Auld's Cove Radar Study- Summer 2015

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Abstract

Here we present results from radar monitoring study conducted at the Strait of Canso near Auld's Cove, NS from June through October 2015. Four 25 kW Furuno radars were installed to record bird movements in relation to the power lines crossing the Strait of Canso at both Auld's Cove and the Canso Causeway. In this report we summarize the data collected and provide an assessment of risk to birds in the study area due to power lines.

Introduction

We recorded the movement of biological targets (primarily birds and insects) in the airspace over the Strait of Canso near Auld's Cove, Nova Scotia. We collected data continuously from four modified marine radars from June through the end of October 2015. We subset these data to look specifically at the area to the immediate south of the power lines, extracting targets that are most likely birds. We then use these data to describe the volume, direction, and altitude of presumed bird targets in relation to power lines crossing the water.

We interpret these data in light of planned construction of additional power lines adjacent to those crossing the strait at Auld's Cove. Specifically, we provide an assessment of whether there is additional risk of bird strikes from the proposed additional power lines to bird movements in the area.

Selection of the study area

Radar units were installed along the shoreline of the Strait of Canso in locations with unobstructed views of the water, within 1 kilometer of power lines crossing the water at Auld's Cove and the Canso Causeway. Three of the units were installed at the Canso Canal facility operated by the Department of Fisheries and Oceans Canada (DFO), and one at the weigh station on opposite side of the strait, operated by Nova Scotia Vehicle Compliance. All are at sea level.

Figure 1. Map of the study area showing radar locations

Methods

Equipment

Four Furuno 8252 (Camas, Washington, USA) X-band (3-cm wavelength) marine radars were deployed in June 2015, using 6-foot XN-13A open-array antennas. The radar antennas made a complete 360° revolution (a scan) every 1.3 sec. Two of the radar units were installed in a typical horizontal orientation to monitor x,y position of biological targets (so no information on height), and two were installed in a vertical orientation to monitor altitude and range of targets. Beam widths of these antennas are 22° at 50% reflectivity, so horizontally-oriented units recorded targets up to 11° above a horizontal plane, and vertically-oriented radars recorded targets in a sector of airspace 22° wide. A horizontally-oriented radar was situated on each side of the causeway in order to detect birds near the surface of the water that would be otherwise obstructed by the causeway. One vertically-oriented radar was positioned to cover the wires at the Auld's Cove location, and the other to cover the causeway. Coordinates of the radar units are shown in Table 1. All output from the radars were recorded using a digitizing card (USRP as modified by inrad.ca (www.inrad.ca) and saved onto external hard drives. Data from the cards were processed initially using a SensorGnome ARU (www.sensorgnome.org) to enable precise (GPS) time stamps on all files. These were post-processed using program radR, an open source, R-based platform (www.radr-project.org, Taylor et al. 2010).

Table 1. Coordinates for radar locations.

Focal area	**Orientation**	**Latitude**	**Longitude**
Auld's Cove Wires	Horizontal	45.651082°	-61.417772°
Auld's Cove Wires	Vertical	45.651895°	-61.418656°
Causeway	Horizontal	45.647020°	-61.411530°
Causeway/Auld's Cove	Vertical	45.642500°	-61.429770°

Dates Monitored

The vertical and horizontal units monitoring the Auld's Cove wires collected data from 15 June through 1 November at the north end of the DFO canal site. The vertical and horizontal radars adjacent to the causeway collected data from 10 June through 1 November. On 31 July, the vertically oriented radar aimed at the causeway was rotated to provide additional coverage of the Auld's Cove wires. Initial tuning adjustments and subsequent power failures and other malfunctions caused loss of data during various time intervals, summarized in **Appendix 1**.

Data filtering and processing

Our objective was to obtain a data set comprising the altitudes of likely bird targets in the area in front of the transmission lines. These data are then used to describe and model patterns of movement of birds throughout the season, at different times of day, and under different weather conditions. The final data sets used for the bulk of visualizations and analysis comprised blips and tracks of birds as detected by the vertical radar at the canal, in a zone approximately 200 m long by 450 m wide in front of the wires at Auld's Cove (and as high as the detection range of the radar, about 1.5 km) (**Figures 2 and 3**). The area assessed by the vertical unit at the weigh station was identical in length to that of the vertical unit at the canal (200 m), but because the leading edge of the wires was at a greater range (1300 m), the resulting width of the area for analysis was 700 m. The procedure used to obtain those data is described in **Appendix 2**.

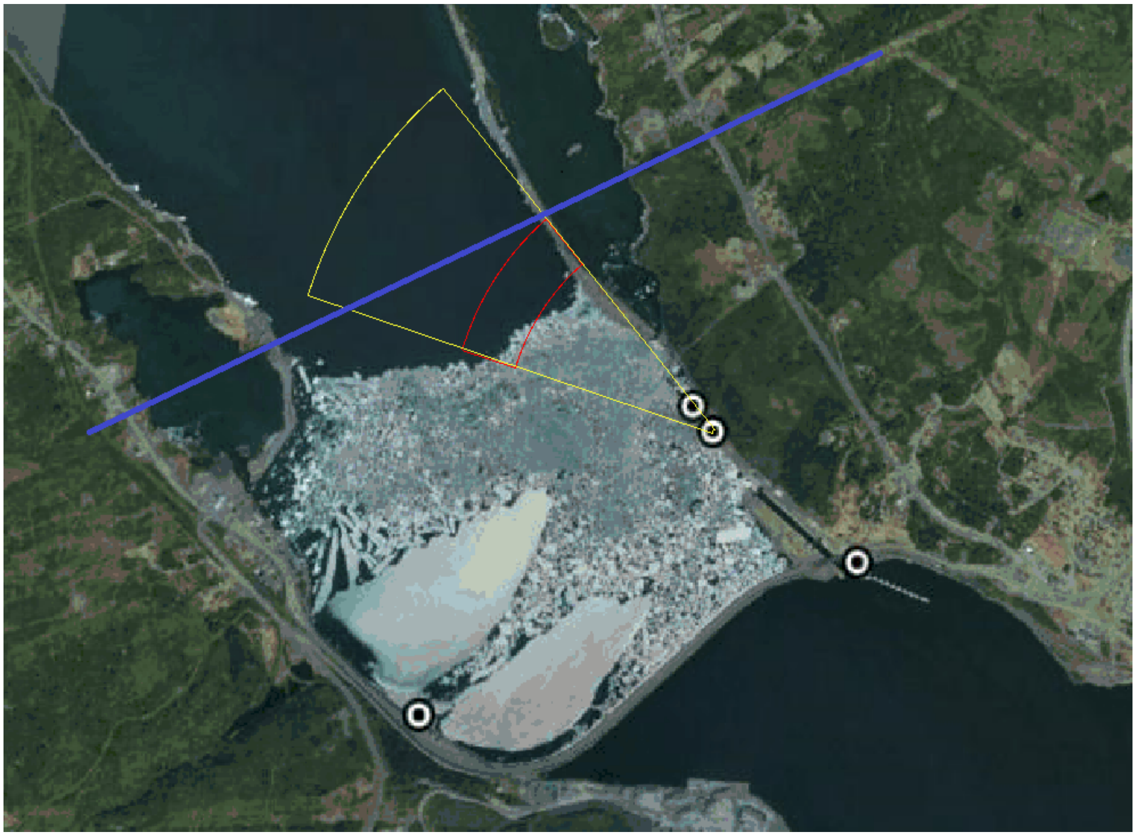


Figure 2. Visualization of radar data in the horizontal plane, depicting the area monitored by the vertically oriented radar at the canal site. The existing transmission lines are marked with a blue line. The area bordered in yellow is the overall detection area of the vertical radar unit, and the area bordered in red is the area used for statistical analyses of altitudes.

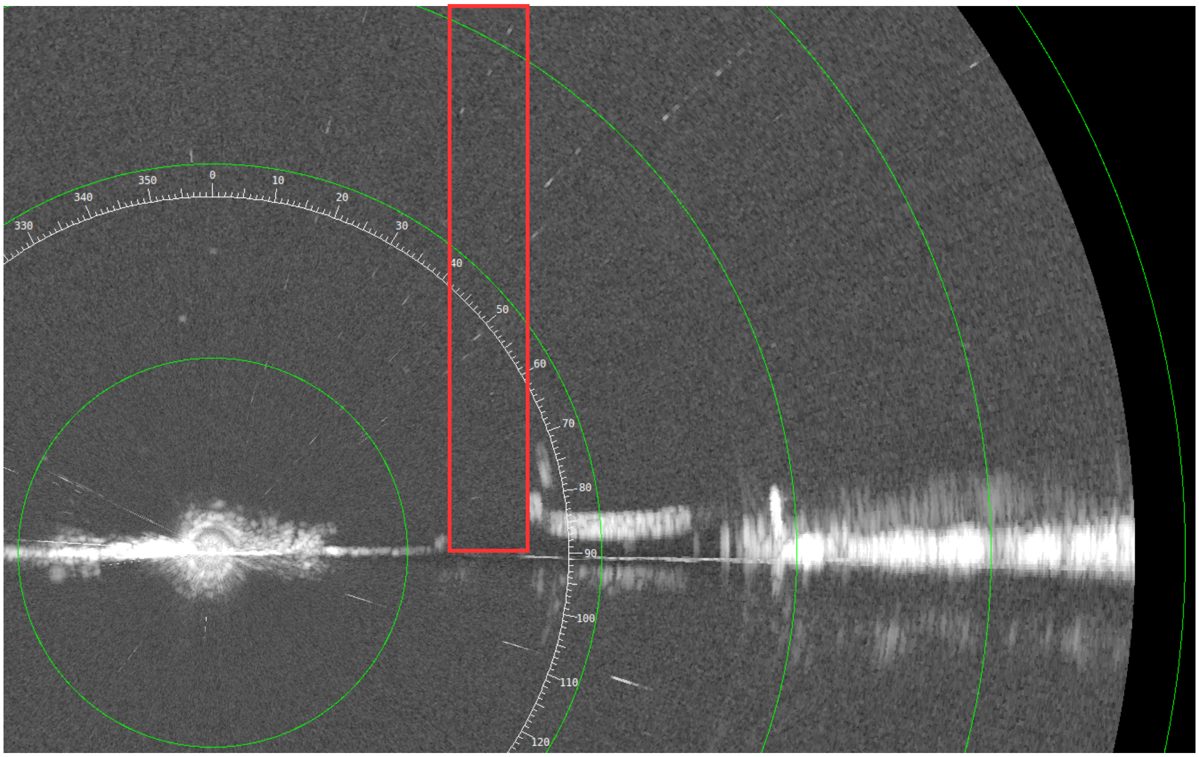


Figure 3. Visualization of radar data in the vertical plane from the canal site. The area bordered in red is the same as that bordered in red in figure 2, and is the area used for statistical analyses. The wires are visible in the radar output to the right of the area in red. Note that the angle between the wires and the location of the radar results in a large area that is obscured by reflections from the wires, which impedes detection of targets at the height of the wires beyond 820 meters (the leading edge of the wires).

Data Analysis

Overall approach.

Our approach was to graphically explore how bird density at different altitudes varied with season, time of day and weather, and then use the results of those graphical explorations to fit appropriate statistical models that estimated the actual effects (and our confidence in them). The analyses focus on data obtained from the vertically oriented radar at the canal site, because it was aimed at the Auld's Cove wires for the duration of the study. The vertically oriented radar at the weigh station was rotated Aug 31 to monitor the Auld's Cove wires. Data from this site are presented in **Appendix 4** as a supplement to compare to the results.

Altitudinal density of targets with distance

We graphically examined how the altitudinal density of targets varied with respect to the distance from the power lines. If targets are being struck by or avoiding the power lines, then we might expect to see patterns of altitudinal density that vary with either distance from the lines or time of day. We reason that these relative densities change with distance from the lines, it likely reflects avoidance behaviour – there should be relatively more individuals in the altitude bins above and below the lines immediately adjacent to the lines than several hundred meters in front of them. The assumption is that individuals divert their flight path up or down, and then correct again within that distance. Furthermore, we reason that individuals will only avoid the area of the transmission line under conditions when they can see it. Thus, we would expect to see avoidance during the day, but not in the darkest parts of the night, or perhaps during sunrise and sunset.

Effects of season, date, time of day, and the wires on altitude of targets

We examined effects of season and time of day on altitude both graphically and statistically.

Dates were assigned to a season as follows: Summer (June 15-August 15; peak shorebird migration and the beginning of neotropical songbird migration), Early Fall (August 15-September 15; the peak of neotropical songbird migration) and Late Fall (September 15-November 1; the peak of temperate-wintering songbird migration and the beginning of waterfowl migration). Targets were separated into altitude classes for some analyses: below the wires (~3-45 m), the same altitude as wires (45-110 m), above the wires (110-150 m), and well above the wires (>150 m). For most statistical analyses, we use only data on the numbers of tracks (a track being a presumed bird target) in at ranges within 200 m of the leading edge of the wires. Because the leading edge of the wires is closer to the radar at the canal side (the East), this means that the maximum extent of the area sampled was further from the wires at its western edge (as illustrated in Fig 2).

