WALKINGBATS
Specialist Environmental Consulting

# AMBERFIELD – PERSISTENCE OF BATS IN THE PRESENCE OF VEHICLE HEADLIGHTS

Prepared for

WESTON LEA LTD

February 26, 2021

Dr Stuart Parsons

## 1.0 Executive Summary

The aim of this report is to determine if bats persist in the presence of headlights. To achieve this, I brought together the results of four separate but interrelated studies to investigate the relationship between bat activity adjacent to active roads, traffic levels, and modelled data on illumination caused by vehicle headlights. It is important to note that it was not the aim of any of the studies referred to in this report to assess the level of effect of headlights as this is beyond the scope of the data available.

Following my consideration of the data it is clear that bats do persist in the presence of vehicle headlights. Modelling also shows that light levels experienced by bats adjacent to roads are similar to those calculated for 3 m into the Bat Priority Areas (**BPAs**) at Amberfield. Levels of bat activity adjacent to roads is also very similar to those at Amberfield. Bats also persist adjacent to roads where traffic volumes are significantly higher than those likely to be experienced at Amberfield.

## 1.0 Background

Research shows that light may impact bats in species-specific ways (Azam et al 2018). Some species are attracted to lit areas and forage on the insects that are attracted to the light. Other species avoid lit areas; flying within the illuminated area will likely make them more apparent to visually guided predators such as owls and thus increase their risk of predation.

The majority of studies of the impact of light on bats has focused on static, persistent lighting such as that emitted from buildings and streetlights (Stone et al 2015). No studies have specifically focused on the impacts of vehicle headlights on bats. One study has suggested that headlights may have an effect on bats and has suggested mitigation similar to that for persistent lighting e.g. using vegetation screening to ensure light levels do not penetrate into bat habitat (Solowczuk 2019). However, Solowczuk (2019) provides no quantitative data to support an effect on bats and the author states that the environmental benefits of the suggested mitigation are under evaluation i.e. none are currently known.

Other studies, including European guidelines (e.g. Voight et al 2018), offer no data on the effects of headlights nor suggested mitigation.

This report brings together the results of four studies that together allow me to investigate if long-tailed bats (*Chalinolobus tuberculatus*) remain active in the presence of vehicle headlights in localities surrounding Amberfield. When combined, the studies aim to determine if long-tailed bats persist in the presence of vehicle headlights. It was not the aim of these studies to determine factors that influence the presence or absence of long-tailed bats at particular sites, but simply to determine if long-tailed bats remain active in the presence of vehicle headlights. I then used the results of the studies to evaluate if bats are likely to persist under lighting and traffic conditions expected to occur 3 m into the boundary of the BPAs at Amberfield.

**3.0 Methods**

Four studies were undertaken to evaluate if long-tailed bats persist in the presence of vehicle headlights.

***Study 1*** (**BML Hamilton**) is an acoustic survey that was conducted by Boffa Miskell Limited at 5 sites adjacent to roads in southern Hamilton between 22 January and 2 February 2021. Detailed methods and results are given in **Appendix 1**. Illumination from an exemplar vehicle's headlights was modelled by LDP Ltd (**LDP**) at the locations of the acoustic monitoring units to understand the illumination levels likely to be experienced by nearby bats (see Study 3 below). Google Street View images of the monitoring sites are shown in **Appendix 2**.

***Study 2*** is based on a review of results from acoustic surveys conducted in 2020 from sites adjacent to the alignment of the Hamilton and Cambridge sections of the Waikato Expressway. The review was conducted using reports supplied by Waka Kotahi New Zealand Transport Agency. From these reports, 3 acoustic survey sites were chosen for further assessment from the Hamilton Section (**WSP Hamilton**) and 4 sites from the Cambridge Section (**WSP Cambridge**).

