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Assessment of Technologies Used to Characterize Wildlife Populations in the Offshore Environment

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KB Larson

December 2011

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Summary

Wind energy development in the offshore environment can have both direct and indirect effects on wildlife, yet little is known about most species that use near-shore and offshore waters in part because of the difficulty involved in studying animals in remote, challenging environments. Traditional methods to characterize offshore wildlife populations include shipboard observations. Technological advances have provided researchers with an array of technologies to gather information about fauna from afar. This report is an effort to update decision makers with the state of the art of the use and application of radar, thermal and optical imagery, and acoustic detection technologies for monitoring birds, bats, and marine mammals in offshore environments and to identify key areas where investment may provide both short- and long-term benefits with respect to the permitting of offshore wind energy development projects.

Characterization of offshore wildlife populations has traditionally occurred with trained observers onboard ships. Although these methods are still used, technological advances have resulted in an array of technologies being deployed to address limitations associated with traditional methods. Tools and techniques reviewed within three broad technology categories (radar, imaging, and acoustic) are described in this report along with discussion of their strengths and limitations.

A variety of radar types have been used to survey flying fauna (birds and bats). Each radar type has characteristics that enable the capture of different types of data to address different research questions, with marine radar being the predominant radar tool for surveying at an individual wind energy project scale. Imaging technologies, including both thermal infrared and high-definition video and still photography, are used from a variety of platforms to address different data gaps. The replacement of observers with cameras when performing aerial transect surveys provides distinct benefits, including a data archive of field observations that allows confirmatory analyses rather than relying on an interpretation of a single observer. Acoustic monitoring, both below water for whales and other cetaceans and for birds and bats above the water, is an integral part of many wildlife characterization efforts and bats have been noted as far as 20 km offshore.

Obviously no single technological tool can be used to acquire the information needed to assess the risk to a fauna population from wind energy development, and often multiple technologies are deployed in concert to gather necessary data. The development stage of most technologies is such that a human observer is still required to analyze and interpret the data to translate them into meaningful information. The increasing use of technological tools is creating a wealth of data, yet the development of tools to turn these data into information is lagging. It is in this realm of data processing—turning data into information— that immediate investment may provide both short- and long-term benefits to the wind energy industry.

Acronyms and Abbreviations

AMAR	Autonomous Multi-Channel Acoustic Recorders
ARP	acoustic recording package
ASR	airfield surveillance radar
CTBTO	Comprehensive Test Ban Treaty Organization
EAR	ecological acoustic recorder
GHz	gigahertz
kHz	kilohertz
km	kilometer(s)
km^2	square kilometer(s)
km^3	cubic kilometer(s)
m	meter(s)
MHz	megahertz
NEXRAD	NEXt Generation RADar
NOAA	National Oceanic and Atmospheric Administration
radar	radio detection and ranging
rpm	rotations per minute
SCADA	Supervisory Control and Data Acquisition
SOSUS	(U.S. Navy) Sound Surveillance System
UAV	unmanned aerial vehicle
WSR	Weather Surveillance Radar

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1.0 Introduction

Wind energy development in the offshore environment can have both direct and indirect effects on wildlife, yet little is known about the vast majority of species that use near-shore and offshore waters in part because of the difficulty involved in studying animals in remote, challenging environments. Characterizing the effects of offshore wind development on wildlife populations and wildlife behavior requires careful and precise measurement of animal activity before and after development. Using technology to perform remote monitoring of the spatial and temporal distribution of wildlife is preferred over traditional methods that may be prohibitively expensive and pose significant safety risks. In addition, remote monitoring technologies offer persistent monitoring and greater data richness than traditional methods.

This report reviews the application of several widely used technologies for monitoring wildlife (birds, bats, and marine mammals) in offshore environments, including radar, thermal and optical imagery, and acoustic detection technologies. The focus of the review was to describe the application of these technologies to characterize offshore wildlife populations and identify major challenges facing the application of the technologies, including challenges to deployment and information extraction. Efforts were made to solicit information from key members of the offshore wind energy research community to supplement information obtained from published literature, technical reports, and scientific presentations.

2.0 Technologies

This section describes the application and key limitations of several technologies that are currently being used for monitoring wildlife in the offshore environment. Technologies described in this section include radar, thermal and optical imagery, and acoustic detection technologies. Emphasis was placed on describing their use to monitor key wildlife of concern for offshore wind energy development, including birds, bats, and marine mammals. Traditional monitoring methods are discussed first to provide additional context for evaluating the technologies presented in this report.

2.1 Traditional Methods

The traditional method for gathering information about the distribution and relative abundance of pelagic wildlife has been ship-based visual surveys. Published observations of pelagic birds made from ocean-going vessels date back to the earliest publication dates of North American bird journals (Nelson 1884; Richards 1909; Willett 1913). Historically, many different protocols were used to record observations of wildlife during ship-based surveys. In general, a trained observer or observers watched for and recorded wildlife observed at the ocean surface while the vessel traveled over a predetermined route. Observers scanned the ocean surface with the aid of binoculars or simply with their naked eyes. When characterizing offshore bird populations, researchers generally record birds during 10-minute observation periods within a 300-m-wide band on one side of the vessel, but the time period and band were often subdivided to count birds in a highly variable oceanographic environment (Tasker et al. 1984).