The altitude of blips retained after the filtering process were plotted using density plots to show the distribution of target altitudes at different seasons, times of day, and distances from the transmission lines. The effects of season, date, and time of day were modelled using general linear models to estimate three effects. The first two types of models are logistic regression models that assess how the numbers of targets at the wires relate to the numbers immediately above and immediately below. Such models assess whether the probability of a target being in the zone around the wires varies with season, time of day and weather. Our rationale is that two groups of birds may be interacting with the wires – those normally at higher altitudes (migrating songbirds and shorebirds) and those normally at lower altitudes (foraging gulls and seabirds). The first comparison (numbers in the wire zone relative to below) assesses whether birds that are typically foraging at low altitudes are interacting with the wires and the second comparison assesses whether birds that are typically migrating at higher altitudes are interacting with the wires.

Specifically, we modelled the logit of the counts of the numbers of birds at the wires relative to those above (or below) against the time of day, the wind speed, the change in barometric pressure and the interactions between time of day and both wind speed and barometric pressure. We also directly modelled (and graphically show) the counts of targets at the wires against the same variables. These models allow for better interpretation of the logistic models described above, by showing how and whether counts vary with time of day and weather.

Effects of weather on altitude of targets

Weather data (wind speed and direction, pressure, temperature, humidity, and visibility) were acquired from Environment Canada's Weather Station in Port Hawkesbury (www.http://climate.weather.gc.ca/). Weather conditions may affect both the volume of birds moving through the airspace, and the altitude of flight. Migratory birds are known to use climatic cues (change in pressure, wind speed and direction) to decide when to initiate flights. Adverse weather conditions such as high winds or low visibility might impinge a bird's ability to avoid collision with the transmission lines. Data from the area in red in Figure 2 from the vertically oriented radar at the canal were examined to determine effects of weather on target altitude.

Correspondence between visual surveys and radar data

Periodic visual surveys were performed by Strum Consulting to record interactions with birds and the transmission lines. During 10-minute segments of these surveys, GPS timestamps were recorded when birds were seen crossing the wires. Altitudes were estimated into bins (skimming the water, well below lines, just below lines, through lines, just above lines, well above lines). The span of the wires across the strait was also divided into segments to record the area where the bird crossed the wires (east over land, east shoreline, east of center, center, west of center, west shoreline, and west over land). Species, direction of travel (N-S or S-N), and number in flock were also recorded. GPS timestamp data was recorded on June 22 and 23; July 3, 13, 21, and 22; and August 13, 14, 20, and 26.

The 10-minute segments performed by Strum Consulting were compared to radar data from the same 10-minute periods from both the vertical and horizontal radar units at the canal site. Single targets were matched to blips using the timestamp information, direction of travel, and altitude bin, and analyzed to determine if the radar data could be used to differentiate different species of birds. The comparison may also determine differences in detection probabilities between visual surveys and radar monitoring.

Results and Discussion

Observation of bird species

In addition to the field surveys conducted by Strum Consulting, observations of bird species using the area were made whenever site visits were conducted, and species observed flying over the Strait of Canso during daylight hours were: Northern Gannets (*Morus bassanus*), Double-crested Comorants (*Phalacrocorax auritus*), Herring Gulls (*Larus argentatus*), Great Black-backed Gulls (*Larus marinus*), Common Terns (*Sterna hirundo*), Rock Pigeons (*Columba livia*), and American Crows (*Corvus brachyrhynchos*). We assume the majority of targets detected by the radar units during this time period were of these species.

Overall pattern of movement of birds by season

The overall pattern of migration as detected by the radar corresponded well with the known pattern of movement of birds through this part of Nova Scotia. There was evidence of nocturnal migration across the Strait of Canso at this site. Altitude profiles, especially in the early fall and late fall seasons indicated increased density of targets of 100 m in altitude after dark. Numbers of birds tracked per hour by vertical radar in are shown in **Table 2,** separated by season, time of day, and altitude.

From July through early August, we see few targets at any altitudinal levels. The targets that are seen during this period represent movements of locally breeding birds (e.g. those that forage in the area such as Double-crested Cormorants, Herring and Great Black-backed Gulls, and Common Terns). There are few high altitude targets detected during this period because songbird and shorebird migration has not yet commenced. Around mid-August and until late-September, we begin to see much larger numbers of targets at all altitudinal levels. This is particularly true at the very high levels during the sunset and midnight periods (see the left hand panel of **Figure 4**). These targets are songbirds and shorebirds migrating at generally high altitudes across the study area. Although most targets during this period pass high overhead, they also stopover regionally, and so we see concurrent higher numbers of targets at lower altitudes (surface and wires). This is particularly pronounced for the sunset period (green line in middle and right hand panels of **Figure 4**) where we see a peak of activity in the mid-half of September. Finally, there is evidence of another peak of activity on the last few days of the study period (late October and the first day of November). At all levels, but particularly at the surface and wire levels, we see large numbers of targets using the strait during this period. This represents the initial movements of seabirds (Northern Gannets, cormorants, gulls and sea ducks) moving through the area on migration, and feeding on local fish resources. In particular, there was a huge influx of billfish into the strait on 31 October that were accompanied by thousands of seabirds.

Effects of season, date, time of day, and the wires on altitude of targets

To examine whether targets are avoiding wires at particular times of day or seasonally, we plotted altitudinal density profiles of targets at different ranges from the wires (**Figure 5)**. These plots show how targets are distributed in the volume of space from the leading edge of the wires to a range of 200 m from the wires (on the canal side) and ~450 m from the wires at the far Western edge of the sampled area, and up to an altitude of 500 m, across the different seasons and time periods. By splitting the density profiles into bins at increasing distances from the wires, we are able to examine whether there is any evidence that targets are changing altitudes as they move towards or away from the wires. We might expect to see such differences at times of day when the wires are visible.

These altitude profiles show avoidance of the wires by birds during some periods, where peaks at low altitudes increase as distance to the wires decreases. These are most evident in the summer period (e.g. at sunset). There is little evidence for avoidance at other periods. Overall, the plots show how the numbers of targets at different altitudes varies considerably across the season and times of day. At some times (e.g. evening periods in late fall) targets are clearly moving beneath the lines in much larger numbers than elsewhere. At other times (e.g. the sunset period in late fall) the peak density of targets is at approximately the same height as the wires.

In **Figure 6,** we re-present these data, but in boxplots by the different altitude bins used hereafter in the report. These more clearly show that during the sunset (1 h after sunset) and midnight periods (middle of the night) the numbers of targets within the wire zone is generally higher than in adjacent (surface and above wire) zone. Whether this represents a lack of avoidance during these time periods, or simply a propensity for the lower flying targets to fly at slightly higher altitudes during these periods, is unknown. The data are from the area depicted in red in **Figure 2**.

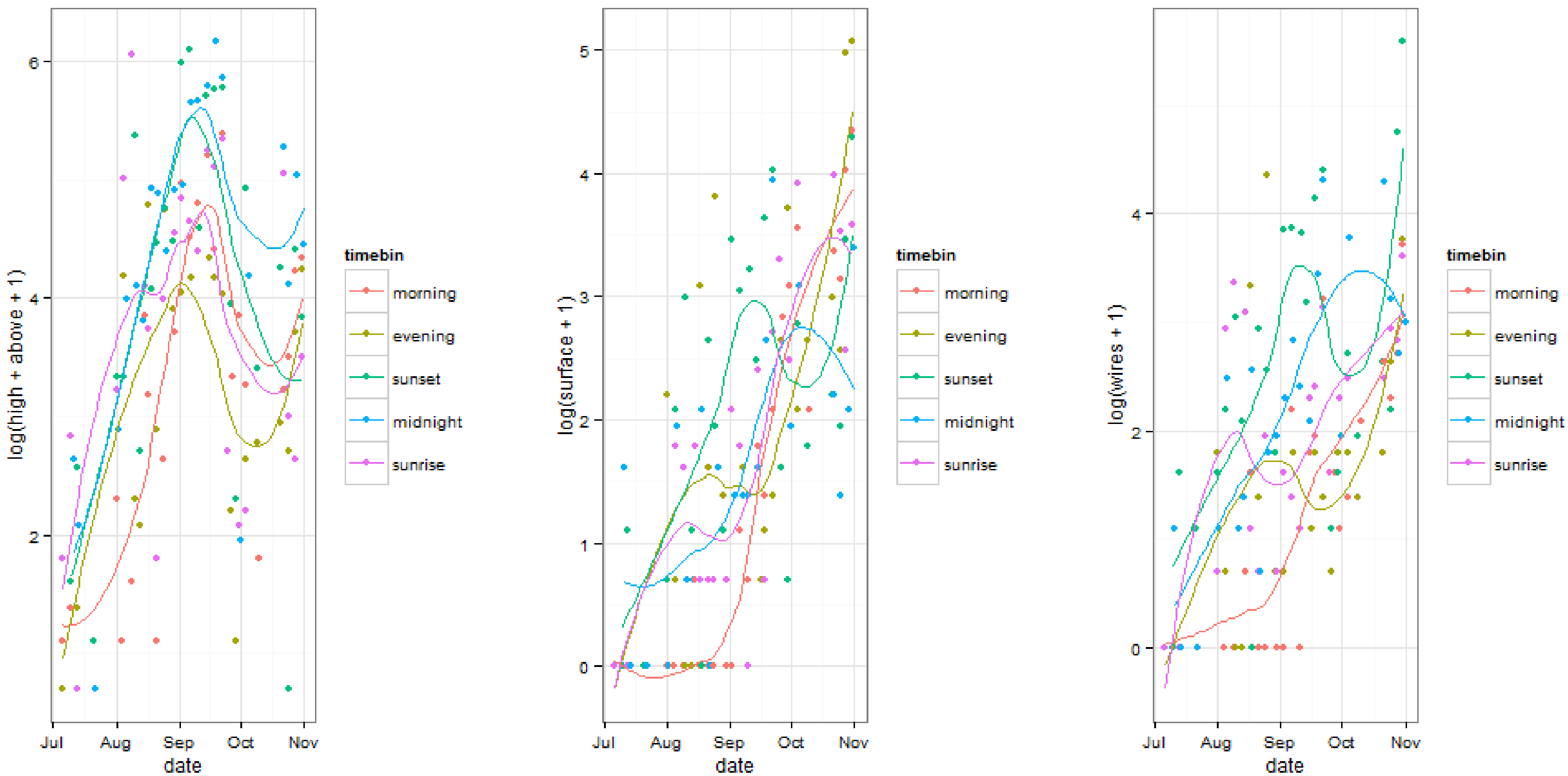


Figure 4. Plot showing the general pattern of movement of targets through the area by season. Each point represents the log of the number of targets detected at different altitudes (above and high above the lines, at the surface, and at the wires) on each sampling day and time through the season. Sampling times are colour coded, and lines are a smoothed (loess) line through the data showing the general trend in the data. See text for further explanation.

Table 2. Birds detected by hour for each vertical radar, with a range between 0 and 200 meters from the closest point on the wires. Note that it is not reasonable to estimate a density of targets (or to compare the numbers of targets between zones) because each zone comprises a different volume, and those volumes are not known exactly. See text for a full explanation of the area sampled (Fig. 2).

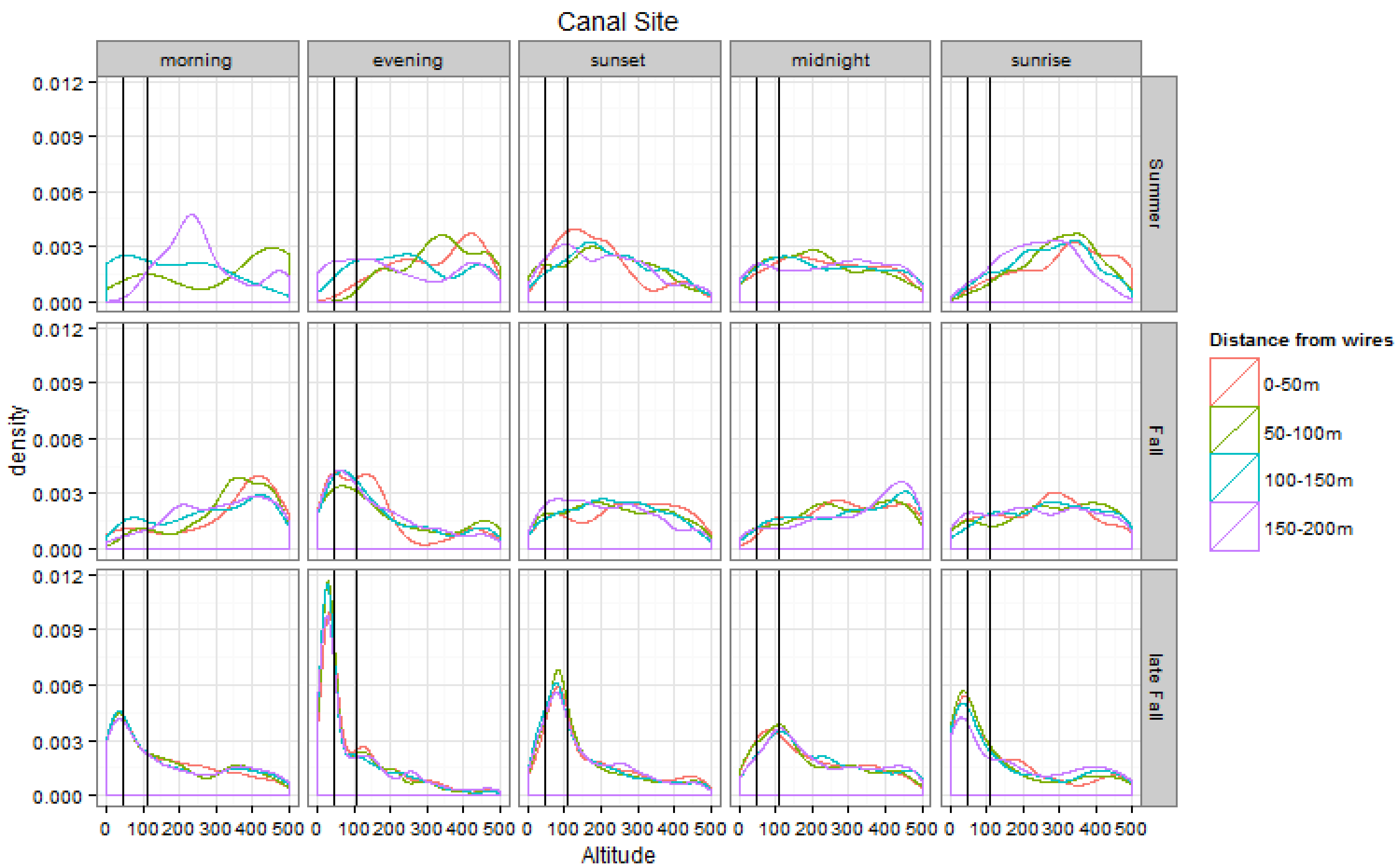


Figure 5. Altitude density profiles at different distances from the wires. Each panel represents one combination of time of day and season, and each coloured line shows the density profile of targets at different distances from the wires, for that combination. The approximate lower and upper heights of the transmission lines are depicted as vertical black lines.

