Can radar technology overcome the current limitations of surveying for the Southern Bent-wing Bat *Miniopterus schreibersii bassanii* at wind farms?

Rob Gration

80 Hobson Street Newport Victoria 3015
Email: wildeqip@yahoo.com

ABSTRACT

The south-west region of Victoria is currently experiencing rapid growth in the number of proposed wind farms. A maternity roost and an unknown number of staging and winter roosts of the Southern Bent-wing Bat *Miniopterus schreibersii bassanii* (*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and *Flora and Fauna Guarantee Act 1988* (FFG Act)) are known from the region. Bat detectors have been the primary tool used to survey for the presence of bats at proposed wind farms, however it was recognized by government agencies that both the survey effort and design could be more rigorous. This has since been addressed with the development of 'Guidelines for bat surveys in relation to wind farms' by the Department of Sustainability and Environment (DSE) in January 2007. The author's recent experience with the guidelines was that they are very effective in identifying most species present and provided information on habitat use. They do not, however, overcome all the technical limitations encountered when undertaking bat surveys, especially for *M. schreibersii bassanii*. These limitations include: bat call parameters overlap for some species, difficulty in quantifying the number of bats using a site, mapping the direction of flight and / or migration paths, the volume of space monitored by a bat detector and placing the bat detector at the height where bats commonly fly. This paper discusses the use of radar technology and I propose it will vastly improve our understanding of site utilization, as well as number of individuals and flight paths of Southern Bent-wing Bats at proposed wind farm sites.

Key words: bat detectors, flight signature, Southern Bent-wing Bat, radar, wind farms.

Introduction

The State government of Victoria has undertaken a commitment to secure a sustainable energy supply for Victoria. The *Victorian Energy Target (VRET) Scheme* requires power retailers to purchase 10% of energy from renewable resources by 2016 (Essential Services Commission 2007). The Sustainable Energy Authority (2003a) state that other potential benefits are that it will limit reliance on coal power generation and thus ensure power supply security and reduce greenhouse emissions.

Renewable energy in the form of wind power is seen as having the best potential for meeting the energy policy goals of the Victorian state government. Whilst it is promoting the development of renewable energy, the state government acknowledges that there needs to be a balance between the triple bottom line factors, i.e. environmental, social and economic. In an effort to balance the potential effects of wind energy development, the Sustainable Energy Authority (2003a) produced the: *"Policy and planning guidelines for development of wind energy facilities in Victoria"*. This document provides developers and interested stakeholders with a framework for ensuring a consistent planning approach for the development of wind energy facilities.

In 1991, a wind resource audit was undertaken across Victoria, with the purpose of identifying locations that would provide the greatest potential for wind power generation. The west and central coasts of Victoria were identified as providing suitable wind resources. Many of Victoria's National Parks and significant landscapes are located in these regions and were identified as providing suitable wind resources. However, wind farm development is excluded in these parks thus protecting 43% of the Victorian coastline and 32% of land 1 km inland from the coast (Sustainable Energy Authority 2003a).

The key environmental legislative framework relevant to wind farm development is the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and Victorian state legislation; *Flora and Fauna Guarantee Act 1988 and National Parks Act 1975.* The specific flora and fauna requirements are as follows:

The flora and fauna found at a site should be considered in relation to:

- Whether species and communities are protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) or *Flora and Fauna Guarantee Act 1988* (FFG Act).
- The sensitivity of any protected species to disturbance; and the potential loss of habitat of species protected under the EPBC Act or FFG Act.

Where there is a likelihood that species listed under either of the aforementioned acts are present, then appropriate

Pp. 185–194 in *The Biology and Conservation of Australasian Bats*, edited by Bradley Law, Peggy Eby, Daniel Lunney and Lindy Lumsden. Royal Zoological Society of NSW, Mosman, NSW, Australia. 2011.

field surveys are required (Sustainable Energy Authority Victoria 2003a).

However, the guidelines are not prescriptive, they do not provide guidance for the degree of survey effort and techniques to be deployed. This is the responsibility of the proponent to discuss and develop with local DSE officers and flora and fauna consultants. Surveys for bats present a higher degree of complexity not associated with general fauna surveys, i.e. bat surveys require the deployment of specialised equipment and techniques. Bat researchers with the necessary skills and experience are in short supply on a state by state basis. The survey effort at wind farms to date has varied considerably with bat detectors utilised as the primary tool (Jacka and Westwood 2003; Harty *et al*. 2005; Jacka and Thatcher 2005; Gilmore and Mueck 2006).

This aim of this paper is to discuss the limitations of technology currently used in undertaking bat surveys at wind farms in general and more specifically when targeting the EPBC Act and FFG Act listed Southern Bent-wing Bat *Miniopterus schreibersii bassanii* in Southwest Victoria. A range of techniques / technology that may be applicable for surveying *M. s. bassanii* at wind farms are evaluated. An example is provided of technology that offers great potential to overcome the current survey limitations for Southern Bent-wing Bats at wind farms.

Miniopterus schreibersii spp.

The taxonomic status of the genus *Miniopterus* is currently being revised worldwide (Goodman *et al* 2008), however two species of *Miniopterus* are recognized in Australia; the Large Bent-winged Bat *Miniopterus schreibersii* which encompasses 3-subspecies and the Little Bent-winged Bat *Miniopterus australis* (Hall and Richards 1979; Dwyer 1995; Churchill 1998; Cardinal and Christidis 2000).

Miniopterus schreibersii was originally classified as two sub-species; *oceanensis,* known as the southern form (Reardon *et al*. 1999), and *orianae,* the northern form (Dwyer 1995). *M. s. oceanensis* is distributed from Queensland to central Victoria and, *M. s. orianae is* found only in Northern Australia (Cardinal and Christidis 2000). Mitochondrial DNA and morphology analysis by Cardinal and Christidis (2000) identified a third sub-species, in this case the study species *M. s. bassanii.* This sub-species is distributed from western Victoria to eastern South Australia (Figure 1).