Ship-based surveys provide information about species distribution and abundance over time and space and have been used to calculate changes in population levels (JNCC 2011). However, standardization of ship-based survey methods continues to be a major issue for comparison across studies. Ship-based counts of are biased by the observation rate of some species, which is related to size, color, and behavior. Weather and observer efficiency also affect survey results, and the presence of a ship can alter animal behavior as well. Ship-based surveys require multiple trained observers that must be proficient at recognizing many species of birds or marine mammals, estimating distances, and implementing data-capture protocols consistently (Camphuysen et al. 2004). To address these limitations, European researchers have standardized and repeated ship-based surveys to better characterize seabird populations, resulting in multiple atlases summarizing seabird distribution patterns. However, the resolution of these atlases is often inadequate for depicting distribution and abundance at the scale of a single wind energy project (JNCC 2011).

Seabird and marine mammal surveys have also been conducted from aerial platforms. As with ship-based surveys, aerial surveys are performed with observers trained in the identification of many species using a specific survey protocol designed for aerial surveys. Aerial surveys provide a snapshot of animal distribution and abundance over a large area and may also provide information in shallow water areas not accessible by boat. Results have typically been provided as the number of animals per kilometer surveyed or number of animals per survey, which can be interpreted as relative density. Variation in detection probabilities influenced by sea state, glare, visibility, etc., can make converting aerial count data to an absolute animal density difficult. Research to develop spatial modeling tools that enable calculation of continuous density estimate surface for individual species at a resolution suitable for before-after control-impact studies was conducted during the mid-1990s (Camphuysen et al. 2004). Disadvantages of aerial surveys include difficulty with species identification, reduced count accuracy, the need for extensive observer training, increased safety risk, and cost, depending on survey scale. The relatively high speed of an aircraft does not allow observation of animal behavior or bird flight direction and height that are necessary to assess the collision risk for a proposed wind energy development.

Vessel and aerial surveys provide baseline information for characterizing bird and marine mammal populations in an offshore environment. Both methods provide information about animal distribution and abundance and provide data for both spatial and temporal modeling of populations that is important in assessing disturbance and habitat loss caused by wind energy development. Both methods are also effective at identifying key habitat such as foraging areas and other factors that may affect animal distribution and abundance. Advantages of these methods are maximized over time through repetition. However, vessel and aerial surveys can be expensive and do not provide all of the information needed to assess risk to wildlife populations from wind energy development. To reduce the time and cost of characterizing offshore wildlife populations, researchers are increasingly using a wide variety of advanced technologies to address limitations associated with traditional methods.

2.2 Radar

Radar is a system that detects objects by emitting radio waves and subsequently receiving radio wave echoes that bounce off of objects in the path of the emitted waves. It was developed during the early 1900s for remote detection of military airplanes and is used to detect both moving and fixed objects, including aircraft, ships, spacecraft, and missiles. Radar observations of birds were noted when the use of radar first began (Buss 1946), and now radar systems are commonly used to detect and characterize the flight behavior of flying fauna (birds, bats, insects). Attributes of the radio wave, namely wavelength, affect its efficiency and effectiveness for various applications. This discovery has led to a multitude of radar types being developed for specific applications, including weather surveillance radar, synthetic aperture radar for mapping landscapes from an aerial platform, Doppler radar that can determine the speed of an object, navigational radar, and even ground-penetrating radar.

This section describes various radar systems used to detect and monitor flying fauna in offshore environments and limitations to the use of this technology. Greater emphasis was placed on the use of marine radar because this radar type has been used most extensively by the wind energy industry and will have greater applicability in the offshore environment than land-based systems.

2.2.1 Weather Radar

Long-range radars, beginning with the Weather Surveillance Radar (WSR)-1, have been developed to track weather phenomena. Subsequent upgrades to the WSR-1 have been used to study nighttime songbird migration in the southern United States since the late 1960s (Able 1970). The current weather radar system in the continental United States, NEXRAD (i.e., NEXt Generation RADar or WSR-88D) is a network of very high-resolution Doppler radars. Operation of the first NEXRAD began in 1992 and the network that virtually blankets the continental United States was fully installed and began operation in 1997 (Figure 1).