Two of the WSP Hamilton survey sites are immediately adjacent to SH1 (Cambridge Road) at Riverlea (sites WSP-H30, 43), while the third is nearby, to the west of Newell Road (site WSP-H33). All four survey sites from the Cambridge Section were adjacent to SH1: one at Oaklea Lane (site WSP-C15), one at the Lloyd property (site WSP-C30), and two at the north-west and south-east approaches to the Karapiro Gully bridge (sites WSP-C21, 18). While survey locations for Cambridge are along the operating Expressway, those for Hamilton are adjacent to nearby feeder roads as the Hamilton Section of the Expressway has yet to open (see **Appendix 3** for survey site locations).

Bat activity levels were extracted from the Waka Kotahi reports, as were the locations of the acoustic monitoring units. Bat activity levels were means for each site calculated over their monitoring periods. Light modelling, based on calculations from the same exemplar vehicle used in Study 1, was undertaken for the locations to understand the illumination levels likely to be experienced by nearby bats (see Study 3 below). The guidelines governing the deployment of acoustic monitoring units and integrity of data collected were the same between Studies 1 and 2. The timing of acoustic surveys was also very similar (January / February).

***Study 3*** - Light modelling was undertaken by LDP to establish the expected light spill effects from an exemplar vehicle at 32 sites within Amberfield and the 12 BML Hamilton and WSP Hamilton/Cambridge sites (**Appendix 4**). In the case of Amberfield, the modelling was used to determine light levels 3 m into the BPA, taking into account the topography of the site. Details of this study are given in Appendix 4. When modelling the maximum illumination for WSP Hamilton/Cambridge sites, LDP used up to a 30 m radius (a conservative estimate of the detection distance of long-tailed bat echolocation calls) around each acoustic bat monitor (**ABM**) location and determined the lux level at the point on this radius closest to the road. This point was on the edge of the vegetation and so a likely area for bats to be flying (O'Donnell 2000, 2001). ABMs at the BML Hamilton sites on the roadside of vegetation (see Appendix 2), detected bats, and received similar levels of illumination to the WSP sites. This confirms that the approach of using the 30 m radius is justified.

***Study 4*** - The number of vehicles using the roads adjacent to the BML and WSP sites were obtained from Hamilton City Council, Waikato District Council and Waka Kotahi New Zealand Transport Agency (**Appendix 5**). Traffic volumes for Amberfield have been calculated as part of the assessment of the Amberfield development and are also provided in Appendix 5.

The 12 BML and WSP sites were selected (by ecologists in partnership with lighting specialists) to represent as best as possible the conditions likely to be experienced within BPAs on the Amberfield site. Criteria used to assess sites were:

- the distance of closest approach of vehicles,
- the angle of incidence of headlights relative to bat habitat,
- horizontal and vertical sweep of headlights, and
- where data was available (WSP sites), levels of bat activity similar to those seen at Amberfield.

A list of sites from Amberfield with similar conditions to BML and WSP sites are given in Table 3, Appendix 4. It was not possible to match traffic volumes likely to be experienced by bats at Amberfield, so BML and WSP sites were chosen that had higher volumes so as to represent a worst-case scenario.

## 4.0 Results

### *4.1 Bat Activity*

At the five BML Hamilton sites, four of the five recorded bat activity, with locations 1 and 5 having on average more than 10 passes per night over the recording period (see Appendix

1). Nightly bat passes at the seven sites taken from WSP Hamilton and WSP Cambridge reports varied from 2.1 to 97. Previous acoustic monitoring on the Amberfield site (summer 2020) showed that the number of bat passes per night varied from 1.9 (ABM 19) to 83.3 (ABM 4)[1].

Although mean bat activity was taken from the Amberfield, BML and WSP sites, comparisons between sites was most appropriately done using medians due to the variability in the data. Median bat acoustic activity was higher at Amberfield when compared with BML Hamilton and WSP Hamilton (Figure 1). However, WSP Cambridge sites were higher than for Amberfield with a median of 20.5 passes per night (c.f. Amberfield = 6.3).