There are two known maternity caves for *M. s. bassanii,* Bat Cave at Naracoorte and Starlight Cave at Lake Gillear, south-east of Warrnambool. At the completion of the breeding season, *M. s. bassanii* disperse to wintering caves throughout south-west Victoria (Cardinal and Christidis 2000). Known wintering roosts for *M.S bassanii* in south-west Victoria are: Grassmere Cave, Panmure Cave, Arch Cave, Yambuk Cave, Mt Eccles, Byaduk Cave, and Mt Napier (Figure 1). To date there is little known about the timing of migration / movement between roosts, flight paths between roosts and foraging areas and whether Southern Bent-wing Bats move on mass, as small groups or as individuals. The distribution of the Southern Bent-wing Bat coincides with the region that has been identified as providing a reliable wind resource needed for the development of wind farms (Sustainable Energy Authority Victoria 2003b).

To date there has been little information of the impact of wind farms on Australian bats when compared to the northern hemisphere. Large numbers of bat fatalities have been attributed to wind turbines in Europe and United states (Horne et al 2008; Arnett *et al.* 2008; Barclay *et al.* 2007; Kunz *et al.* 2007; National Research Council of the National Academies 2007). Horne *et al.* (2008) used thermal infrared cameras to show bat fatalities were directly attributed to a bat striking the turbine. This is in contrast to Baerwald *et al*. (2008) who attributed 90% of bat deaths at their study site to a drop in air pressure near the turbine blades causing internal haemorrhaging of the lungs.

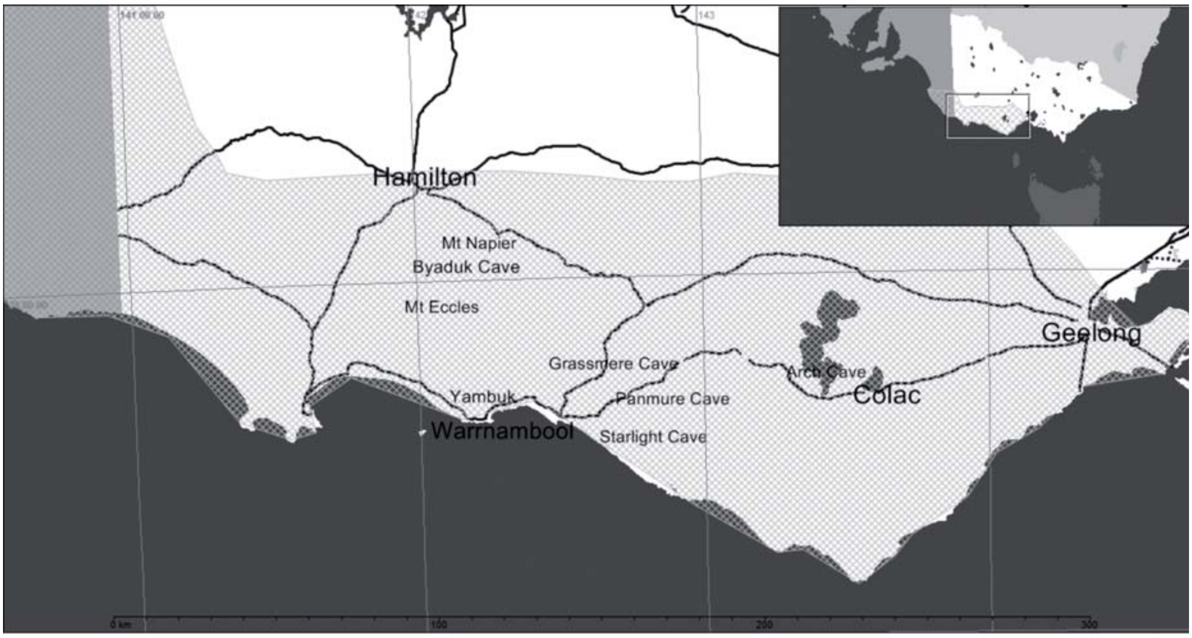

Figure 1. Southern Bent-wing Bat distribution and caves utilised in south west Victoria.

The following characteristics of bat ecology and turbine design have been attributed to bat fatalities at wind farms in North America (Arnett *et al* 2007b; Barclay *et al* 2007; Kunz *et al* 2007):

- bats that migrate long distances
- tree roosting species of bat
- turbines located on forested ridge tops
- low wind speed
- deaths are typically associated with the end turbine strings
- fatalities increased immediately before and after storm fronts
- fatalities increased with tower height.

Bat Survey techniques deployed at wind farms pre and post 2007

Prior to February 2007, there was no consistency in either the timing or degree of survey effort for *M. s. bassanii.* Surveys ranged from no survey to a maximum of 9-days with bat detectors deployed as the primary surveying tool (Jacka *et al*. 2003; Banon *et al*. 2005; Harty *et al*. 2005; Jacka *et al.* 2005; Richards 2005; Gilmore and Mueck 2006; Saunders *et al*. 2006; Smith *et al*. 2006). Lumsden (2007) developed the "*Guidelines for bat surveys* in *relation to wind farm developments*" to address the limitations of previous surveys. The guidelines are to date the most comprehensive in terms of survey design requirements when targeting Southern Bent-wing Bat i.e. timing to coincide with movement between roosts, the use of multiple detectors, surveying each habitat type, use of capture techniques and roost surveys. The guidelines assist the development of the survey design by prescribing:

- the timing of the survey and temporal factors to be considered e.g. survey during *M. s. bassanii* migration period and weather conditions conducive to bat activity,
- the survey effort to be dependent on the number of turbines proposed e.g. one detector for every 3–4 turbines, detectors are to be operated for a minimum of 7-days.
- where applicable a range of techniques are to be deployed e.g. use of capture techniques and exit surveys of *M. s. bassanii* roost sites
- each habitat type at a site is to be surveyed e.g. open paddock, vegetated areas and wetland or water points (creeks, dams etc)
- an assessment of the proximity of the site to cave systems utilised by Southern Bent-wing Bat

Please note: it is not known on what basis the survey guidelines have been based.