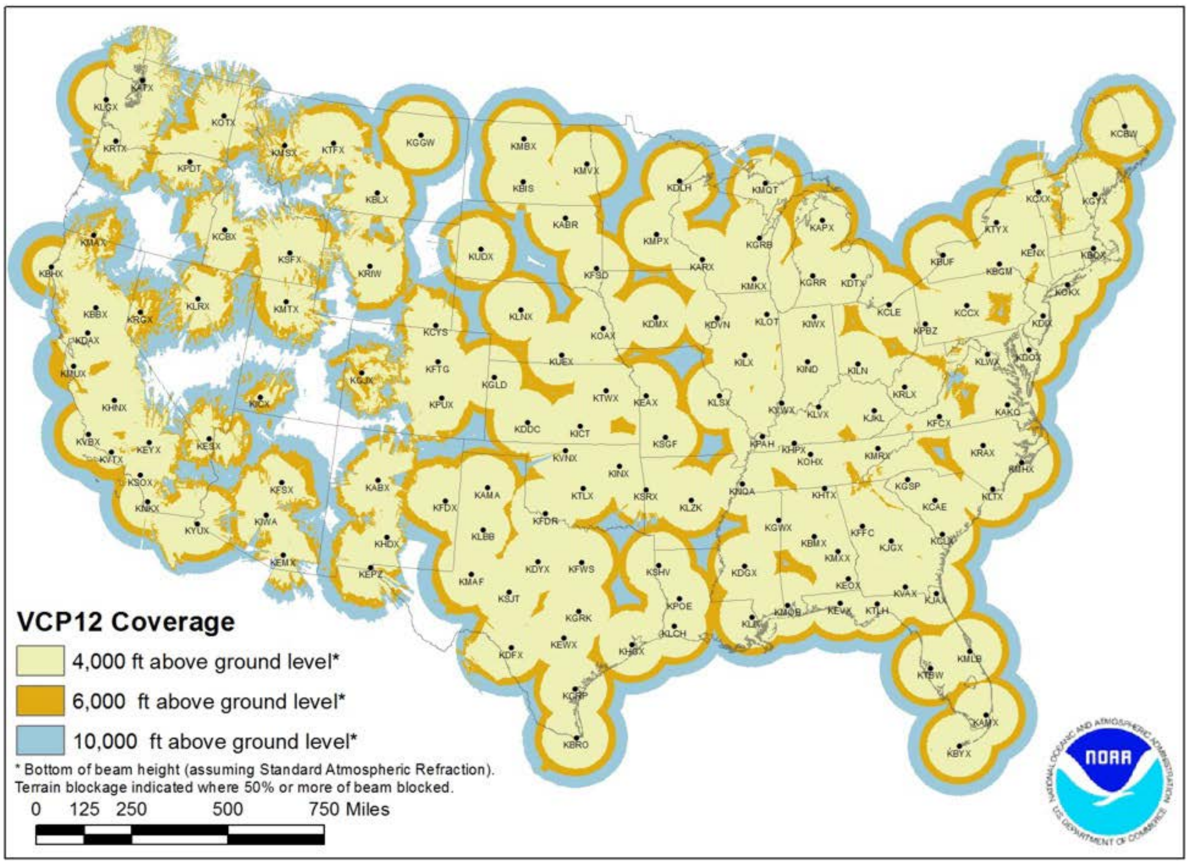

Figure 1. NEXRAD Distribution Throughout the Contiguous United States (Source: NOAA National Weather Service at http://www.roc.noaa.gov/WSR88D/Maps.aspx)

The NEXRAD network operates constantly and can detect objects from 500 to 15,000 ft above the ground at a maximum range of 230 km (Weber et al. 2005). NEXRAD data are recorded and archived, providing a log of phenomena such as landscape-scale bird, bat, and even insect migrations. These data are publicly available and allow researchers to survey and monitor flying fauna. The use of NEXRAD allows the estimation of fauna density in a volume of space (animals/km^3). NEXRAD has been used to identify flocks of migrant birds at a distance of 120 km from the radar site and is better suited for examining movements of large groups of airborne animals. NEXRAD data have been used to identify migration stopover areas and characterize temporal migration patterns (Gauthreaux and Belser 2003; Weber et al. 2005) throughout the United States and may be useful for identifying areas that pose a potentially high risk for bird and bat migrations relative to wind energy development. One significant limitation of NEXRAD is that it cannot characterize the presence of flying biota at small spatial scales. The minimum resolution of NEXRAD data is about 0.2 km^2 at a 40-km range. This resolution does not allow detection of individuals and makes it difficult to filter out echoes from insects (Kunz et al. 2007). Another limitation of the NEXRAD system is radar "shadow" created by the curvature of the Earth's surface, which limits detection of animals flying at low altitudes at extended ranges (Gehring 2010). Ground clutter may also limit the effectiveness of NEXRAD. Ground clutter is radar energy that is reflected from tall structures, including hills, buildings, towers, etc. and usually is detected within 25 miles of the radar. Processing methods have been devised to eliminate ground clutter, but these methods may also eliminate radar echoes from targets of interest.

2.2.2 Airfield Surveillance Radar

Airfield surveillance radar (ASR) is a system of radars used to locate and track aircraft near airports. The current American version, ASR-11, uses a primary radar that operates at the 2700- to 2900-MHz frequency and provides the distance and direction of targets as far away as 60 nautical miles (FAA 2009). Both the ASR-11 and its predecessor, ASR-9, effectively detect both weather and biological targets. ASR systems provide intermediate range (6–10 miles) detection of birds, but their use in offshore environments is extremely limited to areas within this distance of an airport. In addition, data from ASR systems are usually not made available to the public and these systems are not regularly used to track flying fauna.

2.2.3 Marine Radar

Marine radars were developed to detect ships and coastal land targets at intermediate distances for the purposes of collision avoidance and navigation at sea. Marine radars typically operate at the 2- to 4-GHz (i.e., s-band) or the 8- to 12-GHz (i.e., x-band) frequencies. They are relatively small compared to other radar systems, allowing for greater portability. Marine radar units are also relatively inexpensive and effective at detecting small objects. Marine radars can provide a count of targets that pass through the radar beam and accurately estimate the distance of targets within a range of about 400 to 11,000 m from the radar (Bigger et al. 2006; Mabee et al. 2006; Weber et al. 2005). These attributes have made marine radar a popular choice for detecting and monitoring birds at a site-specific scale. In 1998, researchers at the Clemson University Radar Ornithology Laboratory developed one of the first radar systems designed specifically for monitoring birds. This portable system called BIRDRAD contained marine x-band radar (Weber et al. 2005). Marine radar is now widely used to monitor both bird and bat movements at potential wind energy sites and in the vicinity of operating turbines.

