval
- Number of searcher efficiency trial carcasses / decoys to use per size class per season
- Number of carcass persistence trial carcasses to use per size class per season

No DPI value is available for the generalized First Year design because results from searcher efficiency and carcass persistence trials conducted during the first year are required to estimate DPI. The DPI is available only for the Subsequent Years design.

The First Year design component outputs are explained in detail below and also appear as output values in the DST First Year tab.

Turbine Sample

Design

> **RAP searches** conducted at **all turbines, *plus***

> **Full plot searches** at a **predetermined proportion of turbines**, depending on the size of the WEF

- **≤50 turbines — search all turbines.**
- **51-100 turbines — search 50 turbines OR 75% of turbines**, whichever is greater.
- **>100 turbines — search 75 turbines OR 50% of turbines**, whichever is greater.

Justification

Determining the number of turbines to search is key to achieving an adequate detection probability for collision-susceptible species using the airspace in the WEF (see Section 3.3.2). The goal of the generalized First Year design is to achieve a search effort across the whole WEF that produces adequate detection probability for all size classes that have the potential to occur as fatalities.

Searching RAPs at all turbines is quicker and easier than full plot searches, provides fatality information from across the whole WEF regardless of its size, and reduces the likelihood of missing turbine fatality hotspots. However, a RAP-only design will cover only a small proportion of the fall zone at each turbine and so will be able to detect only a small proportion of fatalities potentially present, resulting in low detection probability. This will lead to imprecise fatality estimates, which can limit the ability to identify PCFM target species, a key objective of the First Year design. Searching only the RAP may also miss species that fall further from the turbine. To address these limitations, the First Year design includes full plot searches at a randomly selected, predetermined proportion of WEF turbines.

Possible design adjustments

In some cases, vegetation or other ground conditions will make it impossible to search outside of the RAPs (see Section 3.3.3.2), in which case, just RAPs will be used in the First Year design, with all turbines included in the sample.

Although random selection of turbines for full plot searches is ideal, there may be logistical constraints (e.g., land access) that preclude some turbines as candidates for full plots.

Search Plot Shape and Size

Design

> **RAP** — conduct searches of **turbine and crane pad area** plus **any access roads** to a distance from turbine base **equivalent to the maximum blade tip height**.

- **Full plot** — conduct searches to a radius **equivalent to half the maximum turbine blade tip height**.

Justification

In the First Year design, the maximum tip height of turbines at the WEF influences the size of full plots and the distance to which access roads are searched during RAP searches. This is because the extent of the fatality fall zone around a turbine is broadly related to the size of the turbine (see Section 3.3.3). Linking search plot size to maximum blade tip height in the design method means that search plots are consistently scaled to the fall zone size for any WEF turbine specification.

The First Year design full plot search area accounts for the increasing (human and financial) resources required to search large areas toward the limit of the fall zone and the lower proportion of fatalities found in these outlying areas. Based on a review of fall distance data (e.g., AWWI 2020a; 2020b), limiting full plot searches to a radius equivalent to half the maximum turbine blade tip height has the potential to detect the majority of bird and bat fatalities occurring at a turbine (see Section 3.3.7.1 and Figure 3.6 for more details on fall distances from turbines).

For RAP, searching access roads to a distance equivalent to the blade tip height provides important information about the overall fall zone of fatalities and allows the number of carcasses falling beyond the search area on the turbine and crane pads or within full plots to be estimated. This information is used to improve the validity of the DWP output, which is an essential input into the GenEst fatality rate analysis (Box 3.4 gives more information on DWP).

Possible design adjustments

The DST assumes that full plots will be circular. This was necessary for streamlining the DST, but users may elect or need to choose a square rather than a circular full plot in the field. In these cases, the estimates provided in the DST will be sufficiently accurate.

Transect width

Design

- **RAP searches — 6 m**
- **Full plot searches — 6 m**

Justification

Narrower transect widths result in higher detection probability and more precise fatality estimates. This is particularly relevant for smaller, more difficult to detect species, such as bats, and where environmental conditions (e.g., substrate, vegetation) result in moderate to low visibility within search plots (see Section 3.3.4.1). Before PCFM, not all PCFM target species may be evident, so the design must adequately capture fatality information from all fatality size classes to provide an overview of fatality risk at the site and determine PCFM target species. Deciding on a generalized design with a single transect width for all fatality size classes is challenging. If transects are too wide, detection probability becomes low, especially for bats and small birds, and estimates may be too imprecise to identify PCFM target species. Conversely, if transects are too narrow, human and financial resources required to conduct the monitoring may be unfeasibly high (see Section 3.2.4 for more details on detection probability).

Possible design adjustments

A 6 m transect width is recommended, however, if visibility is high at the WEF site and its surroundings and there is existing PCFM information from the area indicating low risk to bats, a 10 m transect width is a reasonable alternative.

Search interval

Design

> **RAP searches every 7 days**

> **Full plot searches every 7 days**

Justification

Deciding how frequently to conduct a search is related to how long a fatality persists on the ground before it is no longer available for search teams to find it, with longer average persistence times for larger birds and raptors than for small birds and bats (see Section 3.3.6.1). The search interval for the First Year design is set at 7 days so that, when combined with other PCFM component values (e.g., plot size, transect width), the resulting fatality estimates for all size classes should be sufficiently precise to identify PCFM target species.

Bias correction: Searcher efficiency trials

Design

> **12 trials (carcasses or decoys) per season per size class**

Justification

Correcting for the number of fatalities that searchers miss because they are difficult to detect due to their size, color, or condition or the ground conditions at the search plot is essential for calculating unbiased fatality rate estimates (see Section 3.3.7.2). The objective of the generalized First Year design is to provide fatality rate estimates for all species and size classes that could collide with turbines at the WEF so that PCFM target species can be better identified. Searcher efficiency trials should therefore be conducted for all size classes.

The First Year design recommends placing 12 trial carcasses or decoys per size class per season for searcher efficiency trials. For example, a PCFM program with four size classes and four seasons would require 192 trials (12 carcasses x 4 size classes x 4 seasons). For two seasons (e.g., wet and dry), this would require 96 (12 x 4 x 2) trials. This should provide valid searcher efficiency values for each season and for each fatality size class at the WEF turbines (see Appendix B for practical advice on conducting searcher efficiency bias correction trials).

Bias correction: Carcass persistence trials

Design

> **12 trials (carcasses) per season per size class**

Justification

Correcting for the number of fatalities not found during searches because scavengers remove them or they disappear because of weathering, decomposition, or human-related activities is essential for calculating unbiased fatality rate estimates (see Section 3.3.7.3).The goal of the generalized First Year design is to provide fatality rate estimates for all species and size classes that could collide with turbines at the WEF so that PCFM target species can be better identified. Carcass persistence trials are therefore recommended to be conducted for all size classes.

The First Year design recommends placing 12 trials per size class per season for carcass persistence experiments, which should provide valid carcass persistence values for each season and for each fatality size class at the WEF.

Possible design adjustments

Sourcing sufficient carcass persistence trial carcasses is often challenging because there may be few WEF fatalities, and suitable surrogates may be difficult to obtain. In these situations, it may be valid to conduct joint trials with neighboring projects or use available standardized persistence rates (see Box 3.5 for more information).

Bias Correction: Unsearched and unsearchable area

Although not an output of the DST, correcting for the number of fatalities not detected because the area was unsearched or unsearchable is essential for providing unbiased fatality estimates. To achieve this, in the First Year design, the LE will map all unsearched and unsearchable areas before fieldwork begins (see Appendix B *Tasks to be completed by the Lead Ecologist before the start of PCFM fieldwork* for detailed practical advice). This information will be used in conjunction with the location of fatalities within the searched area to calculate the DWP (see Section 3.3.7.1 for more information on the unsearched area, Box 3.4 for principles related to DWP, and Appendix D for the DWP tool used to calculate DWP).

4.1.3 Subsequent Years Design

Unlike the First Year design, there is no prescribed Subsequent Years design. Rather, the DST is developed to inform decision making, taking the user through a series of questions about the First Year design PCFM results, project monitoring objectives, and practical constraints on PCFM at the WEF. The Design Explorer tool within the DST is provided to enable the initial Subsequent Years design to be customized to account for this site-specific knowledge (see Section 4.1.3.3). As with the First Year design, the LE should always guide Subsequent Years design decisions accounting for site-specific knowledge about the WEF and bird and bat ecology at the site.

After implementing the First Year design for the initial year of the PCFM program, the LE should consider whether the fatality data collected are adequate to determine the PCFM target species. If not, the First Year design may need to be repeated for one or more additional years before moving forward with the more tailored Subsequent Years design. Possible reasons for a WEF needing to repeat the generalized First Year design include the following:

Fatality risk is likely to be different between years, for example, if:

- The WEF is near a migratory corridor, and migratory movements through the area are known to vary locally between years.
- Weather or other environmental conditions during the first year are exceptional, resulting in atypical numbers of species or individuals at the WEF.
- The WEF was not fully operational during the first year. This may be particularly important if non-operational turbines are in areas of potentially high risk to birds or bats.

The PCFM design was not implemented fully, for example, if:

- Unforeseen environmental constraints resulted in a reduced search schedule (e.g., exceptional weather conditions limiting access to search plots or making working conditions unsafe for searchers).
- There were practical problems associated with conducting the PCFM program (e.g., significant weaknesses in how the fieldwork was conducted or the data collected or problems acquiring carcasses for bias correction trials).

Individually or together, these types of situations may prompt the LE to conclude that the results have not adequately identified the PCFM target species and therefore require a repeat of the First Year design before a more tailored Subsequent Years design is implemented using the DST.

4.1.3.1 DST Input — Subsequent Years Design

The Subsequent Years design tab is used to optimize the PCFM design once the PCFM target species are better understood through implementation of the First Year design. When using the DST to develop a Subsequent Years PCFM design, the size class of the PCFM target species, ground visibility and recent carcass persistence data are especially important in determining design parameters.

The DST Subsequent Years design tab should be used to inform and update the PCFM design at least annually as conditions and PCFM target species may change during the life of the project or PCFM study duration period.

To generate a recommended Subsequent Years PCFM design the LE needs to input the following information into the DST:

User Interface-Project Setup

Open the **User Interface-Project Setup** tab and check that First Year design responses to questions 1-3 about the WEF (Table 4.1) are correctly entered.

User Interface-Subsequent Years

Open the **User Interface — Subsequent Years tab** and answer questions 1-14 to build a profile of the WEF informed by First Year design PCFM results, project monitoring objectives, and practical constraints on PCFM (Table 4.3).

Table 4.3 DST Subsequent Years tab: Questions 1-14

QUESTION	USER INPUT
1. How large are the turbine pads (average square meters)?	**WEF-specific estimate**
2. Do first year(s) fatality data indicate that the annual turbine fatality rate for *large birds* (over 55 cm) at the project is likely to be a concern[a] or do monitoring objectives for the project focus on *large birds* for some other reason?	**Yes/No**
3. Question 2 applied to *medium birds* (30 -55 cm) and *larger fruit bats* (>30cm)	**Yes/No**
4. Question 2 applied to small birds (<30 cm)	**Yes/No**
5. Question 2 applied to bats (<30 cm) *Fatality concerns for larger fruit bats (also known as flying foxes) should be addressed in Question 3 'medium birds' rather than Question 5)*	**Yes/No**
6. Is it legal to access areas not on the RAP? *Legality of access extending to maximum radius of full plot searches will determine whether full plot searches are possible and should be clarified with WEF management.*	**Yes/No**

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7. Considering the easiest to search areas, how difficult will it be to search for carcasses?[b] *To help determine an appropriate transect width and the DPI for a PCFM design, the DST needs to incorporate the extent to which vegetation cover affects detection of fatalities. Question 7 asks the user to describe the vegetation cover in the easiest to search areas (not including the surface of the RAP). This, combined with the response to question 8, which describes the vegetation cover in the most difficult to search areas provides an assessment of vegetation cover needed to determine transect width and inform the DPI.* *(The LE should use the mapped visibility class information collected during the visit to each turbine before the start of PCFM fieldwork to determine how difficult it is to search the least vegetated search areas (see section in* Appendix B: Tasks to be completed by the Lead Ecologist before the start of PCFM fieldwork). *Based on this assessment, one of four options should be selected from the drop-down list in the User Input column*	> **Very Difficult:** Little or no bare ground; more than 25% of ground cover over 30 cm in height > **Difficult:** Bare ground 25% or less; 25% or less of ground cover over 30 cm in height > **Moderate:** Bare ground 25% or greater; all ground cover 15 cm or less in height and mostly sparse > **Easy:** Bare ground 90% or greater; all ground cover sparse and 15 cm or less in height
8. Considering the most difficult to search areas, how difficult will it be to search for carcasses?[b] *To help determine an appropriate transect width and the DPI for a PCFM design, Question 8 asks the user to describe the vegetation cover in the most difficult to search areas (not including the surface of the RAP). This, combined with the response to question 7, provides the assessment of vegetation cover needed to determine transect width and inform the DPI.* *As with Question 7, the LE should use the mapped visibility class information collected during the visit to each turbine before the start of PCFM fieldwork to determine how difficult it is to search the most-vegetated search areas.*	> **Very Difficult:** Little or no bare ground; more than 25% of ground cover over 30 cm in height > **Difficult:** Bare ground 25% or less; 25% or less of ground cover over 30 cm in height > **Moderate:** Bare ground 25% or greater; all ground cover 15 cm or less in height and mostly sparse > **Easy:** Bare ground 90% or greater; all ground cover sparse and 15 cm or less in height
9. How difficult is it to walk transects off the RAP? *Rugged terrain will make searching more difficult and reduce searcher efficiency, which will be reflected in the DPI values in the DPI table below the Recommended Design table. The LE should (qualitatively) assess how difficult it is to walk transects beyond the RAP surface. This should be assessed during the pre-PCFM visit to each turbine (see section in* Appendix B: Tasks to be completed by the Lead Ecologist before the start of PCFM fieldwork). *Based on this assessment, one of four options should be selected from the drop-down list in the User Input column.*	> **Impossible:** Terrain is such that searchers cannot safely traverse the area while looking for carcasses > **Difficult:** Hilly to steep landscape with abundant rocks, hummocks, hollows, or vegetation that requires a surveyor's attention > **Moderate:** Hilly landscape, or moderate abundance of rocks hummocks, hollows, or vegetation that require a surveyor's attention > **Easy:** Flat to gently rolling landscape with little vegetation and few to no rocks, hummocks, hollows, or other obstacles on the ground
10. Is it safe to search off the RAP? *Hazards such as ruggedness of terrain and risks from animals will determine whether full plot searches are possible. Risks and WEF health and safety protocols should be discussed with WEF management.*	**Yes/No**
11. Based on carcass persistence data from the project area or from a comparable wind project in the vicinity,[c] what is the likely median removal time (days) of a large bird? *The LE will refer to the median carcass persistence time for large birds calculated from the WEF's first year(s) carcass persistence trials (or comparable results from the immediate vicinity) to estimate removal time.*	> **less than 1** day > **1-3** days > **4-6** days > **7-9** days > **10-15** days > **16-20** days or unknown > **20-30** days > **more than 30 days**

12. Question 11 applied to medium birds (30-55 cm) and larger fruit bats (>30 cm, if they occur in the region)	> **less than 1** day > **1-3** days > **4-6** days > **7-9** days or unknown > **10-15** days > **16-20** days > **20-30** days > **more than 30 days**
13. Question 11 applied to small birds (<30 cm)	> **less than 1** day > **1-3** days > **4-6** days or unknown > **7-9** days > **10-15** days > **16-20** day > **20-30** days > **more than 30 days**
14. Question 11 applied to bats (<30 cm)	> **less than 1** day > **1-3** days or unknown > **4-6** days > **7-9** days > **10-15** days > **16-20** days > **20-30** days > **more than 30 days**

[a] Determining if the fatality rate at the project is 'likely to be a concern' may be informed by, for example, project-specific thresholds and/or relevant thresholds defined by national and/or regional stakeholders.

[b] Note that the DST uses this information to inform an assumption about average searcher efficiency that may be achieved at the WEF.

[c] The vicinity is defined as an area (within the same habitat type) that has a similar fatality risk profile and scavenging populations to that of the project site.

4.1.3.2 DST Output — Subsequent Years Design

Once the LE has provided answers to the 14 questions in the User Interface — Subsequent Years tab, the DST automatically **generates a recommended design** and **calculates a DPI value**.

These outputs are located to the right of the question panel, and the LE can use them to make decisions about different study designs. The DPI is calculated like a detection probability (see Section 3.2.4 for how detection probability is calculated) and has been devised as a tool for comparing and ranking study designs. Although it is expected that the DPI for a series of study designs will sort roughly in the same order as actual detection probabilities, the output should not be taken as a prediction of actual detection probability.[36]

The DPI can be used to compare alternative designs in the User Interface — Design Explorer tab of the DST (see Section 4.1.3.3).

[36] The detection probability that a study design achieves will depend on field conditions during the study that are impossible to predict in advance of the study, so DPI predictions from the DST must rely on many simplifying assumptions. For this reason, users should not be surprised if the estimated detection probability differs from the DPI.

4.1.3.3 The Design Explorer

The User Interface — Design Explorer tab within the DST allows the LE to compare a recommended study design generated in the User Interface — Subsequent Years tab with up to two alternative designs created in the Design Explorer tab. For example, the project may be concerned about occasional fatalities of a globally scarce species and wish to sample more turbines than the recommended design sample size. The Alternative Design 1 and 2 columns in the Design Explorer tab allow the LE to test the effect of different sample sizes on DPI values and then allows PCFM components for each design to be modified to arrive at a valid design that provides the best balance between monitoring objectives and available resources.

To use the Design Explorer, the LE would:

User Interface-Design Explorer

Open the **User Interface — Design Explorer tab.** (The Recommended Design output generated in the User Interface — Subsequent Years tab is replicated and displayed on the left side of the worksheet.) To generate alternative designs, enter the following PCFM design component values into the Alternative Design 1 and Alternative Design 2 columns (Table 4.4).

Table 4.4 DST Design Explorer: Input table

DESIGN COMPONENT	VALUES
1. Number of turbines to sample	Enter sample equal to or less than the number of turbines at the WEF
2. Plot type	Select RAP or circular full plot from dropdown list
3. Search radius (m)	Select a search radius greater than 5 m (the DST will impose an upper bound based on the blade tip height; usually it is approximately 200 m)
4. Transect width (m)	Enter a value between 1 and 20 m
5. Search interval (m)	Select value between 1 and 41 days from dropdown list

Once the values are entered for alternative designs 1 and 2, the Design Explorer automatically **calculates an overall value and size class specific DPI values for each alternative design**.

The overall and size class specific DPI values for the recommended (Subsequent Years) design and alternative designs 1 and 2 are presented side by side so that they can be easily compared.

Once a study design is decided on, the LE will need to consider how to record and organize the data that the PCFM fieldwork will generate so that it is compatible with use in GenEst. At this point reading the step-by-step worked example provided in Appendix C and using the freely available GenEst User Guide (Simonis et al. 2018) is recommended to understand how the GenEst fatality estimator handles data.

4.2 WEF-ASSOCIATED OHL DESIGNS—RECOMMENDED PRACTICES

Section 3.4 of this Handbook discussed the components and principles of PCFM design for WEF-associated OHLs; this section discusses recommended practices for designing a PCFM program for this infrastructure and builds on the OHL design components introduced in Table 3.1. Although no DST is available for WEF-associated OHLs, this section provides a reasonable approach for designing a PCFM study. The guidance provided here applies to all OHLs regardless of horizontal length, tower or pole and line height, and voltage.

To ensure that all relevant underlying principles related to components of the PCFM study design have been considered, reviewing Section 3.3 of this Handbook is recommended when developing WEF-associated OHL designs. Box 4.1 provides further guidance on PCFM when electrocution is a primary risk.

4.2.1 OHL Sample

In some cases, it will not be necessary or feasible to include the entire length of OHLs in the PCFM study, and a sampling approach will be necessary. Suggested sampling approaches for various classes of OHL are described in the sections below.

Although sampling can produce accurate estimates of fatalities, **estimates based on a sample describe only the areas that were considered for the sample**. For example, if 15 km of a 20 km OHL is in areas that are considered low risk for birds, and PCFM sampling was restricted to 5 km within higher risk areas, the resulting estimates could be used only to make inference about the 5 km that was considered for sampling. Attempting to make inference about the entire 20 km OHL would not be appropriate because none of the low-risk areas would be represented in the data. These limitations on the kind of inference that is possible when sampling should be considered when designing a study and included when reporting the results.

4.2.1.1 Collector System within a WEF

To align with the World Bank Group Environmental, Health, and Safety Guidelines for Wind Energy, the collector system power lines within a WEF should be buried because above-ground collector lines present high collision and electrocution risks. Where above-ground collector lines are unavoidable, such as for geotechnical or permitting reasons, they should be designed to minimize bird electrocution risk by adequately separating energized and grounded components and using bird-safe pylon designs (for guidance, see Martín Martín et al. 2021 and RPS 2021). They should also be designed to reduce collision risk by routing them to avoid areas of highest risk and deploying mitigation measures (e.g., fitting lines with bird diverters) during construction. PCFM should be carried out over the entirety of any above-ground collector lines or a representative portion of them. Box 4.1 provides additional advice for developing PCFM designs when electrocution is a principal risk.

4.2.1.2 Interconnection Line

WEF infrastructure includes a high-voltage interconnection line (a transmission line, usually overhead) that runs between the WEF and the grid. The developer may build and own this line (or part of it), but ownership is often transferred to the utility for operation and maintenance. Whether the developer or the utility owns it, PCFM is recommended. The sampling approach for this type of OHL may be different where these structures cross high-risk habitats with likely occurrences of PCFM target species *susceptible to collision or electrocution with OHLs* than in areas where this information is unknown. It also differs based on the length of the line, which could be extensive. The following scenarios are envisioned and should be implemented under the guidance of a statistician or ecologist with OHL sampling experience.

Scenario 1: When the interconnection distance between the WEF substation and the grid substation is short (<5 km), PCFM should be conducted along its whole length, with the search corridor divided into standard length sample search plots (e.g., 500 m).[37]

Scenario 2: When the length of the interconnection line makes it unfeasible to survey its full length (>5 km), the following approaches should be considered.

1. **When OHLs cross *known* high-risk habitats** (e.g., wetlands, water bodies, areas of known habitat for large bats) or managed areas (e.g., legally protected areas,[38] internationally recognized areas[39]) with likely presence of PCFM target species *that are susceptible to collision or electrocution with OHLs*:

    a) The section(s) of OHL that traverse these areas (high-risk OHL sections) should be delimited.

    b) The delimited section(s) of the high-risk OHL sections should be divided into segments of equal length (1 km is recommended).

    c) PCFM should be conducted along a standard proportion of each segment (these will be the sample search plots; see Section 4.2.2 for how to determine the width of sample search plots). A recommended benchmark is that sample search plots cover 50 percent of each segment (e.g., a 500 m sample search plot per 1-km segment).

    The length of the segments and proportion within each segment to survey should be sufficient to provide a representative sample of fatalities occurring along the section of OHL. This proportion is to be determined on a project-by-project basis based on the length of the overall interconnection line and accessibility. The survey proportion in each segment should be consistent throughout.

2. **When OHLs cross areas where collision or electrocution risk is *unknown*** in terms of habitat type or presence of PCFM target species susceptible to collision or electrocution with OHLs:

[37] The term "sample search plot" refers to delimited sample areas where PCFM will be conducted along an OHL. The location and length of each plot are determined using the methods described in this section. The width of sample search plots is determined using the method described in Section 4.2.2.

[38] As defined in IFC Performance Standard 6, footnote 16 *"This Performance Standard recognizes legally protected areas that meet the IUCN definition: 'A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.' For the purposes of this Performance Standard, this includes areas proposed by governments for such designation."*

[39] As defined in IFC Performance Standard 6, footnote 17 *"UNESCO Natural World Heritage Sites, UNESCO Man and the Biosphere Reserves, Key Biodiversity Areas, and wetlands designated under the Convention on Wetlands of International Importance (the Ramsar Convention)."* Important Bird and Biodiversity Areas (IBAs) are often co-located with Key Biodiversity Areas (KBAs). If they are not, they should also be considered.

a) The OHL should be divided into segments of equal length (5 km is recommended).

b) PCFM should be conducted along a standard proportion of each segment (these will be the sample search plots; see Section 4.2.2 for how to determine the width of sample search plots). A recommended benchmark is that a sample search plot will cover 20 to 50 percent of each segment (e.g., a 1- to 2.5-km sample search plot per 5-km segment) to be determined on a project-by-project basis.

4.2.1.3 OHLs Not Associated with WEFs

Transmission and distribution lines not directly associated with a WEF may extend regionally over long distances across multiple landscapes and present varied risks to species susceptible to collision and electrocution. The approach to deciding the OHL sample should be determined on a project-by-project basis based on the size of the line, the extent of high-risk OHL sections, accessibility, and resources. A statistician should be consulted to ensure an appropriate sampling design.

4.2.2 OHL Search Plot Shape and Size

The WEF-associated OHL search area is assumed to be a corridor along the centerline of the powerline. The sample search plot perimeter is defined by the length of the plot within each OHL segment (see Section 4.2.1.2) and the estimated limit of the fatality fall zone which forms the outer edges of the corridor. The recommended practice below assumes that the fall zone width from the OHL increases with height:

> **For OHLs less than 25 m high**, the search plot should be four times as wide as the maximum height of the OHL (e.g., for a 10 m high OHL, the searcher would search up to a distance of 20 m on either side of the OHL centerline, and for a 20 m high OHL, the searcher would search up to a distance of 40 m on either side of the OHL centerline).

> **For OHLs more than 25 m high**, the outer edge of the search plot should be 50 m on either side of the OHL centerline.

4.2.3 OHL Transect Width

WEF-associated OHL transects should ideally be parallel to the OHL centerline,[40] with as many transects as necessary to achieve acceptable searcher efficiency rates for the species and size class(es) of interest (see Section 3.3.7.2 for more details on the factors effecting searcher efficiency rates).

[40] A zig-zag search route has been referenced in the literature (e.g., Gómez-Catasús et al. 2020; Lazo et. al. 2016; Martín Martín et. al 2022), but a parallel route is recommended for consistency in terms of the unsearched area. The zig-zag pattern could create a gap in visibility in the middle of each triangle.

OHL sample search plots may require search teams to walk transects[41] that extend over 1 km or more and end a substantial distance away from their starting point (see Appendix B for advice on efficient search strategies along OHLs).

4.2.4 OHL Search Interval

Large birds are likely to be most at risk from collision and electrocution at WEF-associated OHLs, and PCFM will usually be designed to estimate fatality rates for these species. Based on this, the following approach is recommended:

- Set the initial search interval to two weeks (14 days) unless there are data to justify a different search interval.[42]
- After the start of a PCFM program, use carcass persistence results from each year of monitoring to check and, if necessary, adjust the search interval to optimize its effectiveness within the overall study design (see Section 3.3.6 for more details on the relationship between search interval and carcass persistence).

4.2.5 OHL Bias Correction

4.2.5.1 Unsearched and Unsearchable Area

Because of the potential length of WEF-associated OHLs, sample search plots may cross a wider range of habitats and ground cover than PCFM for turbines, and as a result, unsearchable areas may be more likely to change throughout the study year. In these cases, maps of unsearchable areas may need to be created seasonally.

To assess unsearched and unsearchable areas at a WEF-associated OHL:

- Map unsearchable areas at each sample search plot before the start of PCFM fieldwork and revise maps if unsearchable areas change (e.g., because of seasonal changes in ground cover).
- Use unsearched area information in conjunction with location of fatalities within the searched area to calculate the DWP[43] (see Section 3.3.7.1 for more information on the unsearched area, Box 3.4 for further details on DWP, and Appendix D for the DWP tool used to calculate OHL DWP).

[41] In certain circumstances, such as when the OHL line is long, visibility is high, or there are large carcasses with high carcass persistence, use of vehicles to conduct PCFM may be an option.

[42] The initial search interval may be reduced if documented evidence of fatalities from an existing OHL located in a similar habitat and sufficiently close to the WEF-associated OHL indicates that smaller species are likely to be PCFM target species.

[43] If unsearched areas change seasonally, DWP and fatality estimates should be calculated separately for each season.

4.2.5.2 Searcher Efficiency Trials

To provide searcher efficiency information suitable for fatality rate estimates at WEF-associated OHLs:

> Place 12 searcher efficiency trial carcasses or decoys per size class per season across the range of ground cover visibility classes within the search plots.[44]

> Place no more than one trial carcass per 100 m at any given time (see Section 3.3.7.2 for more detail on the underlying principles and Appendix B for practical advice about conducting searcher efficiency trials).

4.2.5.3 Carcass Persistence Trials

To provide carcass persistence information suitable for fatality rate estimates at WEF-associated OHLs:

> Place 12 persistence trial carcasses per size class per season across the range of ground cover visibility classes present within the search plots.

> Place no more than one trial carcass per 100 m at any given time (see Section 3.3.7.3 for more detail on the underlying principles and Appendix B for practical advice about conducting searcher carcass persistence trials).

Box 4.1 Optimizing Recommended Practices for Electrocution Risk

OHL electrocution occurs when a bird or bat makes simultaneous contact with two different electrified parts (conductors) or with an electrified part and a grounded part such as a crossarm. Electrocution typically occurs when large birds, especially raptors, perch or nest on pylons or poles of medium-voltage distribution lines, and carcasses are therefore found below these structures. (Biasotto et al. 2022; Dwyer, Harness, and Donohue 2014; Lehman, Kennedy, and Savidge 2007; Loss, Will, and Marra 2014). Large bats, such as fruit bats, are electrocuted as they hang from distribution line wires, and carcasses are therefore likely to be found below these (e.g., Tella et al. 2020). Electrocuted birds and bats may not always fall to the ground and may remain suspended from wires, at the top of poles, or within the pylon structure.

[44] At a WEF where there are insufficient trial carcasses to conduct dedicated carcass persistence trials at a WEF-associated OHL, the LE may use results from trials conducted to test carcass persistence at the WEF turbines.

When possible, electrocution risks should have been designed out of the project. When this is not the case (if there are existing above-ground collector lines associated with the WEF; see Section 4.2.1.1), and electrocution is identified as a potential risk, the overall OHL PCFM design should take account of the following:

> **OHL sample:** The OHL PCFM design should ensure that sample search plots include areas beneath poles and pylons, as well as directly beneath OHL wires, to ensure that locations where electrocuted birds and bats may fall are searched.

> **OHL searches:** Searchers should check for bird and bat fatalities on the crossarms and around the top of pylons and poles and for bat fatalities hanging from wires. When found, these fatalities should be included in the sample used to derive corrected fatality estimates for the WEF-associated OHL. Use of binoculars is recommended to help identify fatalities.

> **Searcher efficiency and carcass persistence trials:** As part of the WEF-associated OHL PCFM bias trials, at least one large bird and one large bat trial[a] per season should be placed in areas where electrocuted fatalities may fall. For carcass persistence, trial carcasses should have equivalent persistence times to electrocuted fatalities.

[a] Bias trials to test searcher efficiency and carcass persistence for electrocuted fatalities are conducted only for large birds and bats because smaller size classes are unlikely to be electrocuted.

R

4.3 DATA COLLECTION FORMS

To ensure robustness of field data collection, a series of easy-to-print data collection forms is included with this Handbook in Appendices E to J. The data collection forms are designed to be used for turbines and WEF-associated OHLs (see Appendix B for guidance on the use of these forms as part of PCFM fieldwork).

> **Appendix E — PCFM Fatality Record Form:** Used to record details of each fatality found during systematic searches or as chance finds (see Appendix B for how to conduct fatality searches at WEFs and Section 3.5 for information on chance finds). Each fatality found requires a separate PCFM Fatality Record Form. In addition to fatalities, this form should be used to record injured birds and bats found alive.

> **Appendix F — PCFM Search Summary Form:** Each searcher should have a copy of this form and complete it as they work. At the end of each search visit[45] the LE should review all search summary forms and ensure that each fatality record (Appendix E) and searcher efficiency trial corresponds to information provided on the search summary form and that search summaries account for all turbines in the study plan.

[45] For example, if study design is to search 20 turbines every seven days, the first search of all 20 turbines in the first seven days will be search visit 1, the second search of these same 20 turbines in the following seven days will be search visit 2, etc. Similarly, with WEF-associated OHLs, if the study design is to search ten 5-km segments per month, the first search of plots in these 10 segments during the first month will be search visit 1, the second search of the same plots in these 10 segments in the second month will be search visit 2, etc.

> **Appendix G — PCFM Searcher Efficiency Trial Form:** Used to record details on each searcher efficiency trial (see Section 3.3.7.2 for the theory behind searcher efficiency trials, Appendix B for how to conduct searcher efficiency field trials at WEFs, and Section 4.2.5.2 for details about designing OHL searcher efficiency trials). Each trial carcass, surrogate, and decoy requires a separate PCFM Searcher Efficiency Trial Form. The trial administrator will complete this form, not the searcher.

> **Appendix H — PCFM Carcass Persistence Trial Form:** Used to record details of each carcass persistence trial (see Section 3.3.7.3 for the theory behind carcass persistence trials, Appendix B for how to conduct carcass persistence trials in the field at WEFs, and Section 4.2.5.3 for details about designing OHL carcass persistence trials). Each trial carcass requires a separate PCFM Carcass Persistence Trial Form. The person who places the trial and the person(s) checking the carcasses on the required check days will use the same form.

> **Appendix I — PCFM Carcass Freezer Tag:** Each carcass should have its own unique label or tag before being placed in the freezer so that it can be cross-referenced with the relevant PCFM Fatality Record Form (Appendix E).

> **Appendix J — PCFM Freezer Contents Log:** Used to record the contents of the dedicated carcass freezer and check type and number of carcasses available when planning searcher efficiency and carcass persistence trials. Ideally, the log should be kept in a plastic sleeve or binder and attached to or located near the freezer. Every time a new carcass is placed in the freezer, the log should be filled in. The log should be filled in only once for each carcass (e.g., if a carcass is removed from the freezer for a searcher efficiency trial and returned if retrieved, it will not be entered into the log a second time, but if its condition has changed this should be noted on the log sheet).

Freezer stored fatalities. Photo: Inkululeko Wildlife Services

5 DATA ANALYSIS

5. DATA ANALYSIS

Much of the focus of this Handbook has been on the design and implementation of PCFM studies in the field, and many of the elements of the study design are a response to a fundamental problem in bird and bat fatality estimation at WEFs: that the number of fatalities discovered during searching *is only a proportion of the number of fatalities* that the WEF generates. Generating robust estimates of total bird and bat fatalities at a WEF goes beyond fieldwork; it is necessary to analyze those data using fatality estimation tools and present the technical results of the PCFM analysis so that others can understand how results were derived. Section 5 focuses on this and introduces the analysis of spatio-temporal fatality patterns, which also should be considered.

5.1 FATALITY RATE ESTIMATION

To evaluate results generated using fatality rate estimation appropriately, a good conceptual understanding of two core statistical principles—precision and accuracy—is necessary. Understanding these concepts will help the LE decide whether the PCFM design that generated the fatality estimates was sufficient to characterize wildlife collision impacts adequately and inform management. Understanding of precision and accuracy will also provide insights into how PCFM and associated bias correction experiments could be adjusted to improve the value of future estimates. In addition to describing these two concepts, this section provides background on GenEst, the current state-of-the-art estimator referred to in Section 2.3. Interested readers are referred to James and colleagues (2017) for an introduction to statistical concepts and practice and to the references in Table 5.1 for further information on fatality estimation.

5.1.1 Precision

Precision is the ability to specify an estimate within a narrow range of values.

If we were 90 percent confident that a WEF had a fatality rate of 13.1 to 19.9 bats per megawatt per year, it is likely that the management response would be quite different than with a fatality rate of 2.3 to 30.7 bats per megawatt per year.[46] In both cases, the best estimate of the fatality rate is 16.5 per megawatt per year, but in the first case, we are 90 percent confident that the true value is between 13 and 20 bats per megawatt per year, whereas in the second case, the true value could be as high as 31 bats per megawatt per year.