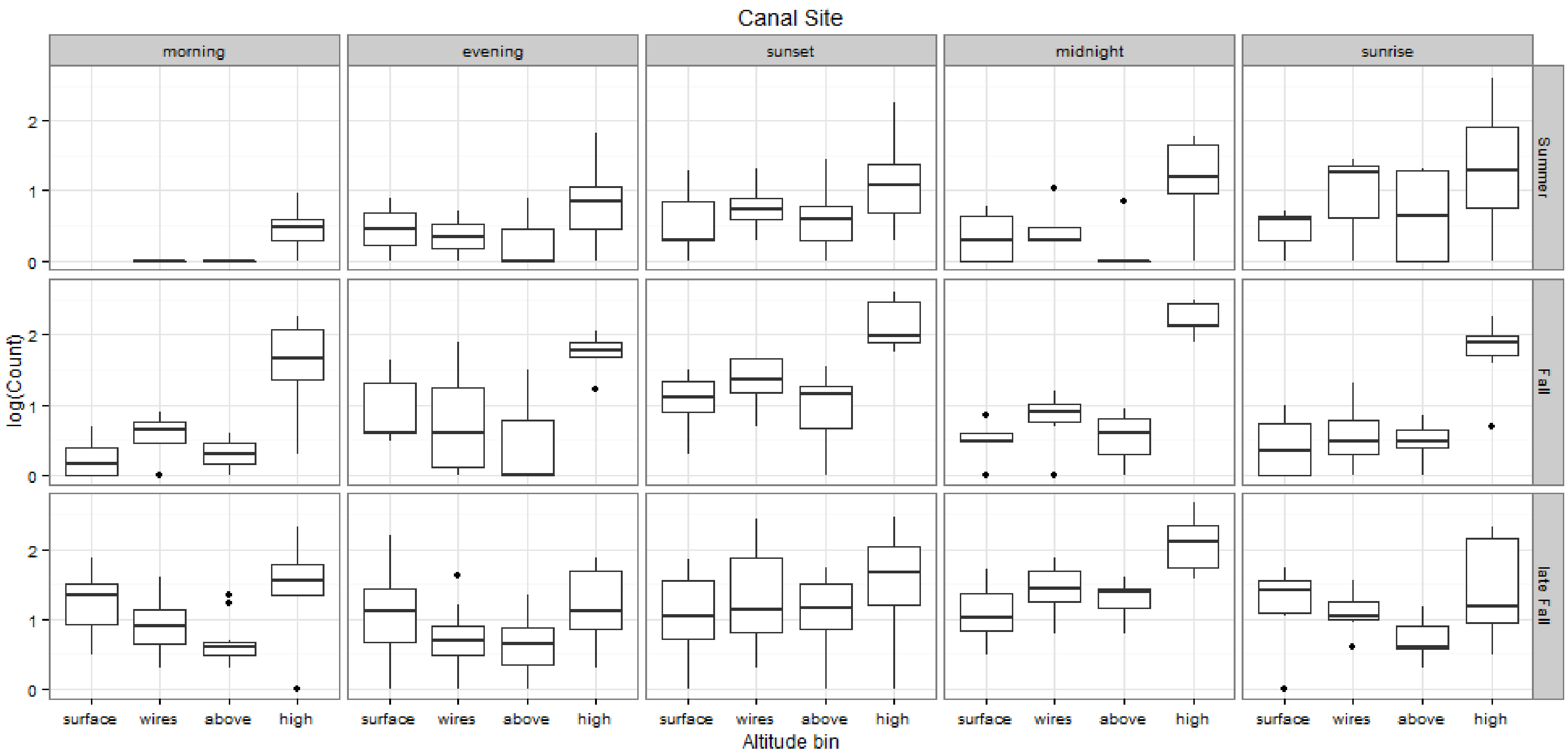


Figure 6. Box plots showing the log(count) of biological targets by altitude bin the area depicted in red Figure 2 of the Auld's Cove transmission lines observed from the canal site. Each box shows the distribution of the counts for a particular altitude bin (on a log10 scale), for a given time of the season and time of night. The dark line in the middle of the box shows the median value for the counts, the top and bottom edges of the box show the interquartile range, and the lines extending up and down show the range of 95% of the data points. The individual dots are beyond those limits ('outliers'). The data are the same as in Figure 3, but presented to better show how the distribution of counts varies across the altitude and time bin variables.

Effects of weather on altitude of targets

Modelling the effects of weather on the counts of targets at different altitudes is complex because the relationships between weather and counts may vary seasonally, by time of day, and at different altitudes. We first graphically examined these patterns ((**Figures 7-11**) to show the general patterns, and to inform further statistical analysis. For each of the following figures, we show how the log (base 10) of the counts grouped by each altitude bin varies for the range of each weather variable. Visibility was not included because there was only usable radar data from one day of the sub-sampled data with low visibility. Most low visibility days were associated with rain, which drowned out biological blips on the radar.

The plots confirm the supposition above; that there appear to be no simple generalizable relationships between the weather variables and the counts of targets moving through the strait. For example, when examining the effects of wind speed on counts (**Figure 7**), we can see that in the summer period, there is a consistent negative relationship between wind speed and the number of targets (across the altitude bins), whereas at sunrise, the relationship is consistently positive (two top right panels in **Figure 7**).

Because of this complexity, for the subsequent statistical analysis, we focus on two weather variables that are most likely (biologically) to influence bird movements: wind speed and change in barometric pressure. For both variables, these initial plots suggest some possible seasonal and time period differences.

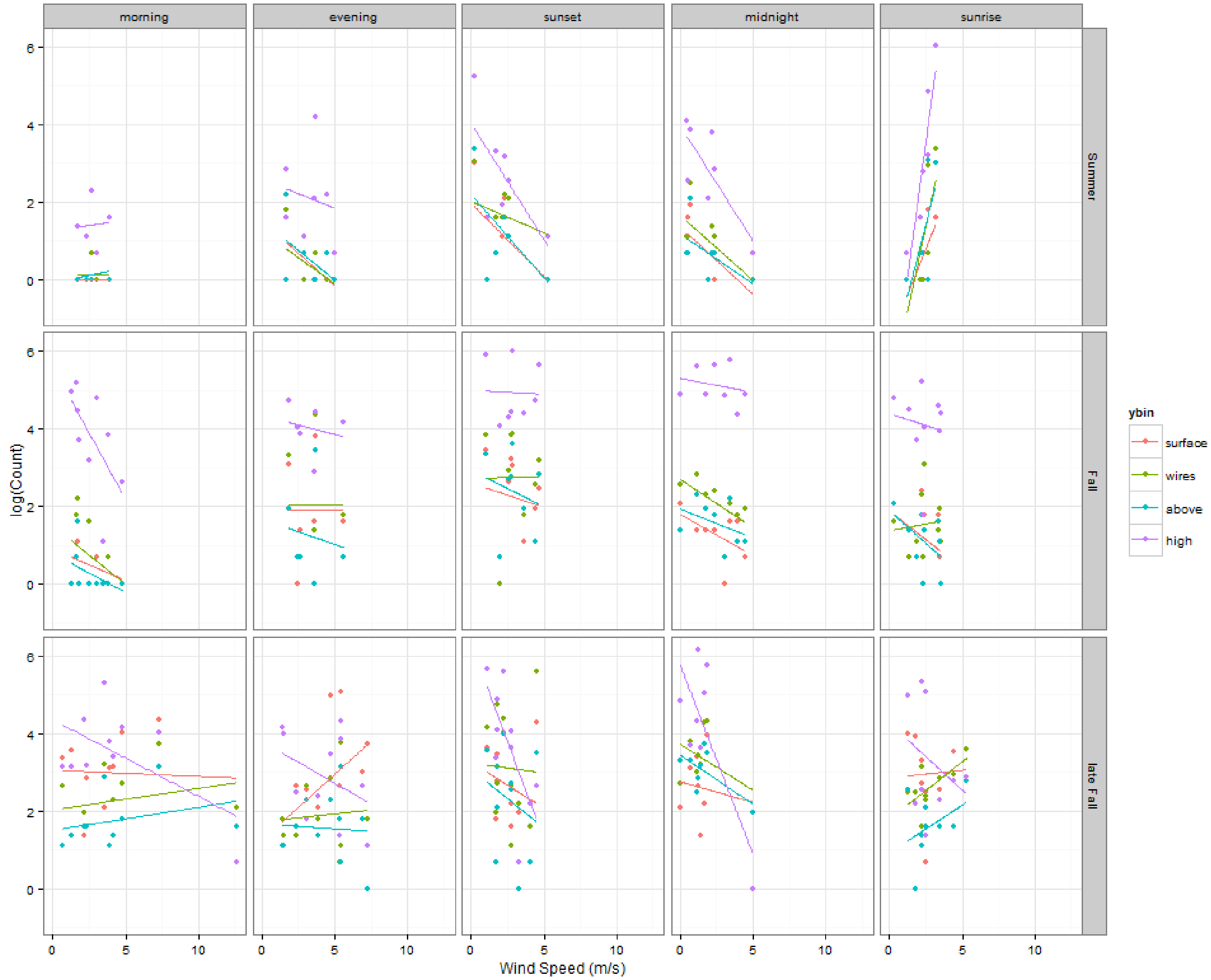


Figure 7. Plot of the log(count in each altitude class) by wind speed (m/s) for the different times of day and season, grouped by distance of targets above the surface.

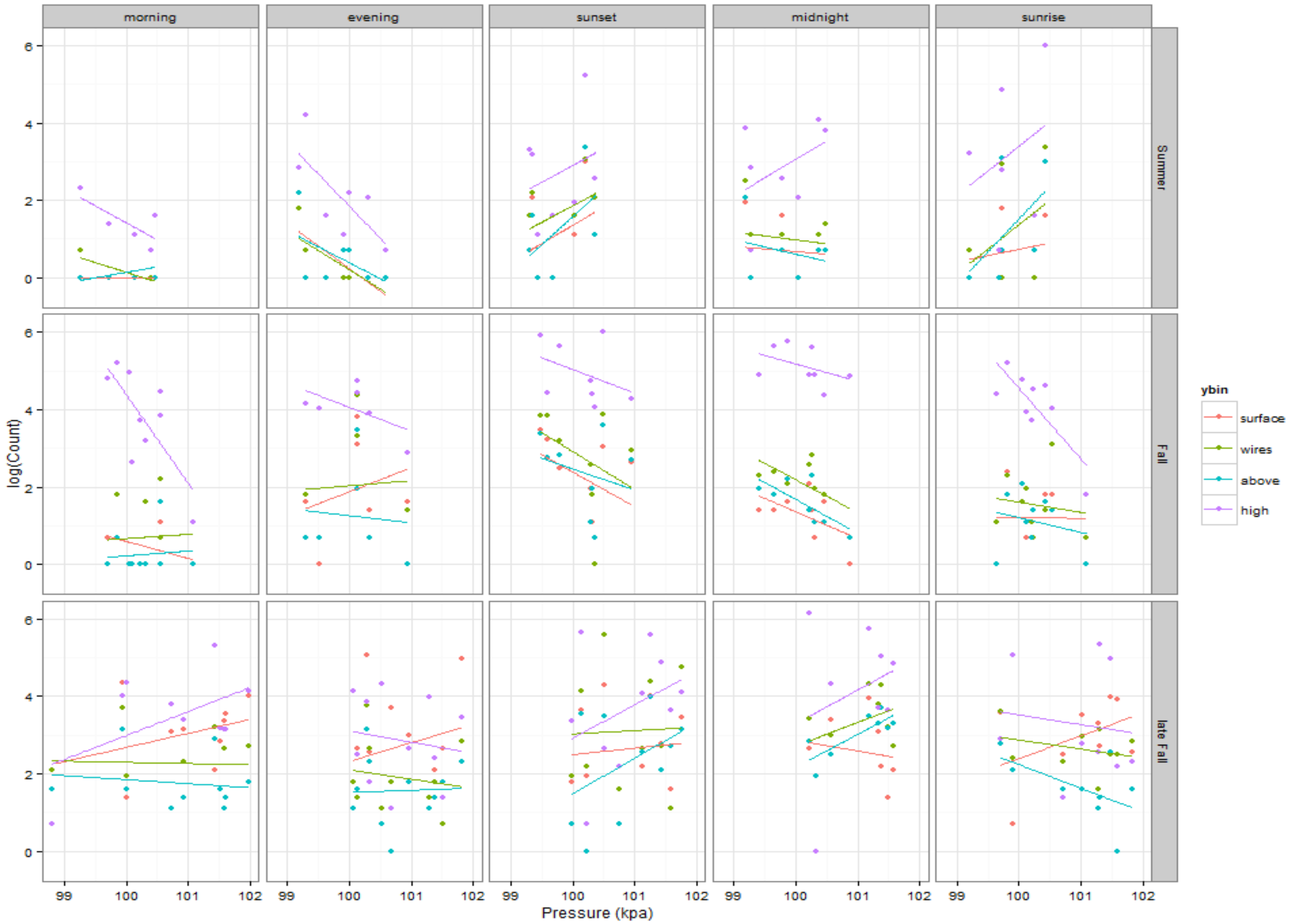


Figure 8. Plot of the log(count in each altitude class) by atmospheric pressure (kpa) for the different times of day and seasons, grouped by distance of targets above the surface.