Both x-band and s-band marine radars are used to detect birds and bats, and both radar types produce a relatively flat fan-shaped beam. When deployed horizontally as designed, marine radar can provide the distances to targets that pass through the beam but cannot provide information about the elevation of the target (Weber et al. 2005). To determine the elevation of targets, researchers deploy marine radars with the beam oriented vertically (Davenport 2010; Erickson 2010; Gauthreaux and Livingston 2006; Johnson 2010). Marine radars have been and continue to be tested as a type of early warning system for land-based wind turbines by integrating radar with visibility systems and turbine SCADA (Supervisory Control and Data Acquisition [telemetry]). When targets reach a certain density within a radar beam, power production can be curtailed until the targets clear the area and are no longer at risk from turbine operations (Erickson 2010).

Despite its beneficial uses, the use of marine radar to detect and enumerate flying animals poses many challenges and risks. Although marine radar may be very efficient at detecting flying objects, determining the source of a radar echo can be problematic. As Nohara et al. (2007) stated, “Identifying what radar target tracks really are is one of the great remaining challenges in avian radar system design.” Researchers have attempted to determine the identity of radar targets using attributes such as target strength with little success because target strength is affected by numerous variables. For instance, the target strength of an echo varies with distance from the radar. A target sampled at a range of 4 km will produce an echo 1/100th the strength of the same target at 1 km. The aspect of a target (i.e., direction of the target’s path relative to the radar) will also greatly influence echo characteristics (Weber et al. 2005). Lastly, a radar echo from a target that passes through the edge of a radar beam is much weaker (e.g., up to 4x) than that of a target centered by the beam. Similarly, radar echoes from a flock of small birds appear to be very similar to echoes from a single large bird, and echoes from large insects may appear to be very similar to a small slow-flying songbird. Researchers have also attempted to classify targets based on behavior and flight characteristics with mixed success.

The range of marine radar, when detecting small objects such as birds and bats, is limited to intermediate distances. Because many of the offshore wind resources are located farther away from land, land-based marine radar survey may not be effective at many locations, requiring remote deployment for surveying offshore areas more than 7.5 km from land (Davenport 2010). Remote deployment of radar offshore poses unique challenges. Reliable survey and detection of targets with marine radar requires the radar be mounted on a stable platform. Platforms used include “onshore looking out” locations such as points, peninsulas, and islands that offer land-based deployment opportunities with extended range. Shipboard radar surveys are also conducted, but ship time is expensive, limited, and affected by weather. Jack-up barges have also been deployed with mixed results and their use may be limited by weather. Marine radars have also been mounted on offshore meteorological towers, but tower space is often limited and towers may not be located near areas of interest and are expensive to deploy. Providing adequate power for remote radar deployment is also an ongoing challenge. Fuel-powered generators have been deployed to both power the radar and recharge battery power, but access to refuel is still needed on a regular basis. Solar-, wind-, or wave-powered battery recharge systems could be developed and used to recharge batteries that would serve as the primary power source to operate radar offshore. Remote deployment also poses a challenge with respect to data access. An automatic functioning radar with point-to-point wireless, cellular, or satellite communications can be used to retrieve radar data (Davenport 2010).

Another factor affecting the effectiveness of marine radar is a phenomenon called wave clutter, where an uneven water surface reflects radar energy creating false targets. The effects of wave clutter are directly related to sea condition and can be compensated somewhat by adjusting the radar mode of operation. However, target detection efficiency may also be affected. Wave clutter can also be eliminated using a "radar fence," which is a physical barrier of either radar-absorbing or -deflecting material that shields the emission of radio waves near the water surface. However, this method decreases the effective sampling area and limits the detection of low-flying animals (Davenport 2010). Clutter maps can be created to identify and eliminate objects detected in the radar field through post-processing of data. Marine radars have been deployed vertically to reduce the effects of wave clutter, but this method surveys different airspace and may or may not provide adequate data to address the research and monitoring need.

Low-flying animals are difficult to detect due to their close proximity to the water surface (see wave clutter description above). One solution to this problem is to include scan-to-scan integration correlation, whereby rotating the radar rapidly (40–120 rpm) enables researchers to differentiate stationary and slow-moving targets (Davenport 2010). Another potential solution is frequency-diversity processing where two radar transmitters with synchronized receivers are used to better differentiate slow-moving targets. A third method, Doppler processing, uses Doppler radar and tracking algorithms to determine velocity differences, allowing separation of small or weak bird targets from background or wave clutter (Davenport 2010).

Radar interference is caused by a number of sources, including operating wind turbines and other shipboard marine radar used for navigation. Some radar operation software systems (e.g., MERLIN, Detect, Inc.) have built-in interference-rejection algorithms and can be used during real-time data capture or data post-processing (Davenport 2010).

Methods for archiving marine radar data for later analysis range from manual recording of information (distance and track) on clear Mylar overlaid onto the video screen, to the use of automated software to save data attributes. Observers have also recorded video footage of the radar scope while manually recording target attributes (Solick 2010). Manual data-capture methods are prone to observer bias in recording distance and bearing, and data quality and quantity may be diminished during times of high target passage rates. Multiple software packages have been used to record marine radar data. Some are commercially available (WinHorizon; d'Entremont 2010), while others are proprietary and are provided with radar systems (DeTect, Solick 2010; Merlin, Davenport 2010). WinHorizon allows for both manual and automatic tracking, but these tools could require significant data processing time (d'Entremont 2010).