I implemented these guidelines at 2-proposed wind farm sites in south-west Victoria in February 2007. My experience with the guidelines were that the increased survey effort was effective in compiling an inventory of the species present when compared to existing database records (DSE 2005) and, provided valuable information on habitat use. They did not, however, overcome the technical limitations associated with targeted surveys for Southern Bent-wing Bat i.e. positive identification, track flight paths, enumerate the number of individuals utilising a site, activity levels and timing of migration. It should be noted that a conservative approach was undertaken when distinguishing Southern Bent-winged Bat calls from Chocolate Wattled Bat *Chalinolobus morio* and, Little Forest Bat *Vespadelus vulturnus* species with similar call parameters.

What are the limitations when surveying for Miniopterus schreibersii bassanii *at wind farms?*

The use of bat detectors has limitations, particularly when surveying for *M. s. bassanii.* These limitations include variation in call intensity (5–25 m), weather conditions, variation in the sensitivity of the bat detector (Larson and Hayes 2000), placement of detectors at a height where activity is likely to occur and the technical competence of the operator. Further to this, a bat detector can only provide a measure of activity and does not provide evidence of the number of individual bats present or their movement across the landscape. In many instances, the quality and length of the bat call may not provide the diagnostic features required to identify to species level. A number of species have similar call features that can only be identified to a genus or species complex if diagnostic features are not present. *Miniopterus s. bassanii* has a call that can be extremely similar to the Little Forest Bat *Vespadelus vulturnus* and Chocolate Wattled Bat *Chalinolobus morio*. In these circumstances, capture techniques at a proposed wind farm site can confirm the presence of *V. vulturnus* and *C. morio,* but are unlikely to capture *M. s. bassanii because* of their foraging / commuting characteristics i.e. high flying 30–40 m (Gration 2007a; Gration 2007b). Given these limitations, the cost / benefits of a range of alternatives are evaluated below.

Extending the use of light tags

Chemiluminescent tags, commonly referred to as light-tags, are cheap and readily available from fishing tackle shops. They consist of a flexible plastic capsule filled with cyalume and a glass vial filled with a reactant. The capsule is bent until the inner glass vial is broken causing a chemical reaction; the reaction then emits light (Barclay & Bell 1988). Light-tags are useful for observing foraging and flight behaviour (Churchill 1998) and for recording voucher calls of free flying bats (Barclay & Bell 1988).

My experience with the use of light tags is that in the right circumstances they can be seen by the naked eye for 100 m or more. This being the case, consider the possibility of significant proportions of *M. s. bassanii* being captured whilst exiting their roost and having light tags attached and then released. Could a second group of fieldworkers spread across the site at the proposed wind farm and use binoculars to observe bats that may fly through the site? The cost of the light tags is extremely low ($1.50 each) when compared to radio-tracking, but the human resource requirements and human observational bias would potentially offset any savings. There could also be animal welfare concerns as roost disturbance may lead to the bats abandoning their roost and light tags may alter their behaviour thus affecting foraging capability due to the need to capture and attach light tags over a number of nights. Although a useful supplementary technique, it would not be suitable as the primary technique.

Blimps & bat detectors

One of the key limitations with the use of bat detectors is raising them to within the rotor swept zone. The current method of recording Southern Bent-wing Bats is by deploying a bat detector at a height of 20–60 m on the meteorological tower erected at a proposed wind farm site. As a consequence only a small area of a site is sampled. Specialist companies provide aerial photography services based on a remotely operated camera mounted onto a miniature helium blimp. Could the use of a number of blimps across a site overcome the logistical limitations of getting a bat detector to a height where Southern Bent-wing Bat are likely to be active? A 6 m long blimp would be required to accept the payload of a bat detector and 12 V battery for long term monitoring. They are capable of being tethered at a height of approximately 100 metres (Southern Balloon Works. 2007, pers comm., 3 March), however, they can only be launched in light winds and the window of opportunity for light winds at a proposed wind farm is very limited. Further to this, the cost of inflating the blimp with helium becomes extremely costly as does the logistical aspects of transporting a number of inflated blimps from site to site.

Thermal imaging & Infra-red cameras

Unlike bat detectors, thermal imaging and infra-red cameras can confidently enumerate numbers (Figure 2) when located at a roost site (Codd 1997; Kunz 2003; McCracken 2003; Grant and Reardon 2004). Thermal imaging is most effective when deployed against a distinct, thermally uniform, contrasting background. It requires a stable power source, the thermal imaging equipment needs to be set at 90° to the flight path for reliable counts and they are expensive (Kunz 2003). Infra-red cameras are considerably cheaper than thermal imaging and can be used in total darkness, however, the quality of the image is directly related to the infra-red responsiveness of the camera and the source of infrared light (pers obs). Both have limited capability in identifying bats to species level. More importantly, they have a limited field of view and thus sample only a small volume of space. As a consequence, I would argue that the information they provide will not overcome the current limitations of surveying *M. s. bassanii* at wind farms.

Can Doppler Shift Radar overcome the limitations of surveying Miniopterus schreibersii bassanii *at wind farms?*

Bracken Caves in Texas is estimated to have approximately 20 million Mexican free-tailed Bats roosting within caves. The subsequent exiting of the bats occurs over a 2 h period. There is an estimated 100 million individuals in south-central Texas alone. A Doppler radar station built nearby by the National Weather Service showed bats and insects radiating across the landscape and recorded bats flying at altitudes of 3.048 km (McCracken and Westbrook 2002). Bruderer and Popa-Lisseanu (2005) then published a paper on wing–beat frequencies and flight speeds of two bats (*Nyctalus noctula* and *Eptesicus serotonis*) and the discrimination between bats and nocturnal birds. This research paper was based on data collected in 1974 and 1975. Although they used what would now be considered outdated technology; a movie camera mounted on ex-military "Sperfledermauas" radar, they were able to demonstrate that bat flight patterns differed from birds and they could measure wing beat frequency and flight speeds. Their conclusion was that radar has potential application for survey of free flying bats.