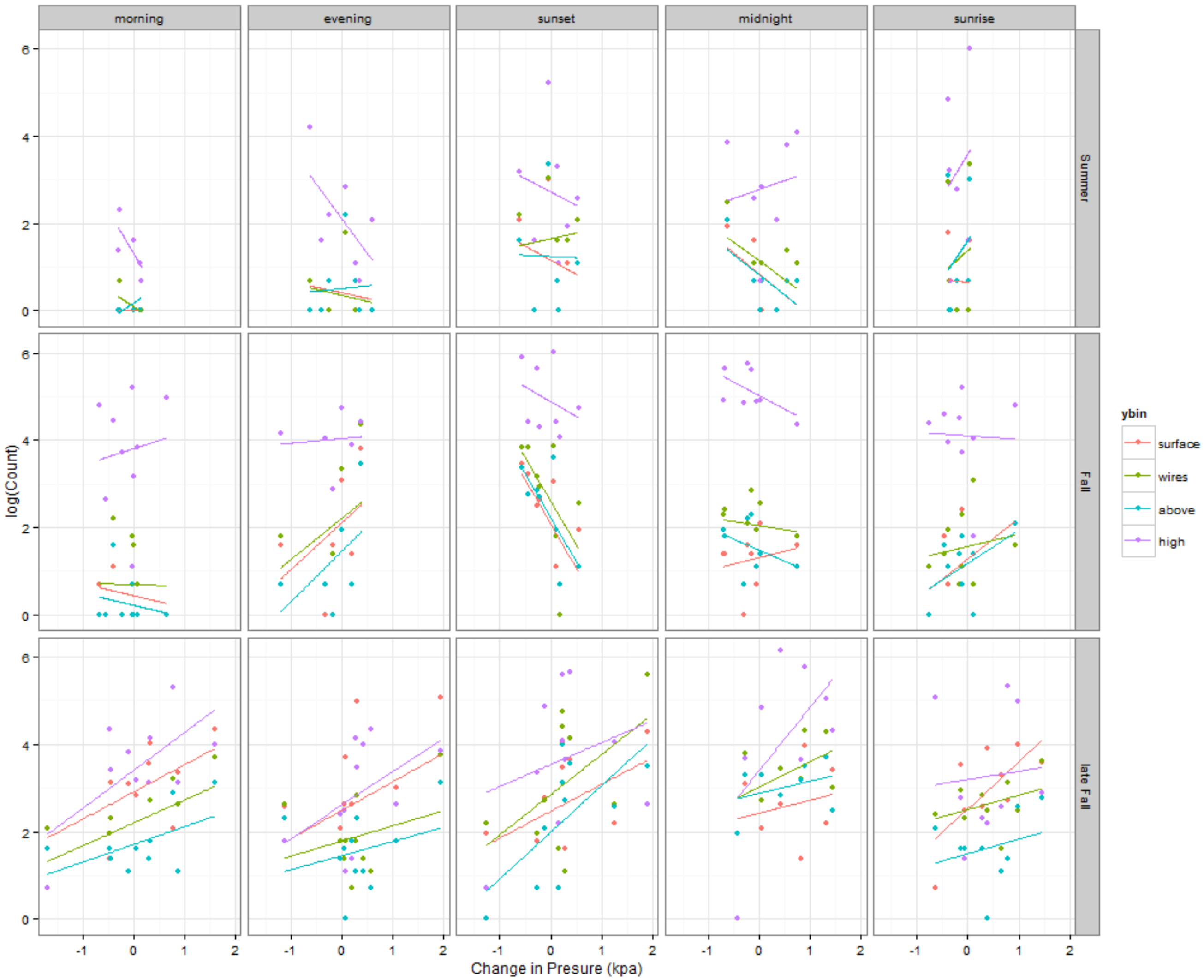


Figure 9. Plot of the log(count in each altitude class) by change in atmospheric pressure (kpa) for the different times of day and season, grouped by distance of targets above the surface.

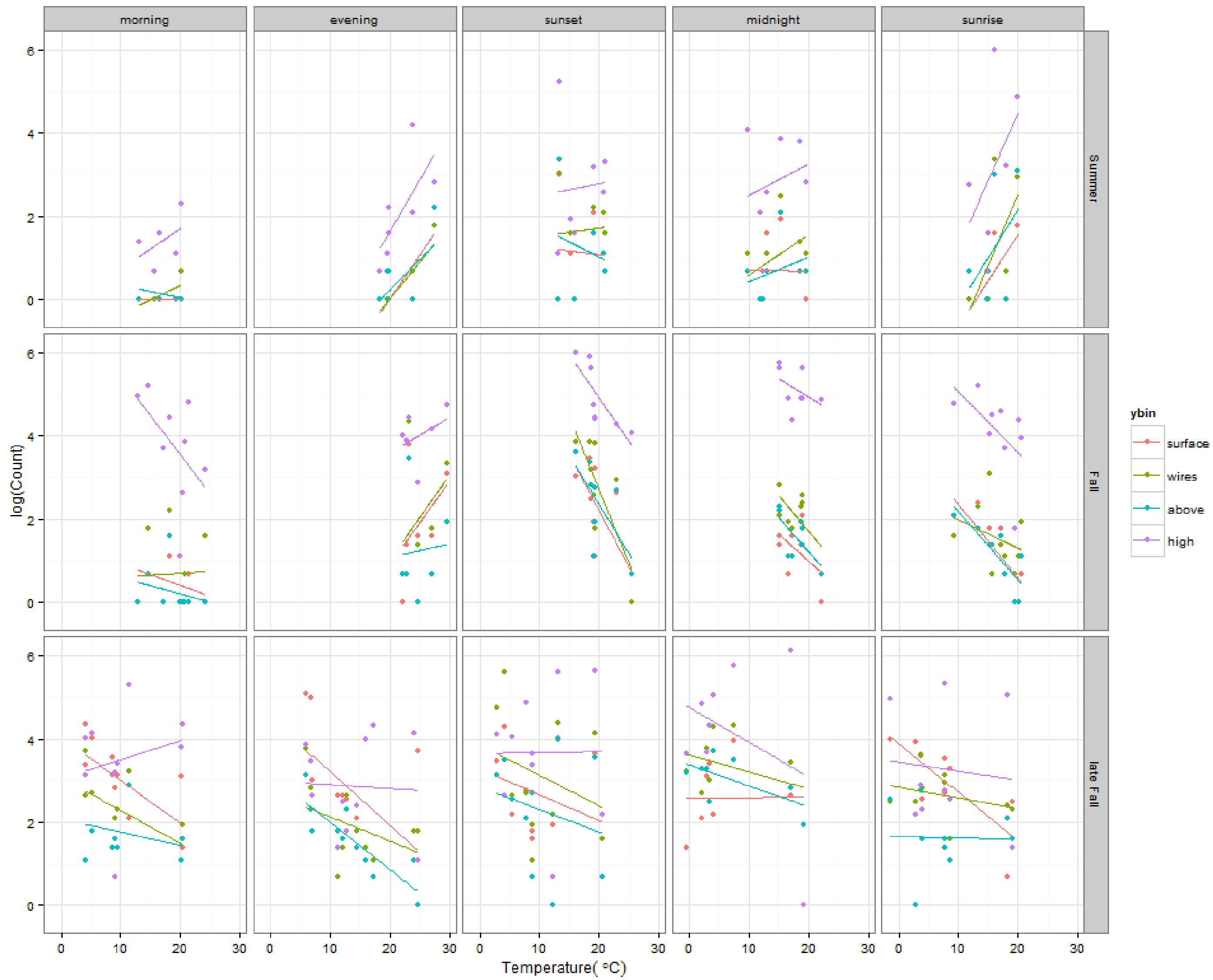


Figure 10. Plot of the log(count in each altitude class) by temperature (°C) for the different times of day and season, grouped by distance of targets above the surface.

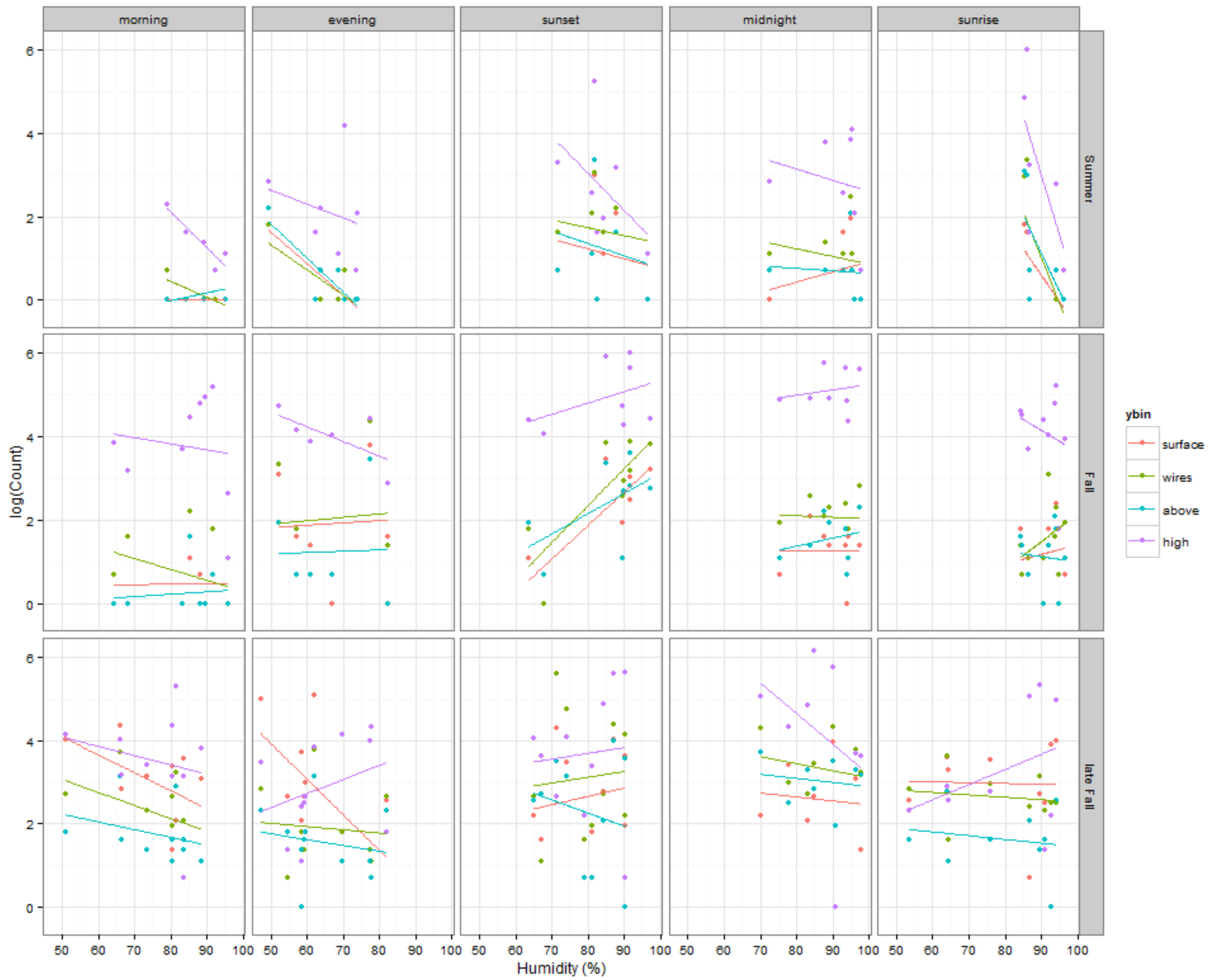


Figure 11. Plot of the log(count in each altitude class) by relative humidity (%) for the different times of day and season, grouped by distance of targets above the surface.