Solutions to many of the issues associated with using marine radar to survey and monitor birds and bats are both simple and complex and vary in their effectiveness. Software developers are also creating new tools to make marine radar more useful for surveying and monitoring of birds and bats. Because of its size, relative expense, and ease of use, marine radar will continue to be used as a remote-sensing tool for offshore energy development in the foreseeable future. Efforts to automate the extraction of targets from radar data, integrate radar with other sensors, and validate and calibrate new avian radar systems are ongoing (Nohara et al. 2007). Research will be required to continue development of technological fixes that limit the issues and shortcomings of marine radar to increase its effectiveness in an offshore environment.

2.3 Imaging Technologies

A variety of imaging technologies are used for counting and estimating the number of pelagic fauna, including thermal infrared imaging, high-definition cameras, and satellite imagery. Although these technologies can provide extensive data, a suite of challenges associated with their use must be overcome. This section describes the use and key limitations of several infrared and electro-optical imaging technologies that are used to monitor wildlife in offshore environments. Specifically, we describe the use of infrared imaging, high-definition cameras, and satellite imagery to gather information about various aspects of the offshore environment. Both still and video imagery technologies are discussed.

2.3.1 Thermal Infrared Imaging

Thermal infrared imaging sensors are sensitive to electromagnetic radiation beyond the visible light spectrum. These sensors create a heat image that is not dependent on reflected light and thus they can be deployed in day or night applications. The detection capabilities of thermal sensors are dependent on the resolution of the image, environmental conditions (fog or rain), and background contrast.

Thermal infrared imaging has been used at both onshore and offshore wind farms to track bat and avian movement around turbines (Desholm et al. 2006; Horn et al. 2008). Early generations of thermal infrared imagery hardware used to monitor wildlife are suitable for detecting rotor collisions at 30 to 150 m. However, the camera field of view typically only covers approximately 30% of the rotor-swept area (42-m rotors). With a large telephoto lens, thermal imaging equipment is capable of detecting small avian targets (passerines) at a distance of up to 3000 m (Zehnder et al. 2001). Significant advances have been made in the past 10 years to improve the resolution of thermal infrared detectors. Newer generation systems allow for extended ability in range and resolution of detection and increase the ability to identify target species. However, improvements in the range of detection have been less significant than those in resolution due to the increased atmospheric attenuation as distance increases.

Thermal imaging has also been used as a survey tool to determine the presence/absence and population sizes of birds and bats at wind energy sites. Thermal imaging cameras have been coupled with fixed-beam radar to provide an accurate count of birds passing overhead (Gauthreaux and Livingston 2006). An advantage of this method is the ability to determine the flight height of targets in the imagery using radar range detection. In addition, the use of thermal imagery allows for better discrimination of targets observed with the radar (birds, bats, and insects). A key limitation of this technology is that extensive manual review of captured imagery is required to quantify targets (Gauthreaux personal communication). Advances in computer vision and measurement can provide solutions to convert the vast data volume to succinct information.

2.3.2 High-Definition Aerial Photography

Airborne observer-based surveys for marine bird populations have been used for many decades to collect count data over very large areas. However, the method suffers from several shortcomings, including the need for highly trained observers, inconsistency in detection probability due to observer bias and variable sea conditions, and lack of ability to archive visual observations for improved accuracy assessment. In an attempt to address these issues, European researchers are pioneering the use of high-definition aerial photography/videography to characterize offshore wildlife resources.

Traditional airborne surveys require a biologist to constantly observe and record sightings while the aircraft follows a pre-determined route. By adding camera-based observation of the survey, biologists can record a digital archive of the survey rather than a log of what was observed. Multiple observers can later analyze the digital images to improve detection and reduce errors associated with observer bias. During data analyses, digital video can be sped up, slowed down, or paused, allowing for better identification of individuals and species. Still photos can be digitally enhanced, zoomed, and re-reviewed by external experts—all actions that are not possible during real-time observation.

Cameras also allow greater flexibility in the survey methods used. Traditional observer-based surveys are conducted at an elevation of about 80 m above the water level, which provides an effective transect width of 2000 m using two observers. High-definition cameras allow the aircraft to fly higher while still providing the information necessary to determine species. This reduces disturbance to the wildlife being surveyed and allows observations of natural behavior. Aircraft speed can be increased when using cameras, thereby increasing survey distances and decreasing aircraft time and cost. With modern, self-triggering air photo systems a single pilot/operator can be responsible for the entire mission. This has a significant impact on the direct costs and risks of a mission because it reduces the number of required personnel from 3 to 1, as well as a harder-to-quantify effect on the reduced risk of placing multiple observers on survey flights. In addition, it is conceivable that unmanned aerial vehicles (UAVs) may be able to perform surveys in the future. However, current regulations limit commercial operation of UAVs in the offshore environment because they must be kept within line-of-sight.

A significant limitation of current camera technologies is that the field of view is greatly reduced compared to an observer's field of view, resulting in a decrease of effective search area (Thaxter and Burton 2009). Typically, this decrease in search area is offset by flying survey routes closer together. Statistics and modeling can be used to infer abundance using data from the narrower transects. However, the added uncertainty introduced from statistical inference into information derived from camera-based surveys can be problematic when directly comparing data or results to traditional observer-based surveys. This flying height/resolution/swath width relationship will continue to improve as higher-resolution cameras become available. Reduced costs associated with camera use may be offset by additional costs incurred during post-processing of digital images.