### *4.2 Light Modelling*

Light modelling showed that median maximum headlight illumination levels expected 3 m into the BPAs were similar to those modelled at the BML Hamilton site (Figure 2). However, the median value for WSP Cambridge sites was nearly double that expected for Amberfield (Amberfield Median = 0.7 lux, WSP Cambridge Median = 1.3 lux). At Amberfield, 69% (22/32) of sites had maximum illumination levels lower than the median for the WSP Cambridge sites, and 81% of Amberfield sites (26/32) had illumination levels lower than the maximum predicted for all WSP sites where bats were active (maximum predicted = WSP Cambridge site 15; the very high value for BML1 site was not used for this comparison; See Figure A1.1 from Appendix 4).

[1] Evidence in Chief of Georgia Cummings. Before the Environment Court 27 July 2020 (EB.0130).

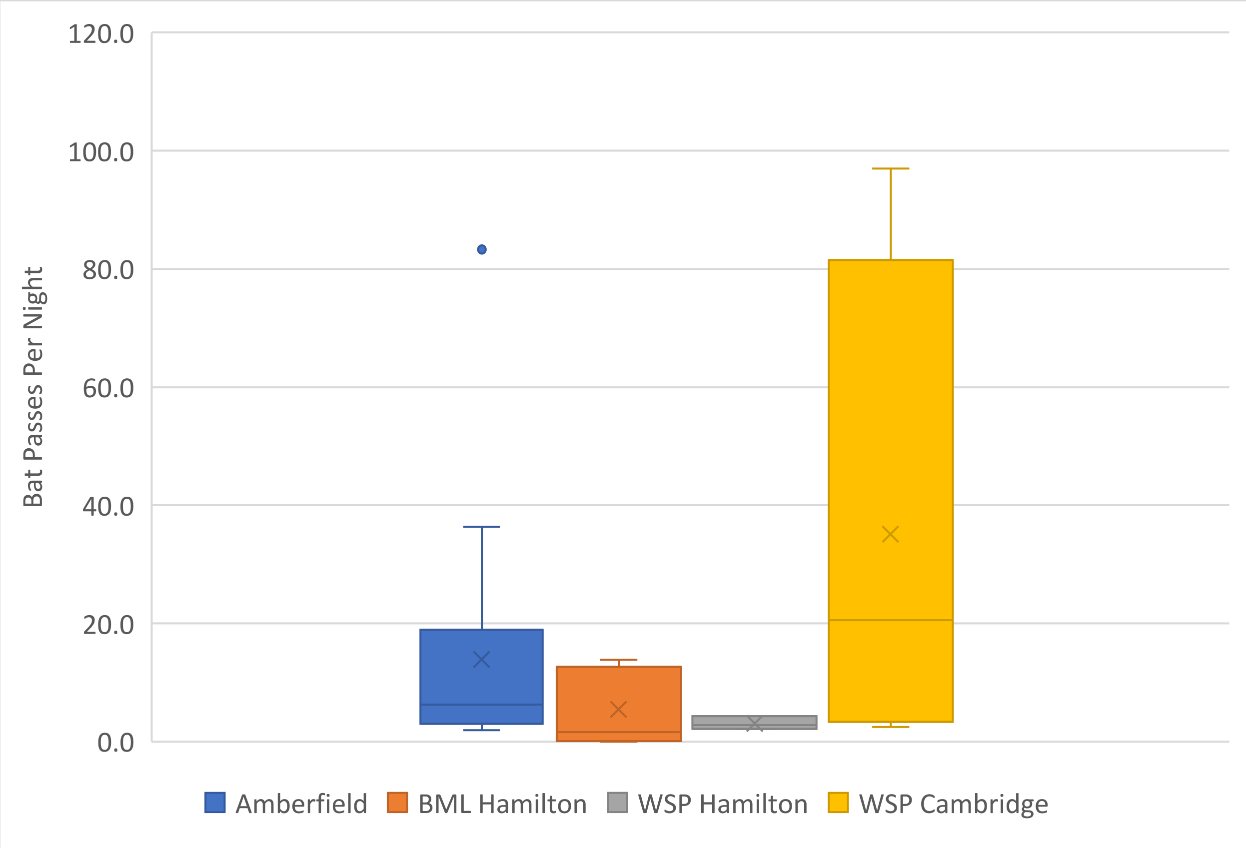


**Figure 1**: Box-Whisker plot for bat passes per night at acoustic monitoring sites at Amberfield (2020, February March[1]) and for the BML Hamilton, WSP Hamilton, and WSP Cambridge sites. The plot shows the minimum value, first quartile, median, mean (x), third quartile and maximum value of a data set. Data is drawn from the BML report in Appendix 1, and WSP Hamilton and WSP Cambridge reports.

### *4.3 Vehicle Traffic*

Actual two-way vehicle counts for BML Hamilton, WSP Hamilton, and WSP Cambridge sites are higher than those estimated on roads within Amberfield between the hours of dusk and dawn in summer (Figure 3). The only exception to this is WSP-Cambridge site 15 which was similar to several Amberfield sites (Appendix 5). It should be noted that vehicle counts are higher at dusk and dawn and this is not evident from means given in Figure 3. Data given in Appendix 5 shows the hourly trends for each site.