Statistical analysis of counts at wires to those above and below and weather.

As shown above, the relationship between the probability of observing targets at the wires and time of day and weather was complex. This general result was confirmed in the statistical analysis. Across the entire set of models, we observe numerous cases where there are statistically significant interactions between time of day and weather, and the different response variables (Appendix 3).

For each analysis, we have provided plots of the predicted values (a way to visualize the effects of each of the independent variables on the response) along with an anova table (see Appendix 3).

For the count models, we see different effects of wind speeds on targets in fall compared to late fall. Very large numbers of targets were observed in the late fall period, primarily at low wind speeds at sunset. (This result is largely a function of the large numbers of seabirds that moved into the straight on the last two days of the study, as noted above). For the models of probability of detecting targets at the same altitude as the wires (versus above or below the wires) we also see a complex pattern of responses. It is beyond the scope of this report and analysis to delve into this complexity further, but it is likely a result of the complexity of response of the bird targets to weather patterns in the area. That is, there are many different bird species tracked, across different stages of their life cycles, and each of those species groups and life-cycle stages exhibit different behavioural responses to weather.

None-the-less we focus here on two of the models and associated plots, to provide a means for interpreting the rest.

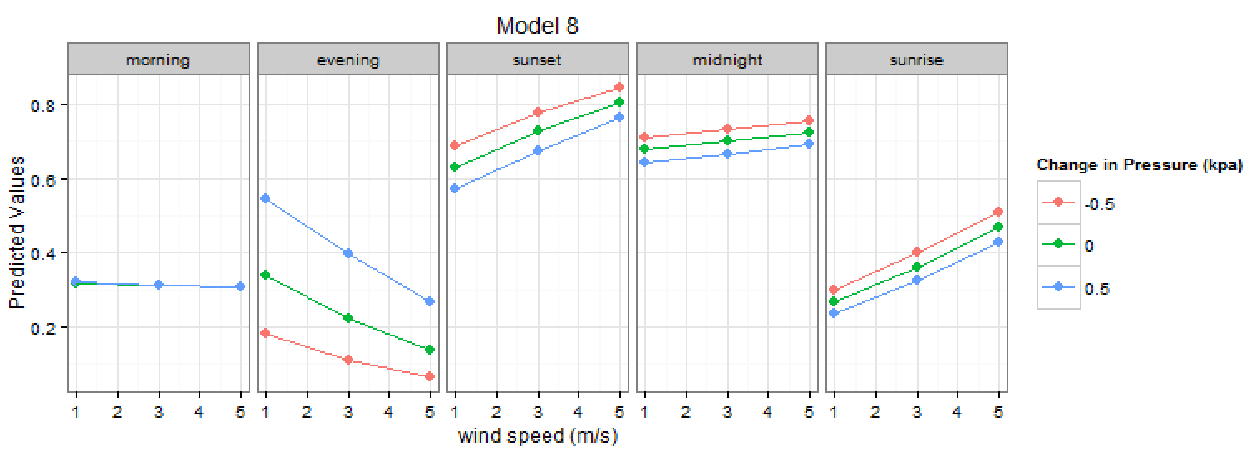


Figure 10. Plot showing the predicted probabilities of a bird being in the zone of the wires (relative to the zone below) during the late Fall period. Shown are the predicted probabilities for five times of day, under wind speeds of 1 through 5 m/s and under a changing, stable or increasing change in barometric pressure. See text for further explanation. Model 8 from Appendix 3.

In Figure 10 we show how the predicted probability of a bird being in the zone of the wires (compared to the zone below) varies with time of day, wind speed and change in barometric pressure. The figure shows that the predicted probability of a target being in this zone is highest just after sunset and at midnight, and is considerably lower in the morning, evening and just before sunrise. The probabilities vary depending on wind speed, but not in a consistent way (for example, in the sunrise period, the probability of birds being in the wire zone increases as the wind speed increases, but the opposite is predicted in the evening. A similar result was found for the fall period (Model 6 in **Appendix 3**).

The result provides evidence that during the late Fall period, targets are more likely to be in the altitudinal bins near the wires (relative to below the wires) at sunset and midnight, compared to other periods ($F_{5, 43}$=13.96, P<0.0001). That result is consistent with our visual interpretation of the general pattern of movement presented earlier, and suggests that targets that typically move at lower altitudes may increase their flight heights during those periods. The result provides evidence that during the fall and late Fall period, when larger numbers of birds are migrating, they are more likely to be in the altitudinal bins near the wires (relative to below the wires) during periods of ascent, migration and descent (e.g. during the night).

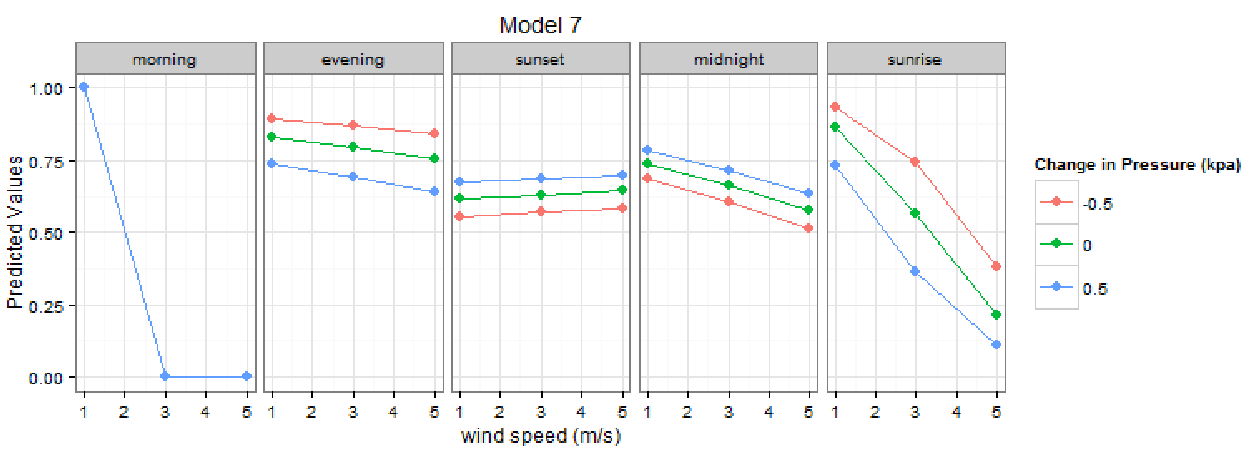


Figure 11. Plot showing the predicted probabilities of a bird being in the zone of the wires (relative to the zone above) during the Fall period**.** Shown are the predicted probabilities for five times of day, under wind speeds of 1 through 5 m/s and under a changing, stable or increasing change in barometric pressure. See text for further explanation. Model 8 from Appendix 3.

In Figure 11 we show how the predicted probability of a bird being in the zone of the wires (compared to the zone above) varies with time of day, wind speed and change in barometric pressure. The figure shows that the predicted probability of a target being in this zone is highest in the evening, just after sunset and at midnight, and in low wind speeds, just before sunrise. The probabilities do not vary with wind speed, except in the morning. A somewhat similar result was found for the late-fall period (Model 9 in **Appendix 3**) except that the probabilities of being at the wires were highest at sunset, during periods of declining barometric pressure.

Correspondence between visual surveys and radar data

We were able to make comparisons between visual surveys and radar data for 13 periods where visual data were collected. During these 13 periods, observers saw 98 targets; during the comparable radar observations, the tracker estimated that 75 targets were found under the wires (~76%). Note that we do not expect the radar to necessarily detect all of the targets seen by the observers (or vis-versa) since some targets visually detected may have been beyond the range of the radar, and conversely, our tracking algorithm may not track all targets actually detected by the radar. Targets that were linked showed the expected relationships between intensity of the reflected beam, speed and target size (**Figure 12)**.

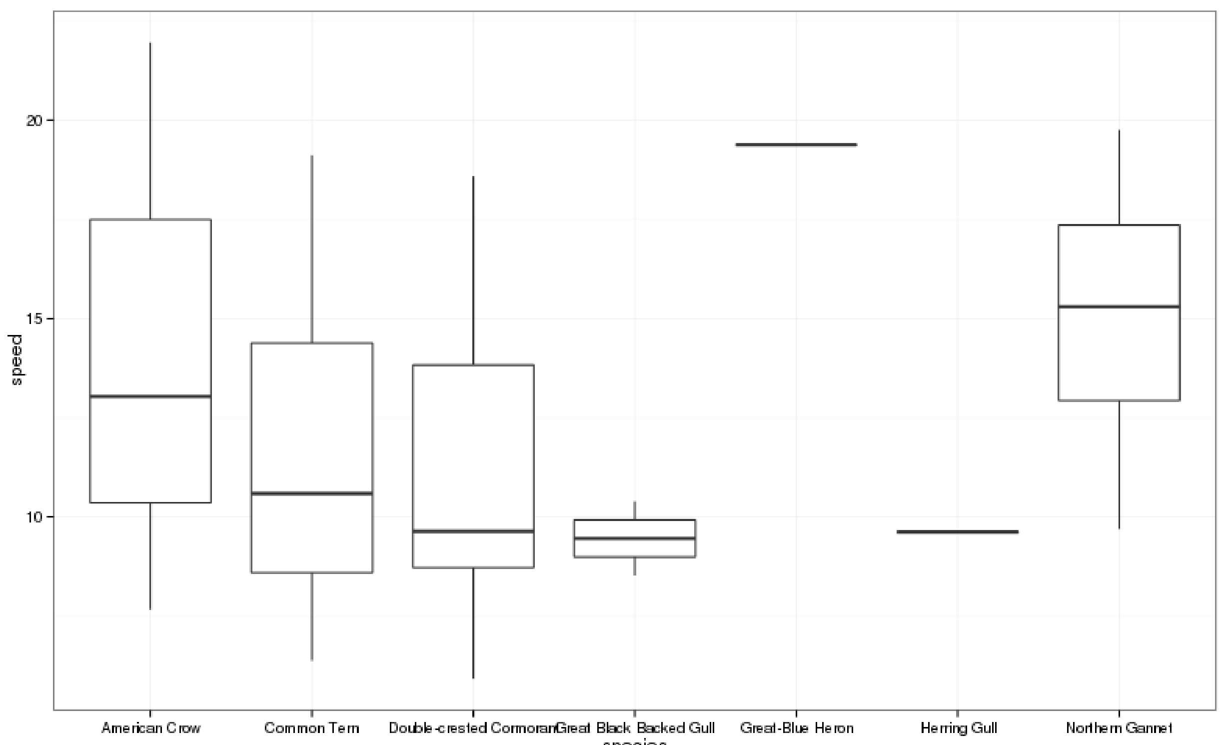


Figure 12. Boxplot showing range of speeds for targets detected both visually and by the radar. These could be used in future to help classify (in a probabilistic way) the targets observed by the radar.

We were able to link tracks from 62 of the 75 targets detected by the radar to the appropriate visual observations. Targets that were not detected by the radar (but that were detected by the field observers) may be targets that were beyond the range of the radar, too close to the surface of the water, or targets that had convoluted paths that were not captured by the tracking algorithm. Targets detected by the radar but not detected by the field observers may have been non-bird targets (insects), non-biological targets, or targets that could not be linked because of our relatively simple approach to linking these observations. There was no difference in the proportion of targets detected by the two methods, by species.

These data confirm that the detection of targets in the zone of the radar is in fact primarily birds. The rationale is that for these sets of tracks where we have linked visual observations of targets and radar tracks (so we know that birds were present in the area at the exact times of the radar observations) the speeds and intensity values are consistent with the measures that we use to filter out other non-biological targets (clutter) and insects (see **Appendix 2** for more detail).

Summary

General

The initial arrangement of the radars (two pointing towards the Auld's Cove power lines and two pointed towards the causeway power lines) was designed to examine target movement with respect to both sets of power lines using vertically oriented radars to determine range and altitude of targets, and horizontally oriented radars to provide x,y positions. The most important metric to assess risk was the altitude of targets moving through the airspace nearest the wires, so data from the vertical radars was focused upon. In the end, we have primarily used the data from the single vertical radar pointed towards the wires on the canal side. The reason for this is that we feel that these data are the most useful, in the sense that they captured the greatest amount of activity close to the wires. The vertical radar at the weigh station, which was rotated to monitor the wires on Aug 31, was more distant (yielding fewer overall detections of smaller targets in the range nearest the wires), and less effective at detecting targets below 10 m in altitude because of the shape of the adjacent shoreline. Without the linkage between horizontal and vertical radar units that was originally envisioned, the horizontal units provided little additional information relative to risk, and were used only for comparisons to field observations.

Patterns of targets within the wire zone as revealed by these analyses

- Birds were detected flying within the zone of the wires at all time periods and at all seasons.

- During the fall and late fall, there is evidence that there are more birds in the wire zone at times of the day when visibility is lower (e.g. sunset, midnight and sunrise) although there is some (not unexpected) variability across days. The reasons we detect more birds in this zone at these times are not known, but may be related to behavioural avoidance of the lines (see 'general observations not captured by these analyses' below).