Although camera-based survey methods have been developed and used by European researchers, this methodology is just beginning to be used in the United States. The advantages of replacing an observer with a high-definition camera seem to outweigh the disadvantages, and increased refinement and widespread use of these of methods should result in greater acceptance.

2.3.3 Satellite Imagery

Although some large species of marine mammals have been observed at the ocean surface in satellite imagery, the spatial and temporal resolution of current satellite imagery is insufficient for conducting surveys of avian and mammalian species in offshore environments. However, satellite-derived data can be used to study indicators of ocean productivity (e.g., chlorophyll content, sea surface temperature, temperature upwellings), which have been shown to be strong indicators of marine animal activity (Haney and McGillivary 1985; Wahl et al. 1989; Nykjaer and Van Camp 1994; Longhurst et al. 1995; Fischer et al. 2000; Butler et al. 2001; Littaye et al. 2004; Ainley et al. 2005; Croll et al. 2005; Palacios et al. 2006). This information could be used to optimize the timing and location of other surveys over large regions. This approach has been used widely for commercial and research fisheries (Brown et al. 1993; Santos 2000; Zainuddin et al. 2006), but rarely used for avian and marine mammal surveys (Schofield et al. 2002).

2.4 Acoustic Technologies

Most marine animals, with the exception of seabirds, spend most of their time below the surface of the water and thus are not easily detected or enumerated by ship-based visual methods. Despite this limitation, ship-based visual surveys have been the predominate method for assessing the distribution and abundance of marine mammals (whales, dolphins, porpoises, pinnipeds) and sea turtles in offshore environments due to technological and logistical constraints involved with detecting animals underwater. A similar problem is faced with monitoring bats offshore because their nocturnal behavior does not lend itself well to the use of visual observation techniques. Acoustic detection technologies have helped address these limitations and are now widely used for monitoring cetaceans and bats, although their use for monitoring bats offshore is relatively new. It is now common practice to conduct simultaneous acoustic and visual ship-based surveys to improve detection of cetaceans. In joint visual-acoustic surveys, acoustic modalities have detected as many one to ten times as many cetacean groups as visual surveys (Mellinger et al. 2007).

This section describes methods of deployment and limitations of the use of acoustic detection technologies used to assess the distribution and relative abundance of cetaceans and bats in offshore environments. In general, there are two types of acoustic detection technologies—active and passive. Active acoustic systems transmit sound and analyze return echoes to discern targets from background. Passive acoustic systems capture vocalizations of target animals from the surrounding environment. This report focuses on the use of passive acoustic detection systems (referred to as passive systems hereafter), because they are the preferred acoustic technology for monitoring cetaceans and bats offshore.

2.4.1 Acoustic Technologies for Monitoring Cetaceans

Passive systems have become the primary technology for wide-area acoustic surveillance of cetaceans. Unlike active systems, they do not pose any risk of interference with cetacean behavior or potential harm to their auditory systems. In addition, passive systems are inherently species-specific because they are designed to detect the vocalizations of specific species or suites of species. Depending on their intended use, passive systems may either be fixed or mobile and may use either directional or omni-directional hydrophones to detect sound emitted from targets. Directional systems are typically used to estimate a distance and bearing to targets in order to determine their location and track their movements, whereas omni-directional systems are used to determine the presence of targets within a given distance of the receiver(s). Passive systems can be automated and can operate day or night in most sea conditions. The most common types of fixed passive systems are cabled hydrophone arrays and autonomous recorders. Cabled arrays are typically deployed in permanent or semi-permanent installations and are designed to provide long-term, continuous monitoring. Because of their expense, cabled arrays are typically owned and operated by government agencies whose original purpose for these systems was antisubmarine warfare (e.g., U.S. Navy Sound Surveillance System [SOSUS]) and nuclear non-proliferation (e.g., hydrophones of the Comprehensive Test Ban Treaty Organization [CTBTO]; Mellinger et al. 2007). These systems typically consist of a series of hydrophones moored to the seafloor that are connected by undersea communication cables to onshore facilities. Government-operated systems, such as SOSUS and the CTBTO system, are primarily installed on continental slopes and seamounts at locations optimized for undistorted long-range acoustic propagation. Cabled hydrophone systems operated by nongovernmental organizations often consist of one or a few hydrophones placed within several kilometers of shore and typically cover only relatively small shelf areas (Mellinger et al. 2007). The benefits of these systems include their near real-time monitoring, location often in pelagic areas where marine mammals are otherwise rare or difficult to monitor, and operation and maintenance being funded by external sources. Disadvantages of these systems include access restrictions due to their military or sensitive nature and recording bandwidths that often are too low to detect most species of cetaceans. The low-frequency bandwidths of these systems generally restrict their detection capabilities to larger cetaceans such as fin whales.