These two hypothetical examples differ only in their precision. In the former case, there is higher precision and hence less uncertainty and better information on which to act. Precision of fatality rate estimates is usually expressed as a confidence interval (CI) around an estimate (e.g., the median). The most important features influencing the precision of fatality rate estimates at WEFs are sample size, detection probability, and natural variability in fatality rates over time and space. Increasing *the level of sampling by increasing plot size*, *reducing transect width or conducting more frequent searches* will increase the precision of fatality rate estimates (narrow the CIs). Fatality rates tend to be variable over time and space, so the ability to produce highly precise estimates is limited, but in general, more intensive sampling efforts will increase the level of precision compared with less intensive sampling efforts.

[46] See Section 5.1.5.4 for instructions on how to derive this metric.

5.1.2 Accuracy

Accuracy is the degree to which an estimate matches the truth.

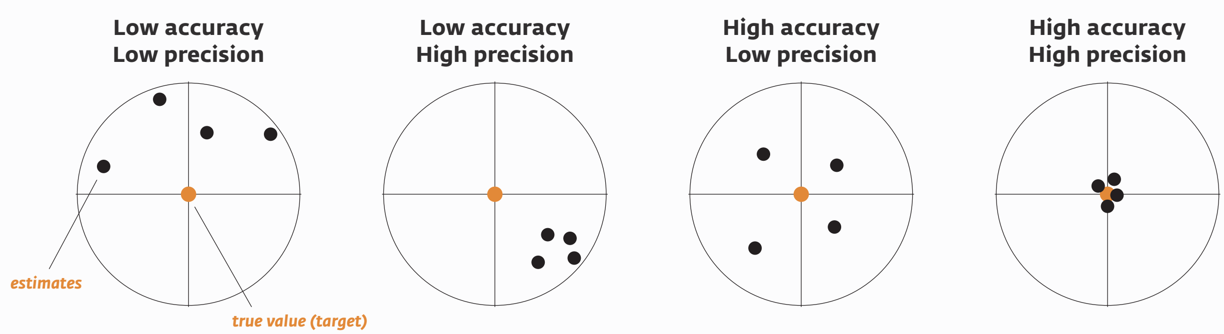
The accuracy of a fatality estimate is a measure of how close it is to the truth, or the true fatality rate at the WEF. Continuing with the hypothetical example above, in which the bat fatality was estimated at 16.5 bats per megawatt per year, what if there was another analysis of the same data, using a different statistical estimator, in which the mean estimated value of total bat fatality was 25 bats per megawatt per year? Whichever of these estimates is closer to the true number of fatalities would be the more accurate estimate, regardless of the precision of either estimate, but how would you know which is more accurate? How would you know which is closer to the true fatality rate? You would not, but if you understand the factors that push the estimate away from this value you can take steps to "correct" the estimates from the influence of these factors and reach a more accurate estimate.

Sources of bias (see Section 3.2.3) are factors that can push an estimate away from the truth, decreasing accuracy. In PCFM studies, the best-known sources of bias, or at least those believed to exert the greatest influence on the accuracy of total fatality rate estimates, are carcasses that fall outside of search plots (see Section 3.3.7.1), searcher efficiency (through carcass detectability; see Section 3.3.7.2), and carcass removal (e.g., through scavenging; see Section 3.3.7.3). All three of these factors decrease raw carcass counts below the true value of project-generated fatality (thereby underestimating true fatality rates). These sources of bias are why it is important to use field and analytical methods associated with bias correction to estimate detection probability accurately so that estimates of total, project-generated fatality rates are not biased.

5.1.3 Relationship Between Precision, Accuracy, and Study Design

The concepts of precision and accuracy in fatality rate estimation in WEF PCFM studies can be understood by considering the relationship of the fatality rate estimates to the true fatality rate (Figure 5.1). Precision and accuracy are related to study design through detection probability (see Section 3.2.4). Higher detection probabilities lead to more precise estimates, and a correct estimate of the detection probability is essential to an accurate estimate of fatality.

Figure 5.1 Relationship between precision and accuracy in fatality rate estimation



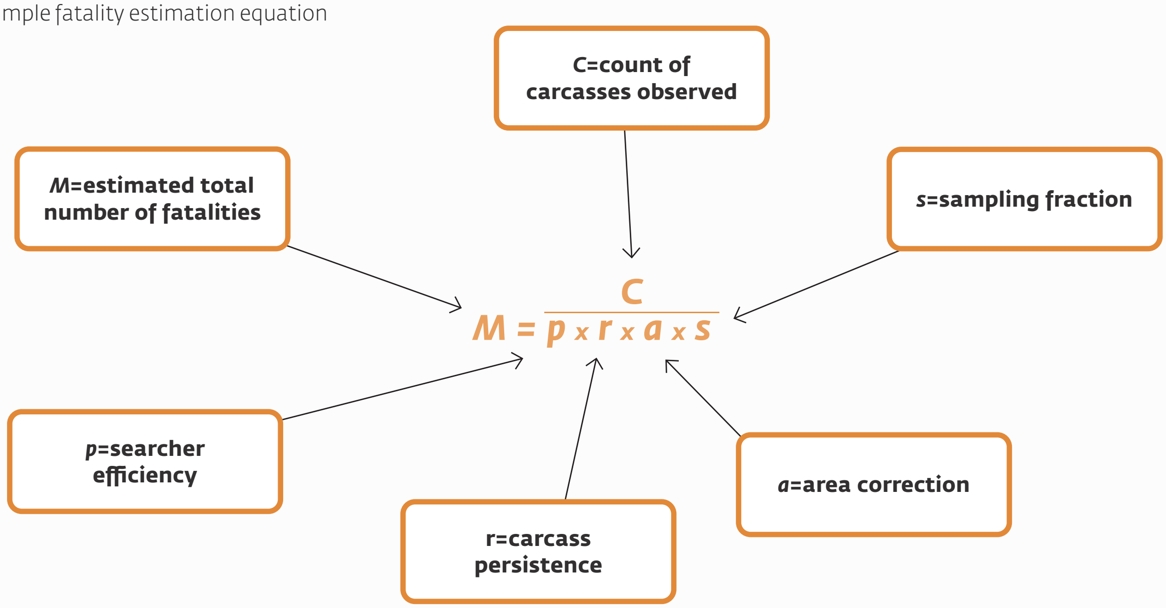
Note: The orange dot in the center represents the "true" fatality rate. This is the "target" that one is trying to hit with the fatality rate estimates (black dots). The four panels show examples of estimates with different levels of precision and accuracy.

5.1.4 Fatality Estimation Tools

5.1.4.1 The GenEst Fatality Estimator

Methods for estimating total wildlife fatality rates at WEFs have evolved considerably since the first models were developed and applied for this purpose in 2004. Most fatality estimators have used data on searcher efficiency, carcass persistence, area searched, and sampling fraction (fraction of turbines searched at a WEF) to estimate fatality rates. A simple equation summarizes the generic features of the common fatality estimators (Figure 5.2).

Figure 5.2 Simple fatality estimation equation



$$M = \frac{C}{p \times r \times a \times s}$$

Although most early fatality estimators were based on solid statistical principles, including correcting for biases, there were differences between them in terms of data required, assumptions, and calculation methods. Not only did the choice of which estimator to use confuse users, the estimators also all produced slightly different results. Most of these tools also required users to have statistical programming capability or the ability to use tools such as R (R Development Core Team 2018).

To address the inconsistencies between estimators, Dalthorp and colleagues (2018) developed GenEst as a universal, user-friendly general estimator that would allow for consistency and facilitate comparison across PCFM studies. GenEst is the easiest to use and most flexible fatality estimation modeling framework available and is considered to be the current state-of-the-art (see Rabie et al. 2021). This Handbook is designed to be compatible with GenEst while recognizing the contributions of previous estimators. As its name suggests, GenEst represents a **Gen**eralization of several of those previous **Est**imators and owes much of its theoretical underpinning to them. Table 5.1 presents the common fatality estimators and their key assumptions, including GenEst.

Table 5.1 Common fatality estimators and their key assumptions

ESTIMATOR	KEY ASSUMPTIONS AND FEATURES	CITATION
SHOENFELD	> Searchers have more than one opportunity to detect a carcass. > Searcher efficiency does not decrease as carcasses age. > Carcass persistence rate is not a function of carcass age. > Assumes a single, average search interval to estimate carcass persistence.	Shoenfeld 2004
HUSO	> Searchers have a single opportunity to find a carcass. > Requires estimates of time since death.	Huso 2011
CARCASS (R PACKAGE)	> Searchers have more than one opportunity to detect a carcass. > Searcher efficiency decreases as carcasses age.	Korner-Nievergelt et al. 2015
GENEST	> Searchers have more than one opportunity to detect a carcass. > Searcher efficiency decreases as carcasses age. > Generalized extension of Huso and Shoenfeld estimators. > More flexible carcass persistence modeling than earlier estimators because each parameter can be modeled as a function of covariates.	Dalthorp et al. 2018

GenEst was designed with an accessible, web-based graphical user interface that, unlike many other estimators, does not require working knowledge of statistical programming languages. GenEst is recommended in most circumstances. Section 5.1.4.2 describes the Evidence of Absence estimator (Dalthorp and Huso 2015; Dalthorp, Huso, and Dail 2017), which is preferable to GenEst under some circumstances, such as for rare species for which the number of carcasses detected is very low (fewer than five) or even zero. Box 5.1 describes how GenEst could be used for fatality estimation for OHLs. Appendix C demonstrates the use of the GenEst graphical user interface and further explains how GenEst generates fatality estimates.

Box 5.1 Fatality Estimation for OHLs Using GenEst

OHL fatality rates can be estimated using GenEst and requires the same input data tables used for turbines: search schedule, carcass observations, searcher efficiency trial data, carcass persistence trial data, and a density weighted proportion (DWP) of area searched table (see *Appendix C: Preparing and Inputting Data into GenEst — The Five Data Files*).

Data from OHL PCFM designs for each of these inputs are compatible with the required data entry format for GenEst. One minor difference is that, in the GenEst Search Schedule table, the sample unit is the segment rather than the turbine (see Section 4.2.1.2). Where OHLs are short (<5 km), and entire length will be searched (see Section 4.2.1.2, Scenario 1) it may be appropriate to subdivide the search corridor into standard length search plots and enter these as sample units in the GenEst Search Schedule table. DWP can be calculated for OHLs using the OHL DWP worksheet in the DWP Tool (Appendix D).

Fatality estimates (fatalities per kilometer) should be reported separately for each segment type identified in Section 4.2.1.2 (the interconnection line).

Small bird fatality. Malachite Sunbird (*Nectarinia famosa*). Photo: Inkululeko Wildlife Services

5.1.4.2

Evidence of Absence

When the goal is to estimate fatalities of rare species, other methods may be preferable to GenEst. Finding the carcass of a rare species is a rare event, meaning that the carcass count of rare species is often zero, and the estimate returned by GenEst will be zero. Huso and colleagues (2015) described this as "absence of evidence" rather than "evidence of absence" of fatalities of the species.

GenEst relies on dividing the number of carcasses by the probability of detection (see Figure 5.2). When detection probability is low, finding zero carcasses may mean that no individuals of the species collided with project infrastructure or that the search was not rigorous enough to detect those individuals. GenEst (and the other common estimators) will always return an estimate of zero if no carcasses are found because 0/(detection probability) = 0 regardless of detection probability.

The Evidence of Absence estimator (EoA; Huso et al. 2015) overcomes the limitations of other estimators for rare species. EoA is a Bayesian model designed for fatality estimation of rare species. It requires all the same information as other estimators (bias trials, area correction, sampling fraction, carcass count), but the fatality estimate produced can be greater than zero even when no carcasses are found. The estimate from EoA can be interpreted as an upper bound on the number of carcasses that could plausibly have occurred, considering the search effort and carcass count. In that sense, EoA can be useful when WEFs have strict thresholds for individual species.

EoA is not treated in any more detail in this Handbook, except to say that it is a special estimator which should be used only when there is a need to put an upper bound on the mortality of individual species, and carcass counts are low (fewer than five individuals). When carcass counts are higher, GenEst is the superior estimator. Readers are referred to Huso and colleagues (2015) and Dalthorp and colleagues (2017) for more information.

5.1.5 Reporting of Data Analysis

Just as PCFM studies are not complete until the field data are analyzed to produce fatality estimates, fatality estimates are not useful unless the data analysis is reported in adequate detail. This section discusses reporting of the details of the PCFM design, the extent to which the design was implemented, raw fatality numbers, fatality estimates, and other associated output from the GenEst analysis—the topics covered so far in this Handbook. Further reporting in the context of *adaptive management*, which includes analysis of data to inform operational mitigation, is included in Section 6.

5.1.5.1 Reporting — PCFM Design Parameters

At a minimum the following six pieces of information should be included when reporting details of the PCFM design for each plot type used (RAP, full plot, OHL plot) and each season included in the study:

- Search dates
- Sampling fraction
- Search plot type and size
- Transect width, search interval
- Number of bias trial carcasses of each type

5.1.5.2 Reporting — Success of PCFM Implementation

After reporting PCFM design parameters, the extent to which the design was implemented should be summarized. This section of the report should use simple tables to compare the planned fatality search effort with the actual search effort and the number of scheduled bias correction trials with the actual number of trials conducted. Reasons for any significant departures from the intended study design should also be explained. For example, if the search interval was twice weekly, but some turbines were unsearched for a period due to turbine maintenance, that should be noted in the report methods.

5.1.5.3 Reporting — Raw Fatality Data

At a minimum the following information should be included when summarizing the raw fatality data:

- **Details for each bird and bat carcass found,** including species, date found, turbine or OHL location, age, sex (if known), and cause of and estimated time since death recorded in a table with one row per carcass.
- **Number of fatalities included in the fatality estimate,** tabulated according to season, plot type, carcass size class, and any other relevant factors (e.g., habitat type, turbine size).

- **Number of fatalities not included in the fatality estimate** (non-collision and off-plot chance finds — see Section 3.5), tabulated according to PCFM target and non-target species and type (off plot, non-collision).

This information should be reported separately for the turbine search and the WEF-associated OHL search. It is often desirable to include additional data in appendices to a report, including raw data from bias trials and fatality searches. Including raw data in a report allows it to be easily accessed and used with data from other studies, for example, for the analysis of cumulative effects.

5.1.5.4 Reporting — Bias Corrected Fatality Estimates Using GenEst

The GenEst software will generate the analysis results (see Appendix C for more information), which can be downloaded from the software as tables or figures. GenEst is flexible in how it reports fatality estimates; estimates can be split according to size class, season, or any number of other categories that are present in the input data (see Appendix C). Results to be reported in the main body of a report should allow a reader to evaluate the sources of bias (see Section 3.2.3 and Section 3.3.7) and the total number of fatalities and fatality rate at the WEF, including the associated OHLs. Results should be presented so that the reader can understand whether there are important seasonal trends in fatalities. All estimates in this section should include the point estimate (the median value from GenEst), as well as the 5th and 95th quantiles of the estimates, which together make up a 90 percent CI (see Appendix C). These results include the following:

- Annual and 6-monthly (or seasonal) fatality estimates **for each carcass size class** for turbines and for the WEF-associated OHL
- Annual and 6-monthly (or seasonal) fatality estimates **for each PCFM target species** for turbines and for the WEF-associated OHLs
- Annual fatality estimates per megawatt for each size class for the entire WEF (including the WEF-associated OHL)[47]
- Carcass persistence and searcher efficiency estimates from GenEst output tables

GenEst produces tables and figures that can be downloaded. Corrected Akaike's Information Criterion(AICc)[48] scores (Burnham and Anderson 2022; see Appendix C Figures C15 and C18) from the carcass persistence and searcher efficiency models used in the analysis should be provided in the report text, and the entire model selection table should be included in an appendix to the report. Additional tables and figures are often useful to graphically illustrate how bias trial results or fatality estimates differ according to season or other factors. To keep the reporting concise, these figures and other relevant additional output from GenEst may be best referenced in the main body of the report and placed in an appendix.

[47] The annual fatality estimate per megawatt can be easily obtained by dividing the fatality estimates and CIs from GenEst by the megawatt capacity of the WEF. For example, a 50-MW project with an annual WEF median fatality rate of 100 bats (95% CI 30-200) would have a fatality rate of two bats per megawatt (95% CI 0.6-4).

[48] AICc is a metric that is used to determine the most appropriate model to fit to the data. The process of using AICc to choose a model is called "model selection."

African Straw-coloured Fruit-bats (*Eidolon helvum*). Photo: Inkululeko Wildlife Services

5.2 ANALYSIS OF SPATIO-TEMPORAL FATALITY PATTERNS

A valuable use of PCFM data is to identify spatial[49] and temporal[50] fatality patterns to inform adaptive management and mitigation actions. This involves identifying turbines or sections of OHLs with a high proportion of fatalities or identifying periods during the year when fatality rates peak. Reliably identifying problem turbines and OHL sections or high-risk periods requires PCFM data from several years. This is because many factors can contribute to a turbine or OHL section having a disproportionately high number of fatalities (e.g., topography, weather, species ecology, food availability). Multiple factors may drive interannual variation, and distinguishing spatial or temporal trends when many variables are involved requires considerable data.

In practice, during the early operational phase, PCFM data may indicate that turbines and OHL sections have high fatalities, but it will not be possible to reliably assess if this is likely to recur. This can present a challenge for the WEF because it may need to implement an adaptive management response well before sufficient data are available to make optimal decisions. This is particularly the case when safeguarding PCFM target species as the project may be required to uphold zero or very low thresholds to meet lender or regulatory requirements (see Section 6.2). The developer must therefore take an ongoing, dynamic approach to understanding and using spatial and temporal PCFM data to inform adaptive management (see Section 6). To make the best use of PCFM data in this context, the following approaches are suggested:

> Report spatial and temporal fatality patterns annually and 6-monthly (or seasonally) to allow emerging patterns to be identified as the project lifecycle progresses (e.g., compare fatality patterns in the second year of operations with first year patterns).

[49] Spatial patterns can be assessed by obtaining per-turbine fatality estimates from GenEst and plotting them onto a map of the WEF with map symbols proportional to the size of fatality estimates.

[50] Temporal patterns are most easily assessed by examining bar charts showing counts of carcasses according to date or GenEst estimates according to week.

> Compare spatial and temporal fatality patterns with other source information that may indicate high levels of bird or bat activity, for example:

- Acoustic bat activity data
- Bird monitoring data
- Proximity of topographic features in the landscape such as slopes and ridges that may be disproportionately used by or risky to large soaring bird species
- Proximity of habitat features used by species recorded as fatalities, such as trees, river valleys, lakes
- Proximity to breeding and roost site locations and regularly used flight routes between these locations
- Proximity to areas of prey aggregations or carrion for birds of prey or vultures
- Occurrence of specific environmental conditions during periods of high recorded fatality (e.g., wind and other weather conditions)

> Review available flight activity data and other relevant literature from the area near the WEF or associated OHLs to further understand the predictability of fatality patterns recorded.

> Consult with a statistician to help determine the consistency of spatial and temporal patterns recorded.

As described in Section 6, adaptive management and mitigation measures should be implemented and reviewed over relevant, specified time periods (e.g., after each migration or breeding season) to evaluate their effectiveness.

Habitat features may influence spatio-temporal fatality patterns at a WEF. Photo: Inkululeko Wildlife Services

ADAPTIVE MANAGEMENT

6

6. ADAPTIVE MANAGEMENT

As described in Section 1 of this Handbook, even with good quality pre-construction baseline data, impacts of WEFs on birds and bats are unpredictable, which is why a well-designed, systematic PCFM program is essential. But how should PCFM data be used to safeguard these species?

Adaptive management is the process of informing and updating the approach to biodiversity management by incorporating the results of monitoring or integrating new findings. As described in IFC's Guidance Note 6, although adaptive management may be described as a practical approach to managing uncertainty, it is not a trial-and-error process but rather a structured learning-by-doing process informed by monitoring.[51]

PCFM underpins a WEF's adaptive management program and, therefore, decision making with respect to on-going mitigation and management of biodiversity throughout the project life cycle.[52] The adaptive management program should be included as part of the project's ESIA and/or its management plans.[53] *Although adaptive management is executed during operations, the types of management actions likely to be required should be considered during the project planning and design phases to ensure that they are adequately resourced*.

This section identifies the components of the adaptive management program and provides information on the adaptive management review process; fatality thresholds, and other adaptive management triggers; management actions; and guidance on roles, responsibilities, reporting, and disclosure.

6.1 ADAPTIVE MANAGEMENT REVIEW

The LE should identify a timetable (frequency) with which to compare PCFM results with the pre-defined project commitments in the ESIA or management plans or review them with respect to government licensing and permitting conditions. If project commitments were not defined during the pre-construction phase, they should be included as part of the adaptive management program (see Section 6.3). The LE should also outline in advance the objectives of the adaptive management review (see Section 6.1.1).

6.1.1 Review Process

The overarching purpose of the adaptive management review process is to ensure that the project monitoring objectives are efficiently fulfilled following an evidence-based approach. The review process is designed to optimize the PCFM study design to identify and detect PCFM target species throughout the study duration and seek efficient use of financial and human resources allocated to safeguarding birds and bats.

[51] Adaptive management is also a key aspect of an effective Environmental and Social Management System (ESMS), which draws on the elements of "plan, do, check, and act" in accordance with established business management processes. IFC's Guidance Note 1, which accompanies its Performance Standard 1, captures the objective of adaptive management by stating that *"effective management programs have an adaptive approach,"* and *"The client should develop and implement procedures to…adapt actions and mitigations as appropriate based on the environmental and social monitoring data. This iterative process promotes flexible decision making that takes into consideration uncertainties, recognizes the importance of variability of the social and natural systems, and can be adjusted as outcomes from management actions, mitigations and other events become better understood"* (Guidance Note 1, para. GN70).

[52] See Section 1.2 for the definition of mitigation in the context of the mitigation hierarchy.

[53] See paragraph GN50 in IFC's Guidance Note 6 (2019) for information on developing a Biodiversity Management Plan (BMP). The WEFs Adaptive Management Plan could be a component of the BMP or a standalone document.

Although the details of the review process will be tailored to the project-specific context and may differ depending on the stage of the operational phase, the underlying structure of the process is similar for all projects, following a sequential approach centered on fulfilling four key objectives as shown below. The review should be implemented based on a predetermined schedule, as well as in response to specific fatality events (see Section 6.1.2). The LE should periodically assess whether fatality thresholds continue to be valid and may also need to consider whether the effectiveness of existing mitigation measures should be formally evaluated (5 and 6 below). These points are elaborated here and in the decision-making process summarized in Figure 6.1.

ASSESSING PCFM RESULTS

1. Determine the adequacy of the PCFM design:

- Are the PCFM estimates sufficiently precise to assess thresholds?
- Does the study design need to be modified to better characterize the risk to size class(es) of higher risk species (e.g., threatened, restricted-range, migratory, congregatory)?
- Should the intensity of monitoring be increased or decreased in a certain season?

Optimizing the design is always appropriate, but especially after the first year(s) of monitoring.

2. Determine the adequacy of the PCFM target species list:

- Considering the project's monitoring objectives, which species should be retained, included or eliminated as PCFM target species?

After implementation of the First Year PCFM design, the PCFM target species should be better understood in the context of the project's monitoring objectives. Evaluating the PCFM target species list is an iterative process and should be reviewed seasonally throughout the study duration.

ASSESSING IMPACTS

3. Determine the implications of the PCFM fatality estimates:

- Do fatality estimates exceed pre-defined thresholds (see Section 6.2)?
- If yes, by how much?
- Do exceeded thresholds put the project in breach of regulatory or lender standards?

Fatality estimates should be evaluated against thresholds (see Section 6.2). It is important that uncertainty around estimates is also evaluated. If CIs are too wide, a more intensive PCFM study may be required to better determine whether thresholds have been exceeded.

MANAGING IMPACTS

4. Determine the adaptive response required:

> When thresholds are exceeded or new findings emerge that alter the risk profile of the project, what mitigation actions should be taken or adjusted (see Section 6.3 below)?

ADDITIONAL ACTIONS

5. Determine the accuracy of thresholds:

As described in Section 6.2, determining numeric thresholds can be challenging given data limitations. If new data on species occurrences become available or if categorization of the IUCN Red List changes, the thresholds should be re-evaluated. Routine reassessment of thresholds should be factored into the review process.

6. Determine the effectiveness of mitigation:

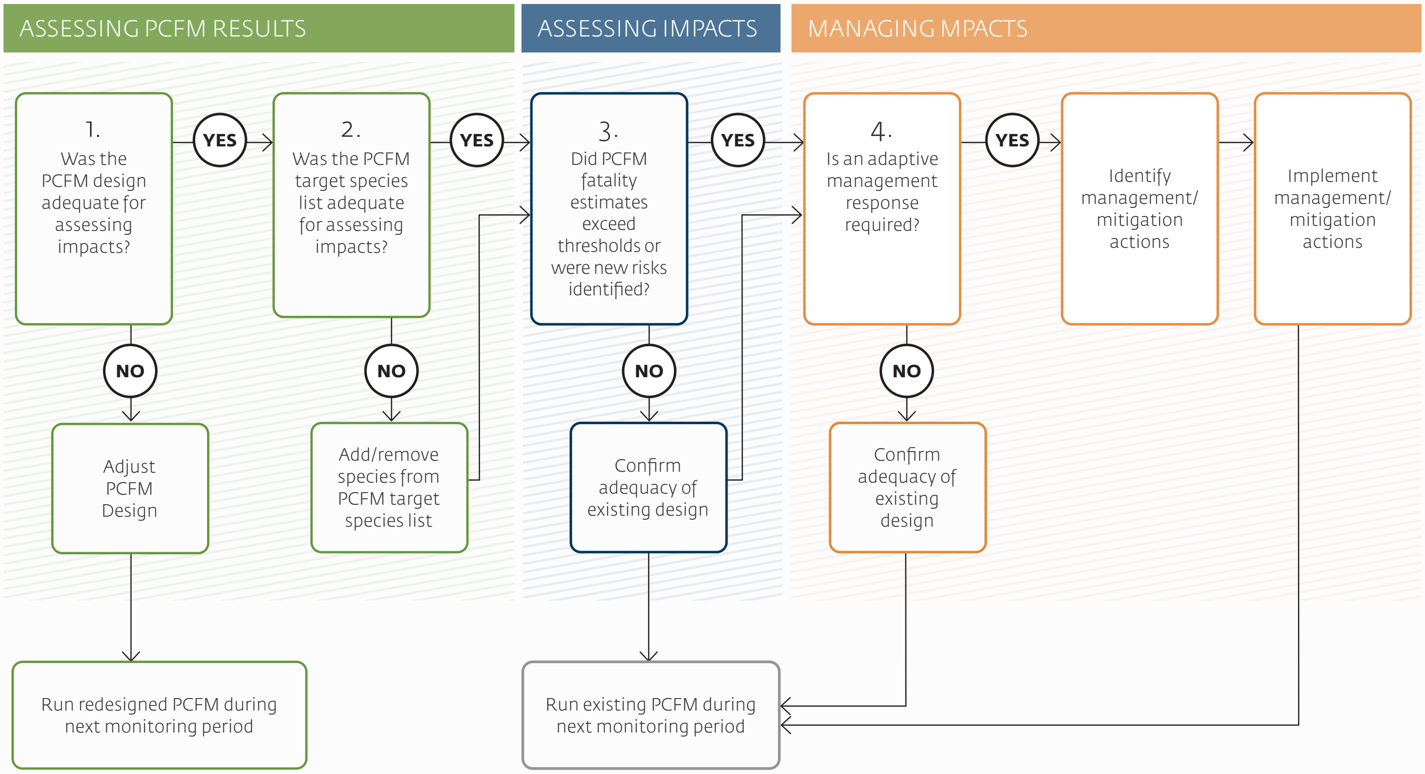
> If a mitigation measure (e.g., use of curtailment to minimize impact) was executed over the previous reporting period, was it effective in reducing fatalities?

One way to evaluate the effectiveness of mitigation, notably with respect to curtailment for bats, is to use an experimental design. The mitigation treatment (e.g., curtailment) would be applied to a randomly selected subset of turbines, and another subset would be left untreated to serve as a control group. That way, the treatment and control groups can be directly compared with one another.[54] Consulting with a statistician is recommended to ensure that the mitigation experiment is likely to produce data that can be used to increase understanding of mitigation effectiveness.[55]

[54] Note that it may not be enough to compare pre-treatment and post-treatment fatality rates because year-to-year variation may interfere with the ability to determine the effectiveness of a treatment.

[55] For example, many types of studies can be executed by assigning turbines to mitigation treatments and control groups at random, but in some cases, particular turbines may be known to have especially high impacts, and mitigation treatments must be applied at high-impact turbines. It is possible to design statistically rigorous experiments in these cases, but doing so requires statistical expertise, which may go beyond the training of the LE.

Figure 6.1 Summary of the four key stages of the adaptive management process



6.1.2 Review Frequency

Adaptive management reviews are recommended as follows:

- **Routinely,** corresponding to the timeframe for generating PCFM fatality estimates
- **As needed,** in response to an unexpected high-risk incident, such as an exceedance of regulatory or lender standards

It is recommended that fatality estimates and PCFM reports are produced every six months or at least annually. If the study generates enough data to produce fatality estimates seasonally, and the risk profile of the project warrants greater scrutiny, or if constraints require that the design is changed seasonally, for example as a result of changes in unsearched area, PCFM reports should be generated seasonally. The DST should be consulted on the same schedule as part of the routine review of fatality estimates (see Section 6.4.2.1).

6.2 ADAPTIVE MANAGEMENT THRESHOLDS AND TRIGGERS

Thresholds are defined as limits beyond which project-related impacts become a concern because further loss of individuals is considered a risk to the long-term viability of a population. Defining numeric thresholds is an important component of an adaptive management program to assess the significance of impacts and determine appropriate management strategies. Regarding project finance in emerging market countries, thresholds have been defined with respect to an annual monitoring period (annual fatality thresholds; see, e.g., IFC 2017). Methods for setting thresholds for multiple years and for the lifetime of the project are available and, although not commonly used at projects in the context of financing in emerging market countries, may be more common in the future.[56]

That said, a principal challenge is how to derive biologically meaningful numeric thresholds when the species-specific data required to do so are limited or absent, *which is often the case in emerging market countries*, especially for bat populations. Despite this challenge, and the inevitable compromises and assumptions that must be made, fatality thresholds can provide a valuable tool for tracking and managing impacts and determining alignment with lender standards (see Section 1.5).

This section provides an overview of, and guidance on developing thresholds and other adaptive management triggers in the emerging market context.

6.2.1 Determining Fatality Thresholds in an Emerging Market Context

As the approaches to threshold-setting may evolve quickly, readers are encouraged to scrutinize and apply the latest methods, assuming data availability, scientific robustness, and applicability to the wind energy sector. The current recommended approach to threshold-setting is provided below.

When there are national or regional fatality thresholds, such as the South African Bat Fatality Threshold Guidelines, developers should adhere to them (MacEwan et al. 2020). When national or regional guidance has not been developed, techniques to estimate threshold-setting include population matrix modeling, population viability analysis (PVA), and potential biological removal (PBR).

For species for which details on a wide range of biological and demographic parameters are available, PVA should be considered as an appropriate approach for modeling future population trends and informing judgment about future population viability. In some cases, especially for high conservation status species, a PVA may have been published that could be evaluated for application as a fatality threshold value. Importantly, PVA estimates have to be established for source populations which could be different from the species populations associated with the WEF, such as in the case of some migratory species (Voigt et al. 2012). In many emerging market countries, however, the information needed to conduct a PVA or other type of species viability analysis is often not available. In these situations, when information on population dynamics is limited, PBR offers a simple, robust calculation (see Dillingham and Fletcher 2011; Niel and Lebreton 2005; Wade 1998)

[56] For an example of methods used to establish long term thresholds see Dalthorp and Huso (2015). The EoA software also has a multiple years component that provides tools for estimating cumulative mortality across multiple monitoring years.

Potential for cumulative impacts may increase where PCFM target species occur in focal areas for wind energy. Photo: Alvaro Camiña

and one potential method to arrive at the threshold in the context of PCFM adaptive management, if used cautiously and informed by expert consultation.

6.2.2 Potential Biological Removal

PBR is a method for estimating the number of human derived mortalities that a wildlife population can sustain each year while allowing it to reach or maintain its optimum sustainable level. (see Wade 1998). PBR is calculated using a) the maximum annual recruitment rate (Rmax), b) a conservative estimate of the population size (Nmin), and c) a recovery factor (F) between 0.1 and 1.0, typically applied to allow for differences in a species' conservation status. The following sections explain the main components of the PBR formula. Section 6.2.2.4 then explains how to derive a threshold for a WEF informed by a PBR value and that takes account of non-project related human derived sources of mortality.

6.2.2.1 Minimum Population Size (Nmin)

Before the minimum population (Nmin) size can be estimated, the spatial extent of the population for each PCFM target species must be defined. Ideally, this 'spatial unit of analysis should be biogeographically determined, but this is often not possible, so the PCFM target species populations are more typically defined at other scales, such as nationally or with respect to a migratory flyway.

Assessing the population size for a selected spatial unit of analysis is also challenging because population size estimates are often approximate in emerging market countries and frequently derived from historical data. This is especially the case for bats, for which reliable estimates are often absent. Recognizing these constraints, a recommended approach is to use the information available and expert judgment through consultation and collaboration with relevant national and regional bird and bat experts to arrive at a reasoned qualitative population estimate. When population size information for the spatial unit of analysis is absent, one option is to use IUCN global or regional population estimates, calculate global PBR values, determine a global threshold, and use this as a guide to assess the threshold for the spatial unit of analysis. If IUCN population estimates are not available, another option is to derive PBR values using global IUCN Red List category population size criteria (IUCN 2012).[57]

6.2.2.2 Maximum Annual Recruitment Rate (Rmax)

The maximum recruitment rate (Rmax) can be expressed as *the maximum annual population growth rate* – 1. With appropriate demographic information, matrix population models can be constructed to estimate the maximum annual population growth rate (Caswell 2001) and from this derive a maximum annual recruitment rate value for a species of interest. When there is insufficient information to calculate this value, it may be reasonable to use a surrogate Rmax value from a species or species group with similar demographic characteristics if these are available. An alternative approach is to use a formula developed by Niel and Lebreton (2005) that uses only adult survival rate and age at first breeding to derive a maximum recruitment rate. Users are referred to Neil and Lebreton (2005) and Dillingham and Fletcher (2008) for additional guidance for calculating PBR using these two parameters.

6.2.2.3 Recovery Factor (F)

The recovery factor (F) is a weighting between 0.1 and 1.0 that is typically used to account for variation in species conservation sensitivity. Following guidance in the published literature (Dillingham and Fletcher 2008; 2011; Niel and Lebreton 2005; Taylor et al. 2000; Wade 1998), it may be reasonable to set F values of 0.1 for Endangered or Vulnerable species, 0.3 for Near Threatened species, 0.5 for species of Least Concern that are declining or for which the population trend is uncertain; and 1.0 for species of Least Concern that are known to be increasing or stable. For Data Deficient species (which include nearly a fifth of all bat species) extinction risk is unknown, meaning that that an extinction risk category of Least Concern or Critically Endangered is equally plausible. For Data Deficient species it may therefore be reasonable to set a recovery factor of between 0.1 and 0.5 with the final value chosen based on the level of precaution warranted by stakeholder concerns and other evidence relevant to the conservation sensitivity of the population being evaluated. The recovery factor can be used as part of an adaptive management system and adjusted to reflect changing conservation status and increases in knowledge about a species during the lifecycle of a project.

6.2.2.4 From PBR Value to Threshold Through Expert Consultation

Establishing a PBR value for each PCFM target species population is the first step in the threshold-setting process, but it does not end there. Importantly, the PBR value provides a sustainable annual mortality limit for **all sources** of human derived mortality. This means that using the calculated PBR value to determine a threshold for an individual WEF would not be appropriate because it would result in a

[57] When using the IUCN Red List category and criteria document (IUCN 2012) be aware that a) different population size values are given in Criteria C and D for each category so the most appropriate value will need to be determined for the population being assessed, and b) the values given are for mature individuals of the species rather than all individuals. Because collision risk applies to all individuals, a correction would be needed to provide an estimate that includes immature individuals. One solution may be to use suitable surrogate species for which both mature and all individuals are reported in the IUCN Red List (www.redlist.org), determine the proportion attributed to non-mature individuals, and use this to calculate an estimate for all individuals of the species.

threshold that was too high. The population is likely to be exposed to non-project related sources of mortality such as, poisoning, hunting and mortality from other WEFs. To account for this, an additional step in the threshold-setting process is to estimate, for each PCFM species, how many of the annual mortalities calculated by the PBR were attributable to non-project related anthropogenic sources.