- There is evidence that these targets comprise both seabirds (gulls, cormorants, gannets, ducks) and higher migrating songbirds and shorebirds, that is, that several groups of species are using this zone.

General observations not captured by these analyses

We did not examine in more detail the precise behaviour of targets in and around the wires. However, it is readily apparent from watching the radar movies of targets, that many species alter their behaviour as they approach the lines. We see two types of behavior – one is a pattern where high-flying targets approach the lines from the north, then turn around and head back out to sea (these are most likely Northern Gannets based on field observation and size of targets on the radar). A second is a pattern of birds circling higher and higher until they reach an altitude that allows them to cross over the lines. These patterns are seen during the day and during the night, and would bear further scrutiny.

Summary: General discussion and assessment of risk

The radar data show that at times, there are large numbers of targets in the altitudinal bins encompassing the wires and that there are proportionally more targets at times when the wires are less visible (sunset, midnight and sunrise).

We conclude from these observations that birds are using the airspace around the wires, and that the probability of birds using that space is highest when the wires are less visible (e.g in the evening and morning, and by extension, when there is rain, snow, or fog). A corollary is that many individual birds likely avoid the power lines under normal conditions, either by circling on one or the other side of them, or by flying over or under them.

Our data were limited in the vertical plane by the angle of the radar to the lines, which reduces the probability of our detect birds close to the wires in the middle or on the far side of the Strait. Similarly, because the wires droop in the middle of the Strait and are highest at the sides near the towers, birds detected at similar altitudes may have been flying over the wires in the middle of the strait or under the wires at the edge, but would have been classified as being at the same height as the wires.

Despite these limitations, the data show that at times, many individual birds, of different taxonomic groups (seabirds/ducks and songbirds) are moving across and through the Strait at the same altitude as the existing and planned wires.

We do not see evidence for consistent effects of weather on these patterns of risk. One possible reason for not observing such effects is that we are not able to differentiate targets detected by the vertically oriented radar in terms of flight speed or behaviour.

The sampling period covered by this study did not encompass spring passerine migration (early April through late May) or late-fall seabird and duck movement. Our radar observations captured one day of late-fall movement (associated with billfish moving into the Canso Strait) which show that in late fall, large numbers of birds are using the area, and those birds are frequently moving through the altitudinal zone encompassing the wires. These limited data suggest that this period is one of higher risk for birds colliding with power lines in the area than other times of the year, because there is both an overall increased volume of birds in the strait, and a higher proportion of birds flying at the same altitude as the wires at night.

References

Matkovich, C. 2011. Radar aerocology: mesoscale nocturnal avian migration and using radar cross section to distinguish among target types. M.Sc. thesis, Acadia University.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Shafique, K., and M. Shah. 2005. A Noniterative Greedy Algorithm for Multiframe Point Correspondence. IEEE Transactions on Pattern Analysis and Machine Intelligence 27:51-65.

Taylor, P.D., J. Brzustowski, C. Matkovich, M. Peckford, Wilson, D. 2010. radR: an open-source platform for acquiring and analysing data on biological targets observed by radar. BMC-Ecology 10:22; doi:10.1186/1472-6785-10-22.

Appendix 1: Table of time periods when radar data was lost due to malfunction

Location	Orientation	Time period	Reason
Canal	Vertical	June 15-July 4	Gain too low. Only large targets detected.
		July 15-17	Display console malfunction
		July 25-31	Display console malfunction. Replaced July 31.
		October 6-21	Work at canal site
Canal	Horizontal	June 15-July 4	Initial Tuning Adjustment
		October 6-21	Work at canal site
Weigh Station	Vertical	June 30-July 4	Power failure
		August 1-14	Power failure
		August 15-28	Unknown
Causeway	Horizontal	June 12-13	Unknown
		August 2-14	Power failure

Appendix 2: Blip filtering settings used to remove clutter and discriminate insect targets.

Data were first filtered to remove clutter (e.g. spurious information from incoming radar signals, reflections due to rain, and backscatter from surrounding vegetation) using program radR (see http://radr-project.org). Targets were then extracted as ‘blips’ and saved to .csv files for analysis in R (R Statistical Core team; V 3.02). A ‘blip’ represents a single point source as detected by the radar (e.g. a bird, insect, the peak of a wave). For each blip we measure multiple characteristics including the mean and peak intensity of the returned signal.

The vertically oriented radars detected targets in a different plane than the horizontally oriented units, and data were processed using separate parameters to reflect these differences. The vertically oriented radars produced smaller blips (number of samples per blip, area) and blips of lower intensity, than blips from the same targets on the horizontal radars. Therefore, for data from the vertically oriented radars, a minimum size of 15 samples per blip was used to initially remove noise from the data (point targets such as birds are not typically ‘large’). The maximum and average intensity of blips were then used to further separate biological targets from other objects (boats, waves, wires, etc.) all of which tend to reflect radar waves quite strongly. For these filters, we retained blips with a maximum intensity of less than 0.8, an average intensity of less than 0.7. Foreign radar pulses (spurious signals from other radars) appear in plots as long thin lines radiating out from the radar unit, and were removed by retaining only blips whose radial span was twice as large as their angular span. (See Table A).

Table A. Parameters for blip extraction.

Orientation	Blip Area		# of Samples		Angular Span		Radial Span		Expression
	Min	Max	Min	Max	Min	Max	Min	Max	
Horizontal	150	20000	13	5000	1	-1	1	-1	int < 0.8 & 2*aspan>rspan
Vertical	50	20000	13	5000	1	-1	1	-1	int < 0.8 & 2*aspan>rspan

Particularly at close distances (<500 m) the vertically oriented radars detected large numbers of small flying targets presumed to be insects, that were not detectable at greater ranges. Data from the vertical radar unit at the canal were sub-sampled to include targets between 620 and 820 m from the radar. The leading edge of the transmission lines was at 823 m, and the wires effectively obscured targets behind them at similar altitudes. There was an area of persistent clutter at the surface of the water at just under 620 m, and insect detections appeared to be minimal at this distance.

Data from the vertically oriented radar at the weigh station were sub-sampled to include targets between the leading edge of the wires (1300 m range) and 200 m from the wires

(1100 m range). Because the radars have a 23° beam width, the section of airspace monitored by the two units on either side of the Strait of Canso do not overlap as extensively as would be expected, and vertical profiles from each most accurately reflect movements of birds in relation to the wires near the shorelines of the Strait of Canso. Birds were detected on both radars over the water in the middle of the strait, but their range from the wires was greater than that of birds close to the shoreline. Birds could be detected closest to the wires along a line from the radar perpendicular to the wires, which was along the shoreline on either side (see **Figure 2**).

On the horizontal radar monitoring the Auld's Cove lines, the region of airspace between the transmission lines and the radar from the wires to 330 m out from the wires was selected for analysis. Only the portion of that airspace directly above the water itself was interpreted, as clutter obscured targets above the land to the East of the straight.

Biological targets could not be isolated during periods of rain on either the vertically or horizontally oriented radars (rain reflects the radar beam, and so most information is obscured). Wind also adversely affected data quality, as blips from waves effectively 'drowned out' biological targets flying over the water. The range at which this occurred increased with windspeed on the horizontal radar units. On the vertical units, wind affected detection of targets at the surface of the water as wave height increased.

We sub-sampled the entire season to obtain a cross-section of days that were of sufficient data quality for analysis. Days were sub-sampled into five, hour-long segments from each day: the hour before sunrise, an hour with the first two hours after sunrise, an hour within the first two hours before sunset, the hour immediately after sunset, and the hour encompassing the halfway point between sunrise and sunset). These time periods will be referred to hereafter, as: sunrise, morning, evening, sunset, and midnight (respectively). The data were further sub-sampled by date, and data from every fifth day were interpreted. If any hour selected in this manner was adversely affected by wind, rain, or the passage of a large boat (which caused reflections of radar signals that were difficult to remove), then data from that hour were selected from the closest date possible, with preference for a later date.

Tracking Targets

Series of blips were linked into tracks for both the vertical radars and for the horizontal radar unit at the canal site north of the causeway. Only the airspace between the wires and the radar unit were interpreted. A multi-frame correspondence tracking algorithm (MFC tracker; Shafique and Shah 2005) implemented in radR (Taylor et al. 2010) was used to link successive detections of the same target to create 'tracks'. Tracks provide information on the direction of travel and speed of targets, and more accurately reflect the volume of targets in the airspace by combining blips from the same target. Only tracks of 4 or more blips were retained to avoid including spurious tracks from clutter. The tracking data successfully removed noise from the data, as random blips throughout the airspace were not connected into tracks. Maximum flight speed was set at 100 kph, gain at 12, and directional coherence at 0.6, and the number of scans to back-track at 2 in the radR tracker plugin. The tracking parameters were set conservatively to ensure that tracks did not include blips from noise, clutter, or combine blips from separate targets into the same track. This method was effective in reducing spurious tracks, however, slowly moving birds or birds moving across the beam on the vertical radar (flying across the Strait of Canso as opposed to along it) were not always recorded as tracks.

Separation from insect targets

Data from the horizontal radar at the canal was used primarily to examine flights speeds of presumed insect targets, in order to allow us to separate those from presumed bird targets on the vertical radar (see ‘Separation from insect targets’ section below.

Visual interpretation of radar data using radR clearly showed that there were many slow-moving, small targets detected close to all radar units, particularly in the evenings in the summer. The horizontally oriented radars detected these targets at greater distances than did the vertical radars (because of the different orientations of the flying objects relative to the orientation of the beam). We examined tracking data from the horizontal radar which indicated there was considerable bimodality when target speed was plotted against intensity (that is, slow targets had lower intensities). It has been shown elsewhere that insect targets are slower and reflect the radar beam at lower intensities than other biological targets (e.g. Matkovich 2011). Similar plots of intensity versus range of tracks also showed bimodality, indicating that our ability to detect targets with lower intensities (insects) decreased rapidly as range increased. On the vertically oriented radar units, we cannot directly measure speed in the x-y plane unless targets are moving more or less parallel to the center of the beam. We extracted data from nights in August with south winds, where we were able to track insects moving through the beam of the vertical radar from south to north up the canal. We confirmed that these were ‘insect nights’ by examining speed and intensity on the horizontal radars. From these ‘co-observations’ on the two radars, we can readily see that presumed insect tracks are not detected by the vertically oriented radar at ranges exceeding about 500 meters. Very small and slow targets were detected in high numbers within 500 meters, but none of the tracks from these targets extended beyond the 500 meter mark.

The information from the horizontal and vertical radars thus lets us confidently state that the observed track data from the vertical radars in front of the lines represents primarily bird targets.

Appendix 3 Model summaries of how weather affects flight altitude and volume of targets by season and time of day.

Analysis of deviance tables are provided for seasonal models of how weather and time of day affected counts of targets at the same altitude of the wires, and counts at the altitude of the wires compared to counts below or above the wires. Plots of predicted values from each of the models are included.

Model 1 Volume of targets at the same altitude as the wires in summer

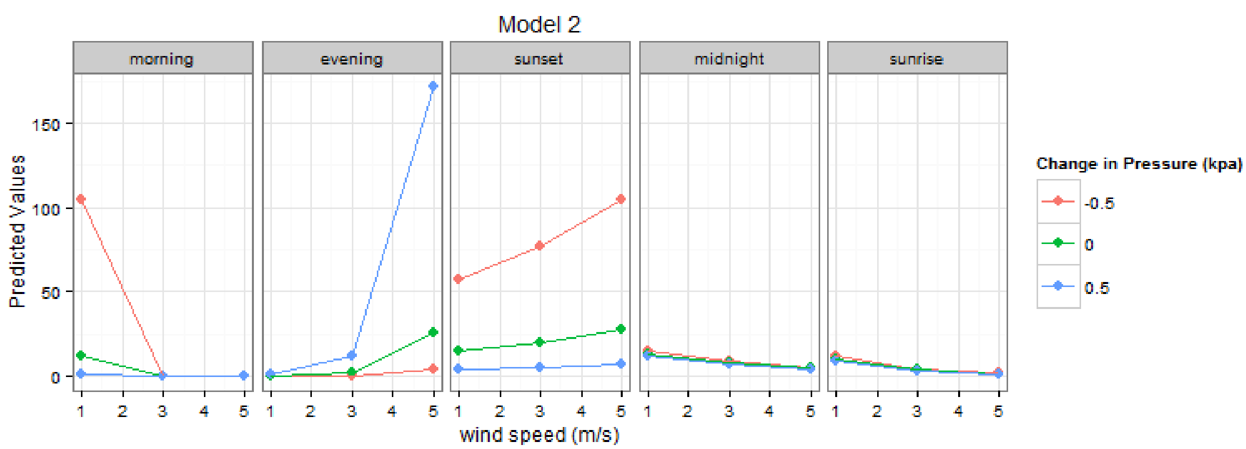
….

