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January 24, 2018

Ms. Barcy F. McNeal, Secretary
Ohio Power Siting Board
Docketing Division
180 East Broad Street, 11th Floor
Columbus, Ohio 43215-3793

Re: Case No. 16-1871-EL-BGN, In the Matter of the Application of Icebreaker Windpower Inc. for a Certificate to Construct a Wind-Powered Electric Generation Facility in Cuyahoga County, Ohio.

Response to October 23, 2017 Entry and Request from Staff.

Dear Ms. McNeal:

On February 1, 2017, as supplemented, Icebreaker Windpower Inc. ("Applicant") filed an application with the Ohio Power Siting Board ("OPSB") for a certificate of environmental compatibility and public need for the Icebreaker Project to be located in Lake Erie eight miles off the shore of Cleveland, Ohio in Cuyahoga County ("Application"). On August 15, 2017, the Administrative Law Judge ("ALJ") established the procedural schedule in this case.

On October 23, 2017, the OPSB Staff ("Staff") filed a motion to suspend the procedural schedule requesting that the Applicant provide supplemental information relating to the pre-construction radar technology monitoring. The specific information requested by Staff was the "recommendation on the viability and precise design of any pre-construction radar" from a large four-point anchor vessel, which was to be provided by Dr. Robb Diehl ("Diehl Report"). The ALJ granted Staff's motion on October 23, 2017.

In accordance with the October 23, 2017 Entry and as requested by Staff, attached is the final Diehl Report dated December 22, 2017.

We are available, at your convenience, to answer any questions you may have.

Respectfully submitted,

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CERTIFICATE OF SERVICE

The Ohio Power Siting Board's e-filing system will electronically serve notice of the filing of this document on the parties referenced in the service list of the docket card who have electronically subscribed to these cases. In addition, the undersigned certifies that a copy of the foregoing document is also being served upon the persons below this 24th day of January, 2018.

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Evaluation of Icebreaker Wind project vendor proposals for radar-based monitoring of flying animals

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Prepared for:

Lake Erie Energy Development Corporation (LEEDCo)

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December 2017

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I. Executive Summary

This report evaluates different radar data collection options proposed by vendors responding to a Lake Erie Energy Development Corporation request for information in relation to a wind energy facility, the Icebreaker Wind project, proposed for western Lake Erie. The evaluation considers five vendor options proposed by three vendors, here referred to as VendorA, VendorB, and VendorC, and is based on 15 different criteria and informed by a variety of radar-related concepts. Among the most important criteria are concern over the ability to gather data on altitude-specific migration traffic rate or density and behavioral response to turbine presence (pre- versus post-construction), and the ability do so with high reliability while avoiding contamination by clutter, primarily from insects and the lake surface. The evaluation was based solely on the ability of these systems to provide useful data toward the goal of understanding the biology of the airspace under review; no consideration was given to vendor cost estimates.

Initial examination of these criteria narrowed the field to two options referred to as VendorA and VendorC (Option2). For reasons expanded upon below, VendorA proposed the approach most likely to succeed among vendor responses and other information provided that forms the basis of this evaluation. This should not be taken to mean VendorA's approach is not without concern, particularly over the ability to track targets in an offshore setting where sea clutter will likely pose a persistent problem that is magnified by a rolling and pitching barge.

Owing to perceived shortcomings of vendor responses, the report concludes by seeking to identify an approach to address the challenge of monitoring vertebrate behavior in an offshore setting that would increase the likelihood of gathering useful data. For this reason, I suggest numerous modifications to VendorA's approach. I also suggest a couple alternative radar configurations that represent advances or variations on some of the vendor design options that may increase the likelihood of gathering useful data in an offshore setting.

II. Introduction

This opinion is offered to inform on how pre- and post-construction biological radar data is gathered in relation to the offshore Icebreaker Wind project proposed for an area within Lake Erie approximately 14 km northwest of Cleveland, Ohio. The report evaluates five vendor options to the Lake Erie Energy Development Corporation (LEEDCo) Request for Information (RFI) from three separate vendors referred to here as VendorA, VendorB, and VendorC. The number of options is necessarily constrained by the limited number of vendor responses, and one wonders what radar configurations might be available from other vendors and whether they might represent more suitable solutions. Although the vendor proposals considered here are specific to this case, certain aspects of the evaluation may have application in other settings.

Among other things, the best radar solutions will minimize ambiguity on the identity of the targets while simultaneously gathering the most accurate data on target altitude and lateral position. The kinds of radar units that come closest to that capability, portable tracking radars (Larkin and Diehl 2012), are rare in biological circles (to my knowledge there are three in the world), because they are costly to acquire and challenging to maintain. Therefore, most studies of this type necessarily make compromises owing to the limits of readily available and affordable technology, and an evaluation of this kind necessarily examines those trade-offs.

The evaluation is narrowly defined. Documents reviewed for this opinion include the LEEDCo RFI, all vendor responses to the RFI, vendor responses to US Fish and Wildlife Service (USFWS) questions, USFWS suggested study characteristics, the WEST, Inc review of RFI responses, and some LEEDCo application figures and exhibits. The report is also informed by discussions with LEEDCo/WEST and biologists within the USFWS. The evaluation was based solely on the ability of these systems to provide quality data toward the goal of understanding the biology of the airspace under review; no consideration was given to vendor cost estimates. Also, this is strictly a technical evaluation of remote sensing equipment (radar) that in no way endorses any specific vendor or takes a position on the proposed wind development itself.

The radar hardware available for these studies consists of repurposed commercial-off-the-shelf (COTS) marine-grade units commonly used for navigation by ships of varying sizes. Although companies deploying these units make at best modest changes to radar hardware (usually the antenna), they often develop sophisticated software processing capabilities to better accommodate the biological mission of these radars. Often the details of post-processing algorithms and the extent to which their performance has been assessed against verified datasets are not known as they are considered trade secrets. As such, I am in a poor position to evaluate certain claims made by vendors about their software capabilities (e.g., target discrimination) except where those claims intersect with the more evident capabilities of their hardware. I am also not evaluating non-radar remote sensing technologies or other forms of data collection that might inform on metrics relevant to this wind facility (e.g., methods for detecting and quantifying animal-rotor impacts in offshore settings).

It is recognized that this report may be received as guidance concerning radar data collection in relation to other wind energy projects. Caution in this regard is advised. The concepts discussed here may not apply elsewhere, since environmental, biological, and geographical circumstances vary from project to project. Also, as with all technologies, advances in hardware and software capabilities are expected that should improve airspace monitoring. With this in mind, I follow my conclusions by offering some alternative approaches for radar data collection that may improve on some of the shortcomings present among vendor proposals. In this way, the report attempts, however modestly, to live beyond its immediate suggestions regarding current vendor capabilities.