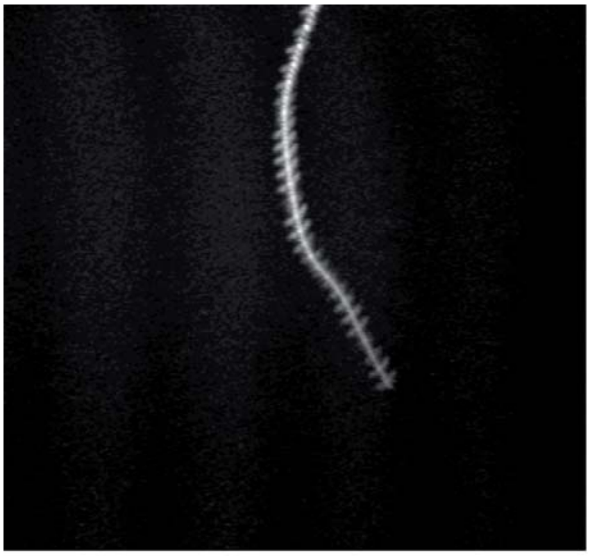

Figure 2. Thermal image of a bat in flight

These two publications beg the question of whether there is more advanced radar technology specifically applicable to bats? A review of the literature indicated that there were two recent examples of the use of advanced radar technology for monitoring both birds and bats.

The principles of Radar

The roots of electromagnetic theory are based in the mid 1800's when James Maxwell, a mathematician and physicist developed the formulas and physical representations of electromagnetic fields. Following on from Maxwell's work, Heinrich Hertz proved that electricity could be transmitted by electromagnetic waves and simplified Maxwell's formulas (Schneider and Martin 2003). The term radar is an acronym based on RAdio Detecting And Ranging (Larkin R.P. 2005).

Radar is based on two principles, echo and Doppler shift. Using audible soundwaves as an example, the echo of a sound wave can be used to determine how far away an object based on the known speed of sound (340 m/s) and the time it takes to hear the return echo. Doppler shift can be used to determine radial velocity (Larkin 2005); a typical example of Doppler shift is the changing pitch of a siren on an emergency vehicle as it approaches and passes. As it approaches, the sound is compressed, thus increasing the frequency of the siren, which then decreases as it passes.

Radio waves used for Doppler shift radar are grouped into five bands; L, S, C, X and K, the relative wavelength and frequency for each band is provided in Table 1 (Everything Weather 2007).

Table 1. Radar wavelengths and their relevant frequency

Wavelength (cm)		Frequency (GHz)
L	15–30	1–2
S	8–15	2–4
C	4–8	4–8
X	2·5–4	8–12
K	0·75–1·2 or 1·7–2.5	27–40/12–18

As is the case where the call frequency of a bat determines its preferred prey size (Hill and Smith 1984), the radar wave lengths used differs depending on their use, with smaller targets requiring a higher frequency.

Historical and recent use of Doppler radar technology

The use of radar to monitor biological organisms has a history dating back to the first use of radar. Birds were first identified as radar echoes in 1945, radar has since been successfully used to detect and monitor moving organisms (Larkin 2005; National Research Council of the National Academies 2007). Over the last 20-years, radar has been increasingly used for risk assessment studies of migrating and threatened species (National Research Council of the National Academies 2007). Radar systems used for biological purposes are based on the commercial marine T-bar antenna radar system used for monitoring weather and navigation. It has more recently been used for monitoring bat activity at wind farms (DeTect Inc 2005; Echo Track Inc 2005). This type of radar system is operationally reliable and has an existing history with bird migration studies (National Research Council of the National Academies 2007). If vertical and horizontal antennas are operated simultaneously they can provide 2·5 D imaging and are cost effective for long-term monitoring and in gathering statistically powerful data sets. A range of other antenna configurations are available, however they are limited by the initial and on-going maintenance costs, limited range and beam coverage (DeTect Inc 2005; Echo Track Inc 2005).

Typical configurations consist of a single antenna that can be manually moved from the horizontal to the vertical and use an X-band wave length (2·5–4 cm) at 10 to 25 kilowatt output. In a vertical orientation the radar scans from horizon to horizon collecting flight height, numbers and direction up to 926 m either side of the radar and 762 above (Figure 3). When operated on the horizontal plane the antenna sends out a 20º fan shaped beam rotating through a 360° plane collecting data to a distance of 3.704–5.556 km depending on power output. Advanced units have both a horizontal antenna and a vertical antenna (Figure 4) operating simultaneously in S-band (8–15 cm) and X-band (2·5–4 cm), respectively. Depending on the power output they can monitor larger volumes than a single antenna (DeTect Inc 2005).

Real-time manual monitoring of raw radar data requires a highly skilled radar ornithologist to interpret what is appearing on the screen (Figure 5). A typical scenario is that they must be able to discriminate between clutter potentially obscuring targets, bats, birds, aircraft and insects, track and time flight paths and note the relative size for later analysis. These operational requirements restrict the data that can be reliably analysed over a 24 h period. The latest technology does not require an operator as it uses computer software with the capability to monitor and process data 24-hours a day. Automation also overcomes any occupational health and safety concerns with the long-term exposure to radio waves. This software can exclude target types, track specific targets based on ground truthing of behavioural characteristics, determine size categories and determine flight paths and height. Figure 6 highlights how advanced radar software analyses can improve on the same raw data shown in Figure 5 (DeTect Inc 2007). Figure 7 not only improves the raw image, but also includes the species recorded based on ground truthed signatures and their numbers.