Given the likely lack of pre-existing quantitative data available, obtaining an estimate of annual mortality from non-project related anthropogenic sources will require consultation with recognized bird and bat experts from the region. It is recommended that this estimate, which may be qualitative, be derived systematically, such as through considering various categories of existing threats and the potential annual mortality that they cause. Once an estimate is agreed upon for each PCFM target species, experts should use this information along with the PBR value to derive a defensible threshold that will not compromise the long-term viability of the population within the spatial unit of analysis. The threshold value will always be lower than the PBR value, often substantially so.

Detailing the PBR-based threshold-setting approach is outside the scope of this Handbook, but the method is more fully outlined and implemented in the Tafila Region Wind Power Projects Cumulative Effects Assessment (IFC 2017), and the South Banat Wind Power Projects Rapid Cumulative Effects Assessment (IFC 2019). Readers are encouraged to review these and other sources.

When developing thresholds in this way, it is particularly important that data gaps and assumptions on which the thresholds are based are clearly documented so that they can be improved if better information becomes available.

Fatality threshold values will vary depending on the degree to which the assessed PCFM target species population can sustain fatalities and remain viable. It is likely that any additional human-derived mortality will compromise the long-term viability of threatened and restricted-range species. In this situation, a zero-fatality threshold may be appropriate, meaning that any fatality recorded will trigger an adaptive management response.[58]

6.2.3 Other Risk Events

Adaptive management responses are not limited to cases in which numeric thresholds are exceeded. New information highlighting a potential change in the risk profile of the project or of a specific PCFM target species may also trigger management action. For example, development of an attractant near the WEF such as a slaughterhouse or a reservoir may increase risk for birds and bats that may warrant new forms of mitigation or other types of monitoring. These risk profile changes are context and location specific, and their relevance should be discussed as part of the adaptive management review process. They include the following:

> ***A change in the IUCN global or national Red List category for a species*** may prompt a reevaluation of fatality thresholds or warrant a change to the PCFM design, with increased or decreased focus on the species.

> ***Evidence of increased risk due to cumulative impacts*** may be caused by other WEFs sited in the vicinity and/or by other sources, such as increased hunting or poisoning. If unforeseen

[58] Note that chance finds of collision and electrocution fatalities outside the search plot (see Section 3.5.2) also should be considered when determining whether a threshold has been exceeded. This is especially relevant for PCFM target species with zero fatality thresholds because a single individual found as an off-plot discovery will exceed the threshold.

cumulative impacts arise during the operations phase, adaptive management responses may include re-evaluating fatality thresholds and collaborating with other WEFs to develop and participate in joint mitigation and inter-site adaptive management strategies.

- ***A change in the physical landscape near the WEF,*** for example a new landfill site, an increase in livestock, a change in livestock disposal practices, new water-related infrastructure, and new or modified drainage or irrigation systems may increase risk. These types of changes in the physical landscape could increase collision risk for specific or multiple PCFM target species and require an adaptive management response, such as implementing new or enhanced mitigation measures or engaging with external entities to develop strategies to modify human activities responsible for the increase in risk.

- ***Near-miss incidents***[59] are relevant when WEFs implement shutdown on-demand of turbines as a mitigation strategy (see Box 6.1). During shutdown on-demand, an example of a near-miss incident would be when a PCFM target species is observed flying through the rotor swept zone unharmed, and shutdown was initiated too late or not at all because of communication problems between bird observers and SCADA operators. Consistent, comprehensive recording of near-miss incidents is important for understanding underlying causes and informing an effective adaptive management response. In the example above, assessment of the near-miss incident records might lead to a change in bird observer or communication protocols as an adaptive management response. When using automated shutdown on-demand systems, false negatives should also be tracked to provide information on near-miss incidents.

Griffon Vulture (*Gyps fulvus*). Photo: Marian Ramos

[59] "Near miss" in this Handbook is similar to the concept as referred to in occupational health and safety practices but applied to birds and bats.

6.3 MANAGEMENT ACTIONS

The core of the adaptive management program may be defined as a series of actions that can be implemented to safeguard PCFM target species in response to an exceeded threshold or other type of risk event. Although site-level mitigation (e.g., curtailment) is the most obvious, other management responses may be warranted as a first step. These include investigation of underlying cause(s) of the fatalities, collaboration with external stakeholders (e.g., conservation organizations, government authorities, other developers), and development of joint management approaches over the landscape-scale.

Whatever adaptive management actions are chosen, they should be anticipated and defined, as much as possible, *in advance of operations*, preferably as part of the ESIA or management plans, rather than on an ad hoc basis during operations. Some WEF mitigation measures involve curtailment that may affect the project's energy output. Without advance consideration in the early stages of project development, this type of mitigation could take the developer by surprise. It is therefore recommended that, for all WEFs, *the project's energy yield assessment should precautionarily account for some level of curtailment for wildlife in case it is required during operations*. This practice is described in Hulka and Conzo (2021) and BID Invest and IFC (2019).[60] In some jurisdictions, turbine curtailment might be required; such is the case in certain districts in Germany (Fritze et al. 2019; KNE 2020).

Management actions should be site- and species-specific and informed by species ecology, spatial and temporal fatality, and activity patterns at the project site. Responses should also be proportional to exceeded thresholds and consider financial and potential regulatory implications. More than one mitigation option may be available to address the risk. As a general rule, the successive breaching of multiple thresholds should be matched by an increase in the measures to protect and promote the viability of PCFM target species.

When multiple WEFs are operating in the same geographical area and close to areas of high biodiversity value, developers are encouraged to collaborate to implement joint mitigation and monitoring measures. This will provide a wider understanding of impacts on PCFM target species and facilitate better informed adaptive management responses and may also result in cost savings.

Box 6.1 provides an illustrative list of mitigation measures to reduce collision risk associated with turbines and with collision and electrocution associated with WEF-associated OHLs. This is a topic extensively covered in other reference documents (e.g., Bennun et al. 2021; BID Invest and IFC 2019; Ledec, Rapp, and Aiello 2011; Rodrigues et al. 2015); readers are referred to these documents, which emphasize the importance of adhering to the mitigation hierarchy.

[60] See Box 6 (*Cuadro* 6) on page 62 of BID Invest and IFC (2019).

Box 6.1 Minimizing collision and electrocution risk through on-site mitigation

Turbine collision mitigation options — birds

- ***Shutdown on-demand:*** The most widely used method involves observers strategically located at vantage points around the WEF implementing shutdown of one or more turbines in response to birds approaching rotor blades. Turbines are restarted once observers determine that birds are no longer at risk (observer-led shutdown on-demand). Shutdowns of this type are typically short (<30 minutes). In some cases, radar is used to assist observers (radar-assisted shutdown on-demand). When WEFs are in areas of intense flight activity (e.g., bird migration corridors), shutdown protocols may allow for a larger proportion of the WEF turbines to be shut down for an extended period (several hours or more) when flight activity is observed or predicted to be particularly high. In addition to observer-initiated shutdown, some automated turbine shutdown systems focused on safeguarding larger bird species have been demonstrated to be effective and may be a good option in some circumstances. The most sophisticated of these systems combine imaging, artificial intelligence, and machine learning to detect target flying bird species and will automatically trigger a shutdown of turbines if a bird approaches within a threshold distance of turbine blades (see McClure et al. 2022).

- ***Livestock management measures*** are required when pastoralism is associated with the WEF site and when vultures or other large scavenging birds are associated with the area, because livestock have the potential to attract these birds, increasing collision risk. Management measures include collaborating with landowners, farmers, municipal authorities, and slaughterhouses to remove livestock carcasses from the WEF and its immediate surroundings; exclude livestock from certain areas during certain times of year; and ensure safe, rapid disposal of carcasses and other material that may attract birds.

- ***Turbine blade painting:*** Increasing the visibility of rotor blades by painting one blade black may reduce turbine collisions for some bird species (Hodos 2003). Blade painting as an effective collision mitigation measure is currently based on a single field study (May et al. 2020), and further research is needed to evaluate its efficacy more fully. At the time of writing, this option is recommended only as a supplementary measure to use in addition to shutdown on-demand.

Turbine collision mitigation options — bats

- ***Blade feathering and curtailment*** is a type of collision minimization measure used mainly for bats that is achieved by slowing or stopping blade rotation (blade feathering) or raising the operational cut-in speed of the turbine (often referred to as curtailment). Curtailment prevents the turbine blades from rotating during periods of low wind speed and high bat activity. Curtailment may be applied to one or more turbines and may be constant for some fixed period of time (blanket curtailment) or vary according to environmental factors and bat activity (smart curtailment). Automated systems designed to curtail turbines in relation to environmental factors and bat activity that are linked to the WEF's (SCADA) systems have also been developed (Hayes et al. 2019).

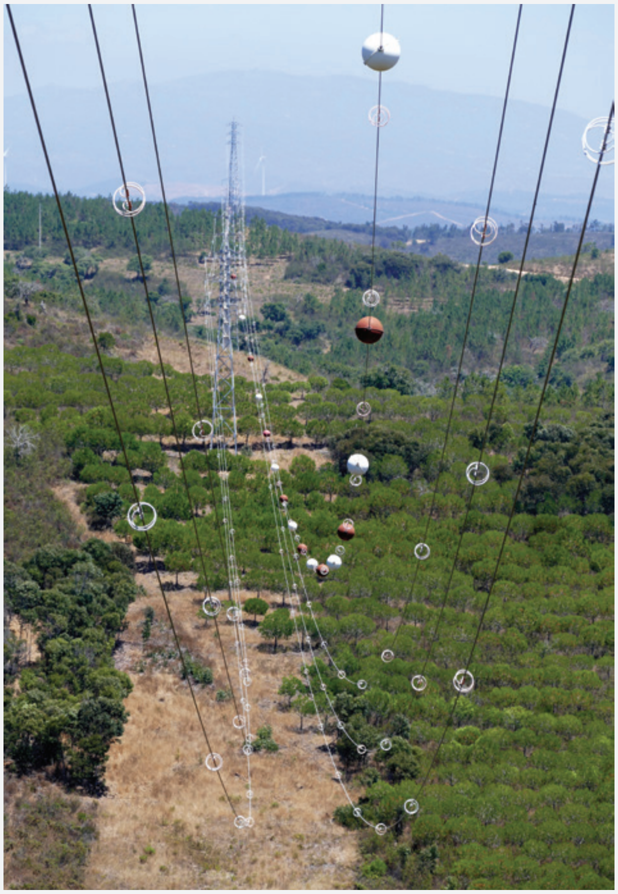
- ***Acoustic deterrents*** involve installation of devices on turbines to deter bats or birds from approaching by emitting noise (for bats, high-frequency sounds within the range of bat call frequencies).

Although acoustic deterrents may be effective for some bat species (e.g., Good et al. 2022; Weaver et al. 2020), evidence is limited, and deployment of this mitigation option is recommended only as a supplementary measure to feathering and curtailment.

OHL collision and electrocution mitigation options

> ***Bird-safe power poles*** can be used with medium-voltage distribution lines, which present a major electrocution hazard for birds, especially medium-sized and large birds, and large bats, such as fruit bats. When it is not possible to bury distribution lines because of geotechnical or other restrictions, bird-safe designs, such as ensuring adequate separation between energized components and between energized and grounded components such that a bird is not able to make simultaneous contact with these components, are essential. For more information, see APLIC (2012), Martín Martín and colleagues (2022), Prinsen and colleagues (2012), and RPS (2021).

> ***Bird flight diverters*** are designed to increase power line visibility for birds, reducing collision risk. This risk is typically highest on transmission lines, although collisions also occur on distribution lines. A variety of suspended and fixed diverters are available, such as spheres, spirals, and flappers. A risk assessment that considers site conditions, species at risk, power line design, and long-term maintenance requirements, among other things, should be conducted to inform the type installed and their spacing and positioning along the lines. Some bird flight diverters (spirals) can entrap birds, which should also be considered in the selection. For more information, see APLIC (2012), Martín Martín and colleagues (2022), Prinsen and colleagues (2012), and RPS (2021).



Multiple bird flight diverters installed on a transmission line. Algarve region, Portugal. Photo: Alvaro Camiña

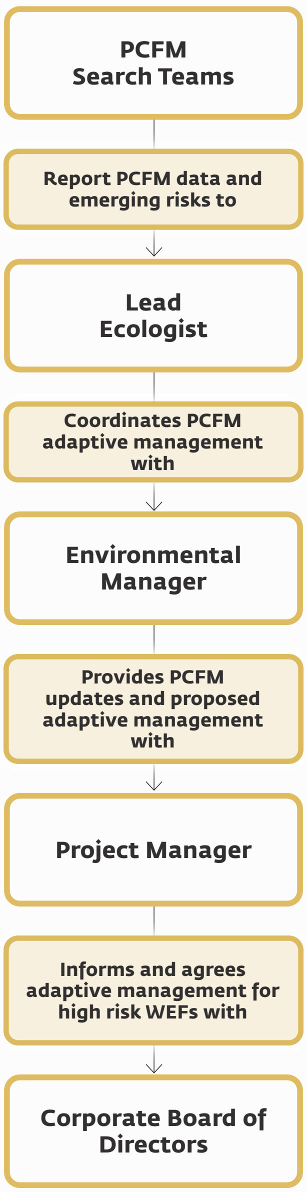
> ***Ultraviolet illumination*** of power lines involves projecting ultraviolet light along power lines to increase visibility and reduce collision risk. Although recent studies have demonstrated the effectiveness of this measure, especially for mitigating nocturnal collisions (see Baasch et al. 2022; Dwyer et al. 2019), further research is needed to confirm its effectiveness for a range of collision susceptible species and locations. At the time of writing, this option would be recommended as a supplementary measure to installing flight diverters.

6.4 ROLES, RESPONSIBILITIES, REPORTING, AND DISCLOSURE

The implementation of adaptive management should be understood at multiple levels of the wind energy company and is not limited to the LE and other teams managing environmental topics. The developer should establish who is responsible for communicating which types of information to whom—internally and externally. This section provides an overview of some of the main types of decisions that should be made at this stage of planning.

See Appendix B, "Implementing PCFM Fieldwork" for detailed information regarding responsibilities of the LE and search teams.

6.4.1 Roles and Responsibilities



A good adaptive management program should clearly state the responsibilities of the persons involved in, as well as those informing the adaptive management review process (see Section 6.1.1). Core roles and responsibilities involve the following persons:

- ***LE and PCFM search teams:*** Search teams should report PCFM data to the LE, who will check the quality of and collate this information weekly and monthly to inform routine and as-needed adaptive management review (see Section 6.1.2). In addition to monitoring fatalities, the LE and search teams should monitor for other types of risk events (see Section 6.2.3).

- ***LE and environmental manager:*** PCFM is one component of the WEF's broader environmental and social management program. The LE should coordinate PCFM adaptive management activities with the WEF's environmental manager as part of the broader Environmental and Social Management System.

- ***Environmental manager and project manager:*** Because mitigation may impact energy yield, the environmental manager must keep the WEF project manager updated about developments so that they can keep the operations teams informed. The operations team may need to be involved in adaptive management review meetings so that any technical or financial implications of proposed measures are fully understood and evaluated. The environmental manager would also be responsible for communicating pertinent adaptive management measures to project lenders.

- ***Project manager and corporate board:*** It is critical that adaptive management measures are well-understood by the WEF project manager. For high-risk WEFs, the corporate board of directors should be aware of and in agreement with adaptive management measures, as informed by PCFM results.

6.4.2 Reporting and Disclosure

Reporting and disclosure are relevant for internal and external purposes. Section 5.1.5 discusses internal reporting with respect to the PCFM data analysis. This section builds on that reporting with respect to roles and responsibilities in the context of adaptive management and illustrates an approach that may be taken.

6.4.2.1 Internal Reporting

WEEKLY

> ***PCFM field data*** provided by the search teams. Checked and collated by the Lead Ecologist

MONTHLY

> ***PCFM field data*** provided by the search teams. Checked and collated by the Lead Ecologist

6-MONTHLY/ANNUALLY

> ***Six-monthly PCFM reports*** (*or seasonal, as indicated in Section 6.1.2*). Produced by the LE, these will include summary PCFM results, GenEst fatality estimates, and data demonstrating the extent to which the PCFM achieved its planned objectives in terms of search effort, bias correction trials etc. The report will also highlight practical and technical problems arising during the monitoring period and recommended improvements to PCFM based on feedback from searchers and the LE. These reports will form the basis of the six-monthly or annual adaptive management review process and will be integrated into the broader environmental and social reporting by the environmental manager to the WEF project manager, lenders, and board of directors.

AS NEEDED

> ***Other reports.*** The LE may need to provide reports in addition to 6-monthly reports to ensure that specific regulatory and lender requirements are satisfied. For example, it is recommended that the developer establish a reporting and rapid adaptive management response protocol for extreme events, such as when *zero-fatality threshold* species are recorded as fatalities or when multiple thresholds are exceeded.

6.4.2.2 External Reporting and Informing Strategic Planning

External reporting and disclosure of PCFM results will depend on the regulatory, lender, and stakeholder context. Developers are encouraged to make PCFM data available to relevant stakeholders, especially for projects in areas with high risks for bird or bat populations, where data-sharing can inform assessment of cumulative population impacts. A common data-sharing and reporting mechanism would facilitate this process, and developers are encouraged to partner with relevant stakeholders. Establishment of a biodiversity technical advisory committee could also inform the project's mitigation strategy through routine review of PCFM results and adaptive management decisions.

At the regional and national levels, a PCFM data-sharing mechanism provides the possibility of conducting meta-analyses to help understand cumulative and population-level impacts to inform future project siting and facilitate strategic planning for the wind energy sector. Wide use of PCFM data can play an important role in directing regional and national policy. Importantly, it can also inform the safeguarding of bird and bat populations given the likely expansion of wind energy in emerging market countries and the presence of a large number of globally threatened, collision susceptible species in these areas.

Wind Energy Facility. Valencia region, Spain. Photo: Alvaro Camiña

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APPENDICES

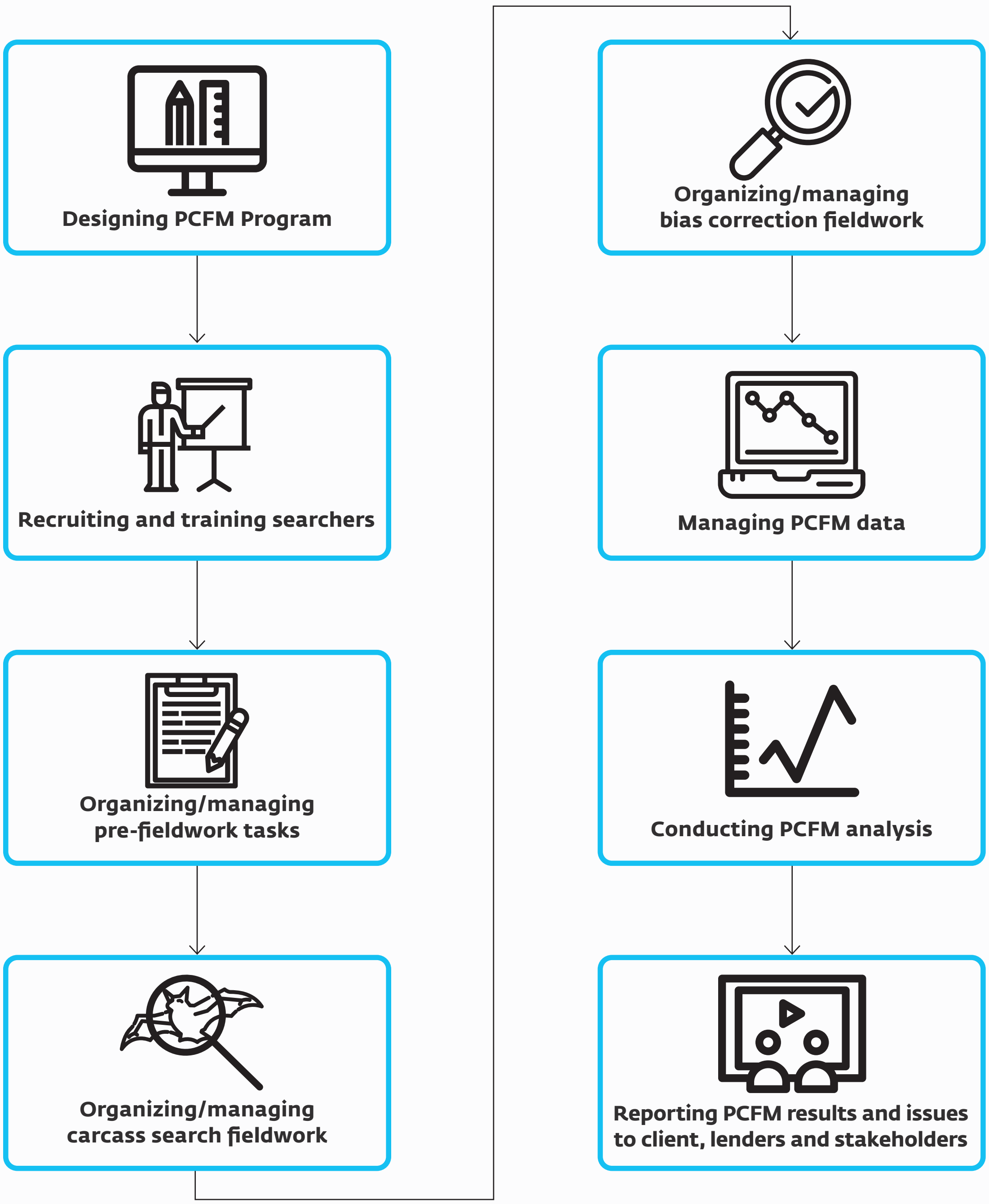
APPENDIX A: PCFM DECISION SUPPORT TOOL

The PCFM Decision Support Tool is provided as a standalone Excel spreadsheet: ***www.ifc.org/windbirdbatmonitoring***

APPENDIX B: IMPLEMENTING PCFM FIELDWORK

Implementing an effective post-construction fatality monitoring (PCFM) fieldwork program at a wind energy facility (WEF) requires an appropriate study design and a well-planned search program managed by an experienced Lead Ecologist (LE) and conducted by an appropriately trained search team. Appendix B provides the LE with practical advice to help organize and manage PCFM fieldwork and collect the high-quality data necessary for generating reliable fatality rate estimates. Figure B.1 summarizes the LE's main tasks during a PCFM program.

Figure B.1 Main tasks of the lead ecologist during a PCFM program



Roles and responsibilities of the Lead Ecologist and search team

To ensure that the PCFM program runs smoothly, it is important that the LE and the search team understand their own and each other's responsibilities. Table B.1 provides a list of the typical responsibilities

Table B.1 Typical responsibilities of the Lead Ecologist and field team of searchers

POSITION	RESPONSIBILITIES
LEAD ECOLOGIST	> **Design and implement PCFM programs** appropriate to the risk profile and stage of the project and informed by underlying PCFM principles (Section 3) and design guidance (see Section 4 and Decision Support Tool — Appendix A). > **Communicate and coordinate PCFM program work** with client and relevant WEF staff. > **Train PCFM search team** in field methods and data collection protocols. > **Organize, manage, and coordinate fieldwork** for PCFM searches, including: • **Preparing and distributing data collection forms,** communication plans, health and safety protocols, etc. • **Arranging appropriate, reliable transpor**t to allow searchers to move between search plots. • **Ensuring reliable communication** during fieldwork between searchers and between searchers and the LE. • **Managing and overseeing health and safety** of field teams and conducting necessary risk assessments. • **Arranging for storage of fatalities at the WEF,** typically in a freezer located within the WEF operation and maintenance buildings. > **Organize, manage, and coordinate fieldwork for bias correction trials, including:** • **Obtaining bias trial carcasses** and arranging for these to be stored at the WEF. Obtaining decoys if these are being used for searcher efficiency trials. • **Administering searcher efficiency and carcass persistence trials** or training and managing a trial administrator to do so.[a] > **Manage data and conduct and report PCFM analysis, including:** • **Conducting daily, monthly, and 6-monthly data quality reviews** to ensure accuracy and completeness. • **Collating all fieldwork data.** • **Conducting and reporting 6-monthly and annual data analysis,** including calculating density weighted proportion (DWP) and generating fatality rate estimates using GenEst software. • **Reporting findings and relevant concerns to client, lenders, and stakeholders** as appropriate.
SEARCH TEAM	> **Conduct fatality searches**. > **Participate in searcher efficiency trials.** > Monitor carcass persistence trials and record and upload associated data. > **Understand and comply with health and safety plans and risk assessments,** site rules, and personal protective equipment requirements. > **Record PCFM data** (fatality observations, searcher efficacy, carcass persistence observations). > **Identify fatalities and provide informative high-quality photographs of fatality incidents** that allow LE or other specialist to review species identification, condition, and general location of fatalities. > **Complete, submit, and store data collection forms** as required.
STATISTICIAN, (IF AVAILABLE)	> **Review sampling designs** and provide advice and guidance on alternative approaches if necessary. > **Help LE conduct report and interpret seasonal and annual data analysis using GenEst.**

[a] In searcher efficiency bias trials, the trial administrator is an individual (often the LE) who places trial carcasses or decoys in the search plot before a search day begins, and checks whether they are still present if searchers do not find them. The person administrating trials must not be a searcher involved in the trials.

Tasks to be completed by the Lead Ecologist before the start of PCFM fieldwork

Effectively implementing a PCFM program safely and efficiently requires considerable pre-fieldwork planning, and it is important that the LE has sufficient time and budget to complete these tasks before the start of a PCFM program. The sections below provide details of the tasks that the LE will need to complete before the start of fieldwork.

WEF biodiversity document review

To ensure that the PCFM program is part of a structured framework and able to fulfil the WEFs monitoring objectives the LE should check that the WEF has developed an adequate Biodiversity Management Plan. This should include numerically derived annual fatality rate thresholds for priority biodiversity values and an appropriate adaptive management mechanism to evaluate and manage project impacts identified through the results and analysis of PCFM data (see Section 6 for more information). The LE should have a good understanding of all aspects of this plan and how it relates to the PCFM program.

Permits, permissions and legal requirements

The LE should ensure that any legal requirements are fulfilled and that any national or sub-national permits required are obtained before the monitoring program starts. These may include requirements related to reporting of fatalities of nationally protected species and treatment of injured species.

The LE should obtain site maps; information on landowners, land users and land ownership; project site access information, and health and safety protocols from relevant WEF staff. The LE should be familiar with this information and be aware of any access or other constraints relevant to the PCFM program at the WEF and, where relevant, WEF-associated OHL.

Determining the turbine sample and the search plot size

Once the number, hub height and blade length of turbines at the WEF is known, the LE can input this information into the DST [User Interface— Project setup tab] to determine the number of turbines to sample and the full search plot size information for the PCFM program. For First Year designs entering this information will provide the number of sample turbines and when relevant, search plot size for full plot searches. For Subsequent Year designs the LE should additionally answer questions 2 to 5 in the Subsequent Years tab of the DST to determine the search plot size. Once the number of turbines to sample and plot size for full plot searches are determined, the LE can randomly select which turbines will be searched and organize a site visit to the WEF to map the unsearched areas and visibility classes at each.

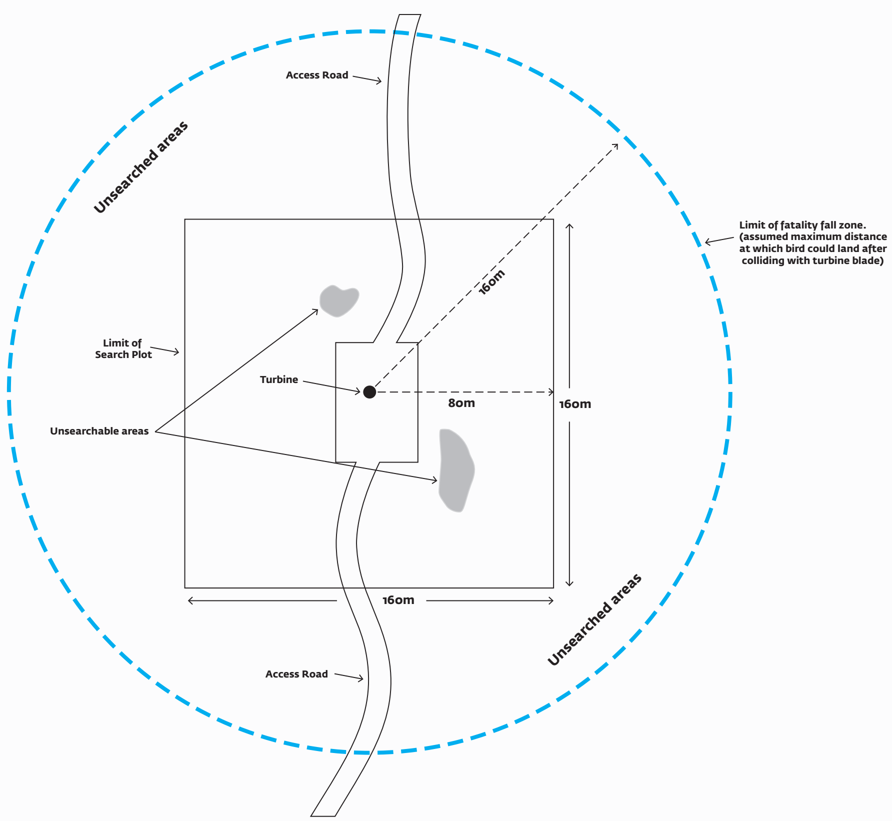
Site visit and mapping of unsearched areas and visibility classes

The LE should arrange to make one or more visits (as needed) to the WEF before the beginning of the PCFM program. Pre-fieldwork visits allow the LE to visit all areas where searchers will be working (e.g., sample turbines search plots, OHL segments and travel routes to and from search plots) and identify issues that might adversely affect the searches or search schedule and ensure that the PCFM program will comply with WEF health and safety requirements.

Additionally, the LE will use these visits to prepare maps of each sample turbine showing the extent of areas that will not be searched and the extent of different ground cover visibility classes.

Unsearched area mapping. To calculate unbiased fatality estimates requires the extent of the fatality fall zone that is unsearched to be quantified (see Section 3.3.7.1 for more information). There are two types of unsearched area: the area beyond the limit of the search plot out to the edge of the fall zone, and unsearchable areas within the search plot that cannot be searched because, for example, slopes are too steep, vegetation is too dense, or the ground surface is too rocky to walk over safely. To quantify the unsearchable areas within search plots the LE will need to visit each sample turbine and identify and map the extent of unsearched areas within the search plot. The LE should preview Appendix C to ensure they understand how these maps will be used. To accurately incorporate the unsearched area information into the fatality estimate, the LE will need to know the proportion of area not searched within each 5 m band around the turbines. Figure B.2 shows a sample turbine with unsearched areas mapped.

Figure B.2 Mapping unsearched areas at a sample turbine with a maximum blade tip of 160 m and a square search plot



Note: In this example the DST recommended a search plot radius of 80m which is used as a minimum distance when defining the square plot.

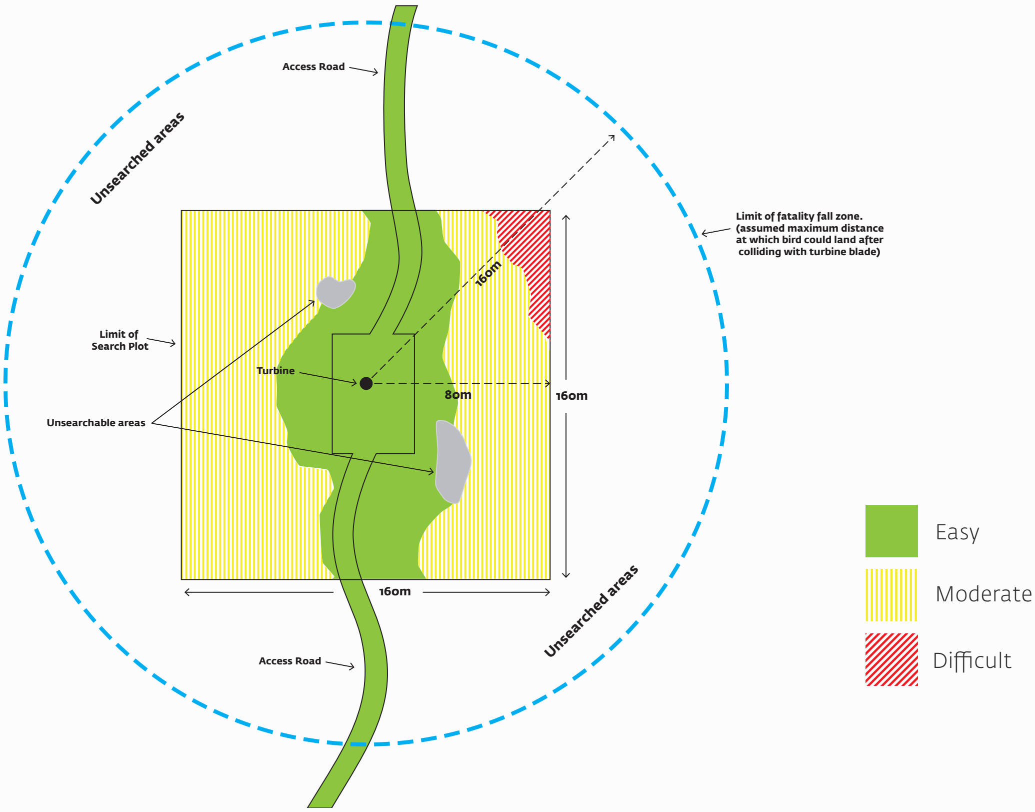
Visibility class mapping. On the same site visit (and as part of the unsearched area mapping activity) the LE should also map the visibility classes at each sample turbine. In this Handbook, visibility classes are principally used to inform responses to questions required by the DST when generating a First Year or Subsequent Years design (i.e., User Interface—First Year tab Question 6 and User Interface—Subsequent Years tab, Questions 7 and 8). For Year 1 designs the visibility mapping is used to assess whether the vegetation height off the RAP at sample turbines is low enough to permit effective searching. In some habitats (e.g., deserts) the answer to this question may seem clear without visibility mapping, however, as good practice it is recommended that this exercise is conducted to provide evidence-based DST input values. This is particularly important when developing a Subsequent Years design as the input will influence the transect width output in the recommended design.

The Subsequent Years tab (see below) defines four visibility classes which should be used as a guide to mapping visibility at sample turbines and then used to inform input into the DST (for First Year and Subsequent Years).

- **Easy:** Bare ground 90% or greater; all ground cover sparse and 15 cm or less in height (e.g., RAP area)
- **Moderate:** Bare ground 25% or greater; all ground cover 15 cm or less in height and mostly sparse
- **Difficult:** Bare ground 25% or less; 25% or less of ground cover over 30 cm in height
- **Very Difficult:** Little or no bare ground; more than 25% of ground cover over 30 cm in height

Figure B.3 illustrates visibility mapping at a sample turbine. As is typical for many PCFM search plots not all visibility classes are present. In this case, no area in the search plot fulfils the 'Very Difficult' criterion.

Figure B.3 Mapping three visibility classes at a sample turbine with a maximum blade tip of 160 m and a square search plot



When this mapping task is completed, the ground cover at sample turbines will be better understood and the LE will be able to answer all questions in the DST for either the First or Subsequent Years design and generate a full recommended PCFM design for the WEF.

Preparation for training the search team

The LE should make sure that fieldwork and safety protocols that will be required or relevant during PCFM monitoring are developed and ready for use before the search team training. These include the following:

- PCFM fieldwork method statement and search schedule
- Quality control protocol for daily checking of raw data for completeness and accuracy and specifying how errors will be corrected
- Attendance protocol for tracking when search team members are present on site (i.e. sign-in/sign-out system)
- Field-tested communication system and protocol, giving details of who is to be contacted for questions arising in the field and the method of communication (e.g., phone call, text, email)
- Handling and care of injured animals protocol

The LE should also print out sufficient copies of all data recording sheets and obtain all equipment necessary to conduct the training of the search team effectively and efficiently.