III. Basis for Evaluation

The LEEDCo RFI calls for study seasons generally consistent with the timing of passerine migration; in fall from 15 August to 31 October, and in spring from 15 April to 31 May. Knowing the primary biological targets of interest, small migratory songbirds and bats (hereafter “vertebrates” except where otherwise appropriate), is relevant to the evaluation, since the efficacy of proposed radar design and operational characteristics varies depending on the animals under consideration. As for larger birds, aerial surveys will map diurnal waterbird distributions. However, waterbirds may be diurnal or nocturnal migrants and subject to the same vulnerabilities as the smaller vertebrates that are the focus of this study. The study design should consider expanding current field seasons to include dates associated with migrating waterbirds. Viable radar operation, data collection, and reporting as described by vendors are evaluated based on the following criteria. These are coded respectively by topic (O#, D#, R#) for reference later in the report.

a. Operation

- O1. Operation overseen by trained or experienced technicians
- O2. Data collection monitored by on-site personnel or remotely monitored to ensure continuous operation with minimal interruption during study periods
- O3. Hardware suitably armored against harsh environment conditions
- O4. Radar setting sufficient to allow threshold levels (≥80%, as specified in the RFI) of reliable data collection with minimal impact from sea clutter and other sources of motion-based noise

b. Data collection

- D1. Automated and continuous operation during the study period with data collection occurring during ≥80% of the study period where precipitation does not obscure data (in two-radar systems, this threshold applies to both radars individually since they gather complementary data). Data collection occurs throughout the diel without bias, or with bias in favor of periods when vertebrate movement is at a low ebb.
- D2. Radars capable of gathering data on sufficient numbers of vertebrates to produce a statistically reliable estimate of key behaviors with hourly or better temporal resolution
- D3. Methods of target recognition minimize the presence of insects while maximizing the inclusion of vertebrates in resulting datasets

D4. Data gathered on target direction, ground speed, and altitude; not necessarily on the same individual

D5. Noise mitigation sufficient to cope with a highly dynamic clutter environment that includes aircraft, sea clutter, and other non-target sources of radar echo

D6. Horizontal and vertical range capabilities of radars sufficient to capture vertebrate movements over an area representative of the scale of the proposed development, especially with respect to the rotor swept area

D7. Radar observations supported by collection of on-site weather information that includes data on wind speed and direction, temperature, and air pressure with high temporal resolution

D8. Use of the same system, approach, and setting for both pre- and post-construction studies to help ensure data comparability

c. Reporting

R1. Altitude-specific traffic rate and/or density and ability to detect evidence of avoidance/attraction behavior in post-construction studies

R2. Methods of quantification account for sources of variation (i.e., detection probability which is a function of sample volume, gain, radar cross-section (RCS), wavelength) which could introduce bias in traffic rate or density estimates, coverage, or other metrics

R3. Study reports provide a clear presentation of results and fully describe methodological approaches

IV. Supporting Concepts

The Basis for Evaluation (III) considers a range of technical issues associated with radar-based data collection on the detection and behavior of flying animals. Below I briefly review some of the topics taken into account in considering vendor proposals. Because many trade-offs exist among the various topics, I cross-reference between topics where appropriate.

a. Antennas

Two different types of antennas are proposed among the vendor responses to the RFI. Open-array antennas, also referred to as a T-bar antennas, are usually COTS antennas that produce a non-radially symmetric fan beam pattern. Operating in the horizontal plane, open-array antennas produce a 'narrow' yet 'tall' beam pattern that generally produces moderate gain. By contrast, parabolic antennas produce a usually narrow radially symmetric beam pattern, sometimes referred to as a pencil beam.

There are trade-offs to these antennas for biological applications. Open-array antennas are generally capable of covering much larger airspaces in a single sweep and require no or little hardware modification. This may leave them more susceptible to gathering data on >1 target within a single sample volume, which can complicate target identity and tracking though this is usually a minor concern. Use of parabolic antennas in biological portable radar work has a long history (e.g., Bruderer and Steidinger 1972). Relatively few radar operations outside academia deploy radars refit to accept parabolic antennas, presumably owing primarily to differences in the nature of their use. They generally sweep out smaller airspaces which may be a disadvantage in circumstances where rapid comprehensive coverage is considered necessary (e.g., airport monitoring for large birds). Parabolic antennas produce a relatively discrete beam pattern and concentrate radio energy in ways that often produce considerable gain. Gain varies with the diameter of the antenna, radar wavelength (IV.h), and RCS of the target (IV.g), and higher gain enables radar sampling at longer ranges than open-array antennas, all else being equal. They also possess much greater ability to locate flying animals in 3-dimensional space, a capability open-array antennas cannot reliably claim.

Depending on the nature of their deployment, antenna types differ in their susceptibility to sea clutter, but all are susceptible (IV.c). COTS open-array antennas operating in the horizontal plane are highly susceptible to sea clutter. Clutter persists even when these antennas are angled in an attempt to elevate the base of the radar beam above the sea surface. The same antennas rotating in the vertical plane are susceptible to clutter when sweeping through the horizon and from ~90° side lobes. Parabolic antennas operating at low elevation are also highly susceptible to sea clutter owing to the presence and impact of side lobes that may themselves have appreciable gain (e.g., Skolnik 1980, pg. 224). The discrete beam pattern of parabolic antennas allows them to be elevated above the horizon so as to potentially avoid some of the impacts from sea clutter. In this way (and not necessarily in relation to target ‘tracking’) either an open-array antenna rotating in the vertical plane or a parabolic antenna considerably elevated above the horizon may be less susceptible to sea clutter and the movement of a floating platform (IV.e) than an open-array antenna operating in the horizontal plane.

b. Aspect

All radar operations will be influenced by aspect, or body orientation with respect to the radar whereby flying animals are more readily detected side-on than head- or tail-on. The extent that aspect impacts quantification by radar varies depending on a variety of factors, not least the manner of data collection and the degree that movements of flying animals exhibit shared orientation. Data on the heights of flying animals gathered by open-array antennas rotating in the vertical plane may be susceptible to variation in body orientation in ways that may impact quantification. When the vertical plane of rotation is parallel to the general direction of movement, flying animals produce long track lengths. However, detection probability decreases on the horizons, since animals detected head- or tail-on produce a smaller RCS. The effect may be particularly acute at S-band if animals detected head- or tail-on become weak Rayleigh scatterers (e.g., Drake and Reynolds 2012, pg. 52). Alternatively, if the plane of rotation is perpendicular to the general direction of animal movement, the radar detects animals side-on throughout its rotation, and the detection probability should be uniform. Heights determined using elevated parabolic antennas may be less susceptible to variation in aspect, because part of the horizontal rotation is always perpendicular to the movement. (This is also true of open-array antennas rotating in the horizontal plane, sans information on height.) Also, animals moving toward or away from a radar are detected obliquely by an elevated beam rather than directly head- or tail-on which should produce higher RCS, all else being equal.