Another widely used class of fixed passive systems is autonomous recorders. These systems consist of a hydrophone and battery-powered data-recording system. Autonomous recorders are moored to the seafloor, often with the hydrophone buoyed up in the water column, for periods of up to 2 years (Mellinger et al. 2007). This approach sacrifices the real-time data collection and multiple-element beamforming available on cabled systems for low cost and portability. Autonomous recorders may be programmed to record sound continuously or according to a sampling plan. These systems are typically deployed in arrays of three to ten instruments to provide areal coverage and allow for localization of sound sources. Data are stored internally so instruments must be recovered periodically to obtain the data. Some designs are capable of automatic detection/classification of sounds, although data are usually still proofed by a human observer. Approximately 30 different autonomous acoustic recorders are currently in use (Sousa-Lima et al. 2009), including but not limited to the National Oceanographic and Atmospheric Administration (NOAA) autonomous hydrophones, Scripps Institution of Oceanography autonomous acoustic recording packages (ARPs, Wiggins 2003; Wiggins et al. 2005), Hawaii Institute of Marine Biology ecological acoustic recorders (EARs, Lammers et al. 2008), Cornell University "pop-up" recorders, Woods Hole Oceanographic Institution whale detection buoys, and Autonomous Multi-Channel Acoustic Recorders (AMARs, JASCO Research, Victoria, British Columbia, Canada).

Another type of fixed passive acoustic detector is radio-linked hydrophones. Radio-linked systems combine a hydrophone on a mooring or shore-fast ice (Clark et al. 1996) with a radio link to a shore station or ship, permitting real-time data collection (Mellinger et al. 2007). New generation radio-linked hydrophone systems such as the QUE-phone, developed by NOAA, operate as a semi-mobile stand-alone instrument that once deployed repeats dives and ascents while monitoring sound in the deep ocean for extended periods of time (Matsumoto et al. 2006). Upon detection of certain acoustic events (e.g., volcanic/seismic activities, calls of endangered marine mammal species), the instrument returns to the surface and transmits data back to land via an iridium/global positioning system communications link.

Detection and classification of marine mammal vocalizations recorded with passive acoustic systems may be done either manually or automatically. Manual detection and classification is performed by a specialist listening to sounds and/or looking at spectrograms of sounds to discern vocalizations from other noise. This method is rarely used in practice because of the volumes of acoustic data typically involved in any passive acoustic survey and observer bias. Many methods of automatic detection and classification have been developed to better handle the volumes of acoustic data, including but not limited to matched filters, energy summation in a certain band followed by statistical classification, image processing techniques in spectrograms, spectrogram-based template matching, neural networks, wavelet decomposition, and band-limited amplitude in either the time series or spectrogram (Mellinger et al. 2007). Selecting which automatic classification method is used depends on the type(s) of vocalizations to be detected and the amount of variability in those vocalizations (i.e., simple classification methods may be appropriate for species with highly stereotyped vocalizations, whereas more complex methods are needed for species with highly variable tonal sounds).

Another challenge with automatic detection is configuring the detector's sensitivity to achieve a certain trade-off between missed calls (false negatives) and incorrect detections (false positives). This is done primarily by the user and requires considerable knowledge of the system, the acoustic environment in which the system will be operating, and variability in the target species' vocalizations and behavior. Primary factors that affect the ability of any passive acoustic detection system to detect marine mammal vocalizations include the frequency, source level, directionality, and vocal behavior of target animals (Mellinger et al. 2007). Lower frequency sounds (e.g., 1–10 kHz) such as those of mysticetes are absorbed significantly less by seawater than higher frequency sounds (e.g., >10 kHz) such as those of odontocetes and thus can be detected at greater distances. The vocal behavior of target animals, which varies with species, age, sex, and season, is also important because it affects the probability of detecting vocalizations.

2.4.2 Acoustic Technologies for Monitoring Bats

Ultrasound acoustic detectors have been used extensively for more than two decades to detect bat species in terrestrial environments. However, their use for detecting bats offshore is relatively new. Ultrasound detectors originally designed for use in terrestrial environments have been deployed on ships and islands to listen for the presence of bats that may forage or migrate in marine environments. Efforts to detect bats off the New Jersey coast have indicated the presence of bats up to 20 km offshore (Geo-Marine 2010). This in addition with other initial findings of bats offshore (Sjollema 2010), have spurred a demand to develop ultrasound detectors better adapted for monitoring bats in offshore environments. Primary technological limitations to conducting acoustic monitoring for bats offshore include the limited detection range of the detectors, lack of suitable platforms for deploying detectors, difficulty detecting bat vocalizations in noisy marine environments, and limited operational lifetime of detectors due to foul weather and corrosive conditions in marine environments.

An added challenge associated with acoustic bat monitoring efforts is interpreting results of these efforts. Results obtained from offshore acoustic monitoring of bats include recorded calls that are analyzed to determine species present. After species determination, data are usually expressed as the number of calls/unit time. Although this information is effective at determining the presence/absence of some bat species, it remains unknown how many bats may actually occur offshore and what levels of risk offshore wind energy developments pose to bat populations.

3.0 Discussion

Issues encountered when characterizing wildlife resources to assess the risks associated with wind energy development are diverse in both nature and scale. As a result, researchers have used a wide array of technologies and techniques to gather information necessary to assess risks to wildlife. Each technology provides unique capabilities that may not be available within other technologies. Conversely, each technology may also present limitations not otherwise experienced with other methods (Table 1).