Determining the number of searchers needed

To determine the number of searchers needed for a PCFM program, the LE should first calculate the total number of days it will take for a single search of all the sample turbines at a particular PCFM project. This will be based on:

- **Total transect length to be searched** (across all search plots)
- **Time required to search transects**
- **Additional time required to carry out the following activities associated with conducting searches:**
  - Set up transects at each search plot
  - Travel between plots
  - Record fatalities
  - Check on-going carcass persistence trials

A hypothetical worked example provided in Tables B.2 to B.5 calculates the number of searchers required to conduct a single search of all sample turbines for a PCFM design with 20 sample turbines each with 160 m x 160 m search plots, a transect width of 10 m, and no unsearchable areas within the search plots. The worked example is provided to help the LE accurately calculate the number of searchers needed for their own PCFM program.

Calculating total length of transect to be searched.

To calculate the total length of the transect to be searched, the LE will need to obtain details of the **turbine sample**, **plot size and shape**, and **transect width** from the DST PCFM design output and the **size and shape of unsearched areas** within plots from maps of these areas created before the start of the PCFM program (see *Determining the sample and the search plot size* and *Site visit and mapping of unsearched areas and visibility classes* above for information on how the LE obtains these details).

Making a scale drawing of each sample search plot showing transects and unsearched areas may be helpful in calculating the total length of transect to be searched.

If the PCFM design has a sample search plot size and shape, transect width and unsearched areas that are the same for all sample plots:

> Follow the method in Table B.2 to calculate the total transect length to be searched for a single search of all sample turbines [final answer in Row 7 of Table B.2].

If sample search plot size and shape, transect width or unsearched areas differ between plots:

> Calculate sub-totals for each group of plots that have the same component values. (Use Table B2, rows 1-6 to calculate sub-totals for each group).

> Sum the subtotals to obtain the total sample length for the PCFM study.

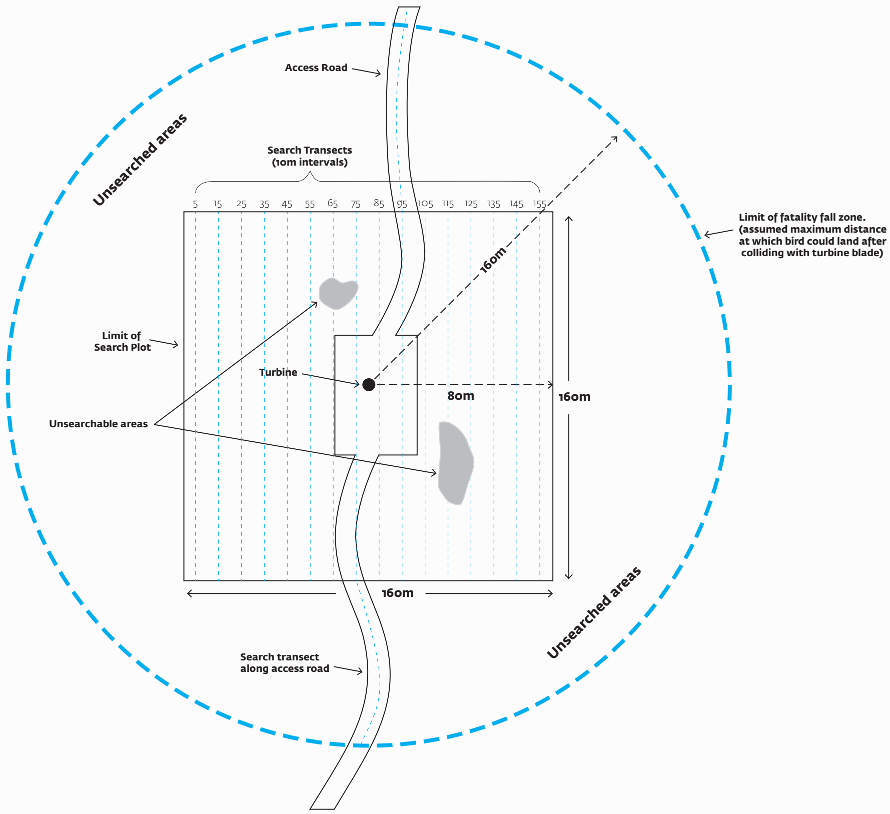
Table B.2 Calculating total transect length to be searched for a single search of all sample turbines

ROW	COMPONENT FOR CALCULATING TOTAL TRANSECT LENGTH	COMPONENT VALUE	EXPLANATORY NOTES
1	Number of sample turbines	20	See text above; this will be the number of sample turbines with the same component values
2	Search plot (m x m)	160 x 160	Square search plot extending to minimum of 80 m from the turbine base
3	Transect width (m)	10	10 m wide spacing between transects (searchers will search 5 m either side of transect)
4	Transect length (m)	150	Search plot length minus 5 m at either end of transect (160 m – (5 + 5 m) = 150 m[a]
5	Number of transects per plot	16	Transects at 5, 15, 25, 35, 45, 55, 65, 75, 85, 95, 105, 115, 125, 135, 145, and 155 m = 16 transects per search plot (see Figure B.4)
6	Total transect length per search plot (m)	2,400	Transect length [Row 4] x number of transects [Row 5]
7	Total transect length per search visit (m)	48,000	Number of sample turbines [Row 1] x transect length per search plot [Row 6]

Note: Worked example—20 sample turbines.

[a]. The worked example has no unsearched areas within any of the sample search plots, so none of the transects are shortened because of unsearched areas crossing the transect line. For search plots with unsearched areas, the transect length for each plot would need to be calculated separately.

Figure B.4 160 X 160 m turbine search plot with transects at 10 m intervals (see Table B2, Row 5)



Calculating time required to search transects

The time required to search transects will depend on ground conditions and height of vegetation and is best estimated by conducting a test transect search at the project or, if available, obtaining evidence from previous searches in similar conditions. This will provide the LE with a search rate that can be used to calculate the time required to search the total transect length for a single search of all sample turbines.

Table B.3 shows how to calculate the time required to search total transect length for a single search of all sample turbines by multiplying the total transect length calculated [Table B2, Row 7] by the search rate [Table B.3, Row 8].

Table B.3 Calculating time required to search total transect length for a single search of all sample turbines

ROW	COMPONENT FOR CALCULATING TIME REQUIRED TO SEARCH TOTAL TRANSECT LENGTH	COMPONENT VALUE	EXPLANATORY NOTES
8	Search rate along transect (pace at which searchers walk [m/s])	1.5	Based on field test or experience of previous bird fatality monitoring search in equivalent landscape
9	Total time to search total transect length per search visit (seconds)	72,000	[Table B.2, Row 7] x [Row 8]
10	Total time to search total transect length per search visit (hours)	20	Divide by 3,600 to convert seconds to hours

Note: Worked example—20 sample turbines.

Additional time required to carry out other activities associated with conducting searches

The LE should add on time needed for the following PCFM-related field activities to arrive at a realistic estimate of total searcher hours required.

- **Setting up transects within a plot:** Likely to be a standard length of time per search plot.
- **Recording fatalities:** Should be based on time needed to record a single fatality and an estimate of the average number of fatalities likely to be found during a single search of all sample turbines. For example, allowing 15 minutes to record a fatality and an estimated average of five fatalities during a single search of all sample turbines will require at least 75 minutes to be added to the overall time required for each search visit.
- **Travel between search plots:** Should be based on actual distance needed to travel between each turbine or power line search plot and take account of practical and landscape constraints and posted speed limits of public, WEF, or project-controlled roads.
- **Checking ongoing carcass persistence trial carcasses:** Should be a standard amount of time per carcass and should include travel time between carcasses if checks cannot be integrated with turbine searches.
- **Work breaks:** As prescribed in relevant protocols for searcher health and safety at the specific project site and to reduce searcher fatigue to maintain consistent detection rates.

Table B.4 shows how to calculate total time required for these additional activities for a single search of all sample turbines.

Table B.4 Calculating additional time required to carry out other activities associated with conducting searches for single search of all sample turbines

ROW	COMPONENT FOR CALCULATING ADDITIONAL TIME REQUIRED TO CONDUCT SEARCHES	COMPONENT VALUE	EXPLANATORY NOTES
11	Time to set up transects at search plots (minutes)	200	Based on 10 minutes per plot for 20 plots
12	Time to record fatalities (minutes)	75	Based on an average of 5 fatalities per search visit and 15 minutes per fatality to record
13	Time for searcher to move between plots (minutes)	285	Based on average of 15 minutes between finishing one plot and starting the next[a]
14	Time to check ongoing carcass trials (minutes)	100	Based on hypothetical estimate of 20 trials (per search visit) x 5 minutes per trial
15	Total additional time per search visit (minutes)	660	Sum of Rows 11 to 14
16	Total additional time per search visit (hours)	11	Divide by 60 to convert minutes to hours

Note: Worked example—20 sample turbines.

[a] For a project with 20 sample turbines the searcher will need to make 19 between-plot walks of 15 minutes each. Therefore the total time walking between plots is 19 x 15 = 285

Total time required for a single search visit to all sample turbines

As the final step, Table B.5 demonstrates how to calculate total time required for a single search visit to all sample turbines by summing total transect search time [Table B.3, Row 10] and additional time required [Table B.4, Row 16]

Table B.5 Calculating total time required for a single search visit to all sample turbines

ROW	COMPONENT FOR CALCULATING TOTAL TIME REQUIRED FOR SINGLE SEARCH VISIT TO ALL SAMPLE TURBINES	COMPONENT VALUE	EXPLANATORY NOTES
17	Total time required to conduct single search of all turbines (hours)	31	[Table B.3, Row 10] + [Table B.4, Row 16] = 20 + 11 =31
18	Total time required to conduct single search of all turbines (days rounded to nearest whole number)	5	Assuming 1 day = 6 hours of work time, allowing for breaks, divide Row 17 by 6 = 31/6 = 5.2

Note: Worked example—20 sample turbines.

Once the LE has calculated the total number of days required to make a single search of all sample turbines, the number of searchers required will depend on the search interval that the PCFM design requires.

Number of searchers required for PCFM designs with different search intervals

Using the five working days required to conduct a single search of all sample turbines calculated in the worked example [Table B.5, Row 18], Table B.6 shows how to calculate number of searchers required for different PCFM design search intervals.

Table B.6 Calculation of number of searchers for PCFM design requiring twice-weekly, weekly, and every-other-week search intervals

TOTAL DAYS REQUIRED FOR SINGLE SEARCH VISIT TO ALL SAMPLE TURBINES	PCFM SEARCH INTERVAL, DAYS	NUMBER OF SEARCHERS REQUIRED
7 [5 working days + 2 weekend days]	3.5	7 / 3.5 = 2 searchers
7 [5 working days + 2 weekend days]	7	7/7 = 1 searcher[a]
7 [5 working days + 2 weekend days]	14	7/14 = 0.5 searchers (equivalent to 1 searcher working part time)

Note: Worked example—20 sample turbines.

a. If a single searcher is conducting searches, the health and safety risks of working alone must be covered in the health and safety training and risk assessment. The WEF should establish a lone-worker protocol.

In addition to calculating how many searchers will be required to conduct the PCFM, the LE should make contingency plans to allow the program to continue when searchers are absent from work.

Recruiting and training the search team

The LE should train searchers in the necessary field and recording methods so that they can conduct PCFM but it is not essential that searchers are trained ecologists. The LE may contract searchers, or the WEF may employ them directly. To demonstrate independence, it is preferable for the LE to hire or contract the searchers directly but the most feasible option may be to make use of staff that the WEF already employs or arrange for the WEF to hire search team members from the local community. In both cases, the LE should be involved in selecting searchers and be provided with the resources to conduct adequate training. If WEF employees or local community members are employed as searchers, it is important that the LE provide the necessary support to the search team, including regular checks on implementation of field methods to ensure that searches are aligned with the PCFM design and are conducted to a high standard.

Training should be provided to all members of the field team of searchers in their principal working language and cover all relevant aspects of the PCFM program. Training should be conducted in a field situation, ideally at the WEF site, where the LE can demonstrate all aspects of PCFM to be practiced by search team members. Specifically, training should:

> Provide a summary of the field activities conducted during a PCFM program

This will include an overview of fatality searches and bias correction trials, with particular emphasis on roles and responsibilities of the fatality field team (see Table B.1 for roles and responsibilities).

> Explain all aspects of health and safety at the WEF

The LE should conduct a risk assessment with the searchers to highlight potential risks associated with their roles and responsibilities. Topics will include environmental risks, site-specific and activity related hazards, and where applicable working alone as a searcher. The LE will provide and explain the protocols and mitigation measures associated with these risks and ensure that appropriate good practice is adhered to throughout the program. As part of risk management, correct use of any personal protective equipment must be demonstrated to searchers. First aid training and fire training may be required at certain WEFs.

> Explain and demonstrate field skills required to conduct PCFM at turbines and along OHL

Training modules should explain and demonstrate good practice relevant to:

> **Transect searching.** Training should emphasize consistency of effort and how to optimize reliability and efficiency (e.g., marking locations of fatalities found during a search, recording data once the search of the turbine is complete). Training should demonstrate appropriate use of a Global Positioning System (GPS) device for recording locations of fatalities; identifying search plot boundaries; and taking informative, good quality photographs of fatalities.

> **Handling and care of injured animals and fatalities.** Training should follow protocols developed for the project, which should align with guidance provided in the *Handling and care of injured animals* and the *Field recording of fatalities* sections below.

> **Searcher efficiency trials.** Training should explain that the principal purpose of searcher efficiency trials is to test for fatalities that searchers missed during fatality searches. It should emphasize that a trial administrator (usually the LE) will place trial carcasses (without the searchers' knowledge) at locations where fatalities could land and will not purposefully "hide" carcasses. The training will also explain that searcher

efficiency trials will take place periodically during the PCFM program. If decoys will be used in trials instead of actual carcasses, this should be explained during the training.

> **Carcass persistence trials.** Training should explain the purpose of carcass persistence trials and provide clear protocols for confirming that a carcass has been removed and not just moved a short distance away (i.e., a careful search of a 10 m radius around the location where the carcass was deposited). There should also be standard criteria that searchers use to determine when a carcass is recorded as removed; two primary feathers connected, or 10 body feathers found within a 5 m x 5 m area (25 m^2) is recommended as minimum evidence that a trial carcass is still present. The same level of evidence should be used to determine whether a carcass is recorded as present during fatality searches.

> **Field data recording, including:**

- **Filling in data collection forms**[1]. The LE should discuss all input fields on every field data collection form (forms available in Appendices E-J) and set up mock searches and bias trials to give searchers practice filling out the various data collection forms under the LE's supervision. Common errors in data recording should be highlighted so that they can be avoided.

- **Photographing fatalities.** Emphasis should be on obtaining good quality, informative photographs adequate to identify a fatality. Carcasses should be photographed:
  - As found, taken from directly above
  - Turned over to show the ground-facing side
  - From different angles to show any features that may help with identification (e.g., head, wings, tail, feet, and additionally for bats, tragus (ear)
  - Showing any injuries
  - Showing the area immediately surrounding the fatality (e.g., relative to the nearest turbine, RAP, OHL)
  - All photographs should have a size reference in view (e.g., ruler).

- **Uploading and storing data.** The LE should demonstrate and give the searchers opportunity to practice (under supervision) how to store and upload data to a server or hard drive. Data should be stored and uploaded (and backed up) as frequently as possible (ideally once per day and no less than once per week).

Field and personal protective equipment

Having the correct equipment facilitates a high-quality PCFM study. A checklist for searchers of recommended essential and non-essential equipment is provided in Appendix K. Recommended personal protective equipment may include a hard hat, reflective vest, steel-toe capped boots, safety glasses, snake guards, full-length trousers, long-sleeved shirts, and sun hats, as directed by the developer and site-specific health and safety protocols. The LE should take direction from the WEF site manager on this topic.

[1] The LE should ensure that all data collection forms and instructions are available in a language that all members of the field team understand.

PCFM clearing searches

The first carcass search visit that the search team conducts (under the supervision of the LE) defines the beginning of the study period and is called the "clearing search," the purpose of which is to clear the search area of any bird or bat carcasses that might have been deposited before the study begins, so that a fatality estimate can be obtained for the study period only. Any new search plots used during the PCFM study (e.g., at the start of a new season, study year) should also be subject to a clearing search.

Bird and bat carcasses found during a clearing search should not be entered into the statistical analysis, but it is important that the search itself be documented and details on what was found recorded. The clearing search does not produce any data that are analyzed but rather serves to clear the search plots of old carcasses so that the fatality estimate is based on a period that starts immediately after the clearing search. These searches are also useful for detecting PCFM target species that may have been killed before the official start of the PCFM.

Any suitable fresh carcasses found during the clearing searches can be saved for searcher efficiency and carcass persistence trials if regulatory permits and project protocol allow (see Box 3.5 for carcass types that may and may not be used).

PRACTICAL ADVICE FOR CONDUCTING FATALITY SEARCHES

At the start of the PCFM program the LE will make sure that each search team member has all necessary data recording forms and equipment required to conduct PCFM monitoring. They will also provide a search schedule giving a daily plan of who will search each of the randomly selected turbines on each search visit. Throughout the PCFM program searchers should record the date when each turbine was searched and other details on the Search Summary Form (Appendix F).

During searches, all fatalities found during PCFM are recorded regardless of whether a First Year or a Subsequent Years design is being implemented and regardless of the PCFM target species. For example, a Subsequent Years design that is optimized for large birds with a relatively wide transect width and long search intervals will not be optimized for bats or smaller birds, but carcasses in these size classes will be found during searches and should always be recorded.

Maintaining data quality is critical for providing accurate input data for use in GenEst. To achieve this, the LE should conduct frequent checks of data completeness and accuracy. For example, after the first PCFM search, data collected should be reviewed to ensure that searchers understand the field methods and data collection forms. This should also provide an opportunity to address any questions about conducting searches and recording data that searchers may have. A minimum of one review each PCFM season is recommended.

Time of day to conduct PCFM searches

Searching at any time of day is generally acceptable, but when PCFM target species include bats, it is preferable for searches to begin early in the morning to reduce the probability of daytime scavengers removing carcasses before searchers detect them. From a searcher perspective, morning searches may also be preferable in summer because temperatures are cooler.

Changing the turbine search order so that the same turbines are not always searched at the same time of day is recommended.

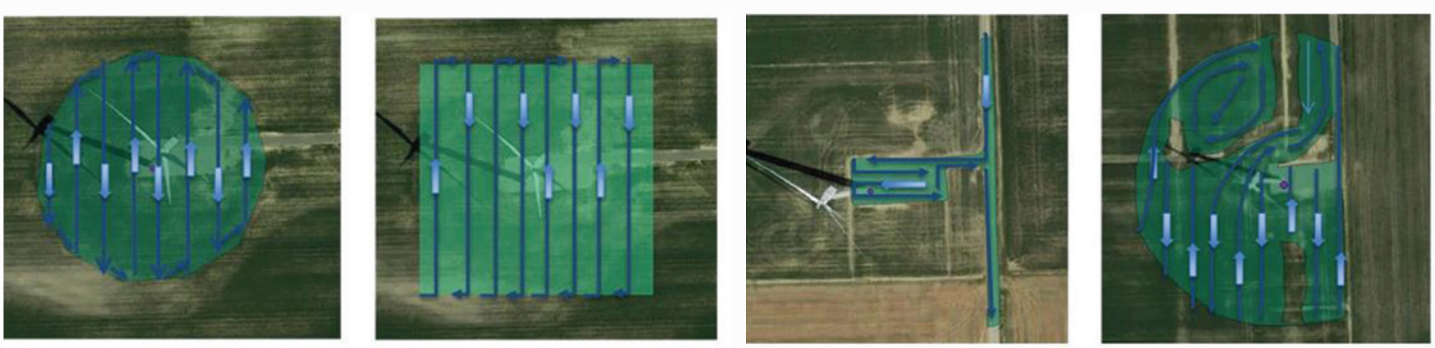
How to conduct PCFM searches

Walked turbine transect searches.

Searchers should systematically walk regularly spaced transects according to the transect width specified in the PCFM design. A searcher will walk in a direction (e.g., north) along a transect until they reach the end, walk along the edge of a plot to the beginning of the next transect and walk the opposite direction (e.g., south). While walking, the searcher scans for fatalities in the area on both sides of the transect out to half the transect width. Searchers should walk the transect lines at a rate of approximately 45 to 60 m per minute (approximately 15 steps per 10 seconds). Once the searcher has walked all transects in this manner, they have searched the entire plot area. For RAP plots, the searcher will walk transects at the same width and rate, focused on the cleared dirt surfaces making up the RAP and not the surrounding land. Examples of walked transects across different plot types are shown (not to scale) in Figure B.5. If searchers have GPS devices, they should keep the track function on while operating the device so transect walk accuracy can be checked and corrective action taken if needed. An example of good tracks downloaded from a GPS device are provided in Figure B.6

It is important that the searcher is not focused on the GPS (so that they do not miss finding fatalities). Instead, the GPS should be switched on and in tracking mode and placed in their pocket or bag to be looked at only occasionally to make sure they are following the correct route.

Figure B.5 Different plot types and examples of ways to search them (Not to scale)



Note: Transect width depends on DST output. Irregular shapes (such as the example on the far right) can be searched in different ways depending on obstacles in the way as long as the transect width is maintained and there is no overlapping.

Figure B.6 Transect tracks downloaded from a GPS device

Walked OHL transect searches

The OHL sample search plots may require search teams to walk transects that extend over one or more kilometers and end a substantial distance away from their starting point.

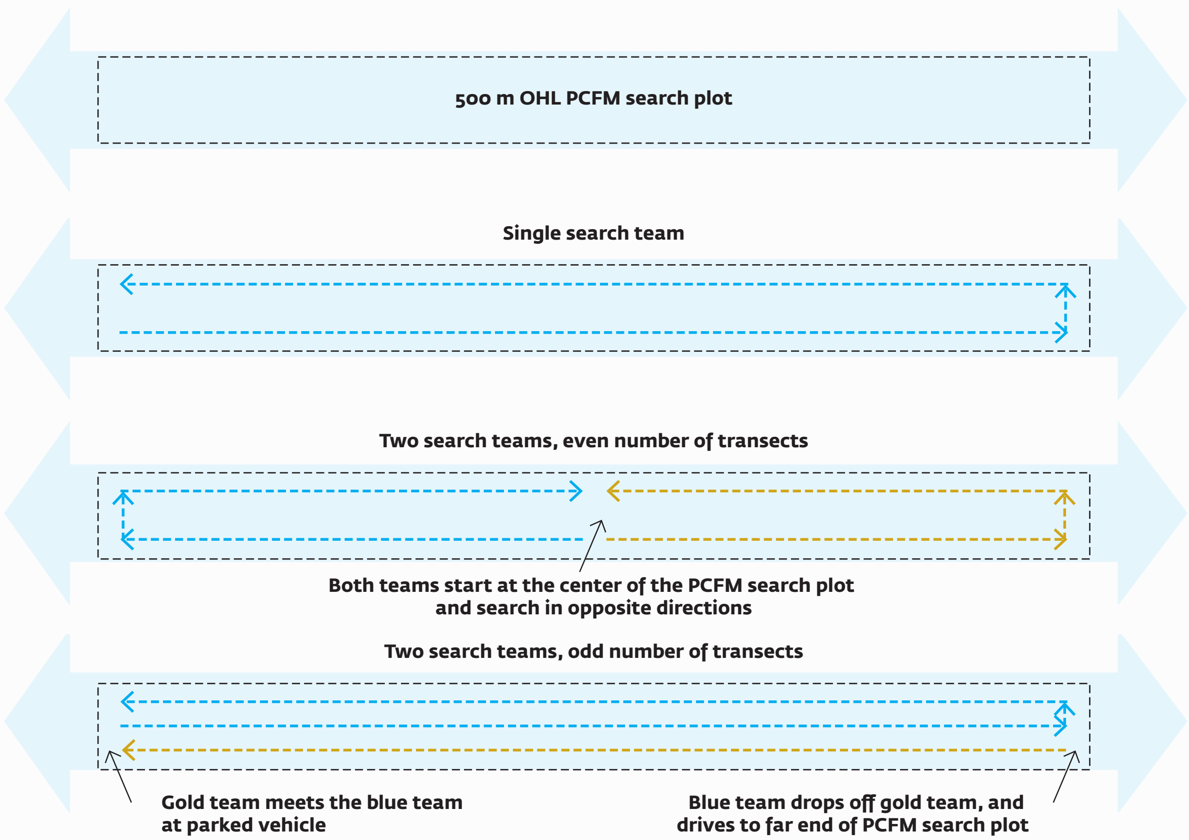
The following transect walk strategies are recommended to minimize the distance that searchers need to walk when conducting PCFM searches along transects within an OHL search plot:

> If **a single field team is using one vehicle** for dropping off and picking up searchers, it is preferable to use a PCFM design that has an even number of transects so that the searchers start and finish their search at the same location (see *Single search team* in Figure B.7).

> If **two field teams are using one vehicle** for dropping off and picking up searchers, there can be an even or odd number of transects.

- If **the PCFM design requires an even number of transect**s, the vehicle remains in the center of the search plot, and searchers walk transects away from the vehicle in both directions (see *Two search teams; even number of transects* in Figure B.7).
- If **the PCFM design requires an odd number of transects**, the vehicle drops one search team at one end of the search plot and then drives the vehicle to the other end before conducting their transect search walk. (see *Two search teams; even number of transects* in Figure B.7).

Figure B.7 Recommended walking routes in PCFM search plots along OHL



Fatalities found along OHL search transects should be recorded, processed, and collected when found and not flagged and returned to later, which may be impractical.

Scanning searches

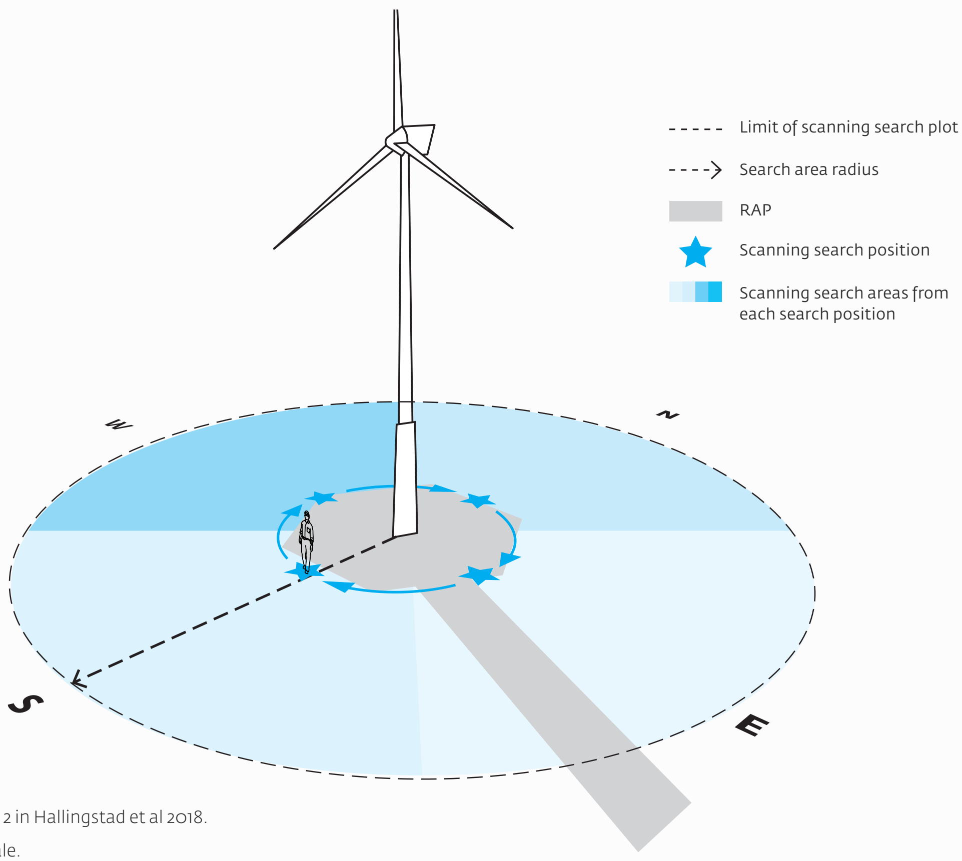
As described in Section 3.3.5 of the Handbook, a visual scanning search is an alternative method of searching for large bird fatalities over large areas. The scanning search is identical to the transect-based search component, with four important exceptions:

- The method is only used for large birds, because small bird and bat carcasses are difficult to detect from a distance.
- Searches are conducted by visually scanning the scan search area from specified observation points rather than by walking transects.
- Unsearchable area bias correction should account for visually unscannable areas (areas that are visually obstructed).
- Searcher efficiency trials require different methods.

Importantly, no turbine should have both a transect-based and a scanning search because the analysis becomes more complicated when both search types are used at one turbine, although it would be acceptable to have transect-based searches at some turbines and scanning searches at other turbines in the same WEF. Given these additional complexities, only an advanced PCFM practitioner should use the scanning search method and with the assistance of a statistician.

Search Method. Scanning searches are conducted by positioning the searcher at a series of points (usually four — one in each cardinal direction) along the periphery of the turbine pad. From each point searchers use binoculars to scan a sector of the ground around the turbine out to a pre-defined distance, usually maximum blade tip height (Figure B.8 illustrates the scanning search method). Any carcasses observed during a scanning search are recorded and documented following the same procedures used in transect-based searches.

Figure B.8 Diagram of typical scanning search



Source: Based on Figure. 2 in Hallingstad et al 2018.

Note: Image is not to scale.

Unscanned areas. Similar to transect-based search plots, scanning search plots must be delineated individually in the field to exclude areas that are unsearchable (unscannable) using this method, because vegetation or topographic relief blocks the view. This information is used to calculate the unsearchable (unscannable) area bias correction factor which is incorporated into the estimation of total large bird fatality.

Scanning search searcher efficiency trials. The design of searcher efficiency trials for a scanning search is slightly different from the design of searcher efficiency trials for transect-based searches because the carcasses are placed in a different spatial pattern. Unlike transect-based searches, in which trial carcasses are placed at random locations in the search plot, for a scanning search, trial carcasses are placed at varying distances from the turbine according to the expected collision fall distribution of large bird fatalities. Appendix D of this Handbook includes a

Searcher Efficiency Trial Placement Tool that guides placement of trial carcasses by generating random distances appropriate for this method.

For a given sample size of scanning searcher efficiency trials (e.g., 20 per season is an acceptable sample size; 15 is a minimum), the search plots where the trial carcasses should be placed should be randomly selected, and the Searcher Efficiency Trial Placement Tool (Appendix D) should be used to generate a random compass bearing (direction) from the turbine and a random distance for each carcass. If the random compass bearing and distance indicate a point that is unsearchable, the trial administrator should skip that point and choose another. The random distance can be as low as zero but should not be further than the maximum radius of the scanning search plot (to ensure that all trial carcasses are placed within the searched area). The LE should ensure that there are no more than two (ideally no more than one) searcher efficiency trial carcasses placed at a time at any one turbine for a scanning search. As with traditional searcher efficiency trials, the LE should track the number of trial carcasses found versus those available. The resulting data will be compatible with GenEst (see Section 5) for fatality estimation, and data can be formatted and processed as usual. Similar to ordinary search plots, an unsearched area correction is required (referred to as the density weighted proportion [DWP] of the area searched) to account for carcasses falling in the area beyond the search plot extent for the scanning searches (usually 100–120 m from the turbine base; see Section 3.3.7.1 for more information on the unsearched area, Box 3.4 for principles relating to DWP, and Appendix D for the DWP tool used to calculate DWP).

Handling and care of injured animals

Birds and bats found injured but still alive should be handled by experienced individuals who are trained in animal rehabilitation, vaccinated against rabies and tetanus, and authorized by regulatory permits or according to specific national legislation and project-specific protocols for handling injured animals. Once captured, the animal must be taken to the nearest animal rehabilitation or veterinary center. If none of the searchers are experienced handlers, the LE should assist (if they are experienced handlers and are nearby). If no one qualified or experienced in animal handling is available, or if care and rehabilitation is not feasible, leaving the injured animal undisturbed is recommended. All injured animals should be treated with care and compassion, and any action taken should be aligned with national and local animal welfare protocols and regulations and relevant cultural heritage values. Searchers should record as much information as possible about injured animals without putting themselves at risk of injury or stressing the animal further.

Field recording of fatalities found during searches

If a fatality is found, searchers should mark the location with a colored marker or flag (for ease of finding it later) and continue to complete the walked transects. Once the transects for that plot are complete, the searchers should return to each carcass found and record the details. Specifically, the searcher should:

> **Mark the fatality location** using a GPS device.

> **Take photographs** (see *Recruiting and training the search teams* above for details on how photographs should be taken).

> **Complete the Fatality Record form** (Appendix E).

- **If authorized, recover the fatality** (Pick up the fatality, using leather or nitrile gloves and put it in a clear, sealable, labelled plastic bag. Fill out a Carcass Freezer Tag (Appendix I) and place the tag in the plastic bag with the fatality).

Labels for the outside of the plastic bag can be masking tape stuck on the outside of the bag and written with a pencil or permanent marker pen, or carcasses can be double bagged, using clear plastic bags, with an additional Carcass Freezer Tag put inside the outer bag. It is advisable that labels are clearly visible without having to take the fatality out of the bag. Keep all fatalities cool to prevent them from rotting. Smaller birds and bats can be kept in a cooler box until the end of the search day, when they should be deposited in a freezer designated for this purpose in the WEF complex. Keeping larger bird fatalities cool (e.g., vultures, cranes, eagles) is more challenging, and searchers may need to go to the freezer more than once on days when large birds are found. Using a Freezer Contents Log is advisable to keep track of fatalities placed in the freezer (Appendix J). Fatalities should be stored in a separate part of the freezer to surrogates used in bias correction trials, so all fatalities found during the PCFM study are easily located if further analysis is required. If searchers are not able to store the fatality, as much information as possible must be recorded at the turbine search plot. In addition to completing all required information on the Fatality Record Form, the searcher should consider providing additional photographs that may help identify the species. When PCFM target species include bird scavengers (e.g., vultures), carcasses should be removed from areas around turbines to avoid potentially attracting these species into high-risk areas.

PRACTICAL ADVICE FOR CONDUCTING SEARCHER EFFICIENCY BIAS CORRECTION TRIALS

To assist with the design of the PCFM program, the DST output recommends the number of searcher efficiency trial carcasses (per size class) that should be used (Appendix A). The following sections provide practical advice on conducting searcher efficiency trials recommended by the DST.

When and where to place searcher efficiency trial carcasses

Searcher efficiency trials should take place in each season and be conducted during scheduled fatality searches. Trial carcasses and decoys should be placed randomly[2] (using the Searcher Efficiency Trial Placement Tool in Appendix D), with no more than two trials conducted at any one turbine to reduce the probability of attracting scavengers to particular locations. If scavenging birds (e.g., vultures) are among PCFM target species at a WEF and carcasses rather than decoys are used in bias trials, random locations close to turbines should not be used because this might attract these species to the turbine collision risk zone. Using the Searcher Efficiency Trial Placement Tool will usually ensure that all visibility classes are properly represented.

[2] Randomly means that trial carcasses are placed i) at turbines selected randomly from those that are being searched and ii) at a random distance and compass direction (bearing) from the turbine base (but ensuring that each trial location is in a searchable portion of the plot). The Searcher Efficiency Placement Tool provides random distance and compass directions (bearings) for trial carcass placement.

Searcher efficiency trial carcasses, surrogates, and decoys

Depending on availability, searcher efficiency trials can use actual bird or bat carcasses found on site; surrogates such as ducks, geese, pigeons, and quail for birds; and dark-colored mice for bats. Artificial decoys can also be used, such as hunting bird decoys, bird toys, or rubber toy bats, but it is critical that these decoys and surrogates look reasonably similar to the carcasses expected on the site; brightly colored toys are not appropriate. Importantly, surrogates used in searcher efficiency trials are not always appropriate for use in carcass persistence trials (see *Practical advice for conducting bias correction carcass persistence trials — Carcass persistence trial carcasses and surrogates* below). If surrogates or decoys are not available, the LE could reach out to regulators or other stakeholders for advice regarding possible alternatives (see Section 3.3.7.2, Box 3.5 for more information on carcasses for searcher efficiency trials, and potential alternative approaches).