c. Clutter

In broadest terms, clutter refers to unwanted radar scatter. Sources of clutter for these purposes include insects, instances where multiple weather (usually precipitation), the sea surface (sea clutter), boats, planes, and turbines in post-construction studies. All vendors consider clutter and offer varying solutions in their reported ability to cope with it. However, sea clutter is a pernicious problem that even a fixed platform is unlikely to resolve. Open-array antennas operating horizontally from a fixed platform over open water experience severe clutter and the problem persists with open-array antennas rotating in the vertical plane and parabolic antennas (S. Gauthreaux, pers. comm.).

d. Data impacts

Missing data can occur for a variety of not necessarily independent reasons including limits to radar equipment, loss of power, malfunction of data gathering equipment, unfavorable data gathering conditions (IV.c, IV.e), and human error. The impact may be local; for example, most magnetron-based radars used in biological research experience a brief period of time during transmission when the radar is essentially deaf to its own echoes. This period is called a main bang or simply bang, and as a result, targets very near the radar are generally undetectable. Data impacts also occur at a seasonal scale; for example, a standard for how much data is necessary to adequately represent seasonal vertebrate movement (≥80%) has been proposed for this project. There is concern that excessive loss of data may render observations related to migratory passage moot if they fail to capture the occasional yet unpredictable large movements that almost inevitably occur with songbird migration. While considerable effort should be made to ensure a robust operation is in place, data loss or drop outs will likely occur.

Comparing data collection during calm and rough sea days would allow assessment of whether data was compromised during poor weather conditions in an effort to inform future sampling efforts. The primary cause of compromised data would likely be the inability to acquire or maintain tracks through successive sweeps of the radar either owing to sea clutter or barge movement. Clutter from the sea and other sources can cause tracking algorithms to produce false tracks that are spurious. Motion of the barge may also cause a target to be dropped and reacquired which may be interpreted as a separate track depending on the sophistication of the tracking software. If present, both of these factors can artificially inflate estimates of traffic rate. The magnitude of these errors would be expected to vary with conditions and the manner in which data were collected.

To help determine the meaningfulness of such loss, it may be useful to supplement offshore radar data collection with analysis of contemporaneous data from the fortuitously close Cleveland, OH NEXRAD station (KCLE). Advances in NEXRAD quantification enable estimates of vertebrate density (Chilson et al. 2012) that could be used to verify migration traffic rate (MTR) or density estimates determined by portable radar. This form of corroboration would help ensure any data drops did not correspond with particularly large migratory movements during the study, recognizing that this approach is imperfect given the complexity of movements that may occur in the vicinity of coasts (Archibald et al. 2017, Diehl et al. 2003) and that KCLE has an imperfect view of low altitude movements (Nations and Gordon 2017).

e. Platforms

Two platforms have been considered for this work, although all vendors propose to deploy radars on a floating barge anchored at four points to minimize platform movement. An alternative is to construct a fixed monitoring platform embedded in the lake bed. The latter has the distinct advantage of being stable in all lake conditions, whereas a floating platform will roll, pitch, and yaw in response to wave action. Differences of opinion exist regarding the practicality of establishing a fixed platform, a concern that is beyond the scope of this evaluation, although I again note here that a fixed platform is unlikely to address the problem of sea clutter (IV.c). Floating platforms have been used to gather radar data on biological targets for many years in support of both basic and applied biology (e.g., Larkin et al. 1979, Alerstam et al. 2001, Desholm et al. 2004).

As an alternative to construction of a fixed platform, vendors could mount just the radar to a stabilizing gimbal fastened to the barge. Vendors do not advocate such an approach, presumably owing to cost and complexity, and an evaluation of the costs and benefits of adopting this approach is beyond the scope of this evaluation. Motion of the platform will necessarily introduce errors into all movement-based radar metrics. Although these would tend to average out assuming no systematic bias in barge movement, certain observations of individual movements may be more sensitive to barge motion (e.g., the movements of animals in the vicinity of turbines in a post-construction study). The effects of barge movement on radar-determined animal movement data can in principle be corrected by sampling the three axes of a vessel-mounted gimbal or inertial measurement unit and use those data to adjust target position observations (Larkin et al. 1979).

f. Post-construction

Response by birds and bats to the presence of wind turbines may be studied as a comparison between pre- and post-construction behavior, which is facilitated by adopting the same study design before and after construction. Detection of behavior consistent with avoidance or attraction during post-construction then becomes a consideration in evaluating vendor options.

Birds and bats may respond differently to turbines with some indication that birds may largely avoid turbines while bats may be attracted (Cryan et al. 2014); however, this is an ongoing area of research. Turbine avoidance will usually take two general forms: lateral change in direction or change in height. Horizontal avoidance of turbines by flying animals moving laterally may be detectable by most radar systems using antennas rotating in the horizontal plane (e.g., Desholm and Kahlert 2005) unless that avoidance behavior occurs within the clutter field of the turbine or is disrupted by sea clutter. Avoidance by increasing height poses different and in some ways greater detection challenges for radar. Detecting change in height may manifest primarily in two different ways that depend largely on radar siting and/or antenna positioning with respect to a turbine. An open-array antenna rotating in the vertical plane can capture these movements for a given turbine for animals approaching from a given direction if the radar is properly sited. A parabolic antenna rotating in the horizontal plane but properly elevated may also capture behavior consistent with these movements, perhaps independent of animals approaching direction and in such a way as to avoid turbine clutter (IV.c).

Attraction to turbines by flying animals might be expected to produce much the opposite behavioral patterns on radar, although the nature of attraction necessarily moves the animal closer to a primary source of clutter. Clutter produced by turbines is dynamic and often obscures nearby animal movement, so the range from the turbine at which flying animals respond matters and may vary with turbine visibility which in turn likely varies with ambient light conditions (e.g., day versus night, moonlight, anthropogenic light).

g. Target identity

Knowing with reasonable certainty the identity of radar targets is arguably one of the greatest challenges facing radar biology and one of the most important to get right. Even “identity” is subject to some interpretation as it could refer to any of a number of taxonomic levels. Depending on certain radar metrics and our knowledge of animal morphology, behavior, and natural history, radar targets may be identified down to species (e.g., O’Neal et al. 2010) or at best to phylum (e.g., most other radar studies that attempt target discrimination). Considerable room for uncertainty in identity is created by the combined effects of the diversity of flying animals, their overlapping biology, and the wide range of hardware, software, and operational properties of radars. All else being equal, as one moves toward more coarse taxonomic classifications, flying animals tend to diverge in their biology and natural history in ways that make them more distinguishable on radar (i.e., it is considerably easier to distinguish vertebrates from insects than it is warblers from thrushes).

Biologists have long sought the ability to distinguishing different target types by their radar parameters. Radars are capable of generating a number of metrics on flying animals including speed, direction, height, track, wingbeat rate, wing flap behavior, RCS, orientation, and in many cases change and rates of change for these metrics.