Existing use of Radar to monitor bats at wind farms

Echo Track Inc (2005) undertook research using radar and highly sensitive microphones to monitor bird and bat activity at six wind farms and six control sites in the Prairie Ecozone of Alberta Canada. A combination of microphones capable of recording either bird calls up to 600 m above the ground or bat ultrasonics approximately 20 m above the ground were also deployed. The typical limitations for sound recording bats were evident, and as a consequence, not all bats were identified to species. In excess of 1 million flight tracks were recorded over 37-nights noting direction, flight speed, altitude and the flight behaviour when approaching turbines and at six control sites. They concluded that a combination of radar and microphones has potential for monitoring bird and bat activity at wind farms. Their findings suggest that both birds and bats avoided the wind turbines by altering both their flight speed and altitude. Although radar can distinguish the flight patterns of bats from birds, indicate target size, numbers, flight height and direction, the limitation of identifying birds and bats to species level is still problematic (National Research Council of the National Academies 2007).

Recent developments in radar technology

The use of radar has been acknowledged as being more reliable, of higher precision and more robust than the use of visual and acoustic surveying techniques for birds and bats (Bruderer and Popa-Lisseanu 2005; Echo track Inc 2005; Kelly *et al*. 2007). Whilst the current use of marine grade radars can provide valuable information on temporal activity, flight path and size class, they do not always have the capability to discriminate between a bat and bird or identify to a species level.

The latest radar technology using military grade radar in conjunction with thermal imaging and ultrasonic bat detectors may overcome these limitations (Kelly *et al*. 2007). Vertical profiling radar (VPR) is currently being trialled in the United States. VPR differs from vertical marine radar in its sensitivity, and is capable of tracking individual targets. If a target is tracked for only a few seconds, a diagnostic wingbeat signature can be recorded (wingbeat frequency and amplitude) taking the form of what looks like a barcode (Figure 7). The radar data can clearly define the horizontal flight paths attributed to a migrating bird and foraging patterns associated with bat activity. There is, however, still some difficulty differentiating between birds and bats in horizontal flight using radar alone. There would still be a need to utilise supplementary techniques such as ultrasonic bat detectors and thermal imaging to develop ground-truthed algorithms. Of particular interest is the capability to monitor the vertical stratification of insect activity and their correlation to bat activity at wind farms (Kelly *et al*. 2007).

Bullen and McKenzie's (2000) research into bat wingbeat frequency and amplitude for Australian bats verified the relationship between wingbeat frequency and mass; this relationship has been acknowledged for birds, bats and insects. Wing beat frequency is proportional to body

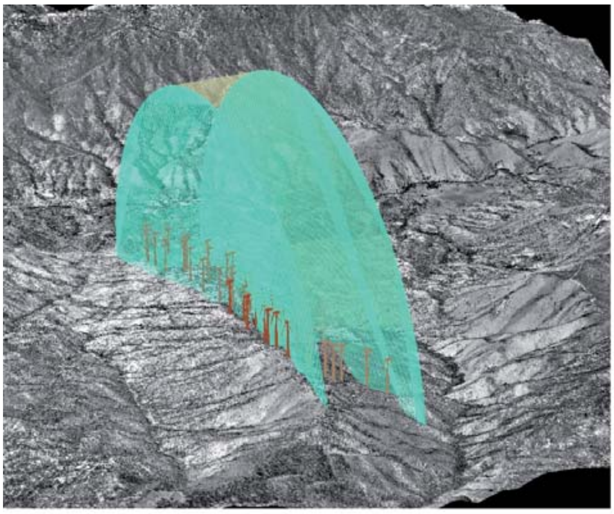

Figure 3. Vertical radar profile. Source: DeTect 2007

Figure 4. Horizontal and vertical antenna system Source: DeTect 2007

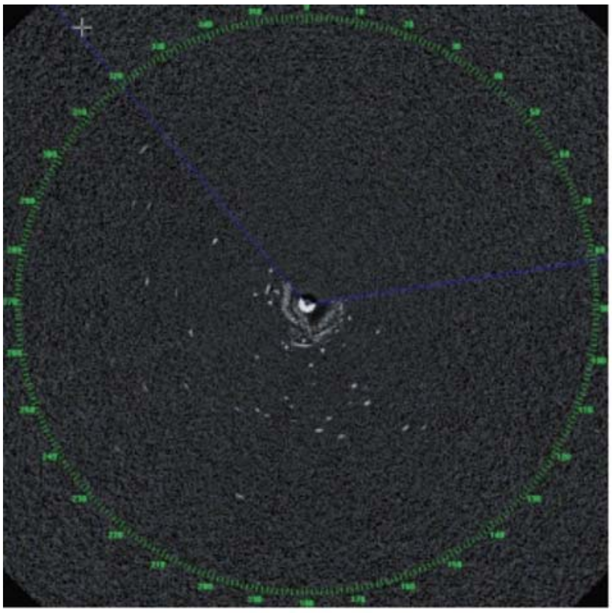

Figure 5. Raw radar data with clutter. Source: DeTect 2007

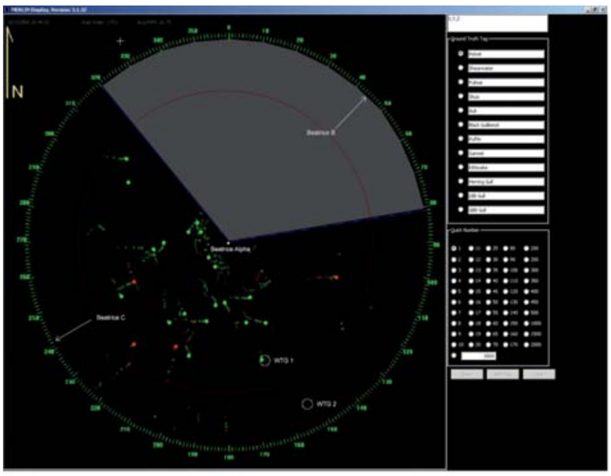

Figure 6. Computer aided radar data. Source: DeTect 2007

Figure 7. A is an insect wingbeat signature. B is a bird wingbeat signature Source: DeTect 2007

mass (Kelly *et al* 2007), although bats have a higher wing beat frequency when compared to an equivalent size bird (Bullen and McKenzie 2000). This relationship forms the basis to discriminate between species using the latest radar technology.