How to conduct searcher efficiency trials

The LE (or designated trial administrator not involved in the searches) should place trials earlier in the morning before normal searches commence. It is essential that searchers are unaware of the timing and location of searcher efficiency trials so that an estimate of typical searcher efficiency can be obtained.

Each trial carcass should be discreetly marked[3] (so that it can be distinguished from actual fatalities) and dropped from waist height rather than being placed directly on the ground and its location recorded using a GPS device. The objective is not to hide carcasses.

Searchers will detect or fail to detect trial carcasses and report results to the trial administrator. At the end of the searches for that day, the trial administrator will check the locations of any trials that searchers did not find to determine whether they were removed (and thus not available to be found) before the search. Any undetected carcasses that the trial administrator cannot retrieve are considered "unavailable" and will not be counted in the data set. In most cases, searchers are allowed a single opportunity to detect searcher efficiency trial carcasses.[4] Searcher efficiency is estimated based on the number of trial carcass/decoys found compared with the number that were 'available' to be found.

Field recording of searcher efficiency trial carcasses

Searchers should record found trial carcasses in the same way as for actual fatalities. The locations of all trial carcasses detected should be reported to the LE (or a designated trial administrator). All information related to the searcher efficiency trial should be recorded on a Searcher Efficiency Trial data collection form (Appendix G).

[3] Markings should be discrete but unmistakable, such as with a small length of electrical tape around a foot or clipped flight feathers.

[4] If the searcher efficiency bias trial design allows multiple opportunities to detect trial carcasses so that GenEst can estimate *k*, the trial administrator must check that the trials are still 'available' to be found after each search attempt. See the GenEst user guide for more details.

PRACTICAL ADVICE FOR CONDUCTING CARCASS PERSISTENCE BIAS CORRECTION TRIALS

When and where to place carcass persistence trial carcasses

Scavengers may be more active during certain periods of the year or may respond to seasonal increases in the presence of carcasses in the landscape. Carcass persistence trials should therefore take place during each season throughout the PCFM program to ensure that seasonal differences in carcass persistence are accounted for in fatality estimates. Trial carcasses should be placed randomly in search plots or similar habitat at the WEF. Randomly placed trial carcasses should provide carcass persistence information that is broadly representative of the habitat within the WEF. No more than two carcasses should be placed near any one turbine to reduce the probability of the scavenging rate being biased high because carcasses in close proximity were more easily detected. When scavenging birds (especially scavenging raptors) are among the PCFM target species, trial carcasses should be placed some distance from turbines to avoid attracting them into high-risk areas.

Carcass persistence trial carcasses and surrogates

Carcass persistence trials should use fresh carcasses or thawed carcasses that were frozen when fresh and stored frozen until use.[5] Actual collision and electrocution fatalities should be used in carcass persistence trials where available and feasible. When actual fatalities are not available, suitable surrogates may be used.

Game birds and domestic poultry have the potential to be scavenged more quickly than wild birds and bats, resulting in fatality estimates that may be biased high. This is likely to be particularly pronounced for birds of prey (raptors) and for large species (e.g., cranes, storks) that are difficult for scavengers to remove. **Only raptors and equivalent-sized large species surrogates should be used to test persistence for these groups.** If raptor surrogates are not available, it may be possible to obtain an appropriate raptor persistence rate from published literature and use it in the fatality rate analysis until a sample of raptor carcasses can be sourced and a persistence trial conducted (see Section 3.3.7.2, Box 3.5 for more information on carcasses for searcher efficiency trials and potential alternative approaches).

How to conduct carcass persistence trials

To determine how long a bird (small, medium, large) or bat persists on the ground, fresh and intact carcasses (or carcasses that were frozen when fresh and stored in a freezer until needed[6]) are monitored periodically over the course of several weeks or until they are removed. Trial carcasses should be discreetly marked so that they can be distinguished from actual fatalities and dropped from waist height rather than being placed directly on the ground

[5] Under no circumstances should carcass surrogates for any type of bias trials be acquired by killing individuals from wild populations of animals. If insufficient carcasses are available to conduct carcass persistence or searcher efficiency field trials the LE should follow advice provided in Section 3.3.7.2, Box 3.5.

[6] Frozen carcasses should be allowed to defrost before being used in carcass persistence trials.

and their location recorded using a GPS device. Each trial should be checked frequently during the first week after placement and then less frequently. The LE should allow time in the searchers' daily routine to check carcass persistence trial carcasses according to the following schedule — Day 1, 2, 3, 4, 7, 14, 21, and 30 (and sometimes longer for raptors) after placing them.

If appropriate, unfound carcasses used for searcher efficiency trials can be left out as carcass persistence trials, but if artificial decoys were used or if most of the searcher efficiency carcasses were found, a stand-alone carcass persistence trial should be conducted.

Field recording of carcass persistence trial carcasses

The date and time the carcass was placed and the date and time it was checked should be recorded. All information regarding the carcass persistence trial should be recorded on a Carcass Persistence Trial Form (Appendix H). The visit on which a trial carcass was last recorded as present and the first visit it was recorded as absent are used to calculate the carcass persistence rate in GenEst. Recording the time of each trial visit as precisely as possible (date and time of day) will increase the precision of the carcass persistence estimates. In addition to contributing to the fatality estimate analysis, carcass persistence trials should be used to inform adjustments to the fatality search schedule in subsequent seasons.

LOGISTICS AND EQUIPMENT REQUIREMENTS

Vehicles

At least one reliable vehicle is needed for a successful PCFM study. (More may be needed depending on the number of searchers and size of the WEF.) The LE or developer may rent vehicles or reach an agreement with searchers to use their own. The LE should consider the need for high-clearance or four-wheel-drive vehicles and arrange for these to be available if needed and should ensure that there are enough licensed drivers to operate the number of vehicles required.

Site accommodation

Searchers may travel to the WEF daily if they live nearby, but if they live too far away to travel daily, closer accommodation should be arranged.

Freezer

Before fatality searches are initiated, a large freezer should be purchased and its location in the WEF operations and maintenance buildings should be agreed upon with WEF management. The freezer should be big enough to store trial carcasses and turbine- and WEF-associated OHL fatalities separately.

APPENDIX C: GENERALIZED ESTIMATOR OF MORTALITY — WORKED EXAMPLE

This appendix demonstrates the use of the Generalized Estimator of Mortality (GenEst) graphical user interface by analyzing a data set that is included with the GenEst software[1]. Screen shots from the graphical user interface (Figures C.1 – C.24) are included throughout this worked example to help users follow along. Numbered dots are used to cross reference text to relevant places in the figures.

Step-by-step illustrated instructions are provided below that will help the user:

> Install the program

> Input a data set for each of the five data types

> Run and understand the outputs from each analysis

> Understand the final fatality estimate output

HOW TO INSTALL GenEst

GenEst is a free add-on package for the free statistical software R. The GenEst user manual (Simonis et al. 2018) describes how to install the GenEst analysis software. It is important to keep up to date with the latest versions of GenEst and R. (Screen captures are from GenEst Version 1.4.8.)

The following provides an example using a data set that is available in the GenEst application and package. To launch the GenEst software, the user must use a web browser and navigate to ***https://connect.west-inc.com/GenEst/*** or install the free statistical programming software R and the GenEst R package on their computer. The steps are as follows:

> Install R following the instructions on the R Project website (https://www.r-project.org/).

> Install the GenEst R package by opening R and typing `install.packages("GenEst", dependencies = TRUE)` in the console and hitting enter.

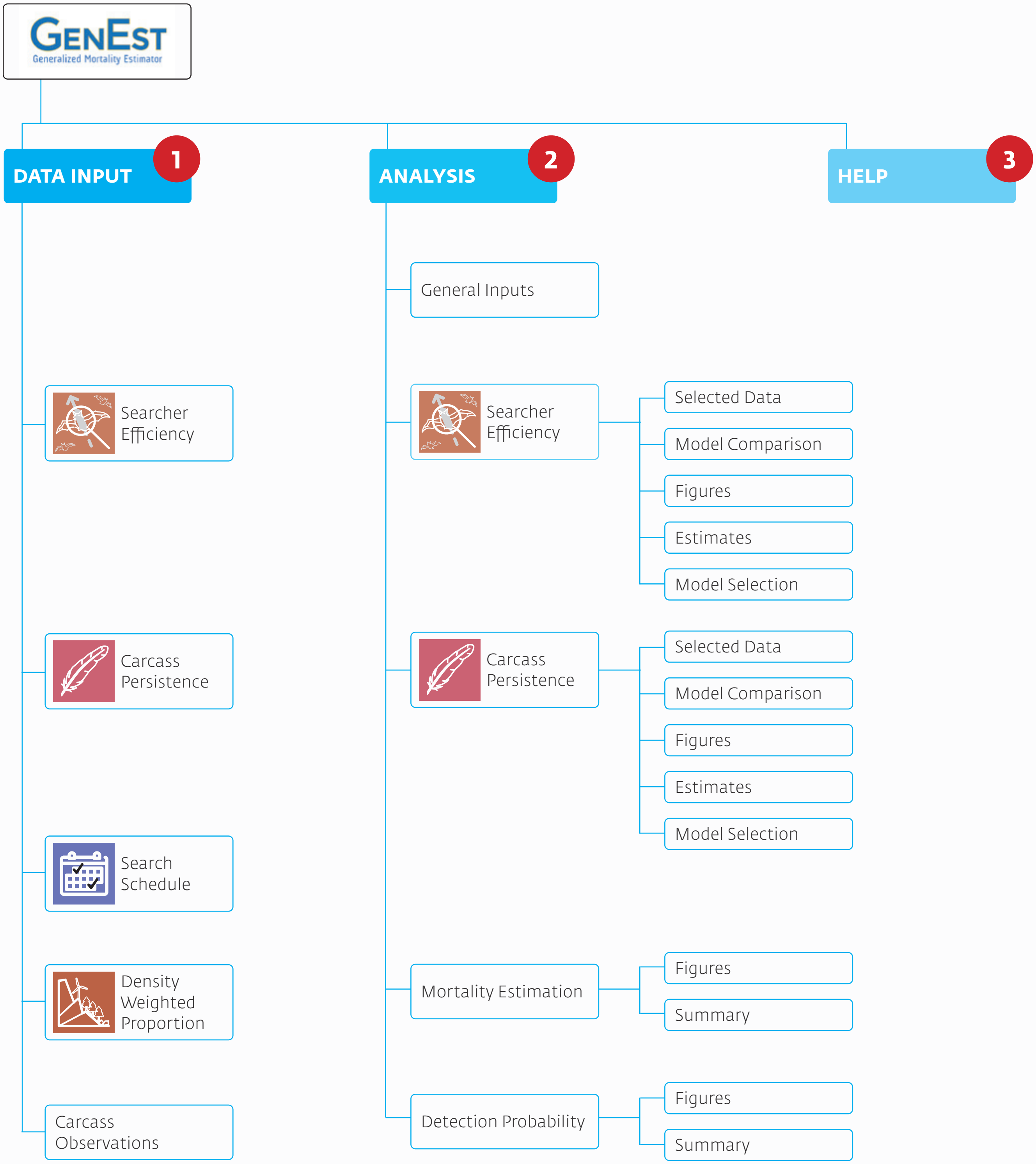
> Once the package is installed, launch GenEst typing `library(GenEst)` and then `runGenEst()` on the line below.

Navigating GenEst

Figure C.1 illustrates the headings of various pages and tabs found in the GenEst software. The three main heading tabs — Data Input 1, Analysis 2, and Help 3 — will always be visible at the top of the page. These lead to all of the subheading tabs. The worked example will include numbered dots (as above) to cross-reference text to the figures.

[1] For users familiar with R, GenEst can also be used from the command line. For more information on implementing R using the command line, open R and type `browseVignettes("GenEst")` into the R console.

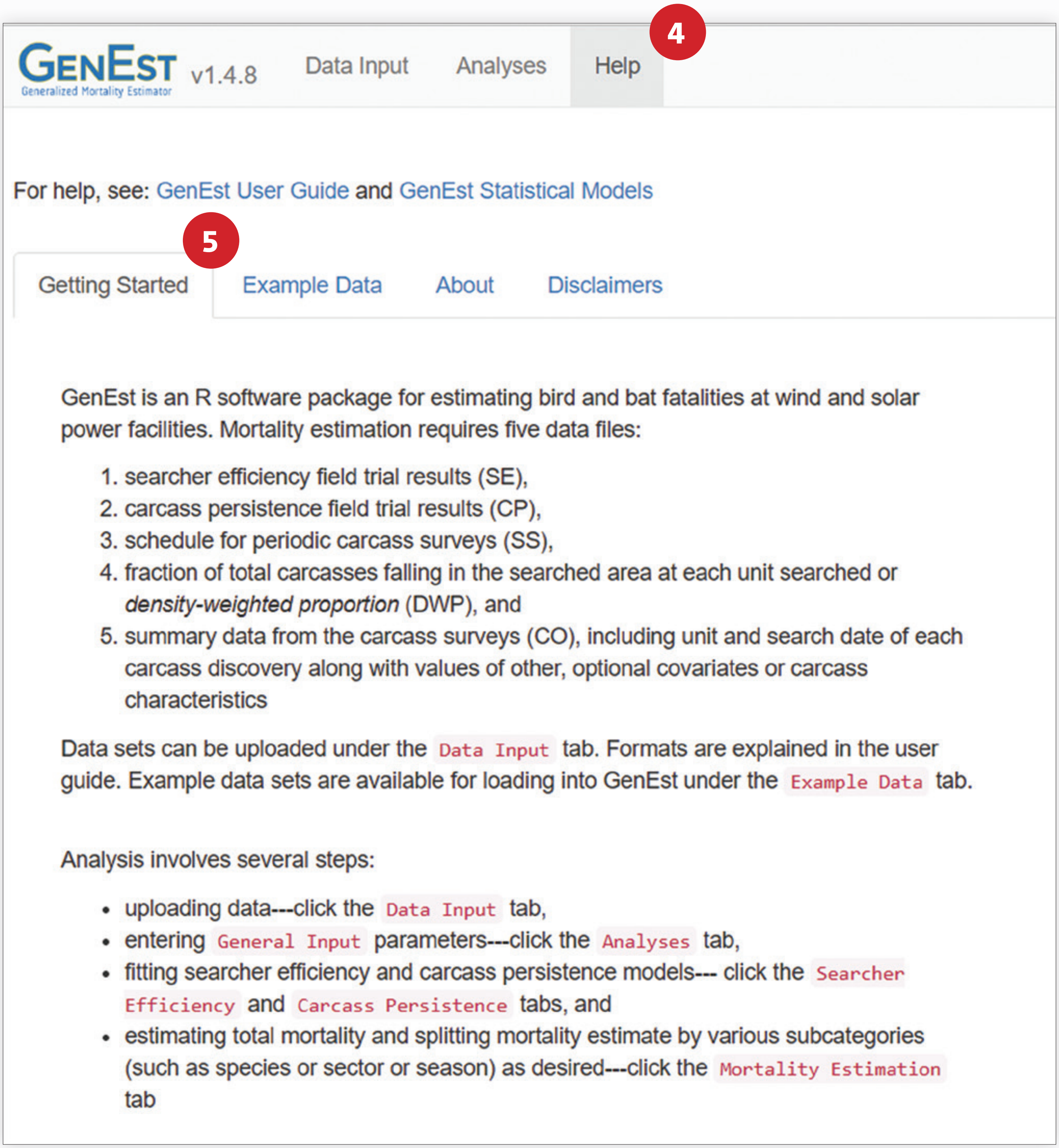
Figure C.1 Flow chart showing tab headings in GenEst software



GenEst Home Screen

When GenEst is first opened, the home screen (Figure C.2) will be displayed. It opens on the main Help tab 4 and Getting Started sub-tab 5. The text here provides a useful introduction.

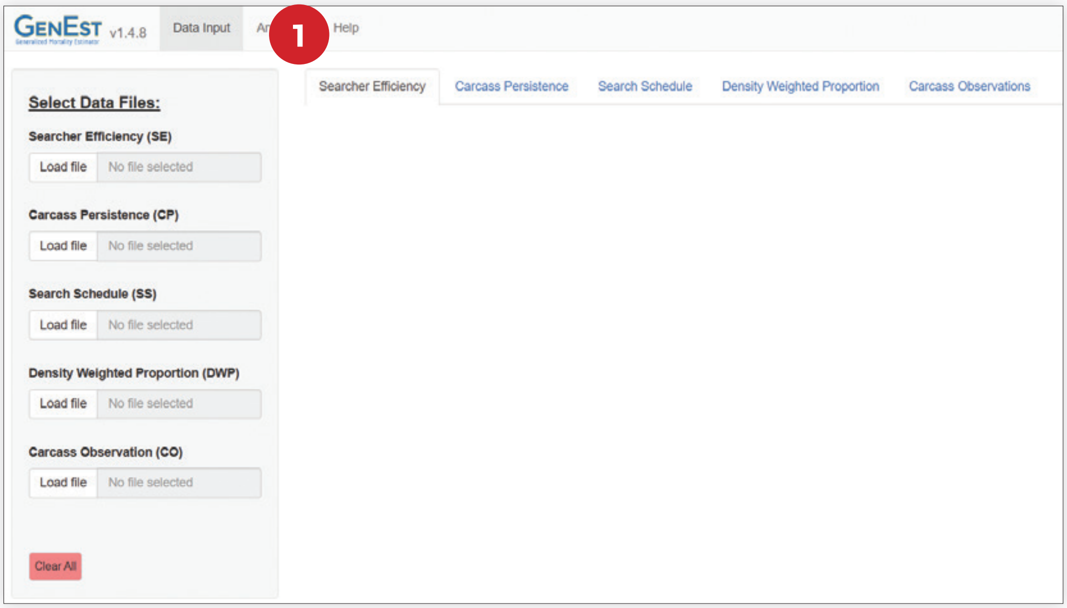
Figure C.2 Screenshot of GenEst software home page.



PREPARING AND INPUTTING DATA INTO GENEST—THE FIVE DATA FILES

The first step in conducting a GenEst analysis is to load all the necessary data. The five input data files are those listed under the main Data Input tab 1 (Figure C.3).

Figure C.3 Display of data input main screen with the five tabs corresponding to the five data files needed to complete a fatality estimate)



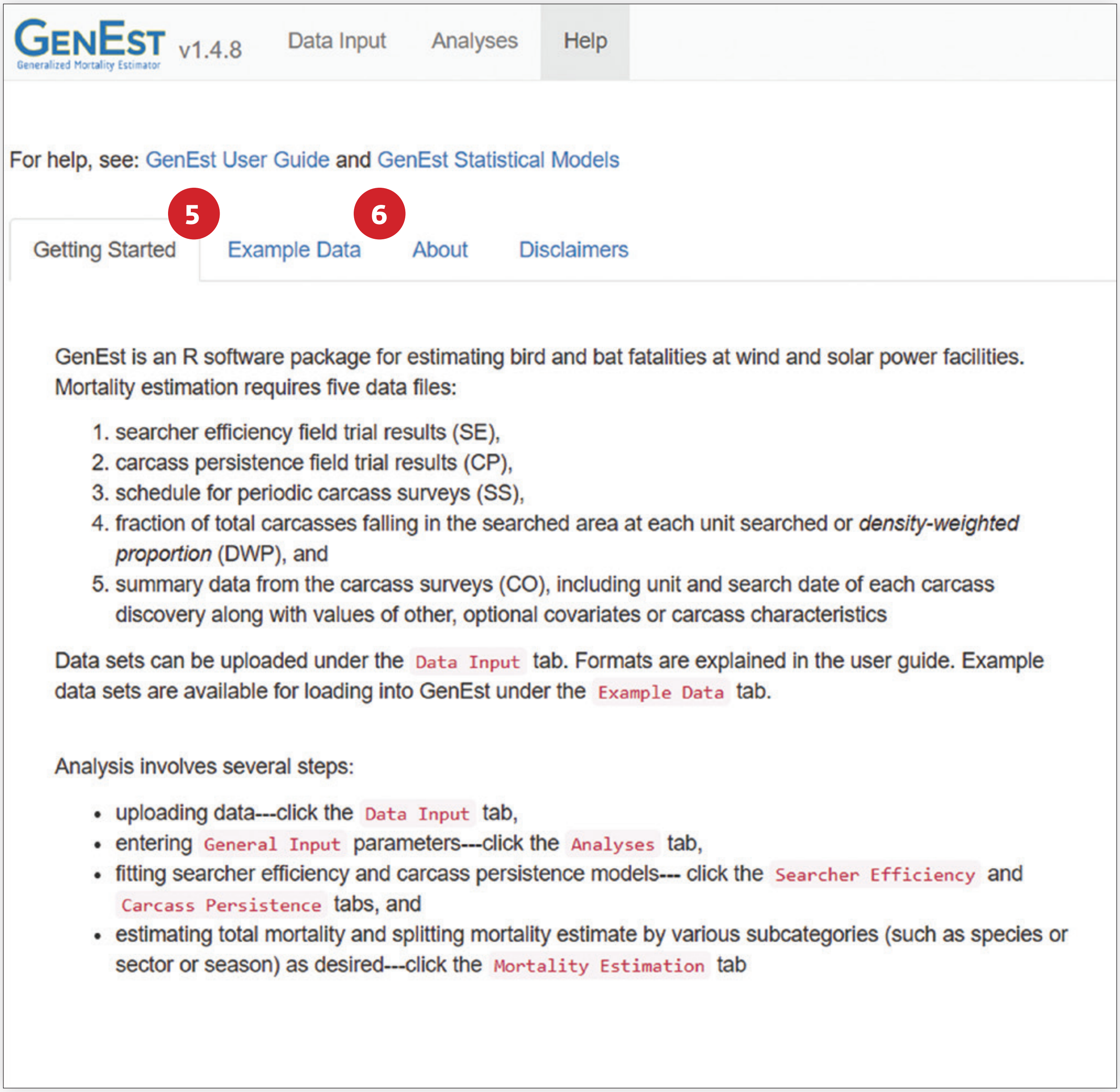
The necessary data files are comma-separated value spreadsheets for searcher efficiency data, carcass persistence data, search schedule data, density weighted proportion (DWP) data, and carcass observation data. These files are described on the Help: Getting Started tab 5 (Figure C.4), and examples of correctly formatted files can be downloaded from the Help: Example Data tab 6 . Users who are not experienced in data analysis may be surprised to find that formatting data is often neither fast nor straightforward. Time and care are required to produce high-quality, correctly formatted data. Box C.1 provides more detail on formatting data.

Box C.1 Formatting input data

It is critical that the data are formatted properly for GenEst. In particular, users should take care to use consistent formatting for dates and consistent column names across data sets (including lower- and upper-case text). For example, GenEst might not recognize "6/6/21" and "6-6-21" as the same date, and will not recognize "Carcass Size" as the same column name as "Carcass size." The GenEst user manual provides data formatting rules that users should read carefully as they prepare their data.

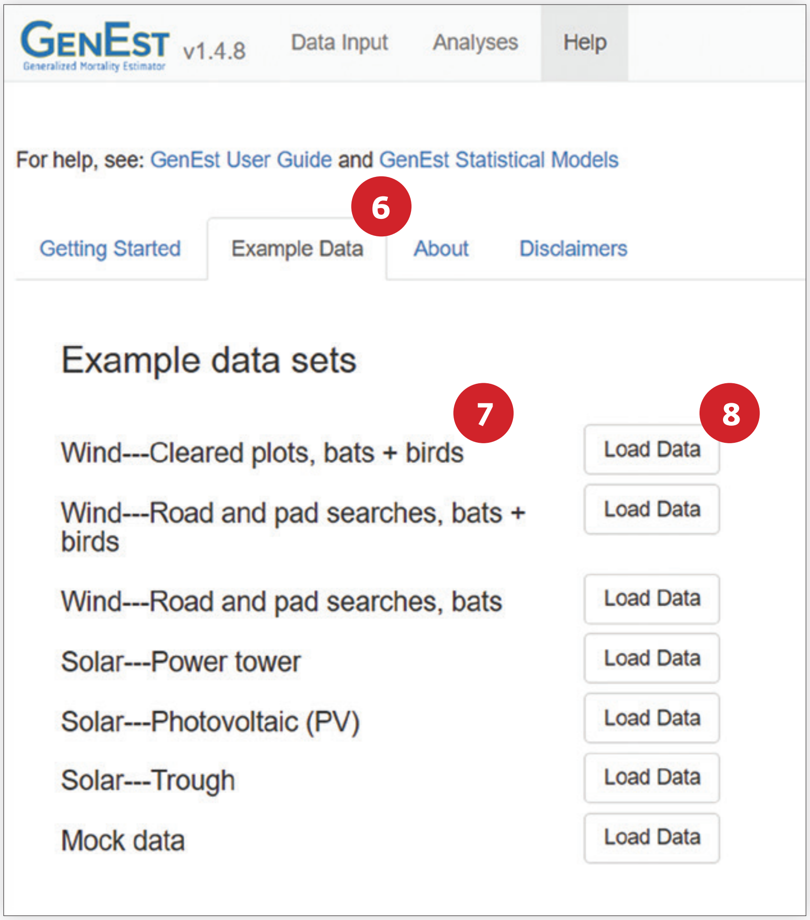
All users should carefully examine the example data provided with GenEst before collecting any data to ensure that it will meet GenEst requirements and formatting. This worked example uses example data provided with GenEst, **but it is critical that users understand that correctly formatting data is essential and requires advance preparation.**

Figure C.4 Screenshot of Help: Getting Started Tab for GenEst software



To load the example data, the user can navigate to the Help: Example Data tab 6 and select a data set to load (Figure C.5). Load the Wind—Cleared plots, bats + birds 7 data set by clicking Load Data 8 next to that data set. Users should explore the other example data sets, especially those similar to their PCFM design.

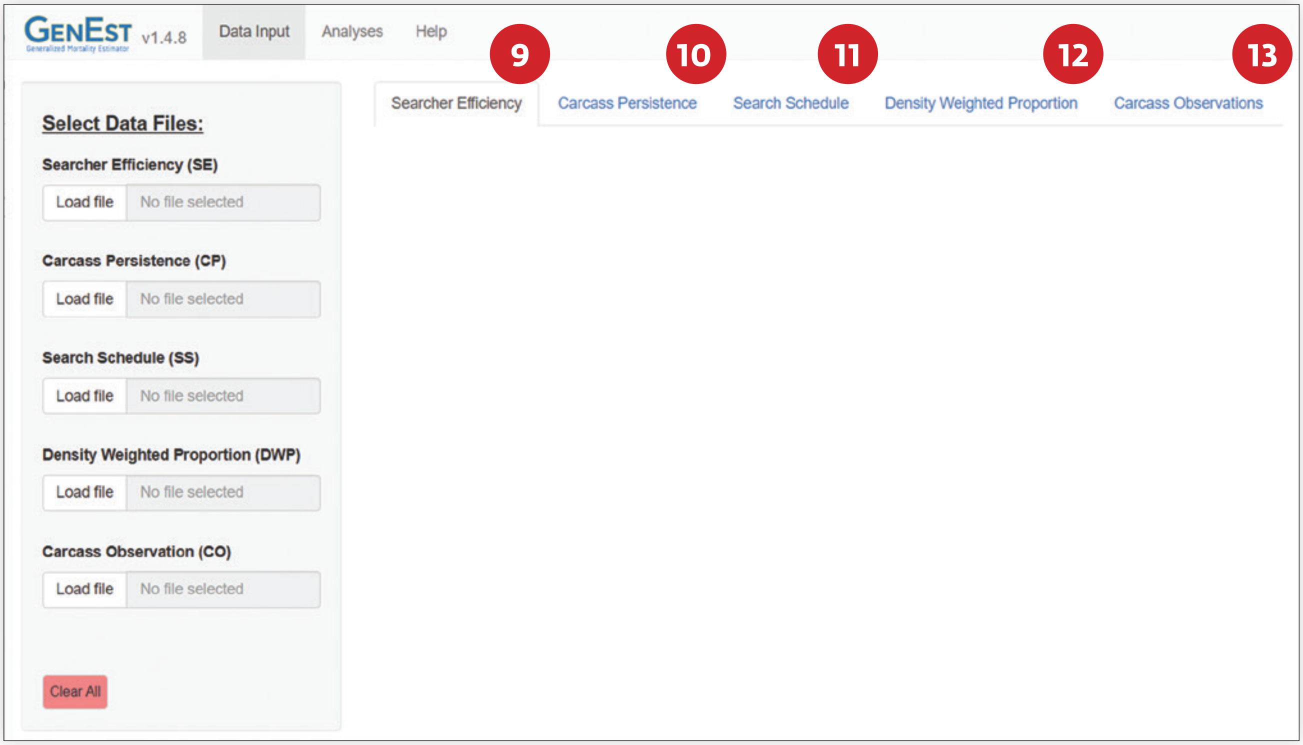
Figure C.5 Screenshot of example data sets available in the GenEst software



Note: The Wind—Cleared plots, bats + birds bats data sets were used in this example.

The program will automatically switch to the Data Input: Searcher Efficiency tab 9 and will display the example data (Figure C.6). Other sub-tabs (Carcass Persistence, 10 Search Schedule, 11 Density-Weighted Proportion, 12 and Carcass Observations 13) can be clicked to view those data. How the data should look when inputted, for each of these five variables, is shown and discussed below.

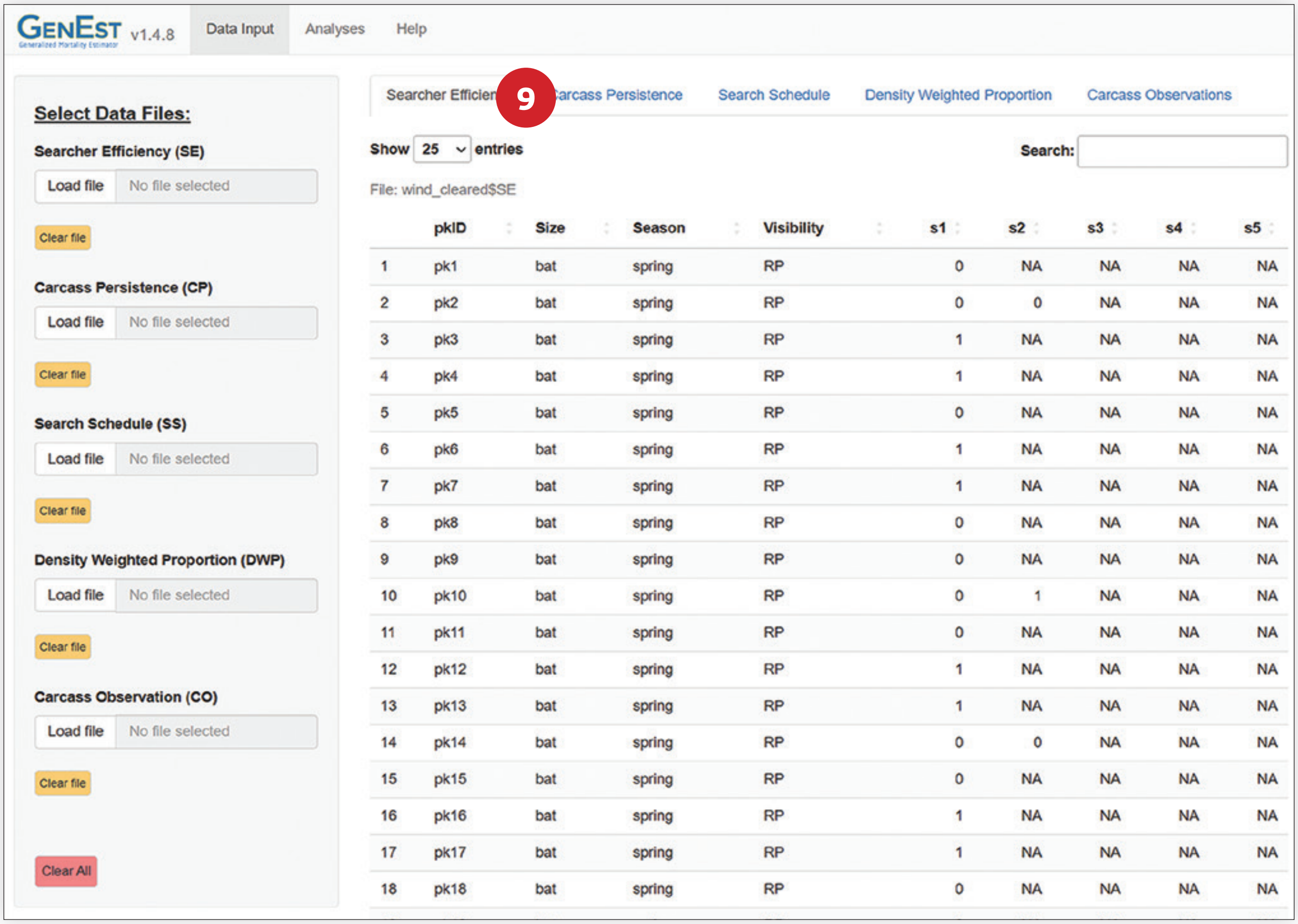
Figure C.6 Display of data input main screen with the five tabs corresponding to the five data files needed to complete a fatality estimate



Searcher Efficiency Input Data

If correctly formatted and inserted, the searcher efficiency data should display in the Data Input: Searcher Efficiency tab 9 (Figure C.7). The columns labelled s1, s2, s3, etc., show the number of searches for which the trial carcass was left out for the searchers to find. A "0" means that the searchers did not find the trial carcass, "1" means that the searchers found the trial carcass on that search, and "N/A" means that the trial carcasses were no longer available for the searchers to find because they had already been found or had been scavenged. Note that each potential covariate (Size, Season, and Visibility) has its own column[2].

Figure C.7 Display of data input: searcher efficiency screen with data correctly inputted

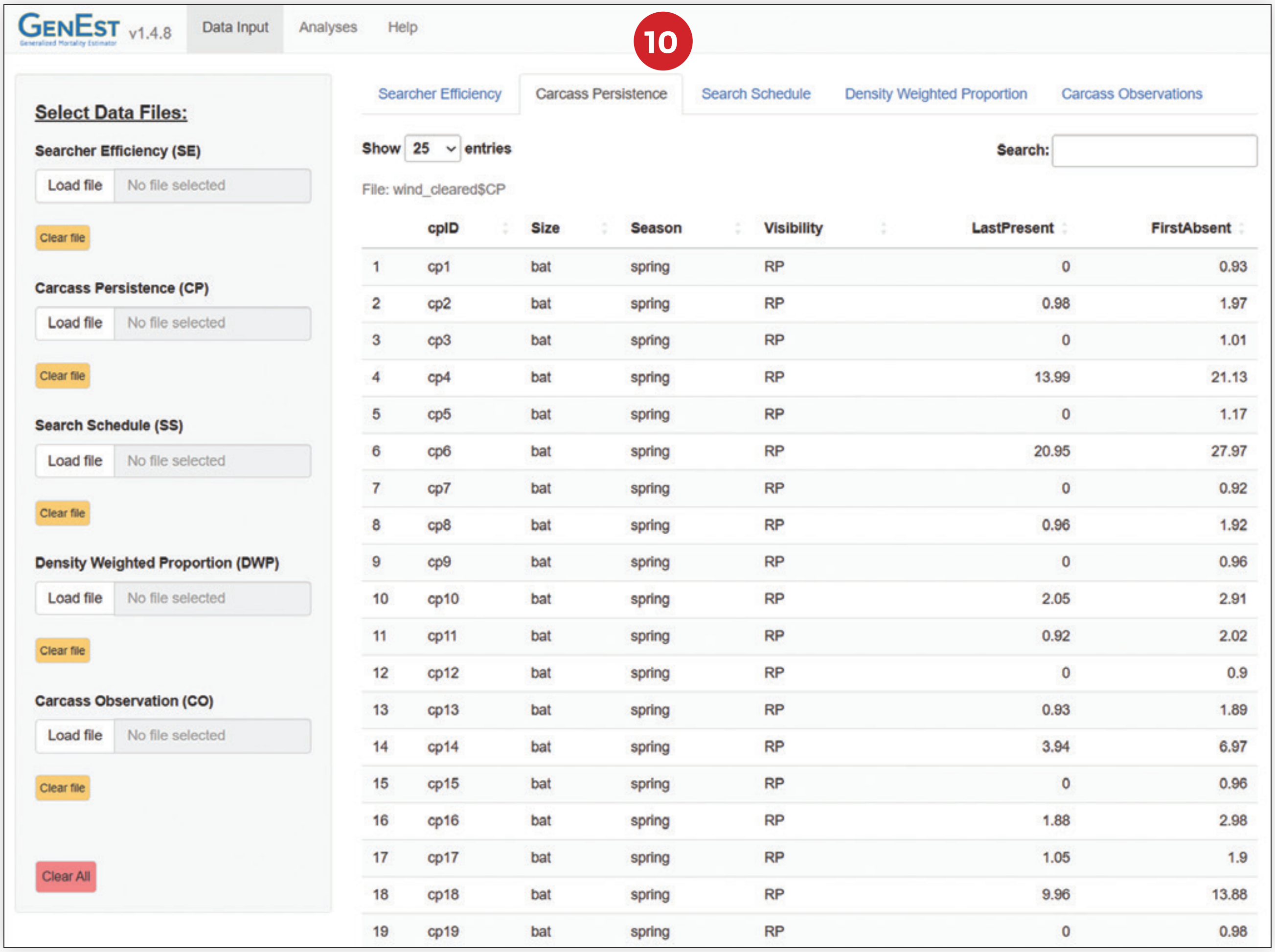


[2] Note that the Wind—Cleared plots, bats + birds' dataset includes information on visibility classes and is used in the worked example analysis as an optional predictor variable to demonstrate how a covariate like visibility may be used. For practical reasons, the Handbook does not specifically recommend that the practitioner collects data to test for effects of different visibility classes on fatality estimates (see Section 3.3.7.2). If a PCFM program has measured searcher efficiency and/or carcass persistence using an adequate sample for each visibility class present in the search plots, then the worked example will help the user handle this data in GenEst.