Given the hazards posed by wind turbines to bats in particular, there is considerable interest in being able to reliably distinguish birds from bats via radar so as to apportion the hazard. Despite their taxonomic differences, convergent evolution together with certain allometric constraints have contributed to there being considerable overlap in the size and behavior of many bird and bat species. Erratic flight often attributed to bats is not necessarily a reliable distinguishing characteristic of bats; bats may well engage in straight-line flight similar to most nocturnal migratory birds, and the flight paths of some bird species can be quite erratic (e.g., common nighthawks, swallows). To date, no published radar methods reliably distinguish bird from bat echoes based on radar properties alone. This is not to be confused with highly reliable radar data on bats captured under idiosyncratic circumstances where knowledge of natural history, not the radar metrics themselves, offers high confidence in the identity of the biological target (e.g., Mirkovic et al. 2016, Horn and Kunz 2008). Fittingly, no vendor specifically identifies the ability to distinguish small birds from bats in radar data, but two give some consideration to distinguishing vertebrates from insects.

Currently, the three primary approaches for attempting to distinguish vertebrates from insects are based on 1) RCS, 2) airspeed, and 3) wingbeat rate. All have advantages and disadvantage. Two of these approaches, RCS and wingbeat rate, are considered among vendor responses. Currently, use of wingbeat rate is considered the most accurate approach to distinguishing vertebrates from insects.

Airspeed

A flying animal's airspeed is its rate of movement with respect to the surrounding air (Gauthreaux and Belser 1998), and vertebrates may be broadly distinguishable from insects by their airspeeds. Vertebrates often exhibit powered flight that produces high airspeeds relative to their insect counterparts which are generally weaker fliers that often essentially drift with the wind and therefore exhibit relatively low airspeeds. Radars measure the ground speed of flying animals, the rate of movement with respect to the ground. Ground speed results from the combined influence of an animal's airspeed and wind speed. A flying animal with an airspeed of 5 $m \cdot s^{-1}$ flying in the same direction as a 5 $m \cdot s^{-1}$ wind will have a 10 $m \cdot s^{-1}$ ground speed. Under windless conditions, ground speed equals airspeed. If local altitude specific wind conditions are known, the wind vector can be subtracted from an animal's ground speed to yield the animal's airspeed. Airspeeds below, say, 7 $m \cdot s^{-1}$ (the thresholds have varied over the years), are more likely insects (Larkin 1991).

Although it does have advantages, the airspeed approach to discrimination is relatively crude. Vertebrate and insect airspeed distributions overlap considerably (Larkin 1991). Vertebrate airspeeds may easily fall below specified thresholds, while not all insects are weak fliers. A more conservative approach would set two thresholds between which targets would be categorized as 'ambiguous'; although the arbitrariness of the thresholds matters, there is the risk of consistently and unwittingly excluding species that classify as ambiguous, and far too many meaningful targets may be excluded from further analysis. There are also challenges to knowing wind conditions at an animal's altitude, especially at sea where only surface data will be collected. Often, surface wind measures are correlated with winds aloft, especially over the low altitudes that concern wind energy. However, wind shear over short altitudinal distances occurs and will introduce error into airspeed estimates. The usual solution to this is to routinely launch radiosondes, an option not available to radar operations considered here, at least not at the radar site. Advantages of this method include that it can be applied using data from widely used track-while-scan radars operating in the horizontal plane; it is independent of operating frequency or antenna type, and it does not rely on sophisticated software for computation.

Radar cross-section

Wavelength matters (IV.h). Arguably one of the great advantages of S-band radar with respect to target discrimination is the theoretically reduced impact of insect clutter (IV.c) in the data. At S-band, most insects are likely to be so-called Rayleigh scatterers, meaning they produce reliably weak radar echoes relative to their larger vertebrate counterparts. This has implications for the resulting biological data. First, the presence of insect clutter should be considerably reduced, especially at range where power density within the radar beam is sufficiently weak that insect echoes are below the noise threshold of the radar (i.e., undetectable). Also, when weak insect echoes do occur, it may be possible to design either real-time or post-processing algorithms that can reliably remove much of this clutter by threshold filtering on RCS. However, owing to their longer wavelengths, S-band radars likely also inadvertently remove small vertebrates in ways that cannot be easily resolved. X-band radars tend to have the opposite problem.

One of the challenges of using X-band radar to study vertebrates is its susceptibility to biological clutter from insects (IV.h). At X-band, small- to mid-sized vertebrates and large insects return radar echoes that are non-linearly related to the actual size of the animal (Vaughan 1985). For these so-called Mie or resonance scatterers, an animal's actual size cannot be readily inferred from its RCS; some insects can actually produce larger echoes than vertebrates. For this reason, insects cannot reliably be removed from radar data by relatively simple RCS thresholding at X-band (Fig. 1), and vendor approaches that use RCS thresholding risk including some large

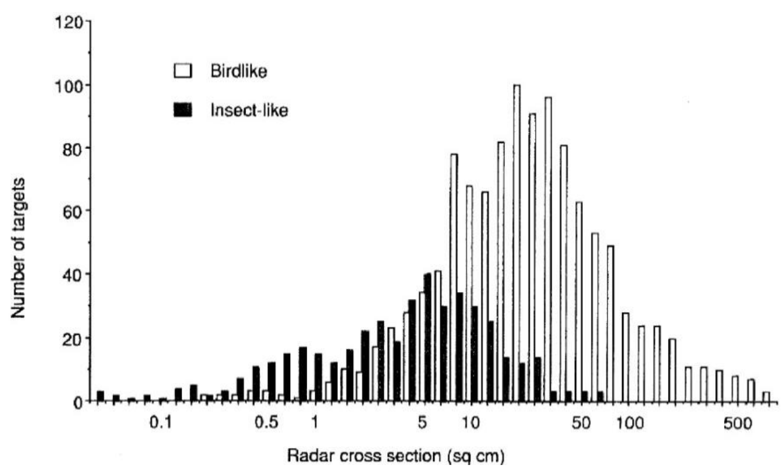

Fig. 2. Estimated radar cross section, σ, of all birdlike ($n = 1159$) (*unshaded bars*) and insectlike ($n = 438$) (*solid bars*) targets for which wing beat data were available

Figure 1. X-band radar cross-sections of bird-like and insect-like targets determined by wing beat rate. Consistent with Drake and Reynolds (2012, pg127) there is considerable overlap between targets types for cross-sections measuring 1-10 cm^2 (from Larkin 1991).

insects and rejecting some small vertebrates. This may be a particular concern for the wind energy industry (which presumably is not interested in deterrence or mitigation associated with insects) if, for example, on a given night insects happen to fly at lower altitudes than vertebrates. As with airspeed, a more conservative approach would set two RCS thresholds between which targets would be categorized as 'ambiguous'. Here again the arbitrariness of the thresholds matters, as there is the risk of consistently and unwittingly excluding species that classify as ambiguous, and far too many meaningful targets may be excluded from further analysis. A more accurate approach might require targets to satisfy both RCS and airspeed thresholds to be classified as vertebrates.