Table 1. Primary Uses, Strengths, and Challenges of Technologies Used to Characterize Wildlife Populations Offshore

Technology/Technique	Primary Use	Strengths	Challenges
Boat Surveys-Observer based	Bird presence, relative abundance, behavior	Identification of species, historic data sets, behavior observation, could estimate flight heights	Expensive, methods not standardized, observer bias, biased by bird attraction to vessels, affected by weather
Aerial Surveys-Observer based	Bird or marine mammal presence, relative abundance, behavior, location	Relatively quick, can cover large areas, identification of species, provides	Difficult species identification, reduced count accuracy and precision, increased safety risk, expensive, methods not standardized.
Radar	Bird and bat detection	Long-range detection of large groups, short-range detection of individuals, not affected by daylight, much off-the-shelf technology, widely accepted	Affected by weather phenomena, ground/wave clutter, does not allow target identification, limited range, stable platform,
Thermal Infrared Imaging	Bird and bat detection, movement patterns, collision detection,	Extended range, effective during darkness	Large data volume, time-consuming data processing
High-Definition Cameras	Aerial characterization of bird and mammal populations	Archive visual observations for later analyses, increased survey protocol flexibility, increased safety, improved identification of species, reduced wildlife disturbance, enhanced behavioral observation	Reduced field of view/transect width, methods not standardized, high cost of equipment, added data-processing and archive costs
Satellite Imagery	Mapping high-value pelagic habitats	Remotely sensed data, very large scale	Not yet widely used for optimizing field sampling
Above-Water Passive Acoustic Detectors	Bat detection	Relatively inexpensive, easily deployed, widely accepted	Limited species differentiation, no population estimates, not well-suited to offshore environments
Underwater Passive Acoustic Detectors	Presence/absence of whales, dolphins, porpoises	Can detect animals while underwater, functional at all times, fixed or mobile, long term and continuous, near real-time monitoring	Limited access to instruments, DoD sensors not optimized for whale detection, may need highly skilled operator

DoD = U.S. Department of Defense

It is clear that no single technology or method of surveying will provide all of the information necessary to assess risk to wildlife from offshore wind energy development, and there are no simple technological fixes that would enable one technology to replace all others. Observer-based surveys have been the standard and provide consistent data that easily can be compared to historical data sets, and regulatory agencies may prefer to maintain continuity among data sets to predict longer-term impacts. Moving from traditional observer-based methods to sensor-based methods can create continuity issues when comparing historic data with more recent data. A good example of this is the replacement of observers with high-definition cameras when conducting aerial surveys to characterize pelagic bird populations (see Section 2.3.2). Observer-based aerial surveys provided a tally of birds observed by one or two trained observers while flying transects. Aircraft had to fly relatively low to allow identification of species, which startled many birds and may have added uncertainty to the data. Observers were trained to only record data from a predetermined width that was estimated by the observer while airborne. These methods did not provide a method of data validation or a measure of observer error. The use of high-definition cameras provides images to be viewed later to identify and tally observations in a more controlled fashion. Counting of individuals can be done on a frame-by-frame basis, reducing estimation errors when large numbers of birds are present. Cameras survey much narrower transects, and the transect width can also be estimated with a very high degree of accuracy. Camera-laden aircraft can also fly at a high altitude, reducing disturbance to birds before they are recorded. Each of these differences creates some uncertainty when comparing camera-based survey data with historical surveys. Most differences between historic observer-based data sets and those derived using high-definition cameras may eventually be addressed with more data mathematical models, but some may never be adequately quantified to look at trends over a time that spans the use of both observer- and camera-based surveys. The advantages of replacing trained observers with high-definition cameras during aerial offshore surveys outweigh the disadvantages, and their use is gaining acceptance within the offshore wind energy community.

One trait common to most of the technologies described in this report is that they generate large volumes of data. The use of technologies to assess real and potential impacts of wind energy development has resulted in an enormous amount of data. Analysis and interpretation of most data sets is still limited to trained observers sifting through volumes of data to glean information. These analyses can be both incredibly time consuming and expensive as well as subject to observer bias. As researchers continue to deploy a greater number and array of sensors, data sets will continue to grow larger and more numerous. However, information, not data, is the key to decision-making, and tools and techniques to analyze these large volumes of data have not kept pace with technological advances. It is in this realm of data processing—turning data into information— that immediate investment may provide both short- and long-term benefits to the wind energy industry.

For example, passive acoustic detectors have been used to listen for cetaceans for more than 40 years. This history is reflected in the number and diversity of data processing tools available to classify sound data to identify species. Also, replacing observers during aerial bird surveys is a fairly recent practice as the quality and resolution of cameras has improved in the digital age. Individual researchers or firms are developing tools for processing data, such as software to eliminate video segments that do not contain seabirds. In a step towards total automation, the Danish National Environment Research Institute has tested an image object-based approach for automatically detecting and counting scoters and eiders off the coast of Denmark (Groom et al. 2009). Its results were promising in that its algorithm automatically identified 100% of male eiders, 97% of female eiders, and 93% of scoters. It should be noted that the color differences between scoters and eiders are extreme (black and white) and automatically classifying species with more subtle color variations will be much more problematic. It is not surprising that the European wind energy community is leading the way in software development to process high-resolution photography because it pioneered the use of such photography in aerial surveying. Conversely, the use of marine radar to detect birds and bats is a relatively new application of an existing technology. A few tools have been developed to record and analyze radar data, but most are not publicly available.

Improvements to the function and use of technologies used for monitoring wildlife populations offshore are expected to continue at an accelerated pace due to the increased demand to develop offshore energy resources in the United States. Better tools for converting data into information are expected to be developed as well, although historically this process has not been in lockstep with technological progress. Greater emphasis on tools to improve data exfiltration and interpretation could provide greater returns on investments already made during past technology development as well as help guide future technology development. Investment in data analysis tools could also shorten the time frame for licensing and permitting, thereby lowering costs of offshore wind energy development in the United States.

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