Carcass Persistence Input Data

Each carcass persistence trial carcass (cpID) is checked on days 1, 2, 3, 4, 7, 10, 14, and 21. If correctly formatted and inserted, the carcass persistence data should display in the Data Input: Carcass Persistence tab 10 (Figure C.8). "Last Present" represents the number of full days (the whole number) and the fraction of the day from the last search (decimal fraction) when the carcass was last seen. "First Absent" represents the number of full days (the whole number) and the fraction of the day from the date the carcass was placed (decimal fraction) to when the carcass was first discovered gone. Note that each potential covariate (Size, Season, and Visibility) has its own column.

Figure C.8 Display of data input: carcass persistence screen with data correctly inputted

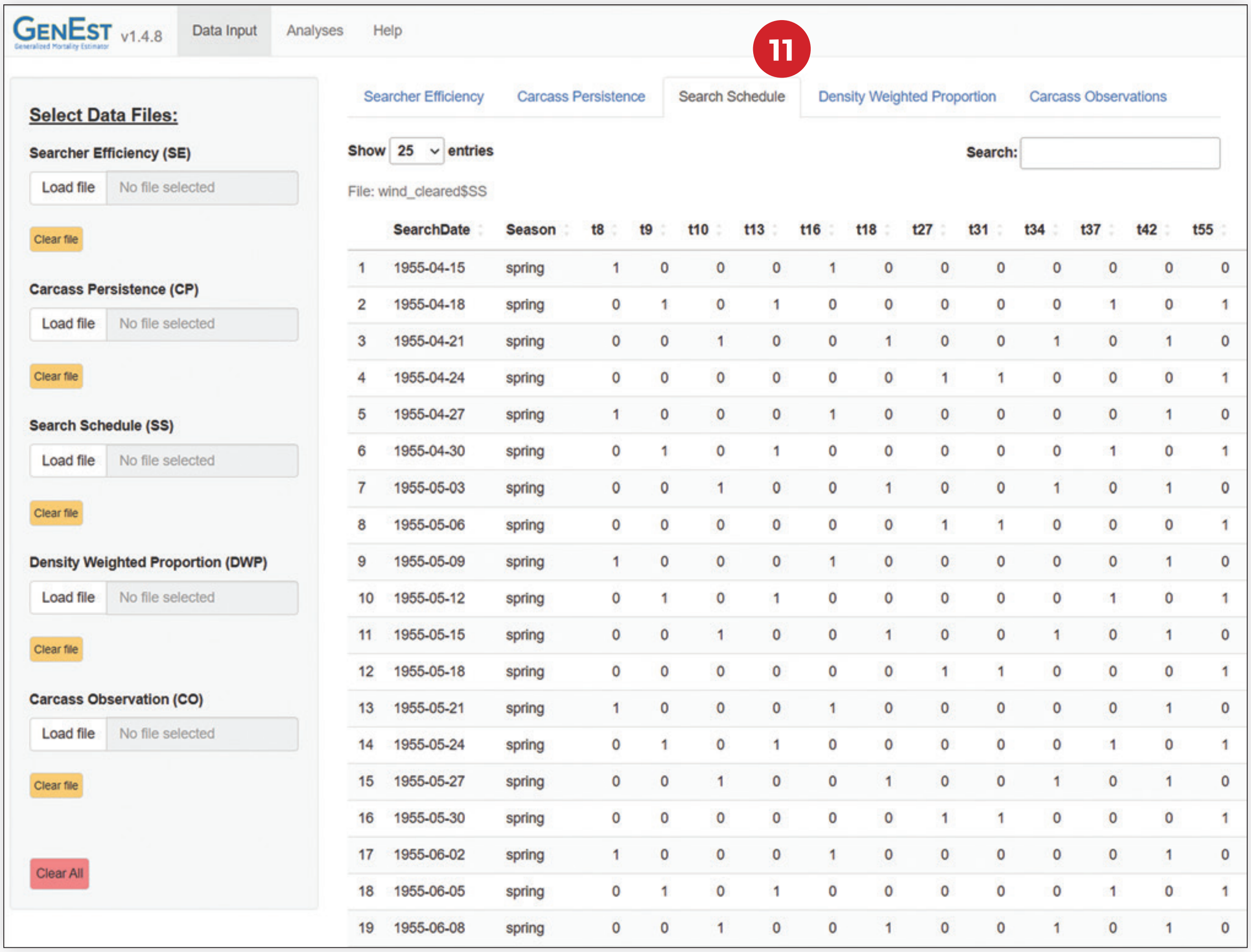


	cpID	Size	Season	Visibility	LastPresent	FirstAbsent
1	cp1	bat	spring	RP	0	0.93
2	cp2	bat	spring	RP	0.98	1.97
3	cp3	bat	spring	RP	0	1.01
4	cp4	bat	spring	RP	13.99	21.13
5	cp5	bat	spring	RP	0	1.17
6	cp6	bat	spring	RP	20.95	27.97
7	cp7	bat	spring	RP	0	0.92
8	cp8	bat	spring	RP	0.96	1.92
9	cp9	bat	spring	RP	0	0.96
10	cp10	bat	spring	RP	2.05	2.91
11	cp11	bat	spring	RP	0.92	2.02
12	cp12	bat	spring	RP	0	0.9
13	cp13	bat	spring	RP	0.93	1.89
14	cp14	bat	spring	RP	3.94	6.97
15	cp15	bat	spring	RP	0	0.96
16	cp16	bat	spring	RP	1.88	2.98
17	cp17	bat	spring	RP	1.05	1.9
18	cp18	bat	spring	RP	9.96	13.88
19	cp19	bat	spring	RP	0	0.98

Search Schedule Input Data

If correctly formatted and inserted, the search schedule data should display in the Data Input: Search Schedule tab 11 (Figure C.9). The search schedule data contains a row for each date that a search occurred and columns for every turbine at the facility. The turbine columns are filled with 0s and 1s, indicating whether the turbine was searched on that date (1) or not (0). A column indicating the season associated with the search date may also be included. Note that the schedule includes a column for the time-based covariate "Season."

Figure C.9 Display of data input: search schedule screen with data correctly inputted

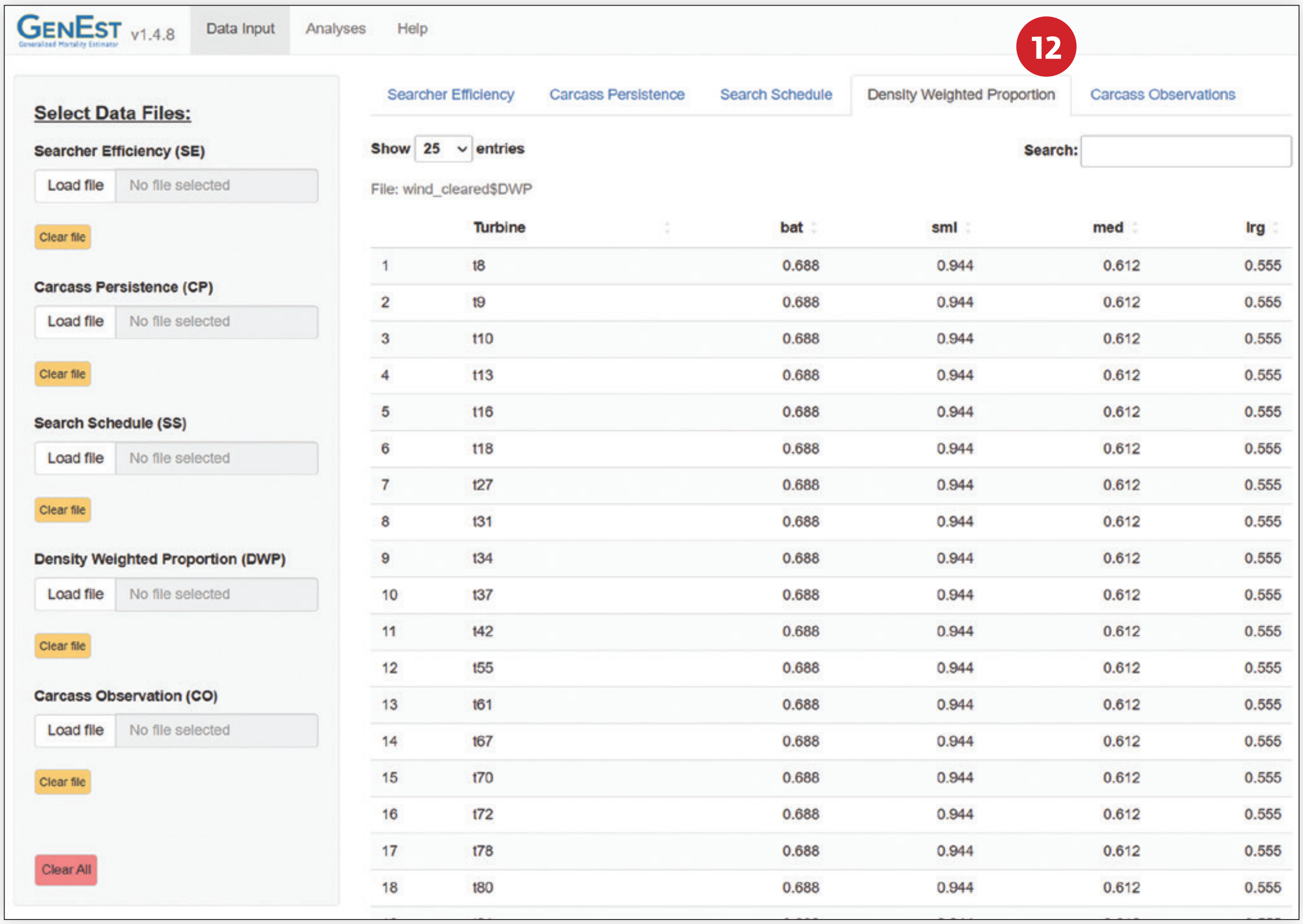


	SearchDate	Season	t8	t9	t10	t13	t16	t18	t27	t31	t34	t37	t42	t55
1	1955-04-15	spring	1	0	0	0	1	0	0	0	0	0	0	0
2	1955-04-18	spring	0	1	0	1	0	0	0	0	0	1	0	1
3	1955-04-21	spring	0	0	1	0	0	1	0	0	1	0	1	0
4	1955-04-24	spring	0	0	0	0	0	0	1	1	0	0	0	1
5	1955-04-27	spring	1	0	0	0	1	0	0	0	0	0	1	0
6	1955-04-30	spring	0	1	0	1	0	0	0	0	0	1	0	1
7	1955-05-03	spring	0	0	1	0	0	1	0	0	1	0	1	0
8	1955-05-06	spring	0	0	0	0	0	0	1	1	0	0	0	1
9	1955-05-09	spring	1	0	0	0	1	0	0	0	0	0	1	0
10	1955-05-12	spring	0	1	0	1	0	0	0	0	0	1	0	1
11	1955-05-15	spring	0	0	1	0	0	1	0	0	1	0	1	0
12	1955-05-18	spring	0	0	0	0	0	0	1	1	0	0	0	1
13	1955-05-21	spring	1	0	0	0	1	0	0	0	0	0	1	0
14	1955-05-24	spring	0	1	0	1	0	0	0	0	0	1	0	1
15	1955-05-27	spring	0	0	1	0	0	1	0	0	1	0	1	0
16	1955-05-30	spring	0	0	0	0	0	0	1	1	0	0	0	1
17	1955-06-02	spring	1	0	0	0	1	0	0	0	0	0	1	0
18	1955-06-05	spring	0	1	0	1	0	0	0	0	0	1	0	1
19	1955-06-08	spring	0	0	1	0	0	1	0	0	1	0	1	0

DWP Input Data

If correctly formatted and inserted, the DWP data should display in the Data Input: Density Weighted Proportion tab 12 (Figure C.10). The DWP is the area correction applied to the estimate to account for carcasses that may have fallen outside the search area (outside the specified plot boundary) and in any unsearchable areas within the plot. It is called a DWP because it is a combination of the carcass fall density (where carcasses are likely to fall) and the proportion of area searched. It is an estimate of the proportion of carcasses that are likely to fall within an area that was searched. GenEst does not estimate the DWP; it is an input the user must provide. Appendix D provides a spreadsheet-based tool that will estimate the DWP. In this example, every turbine has its own DWP value for each carcass size. It is preferred that DWP be estimated for each turbine separately.

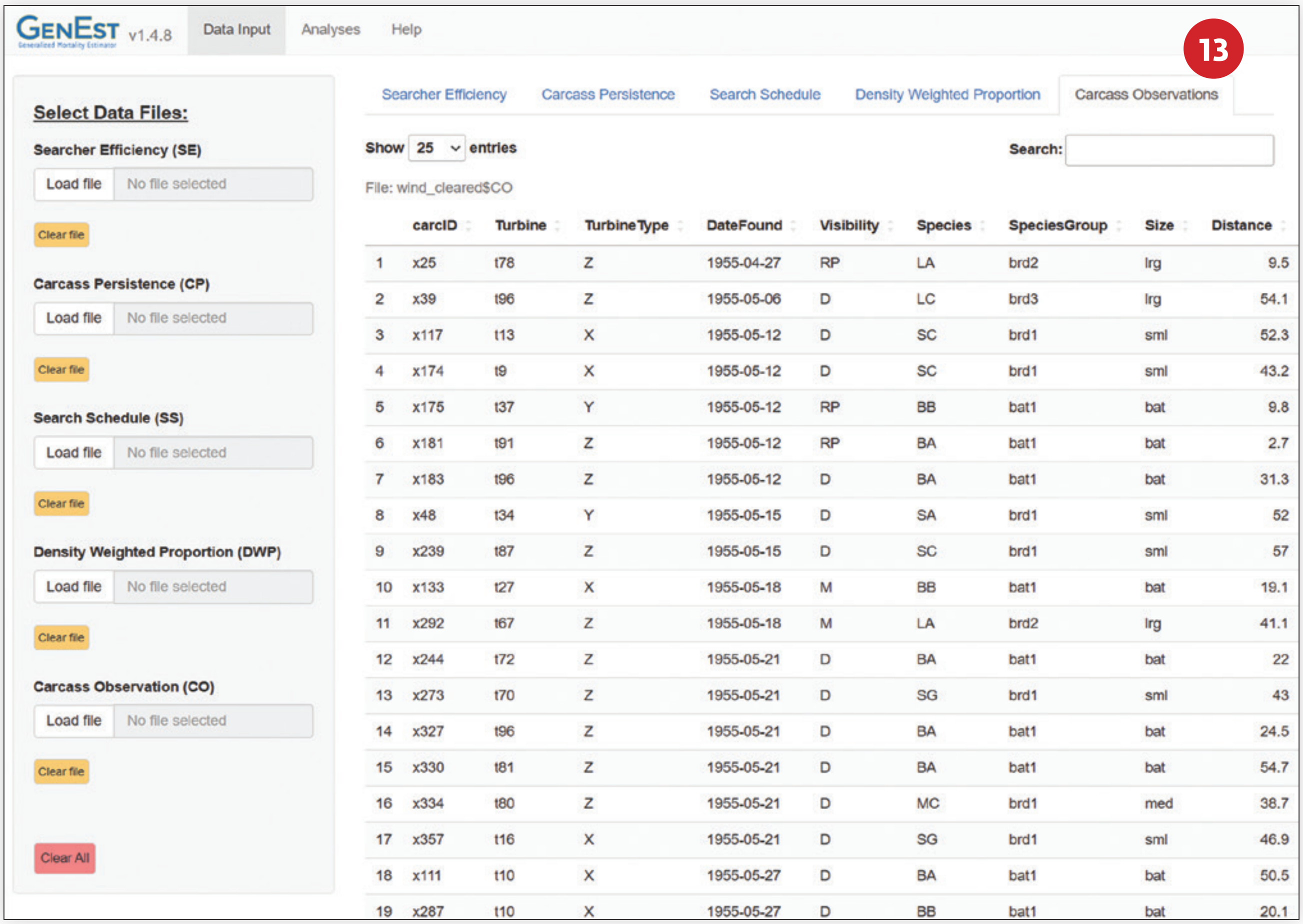
Figure C.10 Display of data input: density-weighted proportion screen with data correctly inputted



Carcass Observations Input Data

If correctly formatted and inserted, the carcass observation data should display in the Data Input: Carcass Observation tab 13 (Figure C.11). In the columns shown on this screen, carcasses will be listed in numerical order according to their carcass identification numbers. Turbine number, Date Found, and Species are essential input variables here, although other variables such as Turbine Type, Visibility, Species Group, Size, and Distance can be included if they are important to the study. **All variables that are important to the study must be included in the searcher efficiency data, carcass persistence data, search schedule (if the variable is time bound), and carcass observations data, and the columns must be named and formatted identically in all data files.**

Figure C.11 Display of data input: carcass observations screen with data correctly inputted

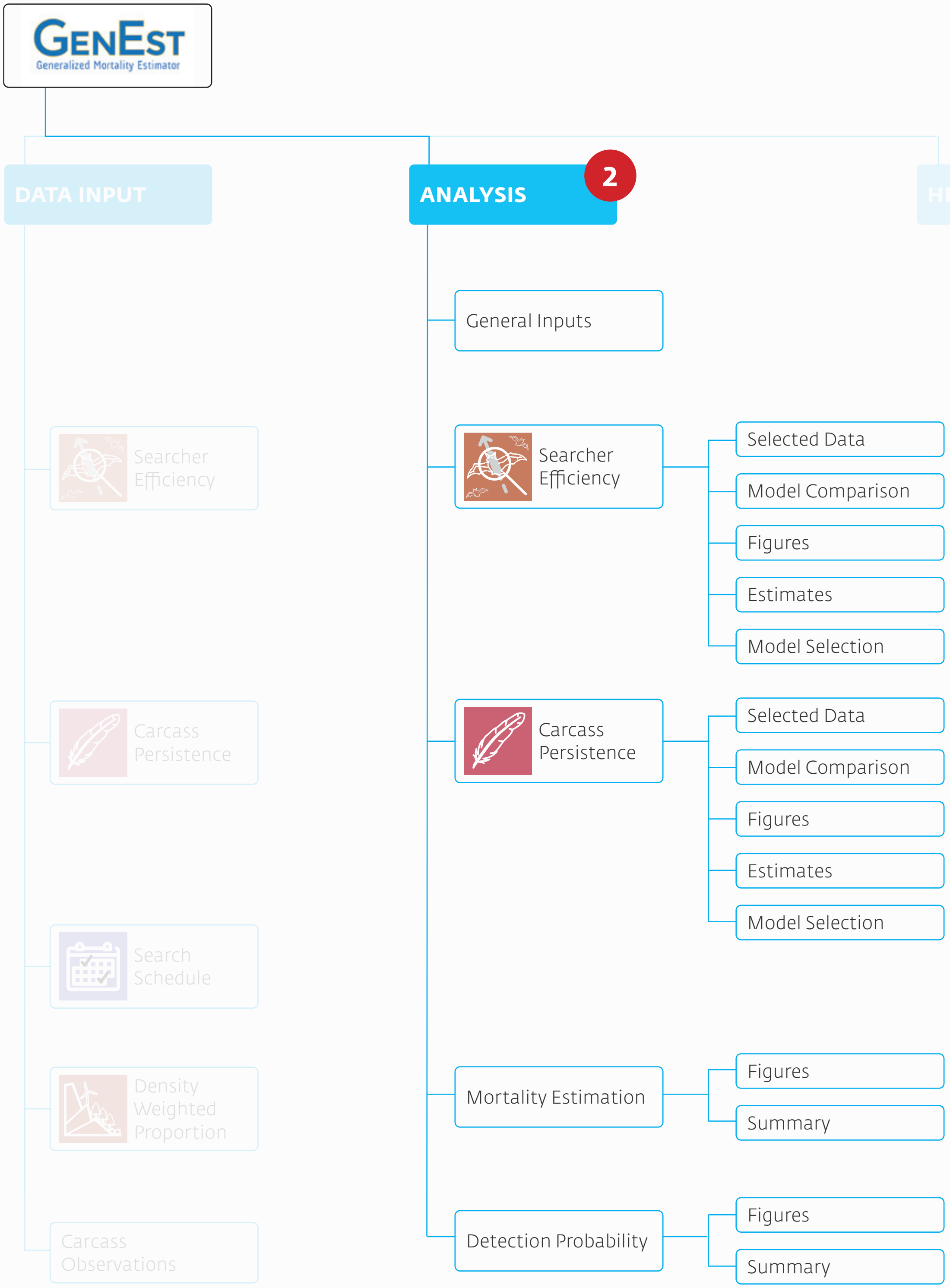


	carcID	Turbine	TurbineType	DateFound	Visibility	Species	SpeciesGroup	Size	Distance
1	x25	t78	Z	1955-04-27	RP	LA	brd2	lrg	9.5
2	x39	t96	Z	1955-05-06	D	LC	brd3	lrg	54.1
3	x117	t13	X	1955-05-12	D	SC	brd1	sml	52.3
4	x174	t9	X	1955-05-12	D	SC	brd1	sml	43.2
5	x175	t37	Y	1955-05-12	RP	BB	bat1	bat	9.8
6	x181	t91	Z	1955-05-12	RP	BA	bat1	bat	2.7
7	x183	t96	Z	1955-05-12	D	BA	bat1	bat	31.3
8	x48	t34	Y	1955-05-15	D	SA	brd1	sml	52
9	x239	t87	Z	1955-05-15	D	SC	brd1	sml	57
10	x133	t27	X	1955-05-18	M	BB	bat1	bat	19.1
11	x292	t67	Z	1955-05-18	M	LA	brd2	lrg	41.1
12	x244	t72	Z	1955-05-21	D	BA	bat1	bat	22
13	x273	t70	Z	1955-05-21	D	SG	brd1	sml	43
14	x327	t96	Z	1955-05-21	D	BA	bat1	bat	24.5
15	x330	t81	Z	1955-05-21	D	BA	bat1	bat	54.7
16	x334	t80	Z	1955-05-21	D	MC	brd1	med	38.7
17	x357	t16	X	1955-05-21	D	SG	brd1	sml	46.9
18	x111	t10	X	1955-05-27	D	BA	bat1	bat	50.5
19	x287	t10	X	1955-05-27	D	BB	bat1	bat	20.1

ANALYZING INPUT DATA

The various sub-heading tabs displayed in Figure C.12 are found under the Analyses main tab 2 .

Figure C.12 Schematic representation of all subheading tabs under the "Analyses" tab

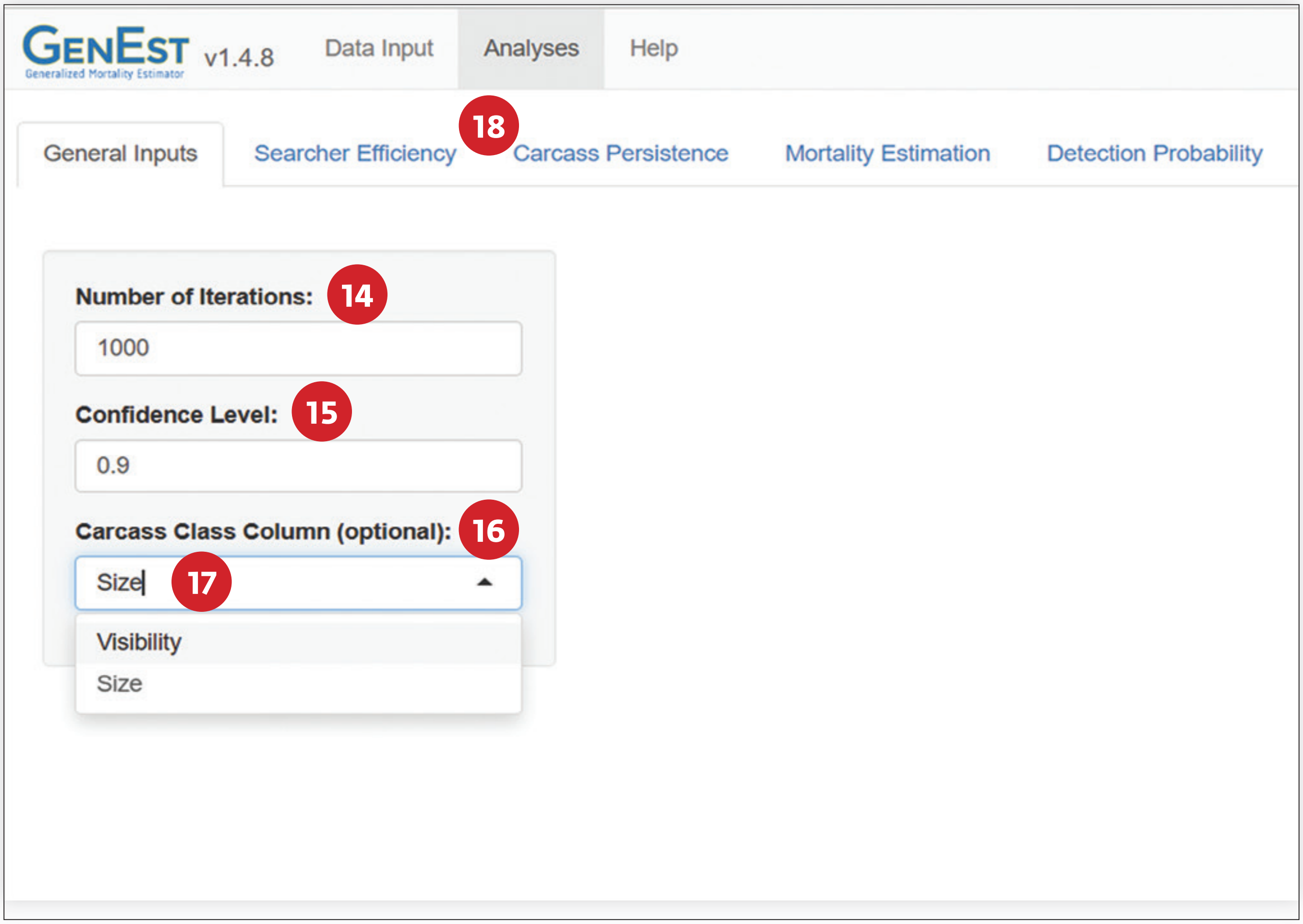


APPENDIX C: Generalized Estimator of Mortality – Worked Example

General Analysis Inputs

A GenEst analysis requires three general inputs (Figure C.13). First, the user specifies the number of iterations 14 to be used for bootstrapping (or simulating from) the model. The bootstrap simulations are used to construct confidence intervals (CIs) on the estimates. A larger number of simulations will improve the accuracy of the CIs but computations will take longer. A generally accepted value of 1,000 iterations was used in this analysis, but users are encouraged to use 5,000 iterations if the computations are not unacceptably slow. Second, the user specifies the confidence level 15 for the analysis. Typical choices are 0.90 (90% CI) and 0.95 (95% CI). The default value of 0.90 was used in this analysis, which is a good choice for good international industry practice. Third, if applicable, the user specifies the carcass class 16 . If the study focuses on one size class (e.g., bats only), the user does not need to select the carcass class. More commonly, the carcass class column allows the user to produce fatality estimates according to type of carcass (e.g., size class). For this example, Size 17 was chosen because the example data include carcass information for bats and small, medium, and large birds. Visibility was another option by which to stratify, but it was not chosen for this example. **Any selected carcass class column must also be present in the searcher efficiency, carcass persistence, and carcass observations data.** After all the above is completed, the user can move to the Analyses: Searcher Efficiency sub-tab 18 .

Figure C.13 Screenshot of landing page for "Analyses" main tab of GenEst software



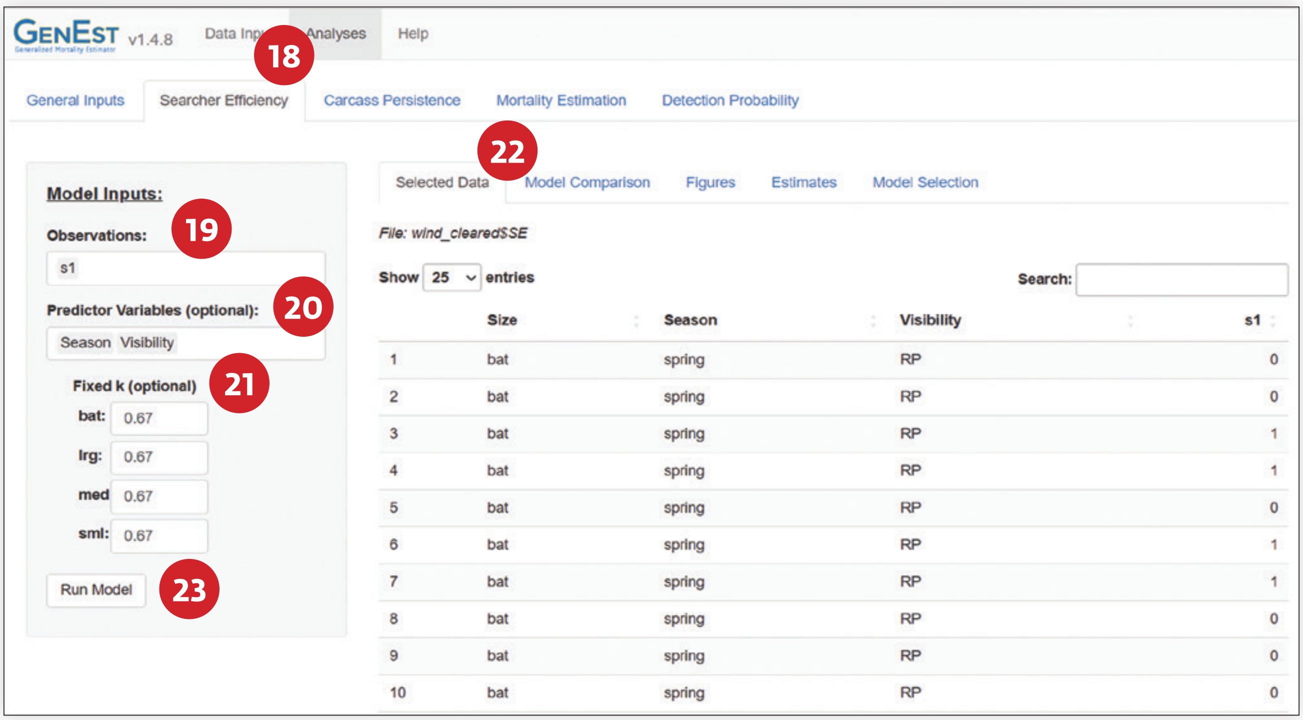
Note: These are global settings needed to run the GenEst analysis.

Searcher Efficiency

The Analyses: Searcher Efficiency tab 18 is empty when first loaded (Figure C.14). The user must specify the model inputs, which are the observations 19, the predictor variables (e.g., visibility class or season) 20, and the value for *k* 21. The searcher efficiency schedule contains a row for each trial carcass (or surrogate) placed and available to be found. The "observations" are a column of 0s and 1s indicating whether the available carcass was found (1) or not found (0). In the example data, the column s1 is the column of 0s and 1s for the first attempt to find each carcass. The data also includes s2, s3, and s4 for data on subsequent searches, but only data from the first search has been used in this example. Searches s2, s3, and s4 could be used to estimate the parameter k, but most practitioners will not have such data so s1 was selected as the observations field.

The user can also specify predictor variables (also known as covariates), such as season or plot type, that might influence searcher efficiency. For this example, season and visibility were chosen. Lastly, because data from a single searcher efficiency trial are being used, *k* = 0.67 was set for all size classes. The parameter, *k* has rarely been estimated, but tends to be near 0.67 in those cases (mostly for bats) where it has been estimated (e.g. Huso et al. 2017, Skalski and Townsend 2017. Once these settings are specified, the Selected Data sub-tab 22 will populate with the chosen data for review, and the user can select Run Model 23 to fit searcher efficiency models.

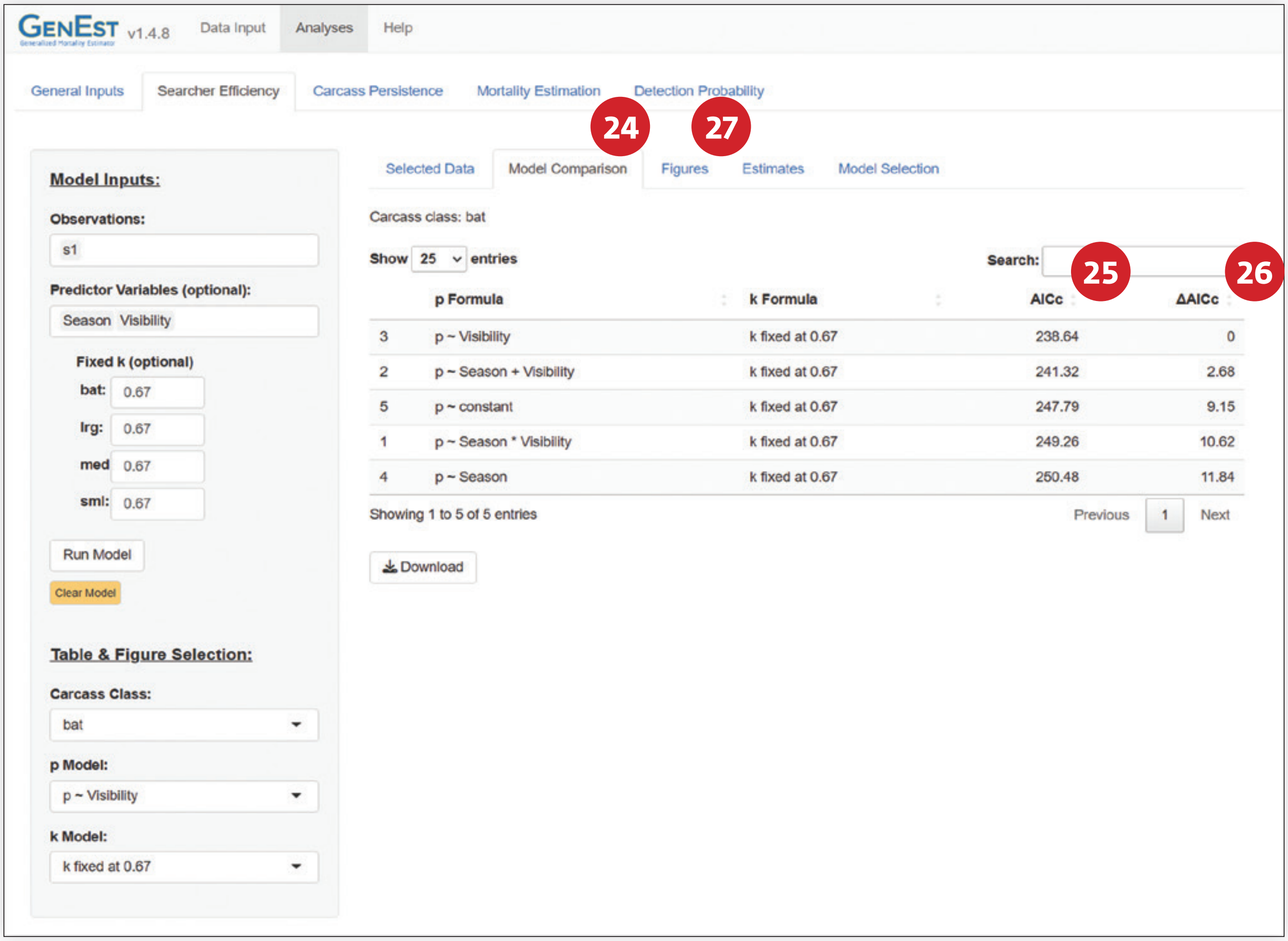
Figure C.14 Screenshot of Analyses: Search Efficiency: selected data tab in the GenEst software



Note: The s1 column was used for the response (trial carcass found or not) and Season and Size as potential predictor variables (covariates).