The comparative cost between the use of Vertical Profile Radar (VPR) and standard bat survey methods

The cost to purchase a turnkey DeTect Inc VPR unit would be in the vicinity of $135k (US), including freighting to Australia, a combined VPR / horizontal antennae unit would cost in the vicinity $260k (US) including freighting to Australia. The rate for hiring a combined VPR / horizontal radar unit is approximately $9.5k (US) per week (Gary Andrews pers comm. 3 January 2008). Based on the authors experience, the cost of hiring a VPR unit is comparable to the fees to undertake a bat survey based on the aforementioned survey guidelines (Lumsden 2007). The advantages with the use of VPR is that it collects considerably more data than traditional survey methods and can monitor bats and birds simultaneously during 24/7 operation (DeTect Inc 2007). VPR units are currently not available for hire in Australia, but it is expected they will in the near future (Gary Andrews pers comm. 3 January 2008).

The purchase of a VPR and / or a combined horizontal antennae unit for use in Australia would be a substantial outlay and it would require a prospective purchaser to undertake a thorough cost / benefit analysis. The purchase of a VPR may prove feasible as the unit not only has application for use monitoring bats but can also be deployed to monitor bird activity at a site whilst monitoring bats. The purchase of a combined VPR and horizontal radar unit also has wider application as they are currently being used at the Florida Space Shuttle launch site and US airbases and public airports to monitor for potential for bird / aircraft collisions (DeTect 2007). Bird and bat strikes are a public safety issue for airport operators in Australia (Robson et al 2006).

The cost of hiring a unit is within the range of undertaking combined bat and bird surveys at a wind farm when deploying DSE (2007) and industry best practice guidelines (Auswind 2006). Current industry practices require a fieldworker/s to be on-site for a substantial period of time. A VPR unit is a portable, unmanned unit towed behind a standard four wheel drive vehicle. It would require one or two fieldworkers for the initial set up and retrieval phase, not unlike what is presently undertaken with long-term Anabat surveys. Due to the large data sets a VPR is likely to record in comparison to current survey practises, it is envisaged that the analysis and reporting stages would require more time to complete.

How could Vertical Profiling Radar (VPR) be applied to Miniopterus schreibersii bassanii *at wind farms?*

As is the case with ultrasonic bat detectors and the need for voucher calls (Lumsden 2007), ground truthing and a library of wingbeat vouchers would be required to confidently identify bats to a species level (Kelly *et al* 2007). As previously discussed Southern Bent-wing Bat has a call that can be extremely similar to Chocolate Wattled Bat and Little Forest Bat (Gration 2007a; Gration 2007b). Bullen and McKenzie (2000) researched the flight performance of 23 species of Australian bats. The flight characteristics of *C. morio*, Southern Forest Bat *Vespadelus regulus*, Large Bent-wing *Bat M. schreibersii and* the White-striped Freetail Bat *Tadarida australis* are utilised in the model below. The first three species were selected for the model as they best represent the species call complex group found at wind farm sites. *Tadarida australis* is included because its flight behaviour is broadly similar to that of *M. s. bassanii* i.e. forages over or above canopy and both are fast flying (Churchill 1998). These species are provided as an example of how flight characteristics can be applied to the use of VPR.

Assumptions

It is assumed that the activity recorded by the radar is that of a bat and that the flight signature for *V. regulus* and *M. schreibersii* (Bullen and McKenzie 2000) is typical of the *Vespadelus* genus and *M. s. Bassanii,* respectively. It is assumed that flight speed in or over an open paddock is more likely to be at the upper end of their recorded flight speed. Based on these assumptions we can initially attempt to discriminate between species based on their body mass (Table 2) and then their flight characteristics (Table 3).

Table 2. Body weight of *M. S. bassanii* species call complex group and *T. australis* (Churchill 1998)

Species	Mean Weight (Grams)
Chalinolobus morio	8.1
Miniopterus schreibersii bassanii	14.6
Vespadelus vulturnus	4.3
Tadarida australis	36.3

Using body mass alone, *T. australis* would clearly show as a larger object than *C. morio* and *V. vulturnus* and most likely *M. schreibersii bassanii.* Not withstanding this, analysing other flight characteristics may ascertain whether they support these initial conclusions.

Using the flight characteristics described in Table 3, it may be possible to differentiate *C. morio* from *M. s. bassanii* based on its coasting behaviour during flight and lower wingbeat amplitude. *Vespadelus spp* can be differentiated not only on its body mass, but also its wingbeat frequency, wing amplitude and flight speed.

T. australis has a loud audible call within the human hearing range and is easily detected with an ultrasonic bat detector. If an ultrasonic detector was used in conjunction with radar, cross referencing with radar data may provide inferences for the likely presence of *M. s. bassanii* and *T. australis* simultaneously at a given point in time.

Conclusion

It remains to be proven whether vertical profile radar technology will positively differentiate *M. s. bassanii* from its call complex cohorts. The question of whether the

Table 3. Flight characteristics of *M. S. bassanii* species call complex group and *T. australis* (Bullen and McKenzie 2000). Standard deviation shown in parentheses

Species	Speed range (ms)	Wingbeat frequency (Hz) mean	Wingbeat Amplitude (degrees)	Coasting In flight
Chalinolobus morio	2·2–7·8	9.04	49.23 (15.39)	Yes
Miniopterus schreibersii spp	5·8–8·9	9·10	92.50 (17.68)	No
Vespadelus regulus	1·4–6·9	10·75	41.38 (6.85)	No
Tadarida australis	3.6–13.5	8·19	90.74 (27.70)	No

mechanical noise of operating the radar affects bat behaviour will also need to studied, this has not been addressed to date . What can't be questioned is that radar technology can provide statistically powerful data sets suitable for long term monitoring, sample large volumes of space, record flight direction and height, and correlate activity to temporal variations and prey availability. It can also provide valuable information on flight characteristics and behaviour of not only bats and their prey, but also birds (Echo track Inc 2005; DeTect Inc 2007, 2006).