Wingbeat rate

Wingbeat rate is considered the most reliable method of distinguishing vertebrates from insects (Schmaljohann et al. 2008). Both wingbeat rate and airspeed-based approaches are also less aspect (IV.b) dependent than RCS-based discrimination. Like RCS, wingbeat rate measurement occurs entirely within the radar domain, no external data sources are required as with airspeed-based discrimination. Insects tend to beat their wings at much higher rates than vertebrates (Drake and Reynolds 2012) which allows for less ambiguous threshold-based discrimination than with other methods. Moreover, the wingbeat patterns themselves aid in discrimination; for example, flap-coast wing beating is characteristic of many bird species.

Measuring wing beat rate requires software and hardware modifications and data sampling procedures that, while relatively well understood, are not common. Multiple vendors already possess some of the necessary software infrastructure (e.g., high-speed AD sampling of radar 'video' signal) upon which to build this capability. The radar beam must be positioned to dwell on the flying animal for a duration long enough to estimate wingbeat rate, generally a half second or longer. This is not possible with the usual antenna rotation scheme found in COTS radars and employed by all vendors. VendorB is able to discriminate using wingbeat rate by rotating a parabolic antenna about a vertical axis thereby sufficiently increasing dwell time on the target. Other applications of this method would require stationary beam sampling strategies (unfamiliar to most users) to obtain wingbeat records. This requires hardware modifications to control antenna position in both elevation and azimuth (VII.a).

h. Wavelength

Vendor responses to the RFI included a total of five radar deployment options, four of those options propose use of X-band (~3-cm wavelength) radars, and one an S-band (~10-cm wavelength) radar. The different bands have numerous advantages and disadvantages, perhaps most relevant among them for these purposes concerns target discrimination in relation to RCS (IV.g).

V. Vendor Proposals

All vendors propose to use an anchored barge as a platform to conduct radar operations (IV.e). Each vendor response is evaluated in part in relation to the ability of their proposed operation to accommodate platform movement owing to sea state. In all cases, it appears vendors propose to work remotely through LEEDCo or some other representative rather than maintain experienced staff on site (III.a.O1). Although the latter is the more desirable approach, remote operation can be effective provided systems are monitored for their operational state in real time, and those acting on vendors' behalf are sufficiently empowered to address issues as they arise.

The effect of sea clutter and platform stability on data collection remains a lingering concern for all vendors in relation to achieving meaningful data collection (III.b.D1), although there is ample precedent for radar-based scientific data collection on floating platforms at sea (IV.e). It is this uncertainty that results in a 'fair' or 'poor' rating for criteria III.a.O4 and III.b.D5 in Table 1.

Three vendor options remove insect targets by threshold sampling on RCS at X-band with seemingly little regard to the considerable variation in RCS across target types (in the case of VendorA, as evidenced by their own citations in the caption of their Figure 1). Specifically, the detection probabilities for each size class of target may vary considerably depending on aspect (IV.b) and for many, the impact of Mie scattering (IV.g) which can be pronounced for vertebrate- and insect-sized targets at X-band. Threshold filtering based on RCS will naturally vary depending on where the threshold is set which in turn will determine how many insects are retained as vertebrates, or how many vertebrates are rejected as insects. Very small insects are likely Reyleigh scatterers at X-band and can reliably be rejected by this method. Only VendorB (Option2) uses wingbeat rate analysis for target discrimination.

Rather than be discursive concerning the various advantages and disadvantages of the vendor responses across all bases for evaluation (III), I attempt to rank the performance of each vendor response for each evaluation criterion in terms of good, fair, and poor in Table 1. The narrative below is reserved for highlights and specific points not evident from the table.

Table 1. Comparison of vendor responses with respect to the Basis for Evaluation criteria (III), assessed as good, fair, or poor.

	VendorA	VendorB (Option1)	VendorB (Option2)	VendorC (Option1)	VendorC (Option2)
Operation					
O1	FAIR	FAIR	FAIR	FAIR	FAIR
O2	GOOD	POOR	GOOD	GOOD	GOOD
O3	GOOD	GOOD	GOOD	GOOD	GOOD
O4	POOR	POOR	FAIR	POOR	POOR
Data					
D1	FAIR	FAIR	GOOD	FAIR	FAIR
D2	GOOD	GOOD	FAIR	GOOD	GOOD
D3	FAIR	POOR	GOOD	POOR	POOR
D4	GOOD	GOOD	FAIR	GOOD	GOOD
D5	POOR	POOR	FAIR	POOR	POOR
D6	GOOD	GOOD	POOR	GOOD	GOOD
D7	GOOD	FAIR	POOR	GOOD	GOOD
D8	GOOD	GOOD	GOOD	GOOD	GOOD
Reporting					
R1	GOOD	GOOD	POOR	GOOD	GOOD
R2	GOOD	GOOD	GOOD	FAIR	GOOD
R3	GOOD	GOOD	GOOD	GOOD	GOOD

a. VendorA

VendorA proposes to measure animal movements using volume scans, essentially stacking data from different elevational sweeps of a parabolic antenna, similar to the manner many weather radars operate. This method is effective for this purpose, although its data refresh rate at a given altitude (and depending on how they post-process data) would be less frequent than that of a rotating open-array antenna.

These differences in temporal resolution should matter little, however, in producing adequately updated information on animal movements (III.b.D4).

Vertical (90° from horizon) scanning directly over the radar would measure animal location in altitude with approximately the same precision as an open-array antenna rotating in the vertical plane. VendorA mentions limitations to this approach, but they do not include any concern over the impact of the main bang (IV.d). Depending on the type of radar, orientation of the antenna, and data processing methods, the range of this deafness may well include the rotor swept area, a possibility that is most acute when the antenna is pointed vertically but may also be a concern at lower elevation angles (V.b).

It is unclear how is the radar is 'tuned' at the start of the season and what sources of error or changes in the environment (other than clutter) require it to self-adjust. It is also unclear what the differences are between adjusted and unadjusted counts, though from context this likely refers to the application or not of detection probability correction. 'Many tools' are claimed for data validation, but it is unclear what is meant by validation, what are the tools, and what metrics require validating.

VendorA's response to the RFI was the most thorough of all the vendors and generally addresses the relevant issues (although I was surprised by the large number of minor grammatical errors). VendorA has experience with radar-based monitoring in relation to wind energy but not in offshore settings.

<u>Advantages</u>

- VendorA is correct in its general assessment of the advantages of a pencil-beam produced by a parabolic antenna over its open-array counterparts, especially in relation to their ability to provide a 3-dimensional position of flying animals (IV.a). This negates the need to deploy a two-radar system, simplifying the overall operation which in turn decreases the likelihood of technical difficulties during operation. However, the single radar design, while attractive from the standpoint of simplicity, also removes any redundancy. Failure of VendorA to track targets owing to barge motion results in complete loss of data, an less likely outcome for two-radar systems employing complementary sampling. Pencil beams are not without error in estimating position, and I would be interested in knowing how VendorA estimates that error which they seem to refer to as covariance, especially in the vertical dimension where even a narrow 4° beam is 35 m wide at 500 m range. Regardless, the practical effects of this uncertainty would be minor and average out across many tracked targets.