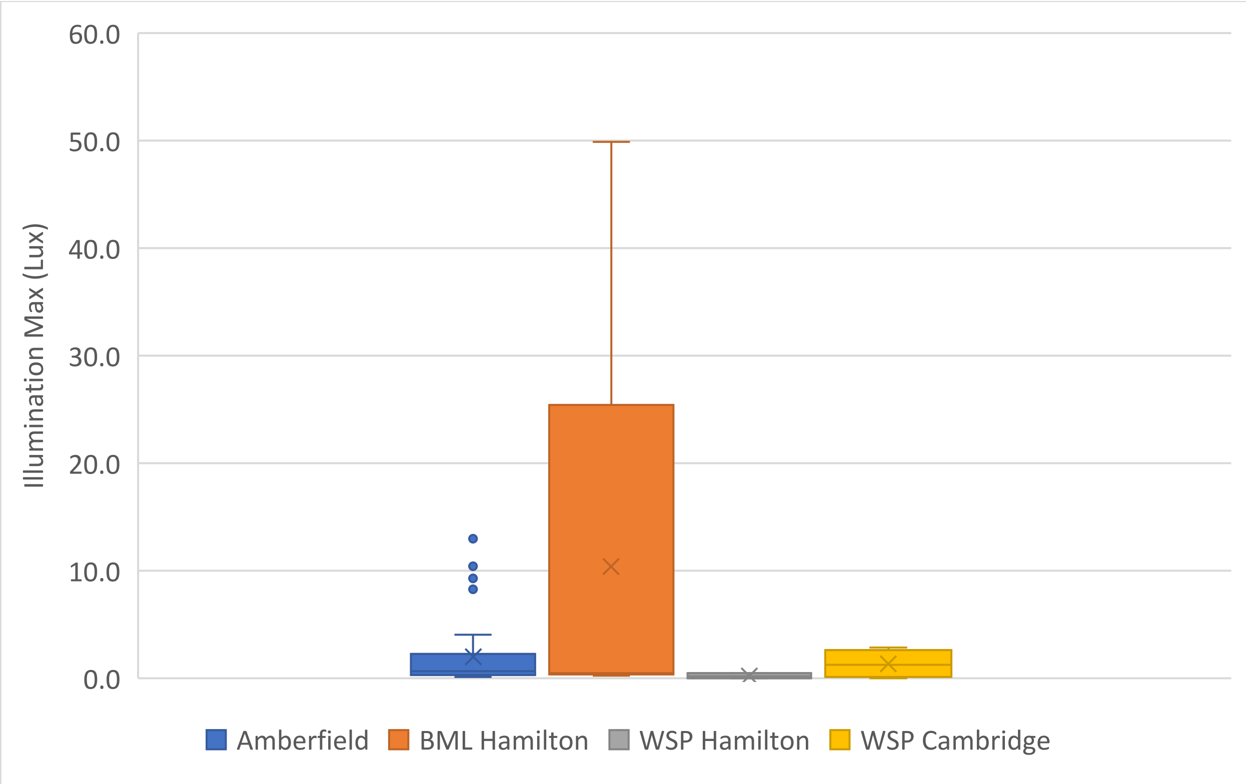


**Figure 2:** Box-Whisker Plot for the maximum illumination levels (in lux) likely to be experienced by bats 3 m into the BPAs at Amberfield, and at acoustic survey sites at BML Hamilton, WSP Hamilton, and WSP Cambridge. The plot shows the minimum value, first quartile, median, mean (x), third quartile and maximum value of a data set. Data is drawn from the LDP report in Appendix 4.

## 5.0 Discussion

The aim of this report is to determine if long-tailed bats persist in the presence of vehicle headlights at localities surrounding Amberfield. To achieve this aim, I have brought together data on bat activity, modelled illumination levels from an exemplar vehicle's headlights, and traffic volumes. This is the only study of its kind for New Zealand bats and as far as I can determine, the first internationally.

In my opinion, having brought together the four studies, the following conclusions are supported:

1) Long-tailed bats persist in the presence of vehicle headlights.
2) Levels of bat activity (bat passes per night) at Amberfield are similar to those detected at sites adjacent to active BML- and WSP-monitored roads.
3) Bats at Amberfield will experience similar intensity of headlight illumination 3 m into the BPAs as bats along the BML- and WSP-monitored roads.
4) The frequency of vehicle passes (headlights) bats are exposed to on the Amberfield site will be far lower than those experienced by bats adjacent to active BML- and WSP-monitored roads.

In bringing together the 4 studies described above, this report is the first to specifically investigate the effect of vehicle lights on bats. Published studies make recommendations on mitigation of static persistent light such as those from buildings and streetlights (e.g. Azam et al 2018; Voight et al 2018). However, no data is available internationally on the effects of headlights, although some studies suggest that bats may be affected by headlights and that mitigation similar to that used for persistent light be used (Solowczuk 2019). Such suggestions are not backed up by data and the results reported here suggest that they do not apply to long-tailed bats in this study, at the calculated light levels. Given the transient nature of headlights, they are unlikely to induce the negative effects of persistent anthropogenic light such as delaying emergence from roosts (e.g. Downs et al 2003; Boldogh 2007) or blocking bat movement (Stone et al 2009).

Long-tailed bats are unlikely to experience the light levels calculated at vehicle height 3 m into the BPAs. Long-tailed bats are known to fly along the edge of mature vegetation, often at the top edge of, or over, the canopy (O'Donnell 2000, 2001; Parsons et al, 1997). Several studies have confirmed that this is also the case for bats at Amberfield and in southern Hamilton (Wildlands Consulting 2018, Davidson-Watts 2018, and acoustic monitoring conducted for Ambefield[1]). Modelling data from LDP shows that headlight maximum