An integrated survey approach is still required; however the addition of radar may provide a greater degree of certainly in establishing if Southern Bent-wing Bats are present at wind farms and its behaviour around the rotors. This would alleviate some of the current limitations of targeted surveys for *M. s. bassanii* and potentially provide more meaningful data to make informed management decisions. The cost of purchasing a Radar system might act as a deterrent for its use in Australia, but the option to hire would most likely overcome this.

It should be noted that two of the larger wind farm developers that operate in Australia, Babcock and Brown and Meridian, have recently purchased Detect Inc radar units to operate at their American and New Zealand wind farms, respectively.

Acknowledgements

David Atkinson and Brad Law provided valuable improvements to the format and content of this paper. Gary Andrews and Adam A Kelly from DeTect Inc provided radar images and technical feedback to my radar questions. Mark Venosta and two anonymous referees provided valuable feedback for improving the manuscript.

References

Alhen, I. 2002. Heterodyne and time expansion methods for identification of bats in the field and through sound analysis. Pp 72–79 in *Bat Echolocation Research, Tools, Techniques and Analysis*, edited by M.R. Brigham, E.K.V. Kalko, G. Jones, S. Parsons and H.J.G.A. Limpens. Bat Conservation International, Texas.

Altringham, J. 1999. *Bats, Biology and Behaviour.* Oxford University Press, Oxford.

Arnett, E. B., Brown, W. K., Erickson, W. P., Fiedler, K.K., Hamilton, B.L., Henry, T.H., Jain, A., Johnson, G. D., Kerns, J., Koford, R.R., Nicholson, C.P., O'Connell, T.J., Piorkowski, M. D and Tankersley, R.D. 2008. Patterns of bat fatalities at wind energy facilities North America. *Journal of Wildlife Management* 72 (1): 61–78.

Auswind. 2002. Best *Practise Guidelines for Implementation of Wind Energy Projects in Australia*: The Australian Wind Energy Association; Melbourne.

Banon, C., Kay, E. and Schutt, S. 2005. *Waubra Wind Farm Planning Permit Call In: Applications 05/0150 & 05/0152 Panel Report*: Department of sustainability and Environment: Melbourne.

Barclay, R. M.R., Baerwald, E.F. and Gruver, J.C. 2007. Variation in bat and bird fatalities at wind energy facilities: assessing the effects of rotor size and tower height. *Journal of Zoology* **85:** 381–387.

Barclay, R. M.R. & Bell, G.P. 1988. Marking and Observational Techniques. Pp 59–76 in *Ecological and Behavioural Methods for the Study of Bat*s, edited by T. H. Kunz. Smithsonian Institution, USA.

Baerwald, E.F., D'Amours, G.H., Klug, B.J. and Barclay, R.M.R. 2008. Barotrauma is a significant cause of bat fatalities at wind turbines. *Current Biology* **18:** 695–696

Behrend, O. and Schuller, G. 2004. New aspects of Doppler-shift compensation in the Horseshoe Bat, *Rhinolophus rouxi*. Pp. 17–21 in *Echolocation in Bat and Dolphins*, edited by J.A. Thomas, C.F. Moss and M. Vater. The University of Chicago Press, Chicago.

Barlow, K. (1999). *Expedition Field Techniques: Bats*. Royal Geographical Society: London.

Bruderer, B. and Popa-Lisseanu, A.G. 2005. Radar data on wing beat frequencies and flight speeds of two bats. *Acta Chiropterologica* 7(1): 73–82.

Bullen, R.D. and McKenzie, N.L. 2002. Scaling bat wingbeat frequency and amplitude. *The Journal of Experimental Biology* **205**: 2615–2626.

Burgess, D., Osmond, T., Wilson, R. and Sanderson, K. 1995. Bat flight speed measured outside the Flinders University Sports Centre. *Australasian Bat Society Newsletter* **5**: 12.

Cardinal, B. R. and Christidis, L. 2000. Mitochondrial DNA and morphology reveal three geographically distinct lineages of the large bent-wing bat (*Miniopterus schreibersii*) in Australia. *Australian Journal of Zoology* **48** (1): 1–19.

Churchill, S. 1998. *Australian Bats*. Reed New Holland: Sydney.

Department of Sustainability and Environment. 2005. *Atlas of Victorian Wildlife*. Department of Sustainability and Environment: Melbourne.

DeTect, Inc. 2005. *An Overview: Radar technology for Assessment of Avian Issues at Wind Energy Project Sites*. DeTect Inc: Florida

DeTect, Inc. 2007. *Avian Radar systems*. DeTect Inc: Florida

Dwyer, P.D. 1995. Common Bent-wing-Bat. Pp. 494–495 in *The Mammals of Australia,* edited by R. Strahan. Reed Books, NSW.

Dwyer, P. D. and Hamilton-Smith, E. 1965. Breeding caves and maternity colonies of the Bent-winged Bat in south-eastern Australia. *Helectite* 4: 3–21.

Echo Track Inc. 2005. *An investigation of a new Monitoring Technology for birds and Bats.* Echo Track; Canada.

Essential Service Commission 19 March 2007. *Victorian Renewable Energy Target (VRET) scheme.* http://www.esc.vic.gov.au/public/VRET/

Everything Weather 19 March 2007. *Radar Bands.* http://wwweverythingweather.com/weather-radar/bands.shtml

Gilmore, D. and Mueck, S. 2006. *Flora and Fauna assessment of the proposed Newfield wind farm, Victoria.* Biosis Research: Melbourne.

Goodman, S.T., Bradmand, H. M., Maminirina, C. P., Ryan, K. R., Christidis, L. L and Appleton, B. 2008. A new species of Miniopterus (Chiroptera: Miniopteridae) from lowland southeastern Madagascar. *Mammalian Biology* 73 (3): 199–213

Grant, C. and Reardon, T. 2004. The use of video taping of fly-outs for the population assessment of cave-dwelling bats. Spoken Paper; 12th Australasian Bat Society Conference; Toowoomba 2004. *Australasian Bat Society Newsletter* 22: 34

Gration, R. 2007a. *Southern Bent-wing Bat and General Bat Activity Report for Proposed Woolsthorpe Wind Farm.* Report prepared by Environmental and Biodiversity Services for Woolsthorpe Wind Farm Pty Ltd, Melbourne April 2007.