- A parabolic antenna and its associated beam properties may be more robust to the effects of sea clutter introduced by roll and pitch of the barge relative to a horizontally rotating open-array antenna. In no way should this suggest parabolic antennas are without concern in this regard (see below).
- VendorA has far more thoroughly studied the Icebreaker Wind project environment and crafted a more detailed and informed response than the other vendors.

<u>Disadvantages</u>

- I wonder about the ability of a 4° beam to maintain target tracking in the presence of seas that cause the barge to roll or pitch by an appreciable proportion of this beam width. Momentarily dropping targets in a track is a reality of any track-while-scan system (IV.d), and VendorA may have software that can cope with this eventuality, though perhaps not to the degree posed by a moving platform. It is entirely unknown to me how much the anchored barge is expected to pitch and roll in response to wave action on Lake Erie.
- VendorA and their equipment are untested operating in offshore environments, so there is the greater risk of otherwise avoidable problems occurring during operation. The vendor addresses many of the known challenges, so the risk is likely relatively minor.
- The capacity for VendorA to elevate their antenna may reduce clutter but is unlikely to eliminate it sufficient to reliably enable data collection on horizontal and altitudinal movements. Considerable unknowns exist depending largely on the impact of side lobes.

b. VendorB

VendorB (Option1) has numerous shortcomings in relation to operation (specifically, II.a.O2 and III.a.O4) and data gathering (specifically, III.b.D3 and II.b.D5) that render it the least desirable among the available options (Table 1). I do not comment on it further here. VendorB (Option2), however, represents a truly unique offering, and although when operating alone it has severe limitations in this particular application, it is nonetheless worth commenting upon. The capabilities of this radar were familiar to me before this evaluation was brought to my attention. The general approach is described in Chapman et al. (2003), and I first learned of this specific radar at a European Radar Aeroecology conference in Rome, Italy in early 2017. I was also invited to be an external reviewer for a graduate thesis from the University of Exeter that demonstrated some of the capabilities of this radar.

<u>Advantages</u>

- VendorB (Option2) rotates, or rather nutates, around a vertical axis in a way that enables it to gather data on height, speed, direction, and identity of the same target.
- VendorB (Option2) is the only vendor response that discriminates targets based on wingbeat rate, the current state-of-the-art (IV.g). Other vendor options discriminate according to RCS thresholding of which there is meaningful overlap between vertebrates and insects at X-band.
- With a nearly vertically oriented scan strategy, this option should be relatively robust against the effects of sea clutter, although the impact of ~90° is a lingering concern.

<u>Disadvantages</u>

- Nutating exclusively about a vertical axis places the radar at maximum exposure to the limits of detecting and identifying animals flying at very low heights. Minimum height matters a great deal in relation to studies of wind turbine impacts. The lower boundary of the rotor swept area for the Vestes V126 turbines proposed for this project as indicated in the “Icebreaker Wind VIA” document is 20 m above the water surface. The radar would sit a few meters above the water surface, further reducing the distance from radar to minimum height of the rotor swept area. The minimum height (above radar) claimed for VendorB (Option2) is 50 m, leaving approximately 30 m of a 126 m diameter rotor height (24%) unsampled. The reasons for this limit are not discussed. The effects of the main bang likely play a large role (IV.d), although this may also be a height below which targets travel too fast through too narrow a beam for wingbeat rate to be reliably estimated. Given the latter, it is not clear whether or not the lower limit of detectability is the same as the lower limit of wingbeat rate-based target discrimination.

- Movement of the beam in response to seas may impact estimates of speed and direction given the manner by which VendorB (Option2) determines those measures (Wills 2017). Specifically, movement of the radar platform during target passage changes the time required for the target to complete its passage through the nutating beam volume which in turn will bias speed estimates high or low depending on the motion. So, while the estimates for individual targets may be suspect, these biases may be expected to average out across many individuals. I also wonder whether sea state might impact target discrimination software which is sensitive to dwell time of the target within the beam. Depending on conditions, this could effectively increase the minimum height above radar at which some targets can be discriminated/counted, further limiting the ability of this unit to monitor the rotor swept area.
- The narrow region of direct monitoring severely limits the ability of this radar by itself to inform on turbine avoidance/attraction behavior in a post-construction study (IV.f).

c. VendorC

In deploying portable Doppler radar, VendorC proposes use of capable and somewhat uncommon hardware in biological circles. This unit purports to confer some advantages to their proposed approach, but these are not critical to successful data collection. VendorC reports the smallest RCS detectable at 5.5 km range as 10 cm and

5 cm for their S- (Option1) and X-band (Option2) horizontal radars, respectively. Overall, more capable hardware and software are invested in horizontal versus vertical monitoring, the latter possibly being the more relevant dimension in this project.

VendorC is arguably the most detailed in terms of data analysis, especially with respect to their statistical approach for determining weather conditions that influence the numbers of vertebrates flying at rotor swept height. If the relationship between weather conditions and animal density at rotor swept height is known, it may be possible to examine historic weather patterns in the area (as is likely already known) to determine the frequency of weather conditions associated with increased risk to flying animals (e.g., Kirsch et al. 2015). While VendorC discusses these capabilities at some length, any vendor that generates raw data on animal movements and weather conditions can provide those data such that a third party might generate the same or similar analyses as needed.

<u>Advantages</u>

- The wide vertical antenna angles (25° and 16°) of the horizontal radars increase the likelihood of maintaining target tracks despite barge movement.
- The Doppler capability of VendorC (Option2) enables a clutter filtering capability that may render it less sensitive to turbine clutter in ways that improve the ability of this radar to detect movements of vertebrates near turbines. This would presumably have value in post-construction studies examining vertebrate responses to actual structure.
- VendorC is the only vendor to offer some mechanism to correct radar-determined movements for the effects of barge roll, pitch, and yaw (3-axis accelerometers, IV.e).

<u>Disadvantages</u>

- VendorC vertical radar observations are gathered once every 5 sec using screen captures, presumably skipping every other sweep. The reason for this is unclear and compromises any effort at target tracking (to the extent that's desirable, see VII.b). MTR or vertically stratified measures of animal density are critical to this application of radar, yet VendorC documents no approach for target discrimination for these data. The “MUSE software” is not operational on the vertical radar presumably because it is based on analysis of entirely different methods of sampling used by the horizontal radars (high speed AD samples of radar ‘video’ signal output). Indeed, target discrimination generally is unclear across all radars, although it appears to be RCS-based on horizontal radars. Discrimination from aircraft are mentioned (which may identify their primary source of business), but there is no mention of insects which are by far the greater source of airborne clutter.

- The tracking advantage noted above assumes that pitch and roll of the barge does not produce sufficient sea clutter to interfere with data collection altogether. The reported false-positive rate for vertebrates when wave heights exceed 1 m is unknown for Option2. Response by VendorC to follow-up questions shows they have not deployed their horizontal radars from boats, so the impact of sea clutter remains a concern.
- Height bins are relatively coarse (50 m) but perhaps workable in pre-construction studies. However, the low spatial resolution compromises VendorC’s ability to document animal responses to the presence of turbines in post-construction studies.