GenEst fits all possible combinations of models, based on the Predictor Variables that the user selects. After the Run Model 23 button is pressed, GenEst automatically displays the Analyses: Searcher Efficiency: Model Comparison tab 24 (Figure C.15), which shows the models fitted and their corrected Akaike Information Criterion (AICc) scores 25 and rankings 26 (see Box C.2 for more information on AICc scores and Box C.3 for more detail on the p-Formula).

Figure C.15 Screenshot of Analyses: Searcher Efficiency: Model Comparison tab of the GenEst Software



Note: This tab shows the ranking of competing models, scored according to corrected Akaike Information Criterion (AICc). The Figures tab can be viewed to compare the model estimates graphically.

Box C.2 Understanding Model Output: Corrected Akaike Information Criterion (AICc) Scores

GenEst uses AICc (Akaike 1973; Burnham and Anderson 2002) to rank models. AICc is a standard model score that evaluates how well a model fits the data. Models with lower AICc scores are better than models with higher AICc scores (but AICc can only be compared between models using exactly the same data set). GenEst automatically ranks the models by ΔAICc, which is a model's AICc value minus the minimum AICc in the model set (ΔAICc = 0 is always the model with the lowest AICc). Generally, models within 2 AICc points can be viewed as receiving similar support from the data (Burnham and Anderson 2002). AICc rank is a good place to start for model selection but a good practitioner will consider all models within 2 AICc points of the top-ranked model and choose the most reasonable of them (see Box C.4). When multiple models fit the data well and have AICc scores within 2 points of one another, the model with fewer parameters is usually preferred because having fewer parameters results in greater precision.

Box C.3 Understanding the p-Formula

The "p Formula" column in Figure C.15 indicates the model, where "p ~" reads: "p as a function of..." For example, in the output in Figure C.15, the top two models are: "p ~ Visibility" and "p ~ Season + Visibility." The "p ~ constant" model (ranked third) has no covariate effects; the "p ~ Visibility" model incorporates the effect of visibility on searcher efficiency (p as a function of visibility).

A searcher efficiency model is automatically fitted for each size class separately based on the size class column indicated in Figure C.11. Figure C.15 shows the results for bats, but the user must inspect models for each size class, which is achieved by choosing a different size class to display in the menu below Model Inputs.

Based on AICc rank, number of parameters, and whether the model is reasonable, the user chooses a model for further evaluation (Box C.4). In the case of bats, the model with visibility as a covariate has the lowest AICc by more than 2 points (the next-ranked model has ΔAICc = 2.68). Therefore, the model with visibility as a covariate, "p ~ Visibility," was chosen, which means that predictions of search efficiency for bats from the model will be unique for each visibility class in the data, and the estimates will not vary according to season. The Figures sub-tab 27 shows differences among the competing model's predictions. Users should examine this graph to ensure that the selected model is making reasonable predictions and choose a different model if there is a problem with the selected model. The GenEst user guide provides information on interpreting these graphs.

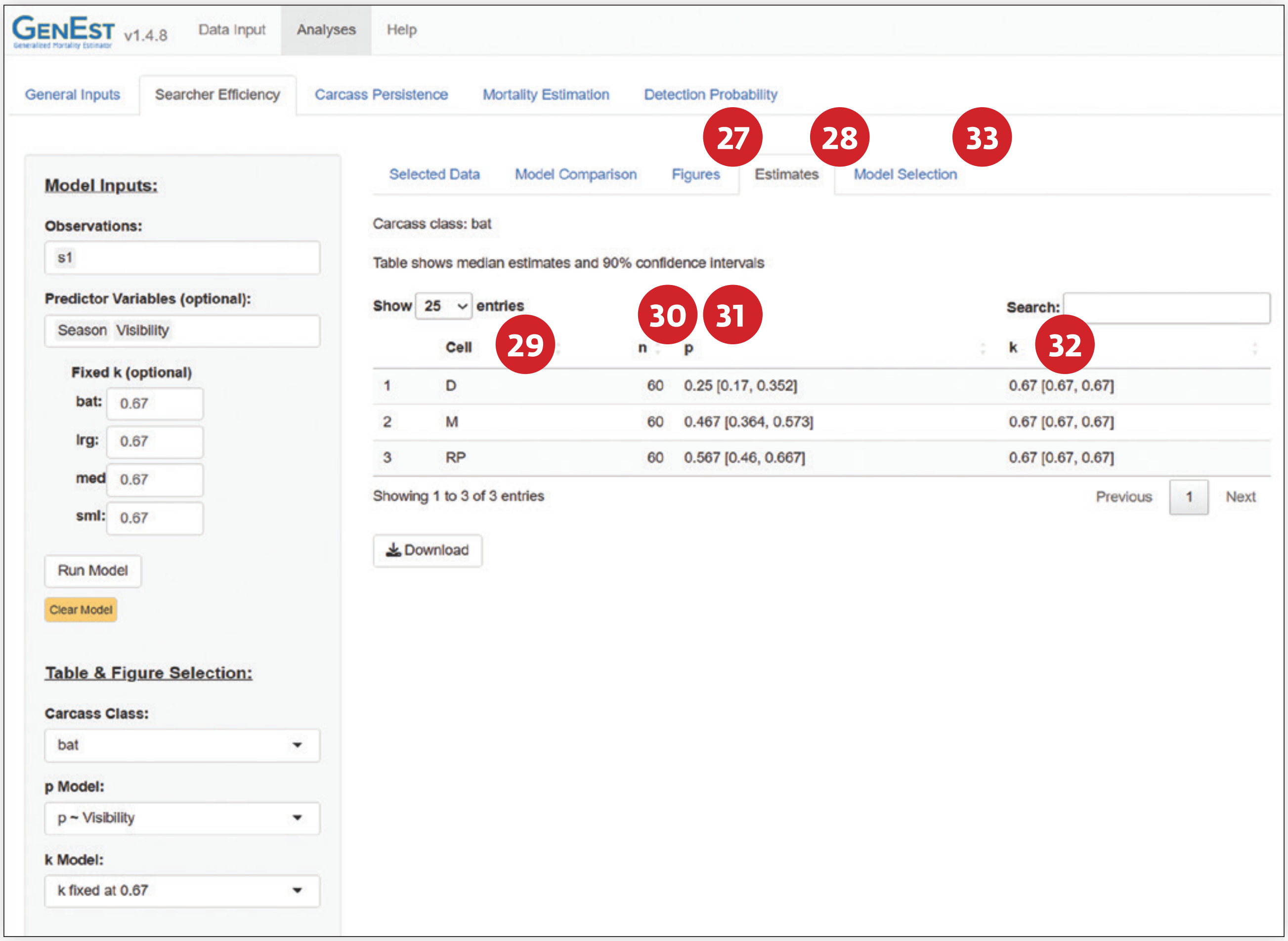
Box C.4 Model Selection

GenEst fits several models to the carcass persistence and searcher efficiency data and leaves it to the user to select the best among them. There are three basic criteria that a user can apply to this task:

1. AICc (Box C.2) gives an objective measure of model fit.
2. For models within 2 AICc points of one another, the model with fewer parameters is usually preferred because having fewer parameters results in greater precision.
3. "Reasonableness" of a model refers to how well the model fits the data and whether it makes sense. It can take some practice to determine whether a model is reasonable. A good way to determine whether a model is reasonable is to look at the 'Figures' sub-tab 27 in Figure C.16 (searcher efficiency) or Figure C.17 (carcass persistence). "Reasonableness" should be assessed by examining the figures and considering whether the model makes sense. For example, if a searcher efficiency model predicted that carcasses were more detectable in tall grass than on a gravel pad, that might be an unreasonable model, and the user should consider whether there is a good explanation for the model. The model may be missing an important covariate (e.g., season, if grass height depends on season, or searcher, if searchers have different skill levels). Alternatively, small sample size can sometimes lead to unreasonable models by chance. In the latter case, it may be preferable simply to remove an unreasonable covariate from the model.

The Estimates sub-tab 28 in Figure C.16 shows the estimates that the model chosen for evaluation in Figure C.15 produced. Four columns are displayed. Cell 29 refers to the group for which the estimate applies (visibility class in this example); n 30 is the sample size within each stratum (or cell); p 31 in this case is the estimated search efficiency and associated 90% CI; and k 32 shows the detection reduction factor, which is constant in this case. Because the model has the lowest AICc (lower AICc is better) and appears to produce a reasonable output, move to the Model Selection sub-tab 33 and select the "p ~ Visibility" model from the drop-down menu. **A model must be selected for each size class after inspection of the competing models for each size class**. GenEst does not automatically select the top-ranked model. The user must select the model manually.

Figure C.16 Screenshot of Analyses: Searcher Efficiency: Estimates tab in the GenEst software



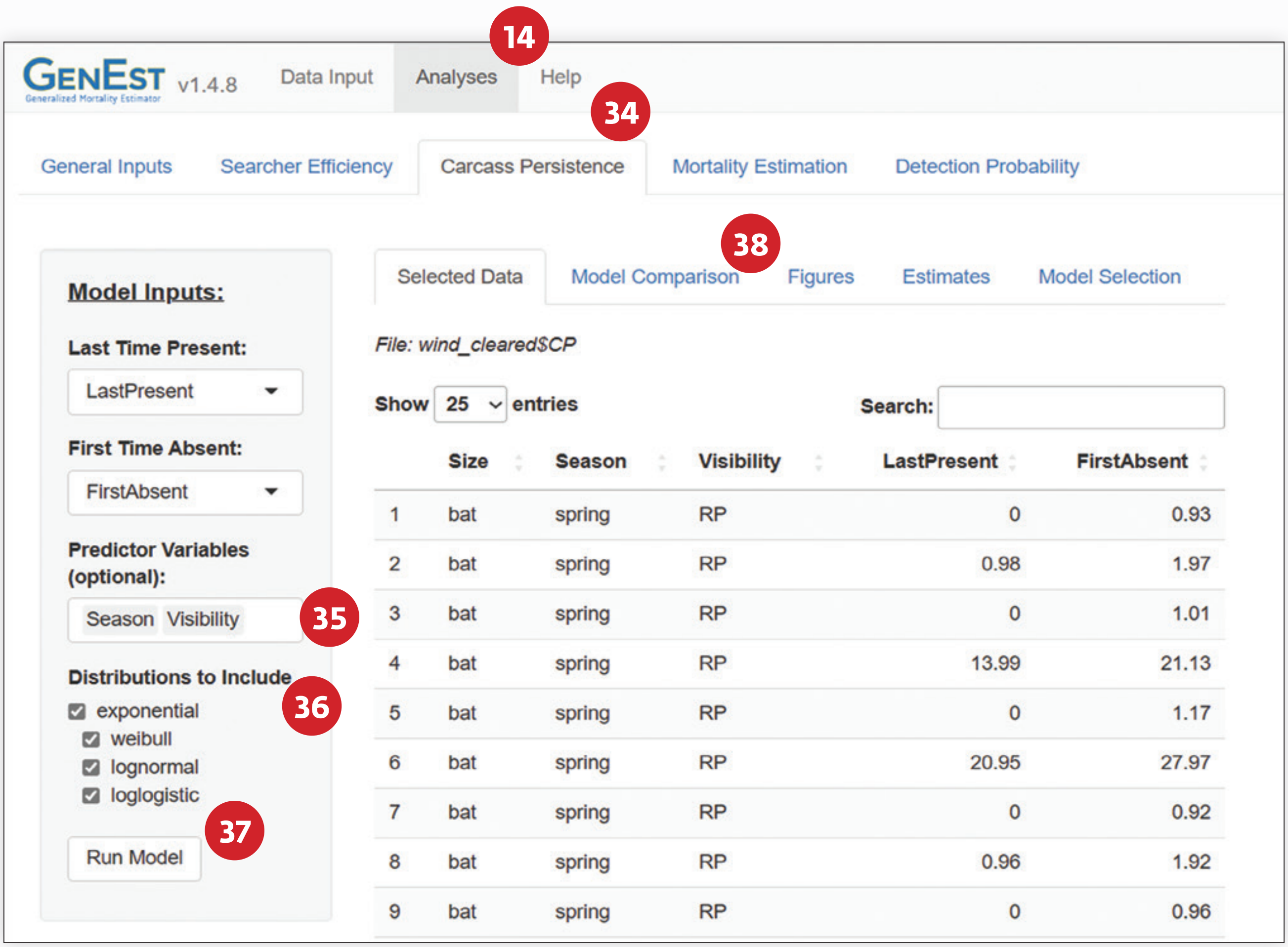
Note: For searcher efficiency, this tab displays the estimated probability of detection and associated confidence interval (CI); k is fixed, so the point estimate and CI bounds are all the same.

In summary, GenEst takes field data on searcher efficiency trials and fits a set of models. The models differ in terms of predictor variables (covariates). GenEst produces searcher efficiency estimates from each model and ranks the models using AICc. The user then selects the model to use for mortality estimation based on AICc ranks, number of model parameters, and an evaluation of the 'reasonableness' of model predictions.

Carcass Persistence

The next sub-tab under Analyses **14** is Carcass Persistence **34** (Figure C.17). GenEst estimates average carcass persistence time (in days) and computes the probability of a carcass persisting through a specified search interval. The data set includes a row for each trial carcass placed on the landscape. Because a carcass is rarely, if ever, observed being removed from the landscape, the observations recorded are the last date and time the carcass was checked and found and the first date and time that the carcass was checked and not found. For example, if a carcass was placed on day 0, a typical carcass check schedule might be day 1, 2, 3, 7, 14, 21, and 30. If the carcass disappeared between searches on days 3 and 7, the last day present would be 3, and the first day absent would be 7. GenEst can produce more precise estimates if users record the date and time when carcasses are placed and checked rather than just the date.

Figure C.17 Screenshot of Analyses: Carcass Persistence: Selected Data tab in the GenEst software

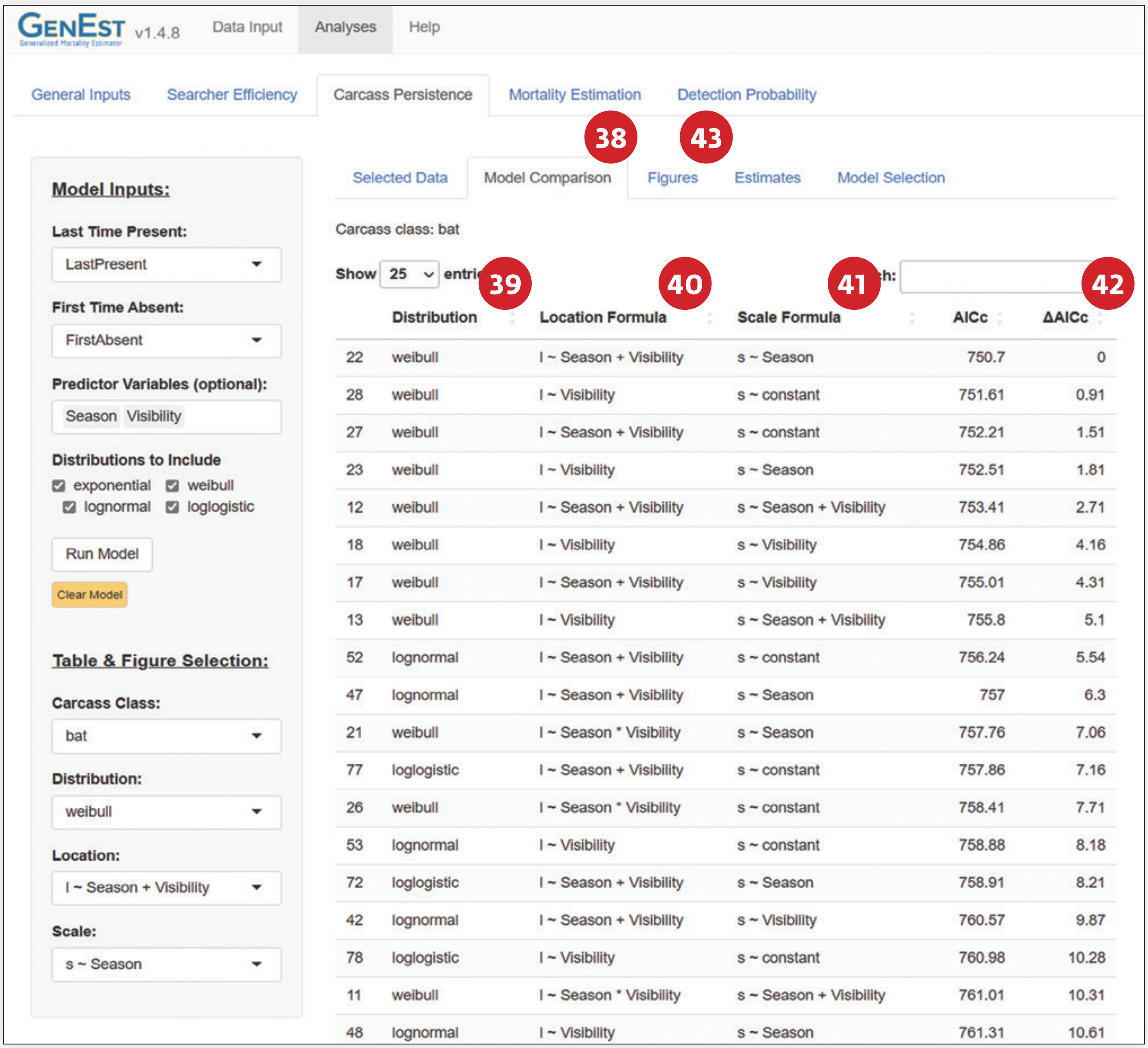


Note: The user selects the appropriate columns for the response data (last date and time present and first time absent). Season and visibility were also selected as potential covariates. By default, GenEst fits four distributions. It is suggested that this default setting is used.

Like the searcher efficiency analysis, the user can specify which predictor variables (covariates) **35** to consider in the set of competing models and which distributions to fit (buttons for Distributions to include **36** in left window of Figure C.17Q). The default is to fit all distributions, and this is suggested as standard practice. Model selection criteria and visual inspections of the fitted models will guide model selection. Clicking the Run Model **37** button results in all models being fitted, and the Model Comparison **38** sub-tab will automatically display.

The Model Comparison tab **38** displays all the fitted models and their properties (Figure C.18): the fitted distribution (Distribution) **39**, the formula for the location parameter (Location Formula) **40**, the formula for the scale parameter (Scale Formula) 41, and the AICc scores (AICc and ΔAICc; Box C.2) 42. Each of these properties will be described in turn. All the carcass persistence distributions fitted by GenEst are parameterized (defined) according to a location parameter and a scale parameter. The location parameter defines the central tendency of the distribution (e.g., the mean of a normal distribution), and the scale parameter defines the spread around the central tendency (e.g., the standard deviation of a normal distribution). The exponential distribution is defined only according to the location parameter. GenEst allows both the location and the scale parameter to vary according to covariates, a feature that sets it apart from other estimators. The AICc column reports the AICc value, and ΔAICc is the difference from the top-ranked model. Like the Searcher Efficiency analysis, the user can compare models by checking the Figures sub-tab 43 and evaluate the estimates of any selected model (chosen via the window on the left of the screen). Users should select a model based on AICc score (lower is better) and check the figures to ensure that the model predictions make sense (Box C.4). Also, like the Searcher Efficiency analysis, the results are displayed with only one size class at a time; the user must inspect models for each size class independently.

Figure C.18 Screenshot of Analyses: Carcass Persistence: Model Comparison tab in the GenEst software

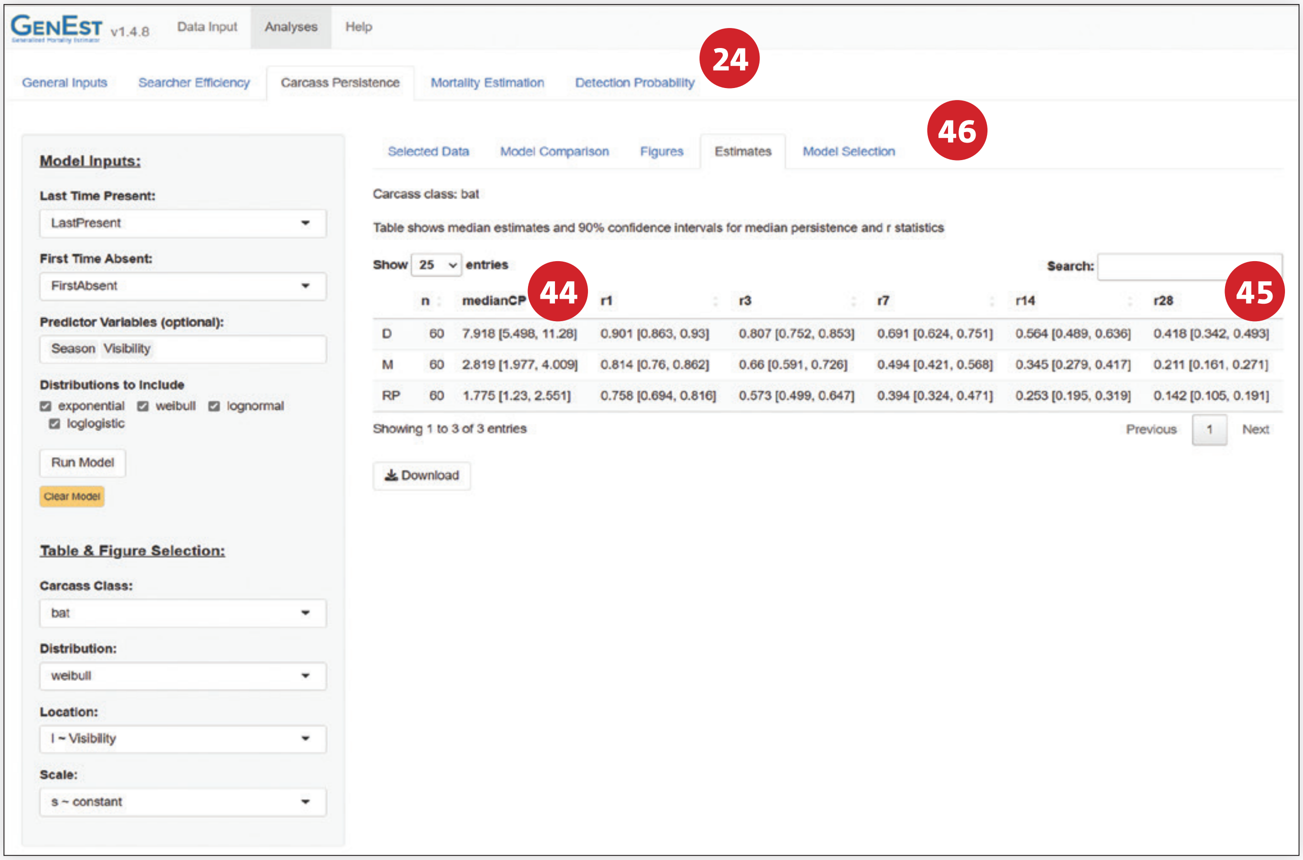


Note: The model formulas are displayed, and the models are ranked according to corrected Akaike Information Criterion (AICc). The user can further evaluate the differences between the models graphically by viewing the Figures tab.

In this example, there are four models with ΔAICc less than 2 (Figure C.19). Because models within 2 AICc points of one another can be considered equally supported by the data, the second ranked model was chosen because it is simpler; the location parameter is a function of visibility, and the scale is constant. Again, Figure C.19 shows the results for bats only; users must inspect models for each size class independently by selecting each size class from the 'Carcass Class' dropdown box.

GenEst produces, for the selected model, the parameters of the persistence distribution (location and scale parameters), the estimated carcass persistence time (medianCP) **44**, and the probability of persistence for several typical search intervals (r1, r3, r7, r14, and r28, with the numbers indicating number of days in the search interval) **45**. Ninety percent CIs for all estimates (as selected in General Analysis Inputs **15**) are reported in brackets following the point estimate. For final mortality estimation, GenEst computes a probability of persistence for each carcass based on the search interval for that search location. The user selects a final model for each size class from the Model Selection sub-tab **46**. As with the searcher efficiency models, GenEst does not automatically select the top-ranked model. The user must select the models manually.

Figure C.19 Screenshot of Analyses: Carcass Persistence: Estimates tab in the GenEst software



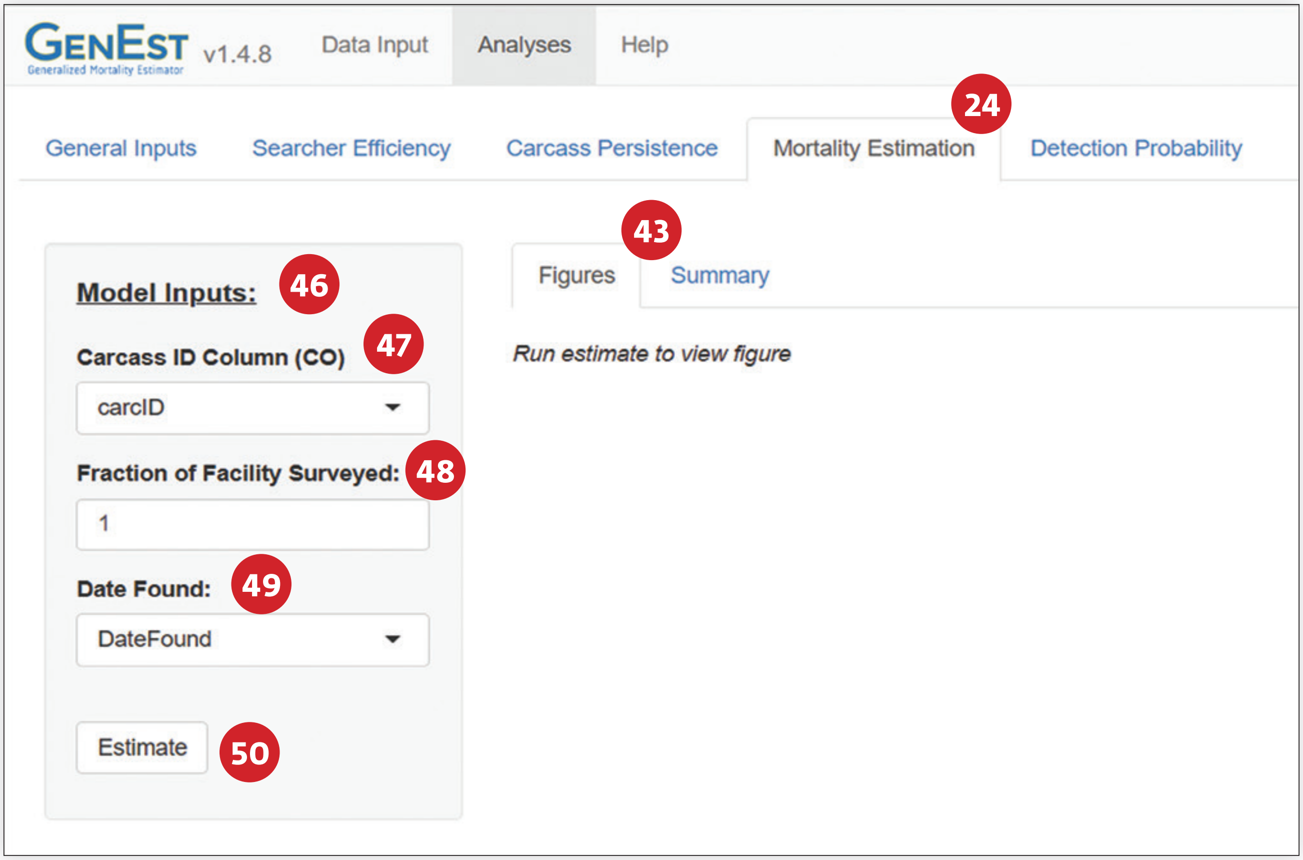
Note: This tab displays the estimates from the selected model, as described in the main text.

In summary, GenEst fits a set of models to the carcass persistence trial data, with the predictor variables of interest selected by the user. All possible models are fit and ranked according to AICc. The user then selects the model to use for mortality estimation based on AICc rank, number of parameters, graphical evaluations of model fits, and reasonableness of the model given the setting and study objectives.

Mortality Estimation

GenEst incorporates the information described above to produce fatality estimates, called Mortality Estimation in GenEst. Clicking the Analyses: Mortality Estimation 24 tab loads a screen with a window for Model Inputs 46 on the left (Figure C.20). The user must specify the column in the carcass observation data set (Figure C.11) that identifies unique carcasses, which is carcID 47 in this example, and specify the Fraction of the Facility Surveyed 48 , which is the number of turbines searched divided by the number of turbines at the facility (or sampled length of transmission line divided by total length of transmission line). For this example, a sampling fraction of 1 will be assumed, meaning that all turbines were searched. Last, the user must specify the Date Found 49 column from Figure C.11. The date found should be a column in the carcass observation data that identifies the date on which the recorded carcass was observed. The user should ensure that all dates on which a carcass was found are marked as searched (1) in the search schedule data set, or GenEst will not complete the estimate.

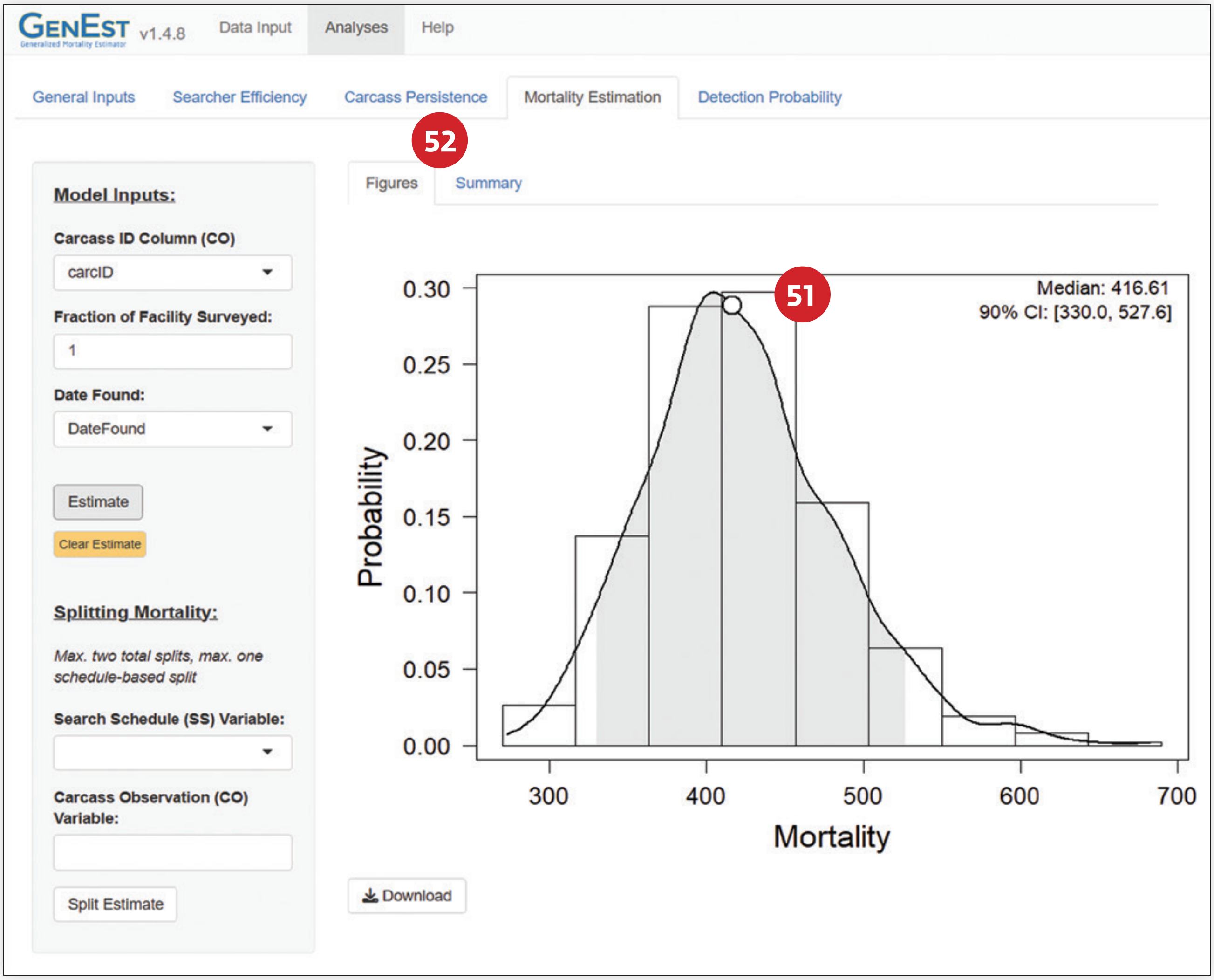
Figure C.20 Screenshot of Analyses: Mortality Estimation tab in the GenEst software



Note: The user must provide the Model Inputs, which are described in the main text.

Once the user inputs are defined, the user can click the Estimate button 50 below the inputs. The Estimate button will not appear if searcher efficiency or carcass persistence models have not been selected. The screen will then display the distribution of total estimated mortality (across all size classes) at the facility during the survey period as a graph (Figure C.21). The high point in the figure is usually near the median estimate (point estimate) 51 , and the shaded regions delimit the CIs. The bars show the histogram of the estimate distributions, and the line is a smoothed density curve of that histogram. The median and CI bounds are also displayed on the top right-hand side of the figure.