Gration, R. 2007b. *Southern Bent-wing Bat and General Bat Activity Report for Proposed Drysdale Wind Farm.* Report prepared by Environmental and Biodiversity Services for Drysdale Wind Farm Pty Ltd, Melbourne March 2007.

Hall, L.S. and Richards, G.C. 1979. *Bats of Eastern Australia*. Queensland Museum, Brisbane.

Hall, L.S. and Richards, G.C. 2004. Flying around underground: cave bats. Pp. 111–126 in *Beneath The Surface: A Natural History of Australian Caves*, edited by B. Finlayson and E. Hamilton-Smith. University of NSW Press, Sydney.

Harty, C., Evans, B. and Kay, E. 2005. *Mt Gellibrand Windfarm Colac Otway Planning Scheme Planning Permit Application PL-SP/05/0257 Panel Report*: Department of Sustainability and Environment: Melbourne.

Harvey, M.J. Altenbach, J.S. and Best, T.L. 1999. *Bats of the United States*. Arkensas Game & Fish Commission, USA.

Hill, J. E. and Smith, J.D. 1984. *Bats: A Natural History.* Rigby Publishers: London.

Horne, J.W., Arnett, E.B. and Kunz, T.H. 2008. Behavioural responses of bats to operating wind turbines. *Journal of Wildlife Management* 71: 123–132

Jacka, E. and Thatcher, A. 2005. *Corangamite Planning Scheme Planning Permit Application: PL-SP/05/01424 Naroghid Wind Farm Panel Report*: Department of sustainability and Environment: Melbourne.

Jacka, E. and Westwood, J. 2003. *Wonthaggi Wind Farm Environmental Effects Statement Permit Application 0266 Panel Report*: Department of sustainability and Environment: Melbourne.

Kelly, A. T., McLaughlin, S. and Smith, A. 2007. *New Ornithological Radar Technologies for Bird & Bat Discrimination and Species Identification.* Detect Inc: Florida.

Kenward, R.E. 2001. *A Manual for Wildlife Radio Tagging.* Academic Press: London.

Kunz, T.H. 2003. Censusing Bats: Challenges, solutions and sampling bias. Pp 9–20 in *Monitoring Trends in Bat Populations of the United States and Territories: Problems and Prospects*, edited by T.J. O'Shea and M.A. Bogan. U.S Department of Interior and U.S. Geological Society.

Kunz, T.H., Arnett, E.B., Erickson, W.P., Hoar, A.R., Johnson, G. D., Larkin, R.P., Strickland, M.D., Thresher, R.W. and Tuttle, M.D. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. *Frontiers in Ecology and Environment* 5: 315–324.

Larkin, R.P. 2005. Radar techniques for wildlife biology. In *Techniques For Wildlife Investigations and Management*, edited by C.E. Braun (6th Edition). The Wildlife Society, USA.

Larson, D.J. and Hayes, J.P. 2000. Variability in sensitivity of Anabat detectors and a method of calibration. *Acta Chiropterologica* 2 (2): 209–213

Lumsden, L. 2007. *Guidelines for bat surveys in relation to wind farm developments.* Dept of Sustainability & Environment: Melbourne

McCracken, G.F. and Westbrook, J. K. 2002. Bat patrol. *National Geographic* 201 (4): 114–123

Menkhorst, P.W. and Lumsden, L. F. 1996. Common Bent-wing Bat. Pp 180–181 in *Mammals of Victoria: Distribution, Ecology and Conservation*, edited by P. Menkhorst. Oxford University Press, Melbourne.

National Research Council of the National Academies. 2007. *Environmental Impacts of Wind Energy Projects.* The National Academies Press: Washington USA.

Neuweiler, G. 2000. *The Biology of Bats.* Oxford University Press, Oxford.

Nowak, R.N. 1994. *Walker's Bats of the World.* The John Hopkins University Press: Baltimore.

Richards, G.C. 2005. *An Assessment of the Bat Fauna at the Proposed MacArthur Wind Farm, Victoria.* Report prepared by Greg Richards and Associates Pty Ltd for Brett Lane and Associates, December 2005.

Robson, S., Blair, D., Luly, J., Pallot, P., Parsons, J. and Shilton, L. 2006. *When bats and planes meet: a proposal to limit the impact of bat strikes in the aviation industry.* Spoken Paper 12th Australasian Bat Society Conference 2006: *Australasian Bat Society Newsletter* No 26: 28.

Saunders, R., Munro, D. and Thatcher, A. 2006. *Permit Application: PL-SP/05/0283 Macarthur Wind Farm Panel Report*: Department of Sustainability and Environment: Melbourne.

Schneider, J. and Martin, L. 2003. *ASU MAT 591: Opportunities In Industry! History of Radar.*

Schuller, G. and Moss, C.F. 2004. Vocal control and acoustically guided behaviour in bats. Pp. 3–16 in *Echolocation in Bat and Dolphins*, edited by J.A. Thomas, C.F. Moss and M. Vater. The University of Chicago Press, Chicago.

Smith, R., Banon, C. and Finn, P. 2004. *Bald Hills Wind Farm Project EES, EES Supplement and Called in Planning Permits Panel Report*: Department of sustainability and Environment: Melbourne.

Sustainability Energy Authority Victoria. 2003a. *Policy and planning guidelines for development of wind energy facilities in Victoria.* Sustainability Energy Authority Victoria: Melbourne.

Sustainability Energy Authority Victoria. 2003b. *Victorian Wind Atlas*. Sustainability Energy Authority Victoria: Melbourne.

Wilkes, K. 1980. *Radio and Radar in Sail and Power Boats*. Nautical Publishing Co Ltd: Hampshire: Great Britain.