VI. Conclusions

Far too many unknowns are present to anticipate the outcome of radar work in relation to this project. Use of a barge magnifies an already existing problem, that seas will introduce clutter into radar data. The question becomes one of identifying what vendor approach among those presented is most likely to yield meaningful data collection. Taking into consideration that not all evaluation criteria are equal in their importance, Table 1 effectively narrows the field to two best options, VendorA and VendorC (Option2). (As a side note, VendorB (Option2) stands out for its novel design and best target discriminating capability. This option might be preferred in stable environments where target detection at minimum altitude and response to structure is not a concern in follow-up studies, although my European colleagues have some concerns over the reliability of ground speed estimates.) Arguably, the most important data criteria for a radar system in relation to the Icebreaker Wind project concern the ability to gather data on altitude-specific MTR or density and behavioral response to turbine presence (pre- versus post- construction comparison to attempt to assess avoidance/attraction), and the ability do so with high reliability (≥80% of available time) while avoiding contamination by clutter, primarily from insects and the lake surface.

VendorC (Option2) may well outperform other options in relation to documenting behavioral response to turbines, however this capability is cast into some doubt given uncertainties associated with how well the Doppler radar performs on vessels in relation to sea clutter. More critically, it appears little attention is given to target discrimination in vertically oriented radar data which may be the most valuable in relation to assessing animal's exposure to wind turbines.

VendorA's use of parabolic antennas has advantages unique among these vendor responses. Many desired capabilities are addressed, perhaps most important among them is the ability to elevate a highly discrete beam as a means of attempting to reduce the impact of sea clutter, if only because this proves challenging for open-array antennas rotating in a horizontal plane (but see below). Less clear is how tracking would perform across sweeps on a rolling and pitching barge. VendorA reports that tracking could tolerate 2° of pitch or roll, but it is easy to envision greater barge movement.

In sum, VendorA proposes the approach most likely to succeed among the vendor responses and other information provided that forms the basis of this evaluation. This is not to suggest VendorA's approach is without concern, particularly over target discrimination, the ability to track from a moving platform, and the impact of sea clutter. Designing a radar study from the ground up is beyond the scope of this review, however I offer some suggestions that may increase the likelihood of gathering meaningful data on vertebrates using VendorA's basic approach.

- Current RCS-based target discrimination might be improved by also including an airspeed-based approach (IV.g). Neither achieves the accuracy of wingbeat rate analyses which a rotating radar prohibits (but see VII.a below). However, the combined approach of requiring vertebrate targets to meet both RCS and airspeed criteria may increase the likelihood of proper target classification. Data on wind is required to estimate target airspeed, and VendorA proposes to gather surface wind data from a barge. The usefulness of surface wind data decreases with altitude owing to wind shear. However, surface wind data are more likely to usefully inform airspeeds at rotor swept heights, since turbines are relatively close to the lake surface.

- Concerning tracking, VendorA may consider refitting their radar with a smaller diameter antenna to increase beam width as a means of increasing the likelihood of maintaining tracks (sensu VII.a). Ideally, a barge pitch and roll test would be conducted to determine whether and/or how frequently barge movement would exceed the ability for VendorA to track.
- Elevation of the parabolic antenna considerably above the horizon would likely result in decreased clutter relative to open-array antennas rotating in the horizontal plane. Clutter will persist, however, and it is likely that even gathering data from a fixed platform will not satisfactorily address the problem (IV.c). As such, and in consultation with my colleague S. Gauthreaux, I suggest an alternative approach. Parabolic antennas radiate in relatively discrete patterns where side lobes, a primary cause of clutter, may be pronounced but distinct. As such it may be possible to considerably reduce the impact of sea clutter by blocking side lobe energy through installation of a radar fence on the periphery of the proposed barge. (The fence is unlikely to work as cleanly with an open-array antenna, because the beam radiates power in a less discrete manner.) To benefit most from the fence, the radar should be positioned relatively close to the barge surface (and must therefore be well armored against freeboard seas). Otherwise the fence must be elevated to capture side lobes which would require assembling more structure. It is unclear how much wave motion would impact the barge, but conceivably the fence could be positioned and the antenna elevated to account for barge movement. (Note, increasing antenna elevation angle will simultaneously tend to increase the lowest height at which the radar can detect targets owing to the impact of the main bang (IV.d).) This

in turn can interfere with directly monitoring heights consistent with the rotor swept area, depending on the angle of elevation and impacts of the bang.) Finally, to further reduce the impact of side lobes, the proposed smaller diameter antenna could be outfitted with a cuff ringed with material designed to absorb radio energy (radar-absorbent material or RAM). Some of these clutter-mitigating tactics are described in greater detail in Larkin and Diehl (2012).

The adjustments described above would require the obvious adjustments to hardware as well as re-computing detection probabilities and adjusting volume scan elevations. These would appear to be relatively minor modifications and the developer could likely bear the cost. Also, concurrent data from the KCLE NEXRAD station could be used to help identify the data consequences for periods when lake conditions may result in data dropouts (IV.d).

Finally, I would hope reports resulting from this work are subject to peer-review, and that track data of individual animals, clutter maps, and reports are placed in the public domain so that others may benefit from the knowledge gained by this effort.

VII. Alternative Configurations

None of the proposed radar configurations is without shortcomings; indeed, it is difficult to envision any reasonable scenario that does not bring some limitation. The conclusions of this evaluation should not promote a static standard, but rather an evolving one that upgrades with advances in technology. Most relevant among the limitations described above are those associated with target discrimination (III.b.D3) and ability to accommodate sea clutter and a moving platform (III.a.O4).

All options offer trade-offs on the ideal capability; to obtain reliable, high accuracy data on ground speed, direction, altitude, and target identity on the same individual, and to do so with sufficient spatial and temporal coverage to detect behavioral responses to turbines. For example, four of five vendor options examined trade better target discrimination capability for spatial coverage. Under some circumstances this may be a desirable trade-off (e.g., airport monitoring for large birds) but perhaps not in relation to wind energy monitoring for primarily small vertebrates. Another example, VendorA forgoes the 2-dimensional comprehensive coverage of open-array antennas in favor of acquiring more spatially constrained 3-dimensional data on individuals using only one radar. The necessity of such trade-offs prompts one to ask: what are the most important capabilities for offshore radar monitoring, and are there alternative radar configurations that might better capture those capabilities? As mentioned in the Conclusions (VI), the most important data criteria for radar systems monitoring flying animals in relation to an offshore wind facility likely concern the ability to gather data on altitude-specific MTR or density and response to turbine presence, and the ability do so with high reliability while avoiding contamination by clutter, primarily insects and sea clutter.