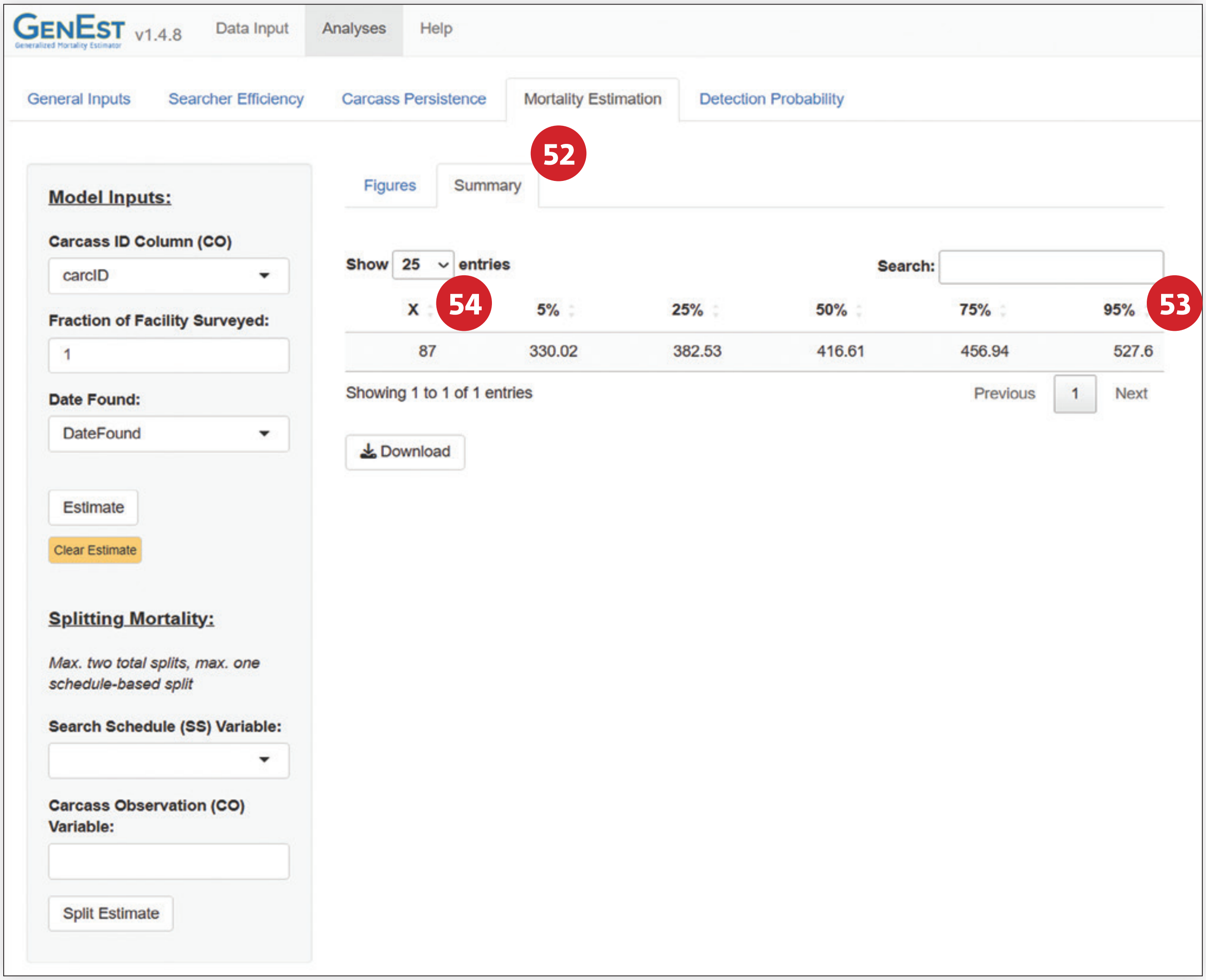
Figure C.21 Screenshot of Analyses: Mortality Estimation: Figures tab in the GenEst software



Note: This tab displays the distribution of the fatality estimate after the user clicks the Estimate button in the window on the left of the screen.

More information is contained under the Summary sub-tab 52 (Figure C.22). Specifically, GenEst reports quantiles (5%, 25%, 50%, 75%, 95% quantiles) 53 of the fatality estimate distribution and the total number of fatalities (carcasses) observed (the X column) 54. For example, the 5% column and the 95% column bound the 90% CI, yielding an estimate of 416.61 fatalities per year with 90% CI = 330.02–527.6 (same as reported on the Figures tab, although the figure reports estimates rounded to 1 decimal place). The estimate can be scaled to per-turbine units by dividing the estimate by the number of turbines at the facility or to per MW by dividing by the number of MW at the facility.

Figure C.22 Screenshot of Analyses: Mortality Estimation: Summary tab in the GenEst software



Note: This tab displays quantiles of the distribution of the estimated fatality rate.

The mortality estimate can be split into groups that the user defines. For example, GenEst can split mortality estimates according to size class in the example, yielding size-specific estimates of mortality (see Splitting Mortality in Figure C.23) 55. Practitioners will typically be interested in fatality estimates per size class. Differences among the splits will depend on the number of observed carcasses associated with each grouping and differences among the bias trial models for those groups. Estimates can also be split according to search date, species, and visibility, among other possibilities. GenEst does not provide warnings for ill-advised splits. In particular, splits resulting in groups with very few (fewer than five) carcasses may produce misleading estimates. For example, it is possible to produce an estimate for every turbine for every search date, but in many cases, this will result in a very small count of carcasses informing each estimate and unreliable estimates.

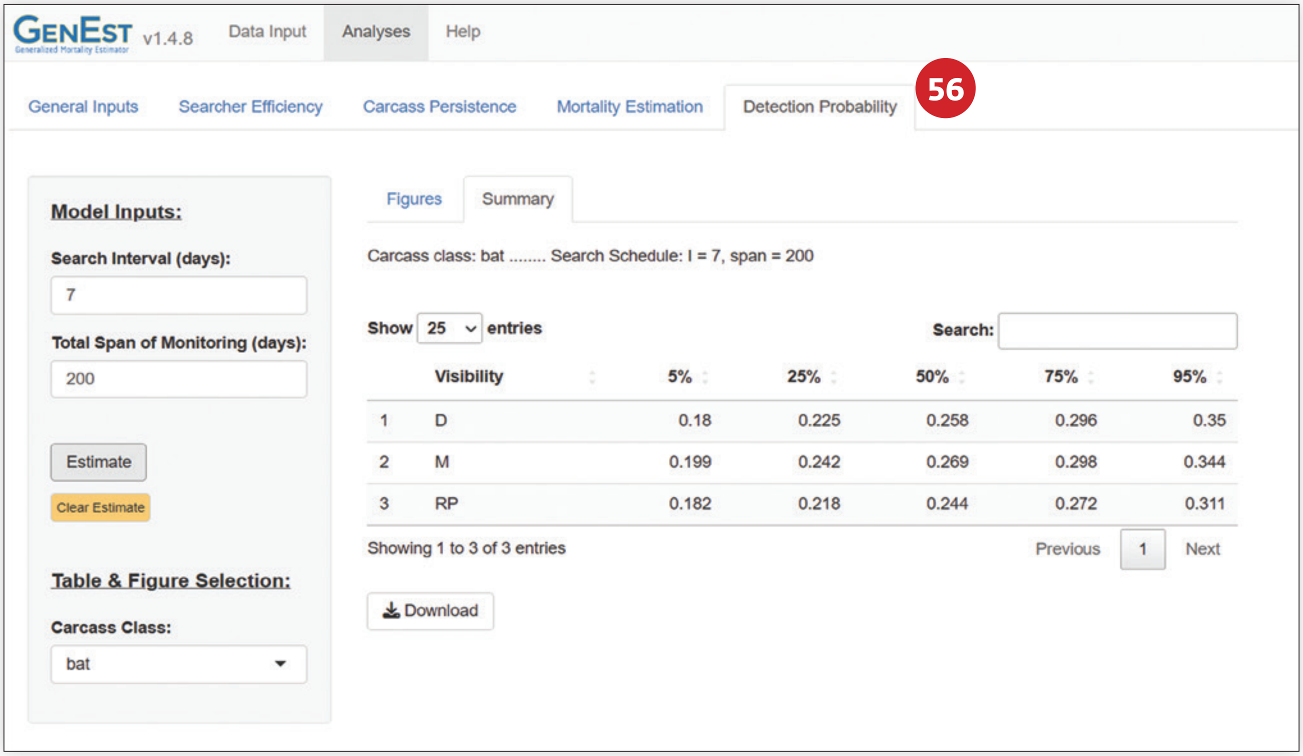
Figure C.23 Screenshot of Analyses: Mortality Estimation: Figures tab in the GenEst software after user selects to Split Mortality According to Carcass Size

In summary, GenEst uses the bias trial models and area correction values to appropriately scale observed carcass finds according to search effort (Figure C.9). GenEst returns a distribution for the estimate, yielding a point estimate and CIs. Importantly, GenEst can split the fatality estimate into relevant groups defined by the user. The CIs for fatality estimates might not be reliable if there are fewer than five carcasses and users are urged not to interpret CIs when there are fewer than five carcasses.

Detection Probability

In some cases, the user may want to report the overall Detection Probability 56 for the study, which is the probability of finding a carcass in the entire study area over a specified period of time. Essentially, the overall detection probability is the denominator of Figure 5.2 without the sampling fraction component: p × r × a. To compute overall detection probability, the user must enter search interval, total span of monitoring in days, and carcass size class (Figure C.24). The value inputted for the search interval depends on the needs of the user. Most commonly, the user will enter the average search interval over the monitoring period. The detection probability that GenEst returns can be multiplied by the sampling fraction to obtain a value that is conceptually similar to the detection probability index (DPI) discussed in Sections 3.2.4 and 4.1.3.2. The DPI is an index rather than a value calculated with data. Although conceptually similar, the DPI will not necessarily be quantitatively similar to a GenEst detection probability.

Figure C.24 Screenshot of Analyses: Detection Probability tab in the GenEst software



Note: The tab reports quantiles of the distribution of the estimate of detection probability for the specific carcass class.

APPENDIX D: DENSITY WEIGHTED PROPORTION (DWP) CALCULATION TOOL AND SEARCHER EFFICIENCY TRIAL PLACEMENT TOOL

The DWP Calculation Tool and Searcher Efficiency Trial Placement Tool is provided as a standalone MS Excel spreadsheet: ***www.ifc.org/windbirdbatmonitoring***

APPENDIX E: PCFM FATALITY RECORD FORM[1]

Project Name		**Searcher Name**	
Carcass ID Code[2]		**Turbine or OHL**[3]	
Search Year		**Search Visit Number**[4]	
Date of Search (yyyy-mm-dd)		**Time of Find** (hh:mm)	
Carcass found within the search plot? Yes ☐ **No** ☐		**Carcass found during scheduled search? Yes** ☐ **No** ☐	

Was this fatality part of a multiple fatality event? Yes ☐ **No** ☐
(e.g., flock of birds colliding with OHL or multiple bats found below one turbine)

Coordinates[5]	**Latitude** (dec.deg.)		**Longitude** (dec.deg.)	

Nearest turbine / OHL segment[6]		**Distance of fatality from turbine / OHL center line** (m)		**Bearing of the fatality from turbine**[7]	

Carcass Size Class[8]	bat ☐	small bird ☐	medium bird ☐	large bird ☐			
Carcass Completeness[9]	complete ☐	partial ☐	feather spot ☐				
Carcass Condition[10]	intact ☐	partially scavenged ☐	decomposed ☐				
Species		**Species group**[11]					
Age	adult ☐	subadult ☐	juvenile ☐	unknown ☐			
Sex	male ☐	female ☐	unknown ☐				
Eyes	round ☐	fluid-filled ☐	dehydrated ☐	sunken ☐	absent ☐	not applicable ☐	
Cause of Death[12]	unknown ☐	collision ☐	electrocution ☐	other ☐ (project related)	other ☐ (non-project related)		
Days since Death[13]	unknown ☐	0–1 ☐	2–3 ☐	4–7 ☐	8–14 ☐	15–30 ☐	>30 ☐
Visibility class where carcass found[14]	easy ☐	moderate ☐	difficult ☐	very difficult ☐			

Photograph Details[15]

Photo number	Date/Time (yyyy-mm-dd. hh:mm)	Description	Filename

Additional Notes

This data collection form is a fieldwork resource (Appendix E) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool.

Instructions for filling in the Fatality Record Form (Numbers on this page relate to numbers on the form)

1 Each fatality found requires a separate PCFM Fatality Record Form.

2 Carcass ID Code should be a unique identifier for each carcass across the whole monitoring program. The Lead Ecologist (LE) should determine the code format. The code should provide as much information about the carcass as possible without being too long. For example, "20220128_T23_HOBA_1" = date found (2022-01-28)_turbine number (T23)_species name (Hoary Bat or HOBA for short)_order found at that turbine during the search (1); if only one carcass was found, this last number will always be "1".

3 State whether the search is for a PCFM program at turbines or for an overhead power line (OHL)?

4 Give the search visit number. A search visit is a single search of all sample turbines or OHL segments. For example, if the study design is to search 20 turbines every seven days, the first search of all 20 turbines in the first seven days will be search visit 1, the second search of the same 20 turbines in the next seven days will be search visit 2. Similarly, at a WEF-associated OHL, if the study design is to search sample search plots of 10 x 5-km segments per month, the first search of plots in these 10 segments during the first month will be search visit 1, the second search of the same plots in these 10 segments in the second month will be search visit 2.

5 The fatality location coordinates (latitude and longitude [in decimal degrees]) should be determined using a Global Positioning System (GPS) device and recorded on the form.

6 Give the turbine number/ OHL segment nearest to the fatality. Each turbine should have a unique number. The LE should provide searchers with turbine numbers using those given in the project layout. OHLs should be divided into segments of equal length with each segment assigned a unique number. Segment numbers should be provided to searchers by the LE.

7 Use a compass or GPS device to obtain a descriptive bearing (north, north-east, east, south-east, south, south-west, west, north-west). This should be the bearing from the base of the turbine to the carcass not the bearing from the carcass back to the turbine. For fatalities found along OHLs give a descriptive bearing to indicate which side of the OHL the fatality was located.

8 Tick the relevant box to indicate the size class of this fatality. Size guide: small birds (<30 cm body length), medium birds (30-55 cm body length), large birds (>55 cm body length). Large fruit bats should be entered in the same size class as medium birds.

9 Tick the relevant box next to the term that best describes the completeness of the fatality. Complete = all parts of the carcass are present. Partial = only part of the carcass remains. Feather spot = feathers are the only evidence of a carcass. The minimum criteria for a feather spot is more than two connected primary wing feathers or more than 10 body feathers in proximity (within a 5 m x 5 m area [25 m^2]). Details of feathers found that do not meet this criterion can be noted in the Additional Notes section.

10 Tick the relevant box to indicate the term that best describes the overall condition of the fatality. Intact = no evidence of scavenging or decomposition. Partly scavenged = carcass has clear signs of predation but some of the carcass remains (e.g., wings) but it is likely that the carcass can be identified to a species. Decomposed = carcass has degraded beyond the point where it can be identified to a species. Note that a carcass categorized as decomposed may also have been subject to partial scavenging.

11 If the species cannot be determined, identifying the fatality to a species group (e.g., raptor or wader) may be relevant to a WEFs monitoring objectives and can be used as a covariate in the analysis. State as unknown if the species group cannot be determined.

12 Cause of death can be difficult to determine, but if there are clues to what caused the animal to die, they should be noted. **It is better to score the cause of death as unknown than to guess.**

13 Tick the relevant box to give an estimate of time of death of the fatality. Estimating time of death is difficult. Scavenging (animal or insect), environmental conditions (e.g., temperature, humidity, precipitation), size and body composition of the specimen, and other factors affect carcass condition and the speed with which carcasses decompose. The LE will review evidence (carcass condition, photographs, completed PCFM Fatality Record forms) from fatalities found during the study to improve time of death estimates. Carcass persistence trial decomposition rates should also be used to increase the accuracy of time of death estimates.

14 Tick the relevant box to indicate the ground surface visibility class where the fatality was found. The LE should ensure that definitions for each visibility class used on the site are provided to searchers.

15 At least five photographs should be taken of the fatality. Carcasses (including feather spots) should be photographed: i) as found, taken from directly above, ii) turned over to show the ground-facing side, iii) from different angles to show any features that may help with identification (e.g., head, wings, tail, feet), iv) showing any injuries, v) showing the area immediately surrounding the fatality (e.g., relative to the nearest turbine / OHL). All photographs should have a size reference (e.g., ruler) and the carcass ID number either written on a white board or sheet of paper. When taking digital photographs, the photo number, date, and time can be made visible in the camera viewfinder. Record this information to assist in associating the carcass with the photograph. Photographs should be saved and stored using the Carcass ID Code (see 2 above) as the file name. Using the example in 2 above, photographs would have file names 20220128_T23_HOBA_1.1, 20220128_T23_HOBA_1.2.

This data collection form is a fieldwork resource (Appendix E) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool.

APPENDIX F: SEARCH SUMMARY FORM[1]

Project Name		**Searcher Name**	
Search visit type[2]	Turbine ☐ OHL ☐	**Search Visit Number[3]**	

Turbine number / OHL segment[4]	**Scheduled search date[5]** (yyyy:mm:dd)	**Searched**	**Not searched[6]**	**Number of fatalities found** (enter 0 if none found)	**Number of searcher efficiency trials found** (enter 0 if none found)	**Carcass ID code(s)[7]**	**Additional notes** (e.g., reasons for no search, weather)
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
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		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				
		☐	☐				

This data collection form is a fieldwork resource (Appendix F) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool.

Instructions for filling in the Search Summary Form (Numbers on this page relate to numbers on the form)

1. The Lead Ecologist (LE) should provide each searcher with a Search Summary form at the beginning of each search visit. A separate Search Summary form should be used for turbine search visits and for overhead power line (OHL) segment search visits. See 3 below for search visit definition.
2. Tick the box to indicate whether the Search Summary form relates to a turbine search visit or an OHL search visit.
3. Give the search visit number. A search visit is a single search of all sample turbines or OHL segments. For example, if the study design is to search 20 turbines every seven days, the first search of all 20 turbines in the first seven days will be search visit 1, the second search of the same 20 turbines in the next seven days will be search visit 2. Similarly, at a WEF-associated OHL, if the study design is to search sample search plots of 10 x 5-km segments per month, the first search of plots in these 10 segments during the first month will be search visit 1, the second search of the same plots in these 10 segments in the second month will be search visit 2.
4. Give the turbine number/ OHL segment searched. Each turbine should have a unique number. The LE should provide searchers with turbine numbers using those given in the project layout. OHLs should be divided into segments of equal length with each segment assigned a unique number. Segment numbers should be provided to searchers by the LE.
5. Give the scheduled search date for the turbine/OHL segment.
6. Tick the "Not Searched" box if it was not possible to search the plot on the scheduled searched date. Give reasons in the "Additional notes" column.
7. Give all Carcass ID codes of fatalities found.

This data collection form is a fieldwork resource (Appendix F) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool.

APPENDIX G: SEARCHER EFFICIENCY (SE) TRIAL FORM[1]

Project Name		**Trial Administrator Name**[2]	
SE Trial Carcass ID Code[3]		**Carcass ID Code**[4]	
Season[5]		**PCFM Type**[6]	Turbine ☐ OHL ☐
Date of Search (yyyy-mm-dd)		**Time of Find** (hh:mm)	

Start Trial-Period (yyyy-mm-dd)		**End Trial-Period** (yyyy-mm-dd)		**Date Placed** (yyyy-mm-dd)		**Time Place** (hh:mm)	

Nearest turbine / OHL segment[7]		**Distance of fatality from turbine / OHL center line** (m)		**Bearing of the trial from turbine**[8]	

Coordinates[5]	**Latitude** (dec.deg.)		**Longitude** (dec.deg.)	

Trial Size Class[10]	bat ☐	small bird ☐	medium bird ☐	large bird ☐
Trial Type[11]	WEF Fatality ☐	surrogate ☐	decoy ☐	

Trial Details[12]	Species/group[11]		Decoy description	

Visibility class at placement site[13]	easy ☐	moderate ☐	difficult ☐	very difficult ☐

Trial Marking[14]	

Trial Results[15]

Attempt	Search Date	Found ?	Available?
1		Yes ☐ No ☐	Yes ☐ No ☐
2		Yes ☐ No ☐	Yes ☐ No ☐
3		Yes ☐ No ☐	Yes ☐ No ☐
4		Yes ☐ No ☐	Yes ☐ No ☐

SE trial used for carcass persistence (CP) trial?[16]	Yes ☐ No ☐	**CP Carcass Trial ID Code**[17]	

Photograph Details[18]

Photo number	Date/Time (yyyy-mm-dd. hh:mm)	Description	Filename

Additional Notes

This data collection form is a fieldwork resource (Appendix G) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool. Cross-references on the instruction sheet are related to sections and appendices in this document.

Instructions for filling in Searcher Efficiency (SE) Trial Form (Numbers on this page relate to numbers on the form)

1 Each trial carcass, surrogate, or decoy requires a separate Searcher Efficiency Trial Form.

2 The trial administrator, usually the Lead Ecologist (LE) places searcher efficiency trial carcasses in the field before searchers arrive for a search and confirms trial carcass availability after the search if surveyors do not find them. **The trial administrator must not be a searcher because searchers must not be aware of the timing and location of searcher efficiency trials.**

3 Each SE trial carcass/decoy should be assigned its own unique identification (ID) code. For example, "SE_20220215_BAT_1" = Searcher Efficiency Trial (SE)_Date Placed (2022-02-15)_Size Class (BAT)_Size Class Trial Carcass Number (1).

4 If the carcass was originally a fatality found at the site, give the Carcass ID Code previously assigned on the Fatality Recording Form (e.g., 20220128_T23_HOBA_01), otherwise leave this box blank.

5 "Season" is defined based on climate, (e.g., summer, autumn, winter, spring; rainy (monsoon), dry) or according to ecological or biological factors (e.g., migration periods, breeding, or non-breeding season). Before trials, these seasons must be defined with start and end dates.

6 Tick the relevant box to indicate whether the trial is for a PCFM program at turbines or for an overhead power line (OHL).

7 Give the turbine number/ OHL segment nearest to the trial. Each turbine will have a unique number. The LE should provide the trial administrator with turbine numbers using those given in the project layout. OHLs should be divided into segments of equal length with each segment assigned a unique number. Segment numbers should be provided to the trial administrator by the LE.

8 Use a compass or Global Positioning System (GPS) device to obtain a descriptive bearing i.e. (north, north-east, east, south-east, south, south-west, west, north-west). This should be the bearing from the base of the turbine to the carcass not the bearing from the carcass back to the turbine. For OHL SE trials, give a descriptive bearing to indicate which side of the OHL the trial was placed.

9 Trial locations must be determined using the Searcher Efficiency Trial Placement Tool (see Appendix D). The trial administrator will navigate to each pre-determined location and place the trial. Once the trial is placed, the actual location coordinates (latitude and longitude [in decimal degrees]) should be determined using a GPS device and recorded on this form.

10 Tick the relevant box to indicate the size class of this trial. Size guide: small birds (<30 cm body length), medium birds (30-55 cm body length), large birds (>55 cm body length). If large fruit bats are used, these should be entered in the same size class as medium birds.

11 Tick the relevant box to indicate the type of trial carcass used. Actual collision fatalities should be used in searcher efficiency trials when available and feasible. (See Box 3.5 for details on suitable surrogates and decoys).

12 State the species or if not known a more general grouping, e.g., vulture, raptor. For decoys briefly describe e.g., rubber bat, duck decoy.

13 Tick the relevant box to indicate the ground surface visibility class where the trial was placed. This should be consistent with the defined visibility classes that the Lead Ecologist has mapped.

14 Briefly describe the trial marking. Trial carcasses should be discreetly marked so that they can be distinguished from actual fatalities. Markings should be discrete but unmistakable, such as with a small length of electrical tape around a foot or clipped flight feathers (see Appendix B).

15 Fill in details of each search attempt in the table. If the SE trial design only allows one attempt to find the trial leave the other rows blank. After the first search, the trial administrator must check whether the carcass, surrogate, or decoy is still present and therefore was 'available' to be found by the searcher. If the carcass, surrogate, or decoy is no longer visible at the placement location, the trial will not be included in the searcher efficiency trial. If the searcher efficiency bias trial design allows multiple opportunities to search for a carcass, surrogate, or decoy, the trial administrator must check that they are still 'available' to be found after each search event. Decomposed carcasses should not be used for subsequent search attempts.

16 Intact carcasses used for SE trials may be left to test carcass persistence. State if the SE trial was subsequently used for this purpose.

17 If the SE trial is used as a carcass persistence trial, it should have a dedicated Carcass Persistence Form with a CP Carcass ID code assigned. Provide the CP Carcass ID code on this form as a cross reference.

18 For record keeping, at least two photographs of the trial carcass/decoy at the time of placement showing its location should be taken. When taking digital photographs, the photo number, date and time can be made visible in the camera viewfinder. Record this information to assist in associating the trial with the photograph. Photographs should be saved and stored using

19 the SE Trial ID Code as the file name (see 4 above). Using the example in 4 above, two photographs would have file names. SE_20220215_BAT_1.1, SE_20220215_BAT_1.2.

This data collection form is a fieldwork resource (Appendix G) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool. Cross-references on the instruction sheet above are related to sections and appendices in this document.

APPENDIX H: CARCASS PERSISTENCE (CP) TRIAL FORM[1]

Project Name		**Trial Administrator Name**[2]	
CP Trial Carcass ID Code[3]		**Carcass ID Code**[4]	
Season[5]		**PCFM Type**[6]	Turbine ☐ OHL ☐

Start Trial-Period (yyyy-mm-dd)		**End Trial-Period** (yyyy-mm-dd)		**Date Placed** (hh:mm)		**Time Place** (hh:mm)	

Nearest turbine / OHL segment[7]		**Distance of trial from turbine / OHL center line** (m)		**Bearing of the trial from turbine**[8]	

Coordinates[5]	**Latitude** (dec.deg.)		**Longitude** (dec.deg.)	

Trial Size Class[10]	bat ☐	small bird ☐	medium bird ☐	large bird ☐
Trial Type[11]	WEF Fatality ☐	surrogate ☐		
Trial Details[12]	Species/group[11]			
Visibility class at placement site[13]	easy ☐	moderate ☐	difficult ☐	very difficult ☐
Trial Marking[14]				
Condition of carcass at time of placement[15]	fresh ☐	thawed ☐		

Check Day[16]	**Check Date**[17] (mm:dd)	**Check Time** (hh:mm)	**Carcass Completeness**[18]	**Carcass Condition**[19]	**Photo Numbers**[20]	**Checked by**	**Notes**

Additional Notes

This data collection form is a fieldwork resource (Appendix H) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool. Cross-references on the instruction sheet are related to sections and appendices in this document..

Instructions for filling in Carcass Persistence (CP) Trial Form (Numbers on this page relate to numbers on the form)

1 Each trial carcass and surrogate requires a separate Carcass Persistence Trial Form

2 The trial administrator, usually the Lead Ecologist (LE) is responsible for placing trials and ensuring that they are checked at the prescribed intervals (see 16 below).

3 Each CP trial carcass should have its own unique identification (ID) code. For example, "CP_20220215_BAT_1", = Carcass Persistence Trial (SE)_Date Placed (2022-02-15)_Size Class (BAT)_Size Class Trial Carcass Number (1)

4 If the carcass was originally a fatality found at the site, give the Carcass ID Code previously assigned on the Fatality Recording Form (e.g., 20220128_T23_HOBA_01), otherwise leave this box blank.

5 "Season" is defined based on climate, (e.g., summer, autumn, winter, spring; rainy (monsoon), dry) or according to ecological or biological factors (e.g., migration periods, breeding, or non-breeding season). Before trials, these seasons must be defined with start and end dates.

6 Tick the relevant box to indicate whether the trial is for a PCFM program at turbines or for a PCFM at an overhead power line (OHL).

7 Give the turbine number/ OHL segment nearest to the trial. Each turbine will have a unique number. The LE should provide the trial administrator with turbine numbers using those given in the project layout. OHLs should be divided into segments of equal length with each segment assigned a unique number. Segment numbers should be provided to the trial administrator by the LE.

8 Use a compass or Global Positioning System (GPS) device to obtain a descriptive bearing i.e. (north, north-east, east, south-east, south, south-west, west, north-west. This should be the bearing from the base of the turbine to the carcass not the bearing from the carcass back to the turbine. For OHL CP trials, give a descriptive bearing to indicate which side of the OHL the trial was placed.

9 Record trial location coordinates (latitude and longitude [in decimal degrees]) from a GPS device.

10 Tick the relevant box to indicate the size class that is relevant to this trial. Size guide: small birds (<30 cm body length), medium birds (30-55 cm body length), large birds (>55 cm body length).

11 Tick the relevant box to indicate the type of trial carcass used. Actual collision fatalities should be used in carcass persistence trials when available, fresh and feasible. (See Box 3.5 for details on suitable surrogates).

12 State the species or if not known a more general relevant grouping, e.g., vulture, raptor.

13 Tick the relevant box to indicate the ground surface visibility class where the trial was placed. This should be consistent with the defined visibility classes that the LE has mapped.

14 Trial carcasses should be discreetly marked so that they can be distinguished from actual fatalities (see Appendix B).

15 Tick the relevant box to indicate the condition of the carcass at time of placement. Carcass persistence trials should use fresh carcasses or thawed carcasses that were frozen when fresh and stored frozen until use.

16 Enter the scheduled check day. At a minimum CP trial should be checked 1, 2, 3, 4, 7, 14, 21, and 30 days after they are placed (see details in Appendix B).

17 The "Check Date" column should always give the date that the carcass was actually checked. For example, if it was not possible to check a carcass on day 30 but it was checked a day later, the date given in the "Check Date" column should be the date on Day 31, and not the scheduled date i.e., Day 30.

18 Assign one of the following carcass completeness categories. Complete = all parts of the carcass are present. Partial = only part of the carcass remains. Feather spot = feathers are the only evidence of a carcass. The minimum criteria to be defined as a feather spot are more than two connected primary wing feathers or more than 10 body feathers found in proximity (within a 5 m x 5 m area [25 m^2]).

19 Assign one of the following carcass condition categories. Intact = no evidence of scavenging or decomposition. Partly scavenged = carcass has clear signs of predation but some of the carcass remains (e.g., wings). Decomposed = carcass has degraded beyond the point where it can be identified to a species. Note that a carcass categorized as decomposed may also have been subject to partial scavenging.

20 For record keeping, at least two photographs of the carcass and its location should be taken. When taking digital photographs, the photo number can be made visible in the camera viewfinder. Record this information to assist in associating the trial with the photograph. Photographs should be saved or stored using the Carcass Trial ID Code (see 4 above) as the file name. Using the example in 4, above, photographs would have file names CP_20220128_BAT_1.1, CP_20220128_BAT_1.2.

This data collection form is a fieldwork resource (Appendix H) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool. Cross-references on the instruction sheet above are related to sections and appendices in this document.

APPENDIX I: CARCASS FREEZER TAGS[1]

Project Name		**Carcass ID Code[2]**		**Searcher[3]**	
Carcass Source	systematic search ☐	chance find ☐	trial surrogate ☐		
Carcass Size Class[4]	bat ☐	small bird ☐	medium bird ☐	large bird ☐	
Date Stored		**Stored by[5]**		**Turbine/OHL Segment[6]**	

Project Name		**Carcass ID Code[2]**		**Searcher[3]**	
Carcass Source	systematic search ☐	chance find ☐	trial surrogate ☐		
Carcass Size Class[4]	bat ☐	small bird ☐	medium bird ☐	large bird ☐	
Date Stored		**Stored by[5]**		**Turbine/OHL Segment[6]**	

Project Name		**Carcass ID Code[2]**		**Searcher[3]**	
Carcass Source	systematic search ☐	chance find ☐	trial surrogate ☐		
Carcass Size Class[4]	bat ☐	small bird ☐	medium bird ☐	large bird ☐	
Date Stored		**Stored by[5]**		**Turbine/OHL Segment[6]**	

Project Name		**Carcass ID Code[2]**		**Searcher[3]**	
Carcass Source	systematic search ☐	chance find ☐	trial surrogate ☐		
Carcass Size Class[4]	bat ☐	small bird ☐	medium bird ☐	large bird ☐	
Date Stored		**Stored by[5]**		**Turbine/OHL Segment[6]**	

Instructions for filling in Carcass Freezer Tags (Numbers on this page relate to numbers on the form)

1. Each carcass requires its own tag. This form contains five tags that can be cut along the dotted lines. Before storing carcasses in the freezer, double bag each one, with the carcass tag placed in between the two bags. It is preferable that the outer bag is clear and the tag be placed so that it is readable without having to open any bags
2. If the carcass was a fatality found during PCFM searches at the project, provide the Carcass ID Code assigned to this fatality. If the carcass is a trial surrogate leave blank.
3. If the carcass was a fatality found during PCFM searches at the project, give the name of the searcher who recorded the fatality. Otherwise leave blank.
4. Tick the relevant box to indicate the size class of the carcass. Size guide: small birds (<30 cm body length), medium birds (30-55 cm body length), large birds (>55 cm body length). If large fruit bat carcasses are found, they should be entered in the same size class as medium birds.
5. Give the name of the person who stored the carcass in the freezer.
6. For fatalities found during systematic searches or as chance finds within search plots give the turbine number or OHL segment where the fatality was found.

This data collection form is a fieldwork resource (Appendix I) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool.

APPENDIX J: FREEZER CONTENTS LOG

Project Name		

Date Stored	Carcass ID Code[1]	Project Fatality	Bias Trial Surrogate	Surrogate Source[2]	Carcass Size Class[3]	Species/ Group[4]	Carcass Completeness[5]	Carcass Condition[6]
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					
		☐	☐					

Instructions for filling in Freezer Contents Log (Numbers on this page relate to numbers on the form)

1 For fatalities found during PCFM searches at the project give the Carcass ID code from the Fatality Record Form (Appendix E). For trial surrogates leave blank.

2 For trial surrogates state the source of the carcass e.g. road kill. For other carcasses leave blank.

3 Give the size class of the carcass. Size guide: small birds (<30 cm body length), medium birds (30-55 cm body length), large birds (>55 cm body length). Large fruit bats should be entered in the same size class as medium birds.

4 State the species or if not known a more general relevant grouping, e.g., vulture, raptor.

5 For project fatalities assign the carcass completeness category given on the Fatality Record form (Appendix E). For surrogates leave blank.

6 For project fatalities assign the carcass condition category given on the Fatality Record form (Appendix E). For surrogates leave blank.

This data collection form is a fieldwork resource (Appendix J) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool. Cross-references on the instruction sheet above are related to sections and appendices in this document.

APPENDIX K: ESSENTIAL FIELDWORK EQUIPMENT

- ☐ **Field binder** file containing:
  - ☐ **Health and safety plan** and **risk assessment and protocol**, including details on an emergency response plan; next-of-kin contact for each team member; and name, address, and phone number of nearest hospital
  - ☐ **Injured animal handling protocol**, including name, address, and phone number of nearest wildlife rehabilitation center or veterinary clinic (if such a facility exists nearby)
  - ☐ **Relevant training certificates** or copies of the same
  - ☐ **Multiple copies of data collection forms**, including:
    - ☐ Fatality Recording Form (Appendix E)
    - ☐ Search Summary Form (Appendix F)
    - ☐ Searcher Efficiency Trial Form (Appendix G)
    - ☐ Carcass Persistence Trial Form (Appendix H)
    - ☐ Carcass Freezer Tags (Appendix I)
    - ☐ Freezer Contents Log (Appendix J)
  - ☐ **Guide for codes** used in data entry
  - ☐ **Species list** (highlighting PCFM target species) with descriptions and photographs or illustrations
  - ☐ **Copies of any required permits** (e.g., collection and handling of dead specimens, transport of carcasses)
- ☐ **Personal Protective Equipment** (PPE) prescribed by wind energy facility or Lead Ecologist
- ☐ **First aid kit**
- ☐ **Vehicle emergency kit**
- ☐ **Communication device** (cell phone, two-way radio or satellite phone)
- ☐ **Drinking water** (at least 5 liters)
- ☐ **Food**
- ☐ **Sunscreen**
- ☐ **Camera**
- ☐ **Whiteboard and wipeable marker** to display Carcass ID Code in fatality photos
- ☐ **Global Positioning System (GPS) device**
- ☐ **Compass**
- ☐ **Ruler**
- ☐ **Clipboard** (for use with data collection forms)
- ☐ **Pens or pencils** for completing data collection forms
- ☐ **Permanent or freezer marker pens**
- ☐ **Gloves** for handling carcasses (leather and nitrile)
- ☐ **Scissors** or nail clippers and tape for marking trial carcasses
- ☐ **Sealable clear plastic bags** of various sizes
- ☐ **Marking tape or labels** for freezer bags

Other Fieldwork Equipment that may be needed

- ☐ **Electronic tablet** for recording data electronically
- ☐ **Rangefinder**
- ☐ **Calipers** if more accurate forearm length measurements of bats are required
- ☐ **Containers for fatalities collected as voucher specimens and for DNA samples** (e.g., Ziploc bags, vials, ethanol)
- ☐ **Motion sensor camera** for carcass persistence monitoring
- ☐ **Insect repellent**

This checklist is a fieldwork resource (Appendix K) provided in IFC 2023. Post-construction Bird and Bat Fatality Monitoring for Onshore Wind Energy Facilities in Emerging Market Countries. Good Practice Handbook and Decision Support Tool.

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