- model did not properly converge (there was likely little variation in the weather variables)

Model 2. Number of targets at the same altitude as the wires in fall

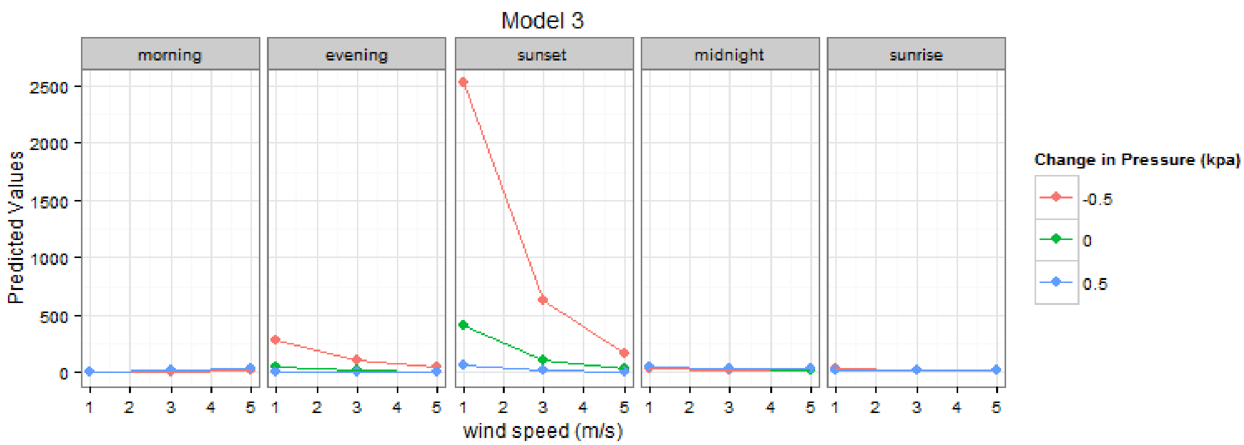
```
Model: Negative Binomial(1.6709), link: log
Response: wires
Terms added sequentially (first to last)
```

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)	
NULL			40	644.93		
timebin	5	576.74	35	68.18	< 2.2e-16	***
mean.wspd	1	0.97	34	67.21	0.324454	
mean.chg.press	1	0.51	33	66.70	0.475588	
timebin:mean.wspd	4	8.78	29	57.92	0.066860	.
timebin:mean.chg.press	4	17.07	25	40.85	0.001872	**



Model 3. Number of targets at the same altitude as the wires in late fall

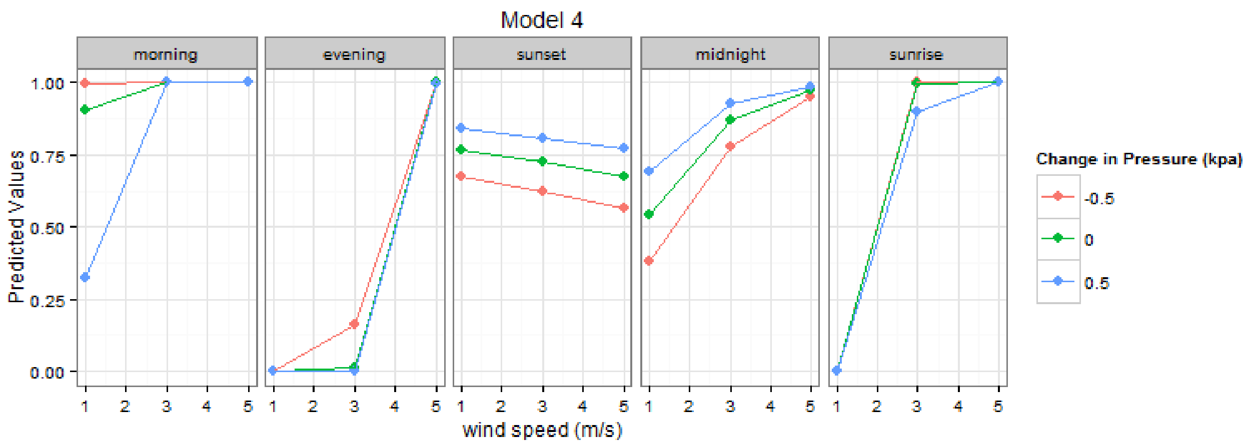
```
Model: Negative Binomial(1.6656), link: log
Response: wires
Terms added sequentially (first to last)


                      Df Deviance Resid. Df Resid. Dev Pr(>Chi)
NULL                                     48    1959.90
timebin                5  1889.87        43      70.04   <2e-16 ***
mean.wspd              1     2.62        42      67.42   0.1054
mean.chg.press         1     0.02        41      67.39   0.8782
timebin:mean.wspd      4     5.69        37      61.70   0.2236
timebin:mean.chg.press 4    12.86        33      48.85   0.0120 *
```



Model 4. Probability of targets at the wire altitude relative to the area below -- Summer.

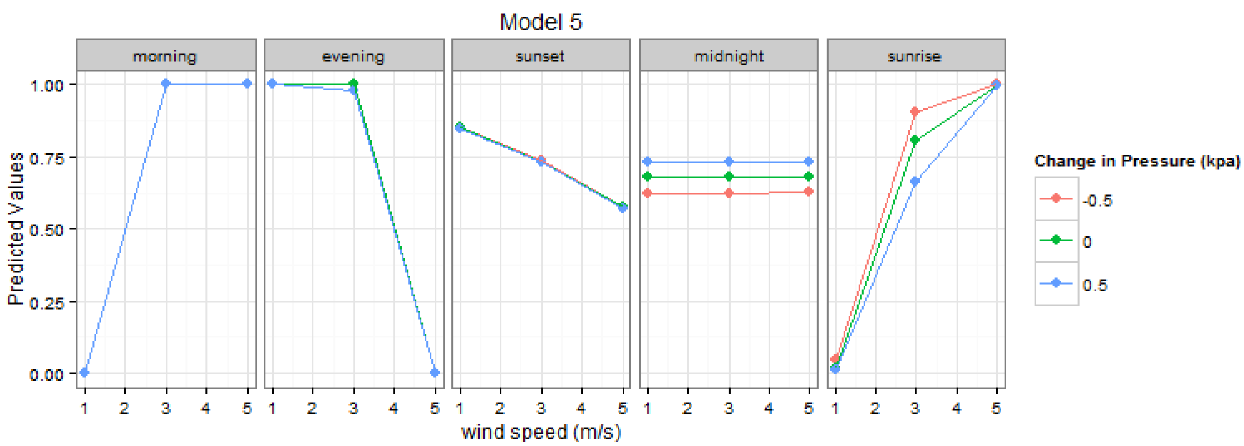
```
Response: cbind(wires, surface)
Model: binomial, link: logit
Terms added sequentially (first to last)
```

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)	
NULL			17	44.878		
timebin	5	32.682	12	12.196	4.352e-06	***
mean.wspd	1	1.404	11	10.792	0.23605	
mean.chg.press	1	3.366	10	7.426	0.06656	.
timebin:mean.wspd	3	3.320	7	4.106	0.34483	
timebin:mean.chg.press	2	0.347	5	3.758	0.84055	



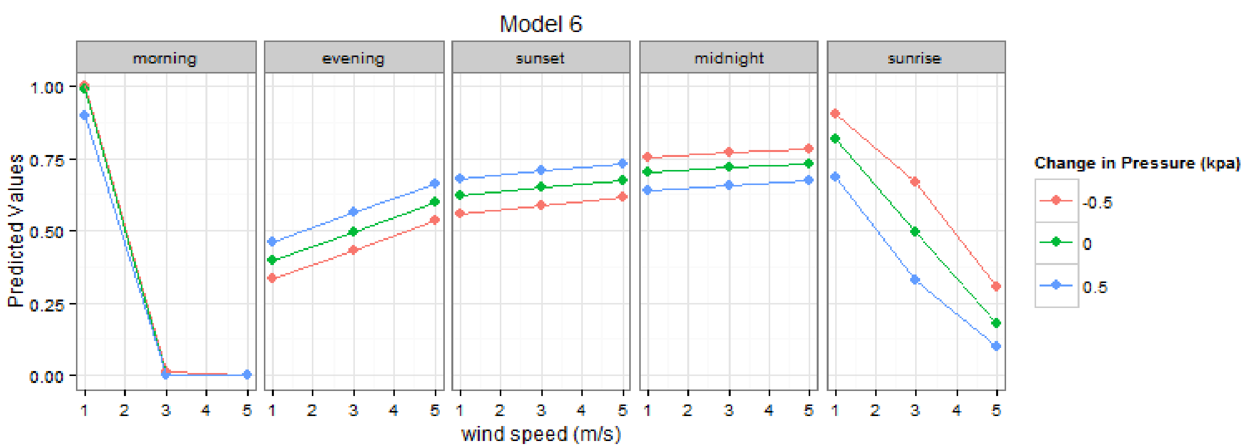
Model 5. Probability of targets at the wire altitude relative to the area above -- summer.

```
Response: cbind(wires, above)
Model: binomial, link: logit
Terms added sequentially (first to last)


                     Df Deviance Resid. Df Resid. Dev Pr(>Chi)
NULL                                   22    27.4597
timebin               5   4.1288         17    23.3310  0.53103
mean.wspd             1   5.1634         16    18.1676  0.02307 *
mean.chg.press        1   0.3323         15    17.8353  0.56431
timebin:mean.wspd     4  10.6132         11     7.2222  0.03127 *
timebin:mean.chg.press 3   0.5671          8     6.6551  0.90392
```



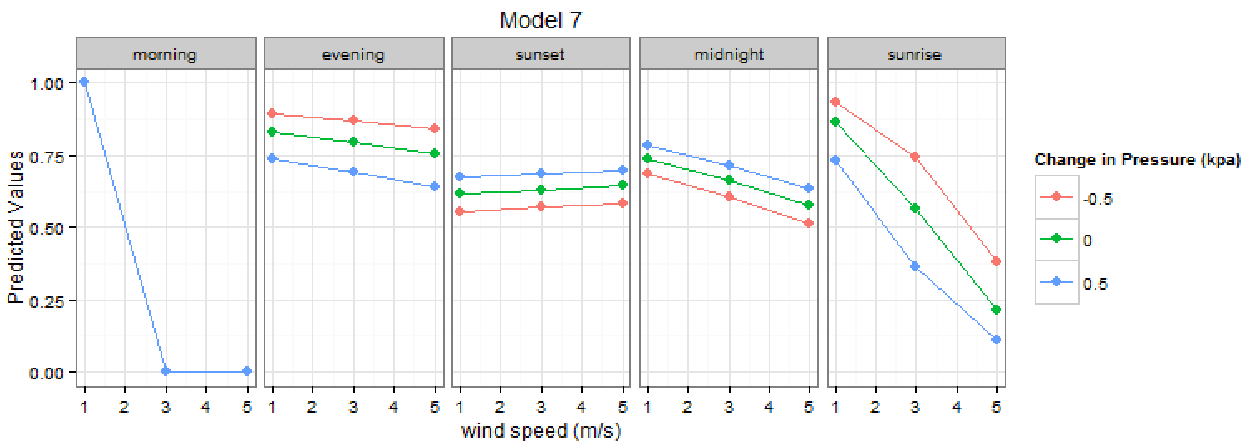
Model 6. Probability of targets at the wire altitude relative to the area below -- fall.

```
Model: binomial, link: logit
Response: cbind(wires, surface)
Terms added sequentially (first to last)


                      Df Deviance Resid. Df Resid. Dev Pr(>Chi)
NULL                                    35     96.027
timebin                5   60.481       30     35.546 9.67e-12 ***
mean.wspd              1    0.098       29     35.448  0.75388
mean.chg.press         1    0.442       28     35.006  0.50610
timebin:mean.wspd      4   11.311       24     23.694  0.02328 *
timebin:mean.chg.press 4    7.469       20     16.226  0.11309
```



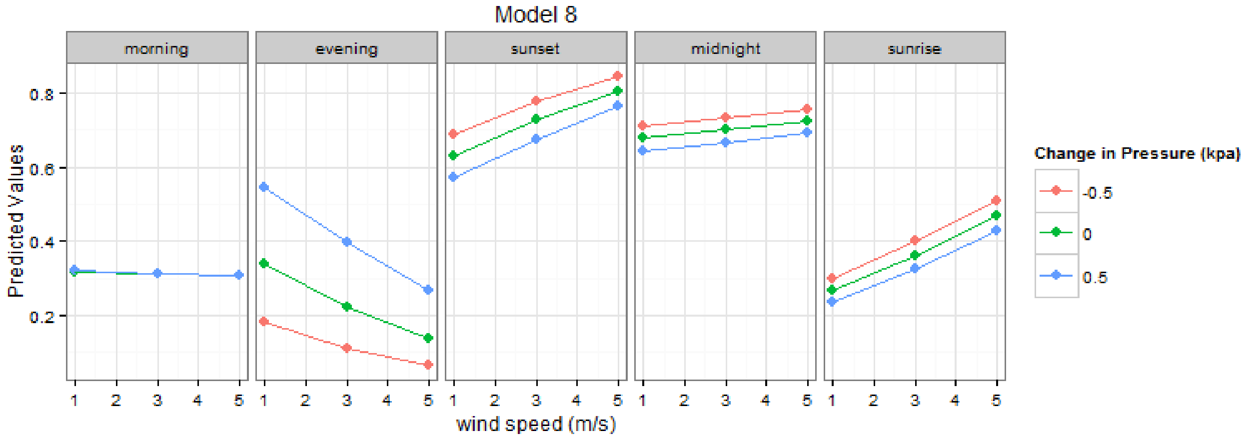
Model 7. Probability of targets at the wire altitude relative to the area above -- fall.

```
Model: binomial, link: logit
Response: cbind(wires, above)
Terms added sequentially (first to last)


                       Df Deviance Resid. Df Resid. Dev  Pr(>Chi)
NULL                                      35    124.223
timebin                 5   81.333        30     42.890 4.414e-16 ***
mean.wspd               1    0.559        29     42.331   0.45470
mean.chg.press          1    0.169        28     42.162   0.68105
timebin:mean.wspd       4    7.787        24     34.375   0.09972 .
timebin:mean.chg.press  4    9.728        20     24.647   0.04527 *
```