Below I suggest a couple alternative radar deployment scenarios that represent advances or variations on some of the vendor design options suggested here. The people employed by these and other vendors are often highly knowledgeable, and it would surprise me if some of the concepts presented below have not been considered. Investing in research and development (to the extent required) and deployment is another matter, however. What works best serving a flight safety role may not be as well suited to wind turbine monitoring of the kind considered here. There is a tendency among the vendors to promote the comprehensiveness of coverage by one mechanism or another (e.g., stacked volume scans, wide-angle sweeps using open-array antennas). However, the goal here, as with many other wind operations, is to learn something about MTR or animal density, how that density is vertically stratified, how animals respond to stimuli or structure, and how these measures vary through time. With the possible exception of response to stimuli/structure, comprehensive data collection is not required for such measures.

a. Adaptable sampling

None of the vendor options satisfactorily addresses all the challenges such operations face in an offshore context and in other settings as well. Target discrimination is a persistent concern in radar biology, and one of the most common shortcomings among vendors concerns target discrimination where only VendorB

(Option2) employs the current state-of-the-art of wingbeat rate analysis. In this option, the confined airspace monitored increases dwell time on the target allowing wingbeat rate estimation but also limits the radar in other ways that are important to these studies and presumably others (V.b). As with VendorB (Option2), VendorA also employs parabolic antennas and does so with some sophistication by including elevation control, but continuous rotation at angles considerably less than 90° (vertical) prevents the radar from gathering wingbeat rate data.

A common property among all vendor options is a rotating antenna where reliance on the internal COTS azimuthal motor essentially drives all data collection. This is an appealing option; the motors are time-testing, highly reliable, and armored against harsh environmental conditions. COTS antenna rotation is also well suited to airport monitoring concerning bird aircraft strike hazards, which may comprise the bulk of many vendors' business. However, programmable azimuth and elevation control allows highly customizable sampling strategies that can be finely tuned to the needs of a given study. As vendors are no doubt aware, obtaining control over azimuth represents a considerable but hardly extraordinary hardware and software modification.

Consider an X-band radar outfitted with a ~6° parabolic antenna and software control over antenna position in azimuth and elevation. A sampling strategy that alternates between stationary beam sampling (Drake et al. 2002) and rotation enables serial data collection on wingbeat rate, altitude, and speed and direction from one radar (see Drake and Reynolds 2012, Ch. 5). The parabolic antenna would possess generally advantageous clutter mitigating properties if paired with modifications described above (VI), and the wider beam width would limit the impact of sea motion on target tracking where a barge or boat serves as the data collection platform. Trade-offs remain, but they are likely more tolerable. For example, the wider beam produces larger sample volumes (but still on par with most open-array antennas) that are more likely to include clutter in the form of multiple targets. The antenna also produces less gain (again, still on par with most open-array antennas) which limits range but not critically in this application. Detection of avoidance/attraction behavior would be consistent with VendorA (V.a). I am unaware of any vendors, including those not responding to this RFI, capable of implementing such a strategy in the near term.

b. Orthogonal sampling

In this concept, vertical sampling is favored over comprehensive horizontal sampling, because it focuses on altitude-based metrics (e.g., altitude-specific MITR) and would limit but not eliminate the impact of sea clutter. As discussed in Conclusions (VI), it may be possible to deploy a radar fence on a barge-sized structure to limit the impact of ~90° side lobes in a manner similar to that described in Buler and Diehl (2009).

Most applications of biological radar use a rotating antenna to enable a track-while-scan capability that allows sequential locations on a target to be linked into tracks that allow estimates of target speed and direction. However, the speed and direction of individual animals is not required to obtain estimates of mean speeds and directions of populations of animals moving through an airspace.

In this approach, two radars with open-array antennas are deployed rotating in orthogonal vertical planes (Figure 2). Each radar by itself will usually show some rate of animal movement along the axis of rotation but this is not a reliable indicator of speed for that individual, since we do not know its direction of travel. However, when averaged across a number of individuals, this mean relative speed constitutes one component of a two-dimensional vector. Combining the relative speed components from the two orthogonal planes would allow one to compute height-specific mean and standard deviation speeds and directions. The calculation can be repeated hourly or over whatever time frame allows sufficient samples to accumulate for the calculation (it would not require many) to estimate the

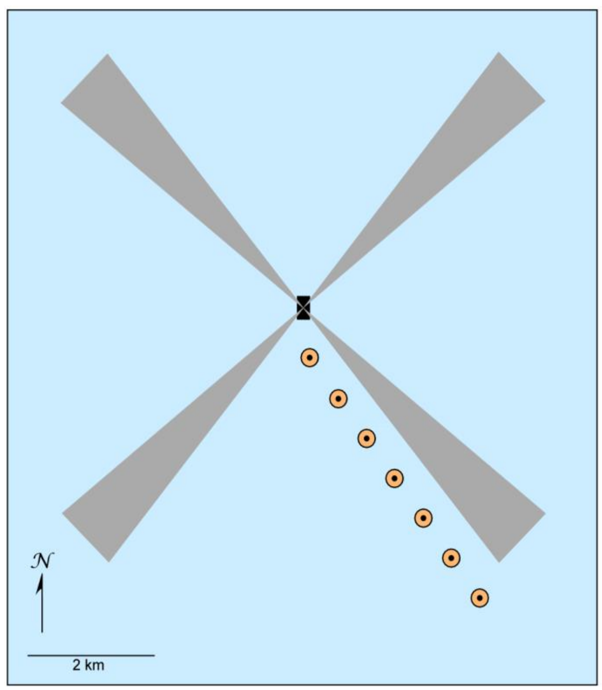

Figure 2. Conceptual layout of the orthogonal orientations of the vertical planes of rotation of two open-array antennas as they might be positioned during fall migration. During spring, the system would adopt a mirror configuration with respect the turbine array. The black rectangle represents the platform supporting the radars, gray wedges approximate the hypothetical horizontal coverage of 12° fan beams, and orange circles represent turbines.

components. Careful deployment with respect to a given turbine array should enable examination of behavioral response to turbines, especially where pre-construction data are available as reference, but the analysis would be more nuanced than examining tracks measured by horizontally rotating radars.

This approach relies on available software and hardware technology, so it should be relatively cost effective to deploy. Since it employs rotating antennas, the ability to use state-of-the-art target discrimination is compromised (only RCS-based approaches are possible; airspeeds cannot be used since the ground speeds of individuals is unknown) in favor of simplicity, cost effectiveness, clutter mitigation (from the sea and possibly turbines as well, depending on implementation), and the ability to examine behavioral response to structure, in this case turbines. Behavioral response may be subtle (which does not mean undetectable) given the limited coverage. As with other radar arrangements, pre- versus post-construction movement along, say, the southeast coverage area can be compared. It would also be possible during to compare movements along the southeast coverage to its counterpart to the northwest which would serve as an internal control of sorts. The desire for clutter mitigation is primarily but not exclusively a response to concerns over sea clutter in this evaluation. As with vendor responses, movement of a supporting barge or other floating platform would introduce error into vector component estimates of speed and direction, although these may average out (IV.e).

VIII. Acknowledgements

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