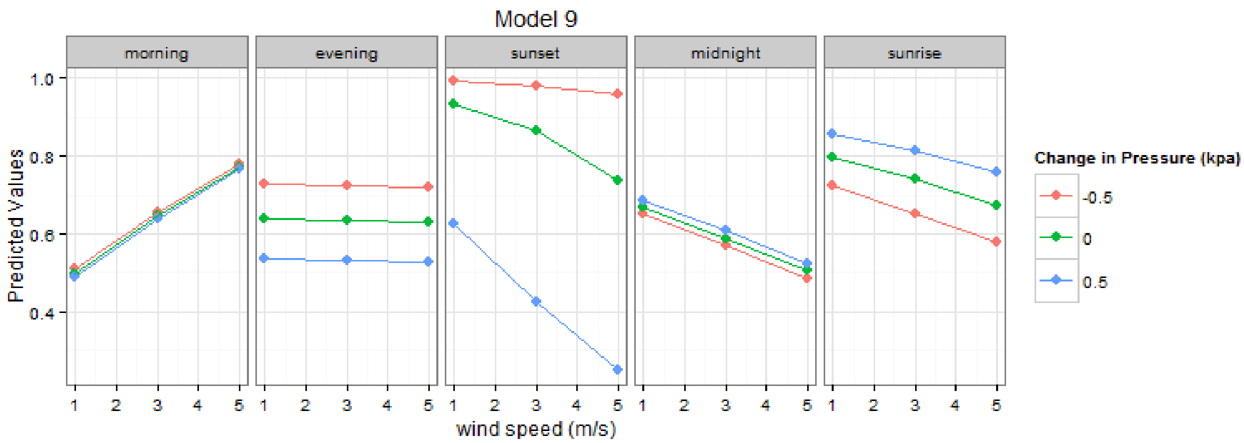
Model 8. Probability of targets at the wire altitude relative to the area below -- late fall.

```
Model: quasibinomial, link: logit
Response: cbind(wires, surface)
Terms added sequentially (first to last)


                      Df Deviance Resid. Df Resid. Dev       F    Pr(>F)    
NULL                                     48     744.75                      
timebin                5   484.21        43     260.54 13.9569 2.366e-07 ***
mean.wspd              1    14.94        42     245.59  2.1538    0.1517    
mean.chg.press         1     2.09        41     243.50  0.3018    0.5865    
timebin:mean.wspd      4    15.29        37     228.21  0.5508    0.6997    
timebin:mean.chg.press 4     5.63        33     222.58  0.2030    0.9349    
```



Model 9. Probability of targets at the wire altitude relative to the area above -- late fall.

```
Model: quasibinomial, link: logit
Response: cbind(wires, above)
Terms added sequentially (first to last)


                      Df Deviance Resid. Df Resid. Dev       F    Pr(>F)
NULL                                     48     471.26
timebin                5  309.371        43     161.89 21.7489 1.394e-09 ***
mean.wspd              1    1.312        42     160.58  0.4611   0.50185
mean.chg.press         1    0.175        41     160.40  0.0616   0.80556
timebin:mean.wspd      4   29.335        37     131.07  2.5779   0.05549 .
timebin:mean.chg.press 4   38.375        33      92.69  3.3722   0.02026 *
```



Appendix 4 Plots of data from the second vertically oriented radar at the weigh station site.

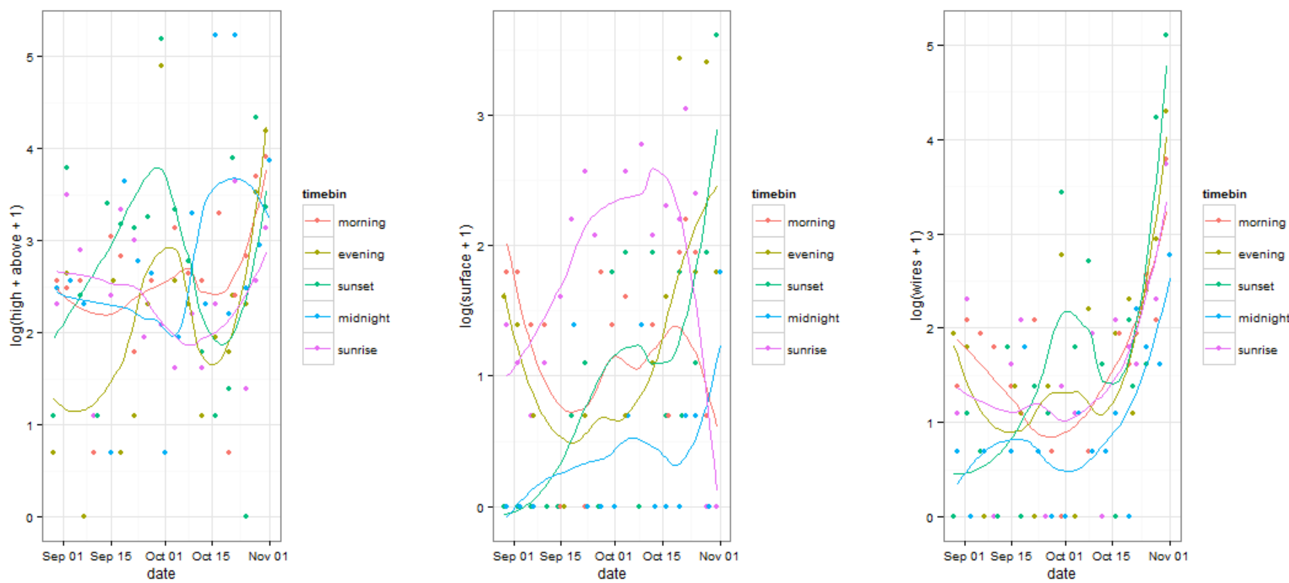


Figure **13.** Plot showing the general pattern of movement of targets through the area by season, observed from the weigh station site. Each point represents the log of the number of targets detected at different altitudes (above and high above the lines, at the surface, and at the wires) on each sampling day and time through the season. Sampling times are colour coded, and lines are a smoothed (loess) line through the data showing the general trend in the data. See text for further explanation.

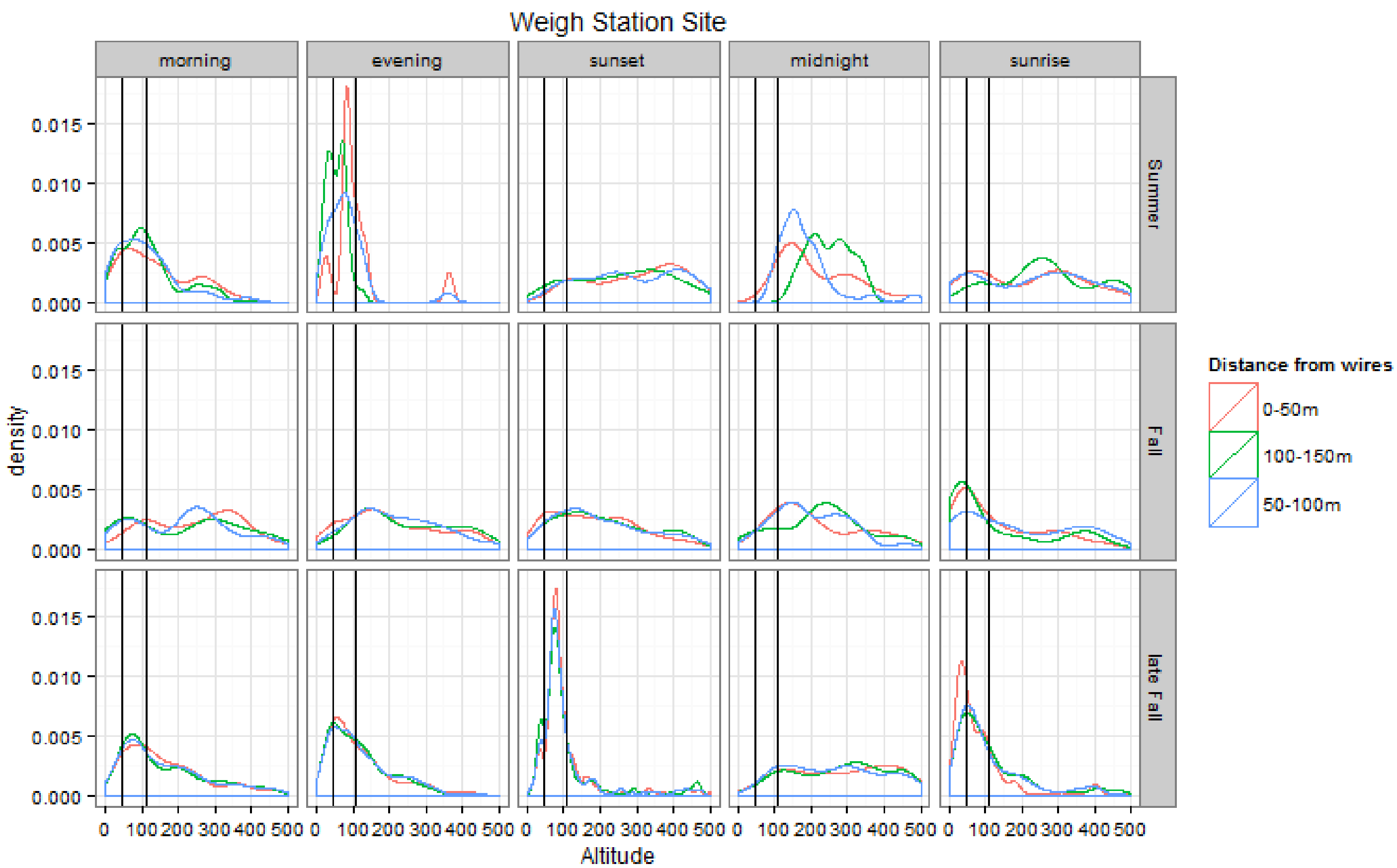


Figure 14. Altitude density profiles at different distances from the wires, observed from the weigh station site. Each panel represents one combination of time of day and season, and each coloured line shows the density profile of targets at different distances from the wires, for that combination. The approximate lower and upper heights of the transmission lines are depicted as vertical black lines.

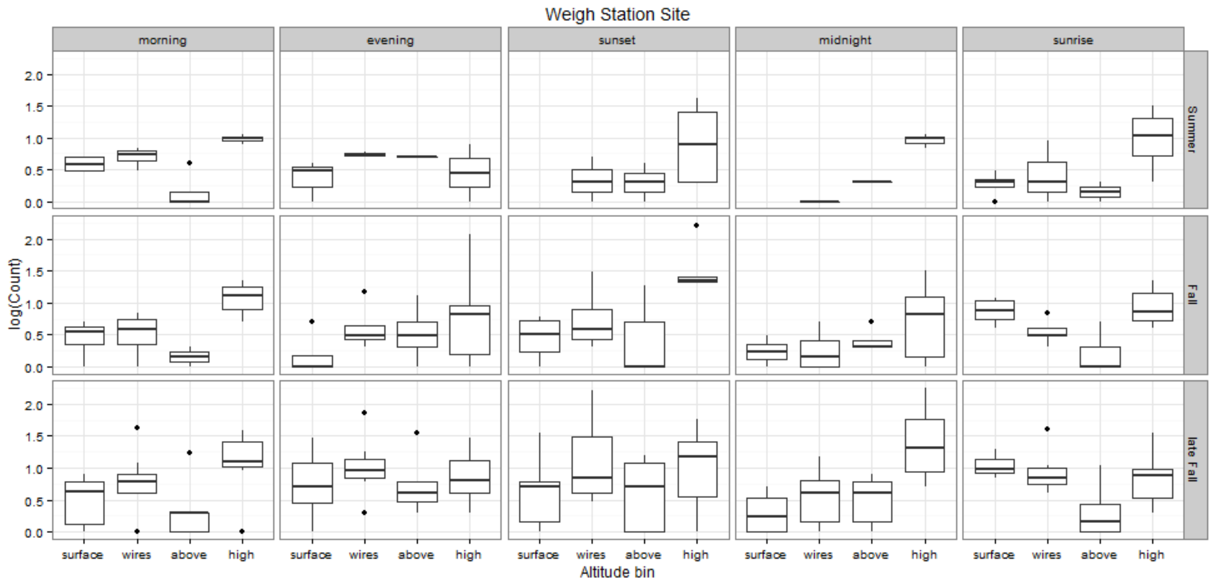


Figure 15. Box plots showing the log(count) of biological targets by altitude bin the area in front of the wires, observed from the weigh station site. Each box shows the distribution of the counts for a particular altitude bin (on a log10 scale), for a given time of the season and time of night. The dark line in the middle of the box shows the median value for the counts, the top and bottom edges of the box show the interquartile range, and the lines extending up and down show the range of 95% of the data points. The individual dots are beyond those limits ('outliers').