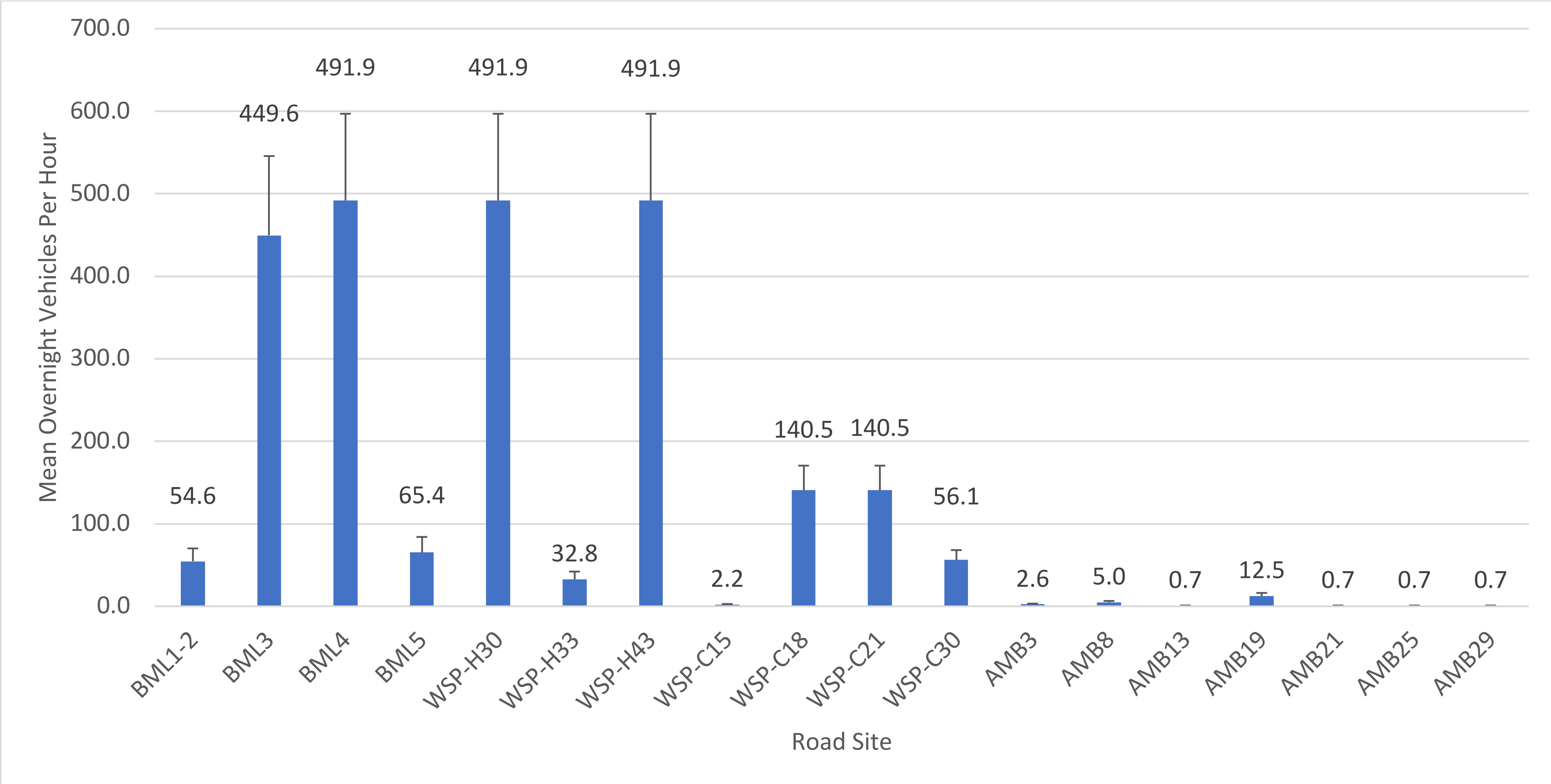


Figure 3: Mean two-way vehicle counts per hour at BML Hamilton (**BML**), WSP Hamilton (**WSP-H**), and WSP Cambridge (**WSP-C**); estimated for Amberfield (AMB; see Appendix 5 for further details). Values are for summer only between 20:00 and 06:00. Error bars represent ± 1 standard error of the mean. Several sites have the same mean traffic counts because the same data was used to for traffic counts as they are on the same road. Data is drawn from the TP Consulting Traffic Memo in Appendix 5.

illumination 3 m into the BPA reaches 0.1 lux at a height above 11 m regardless of whether or not screening is in place (see Figure 5, Appendix 4); a height similar to that of the East-West Shelterbelt. Finally, the highest levels of bat activity on the Amberfield site are on the river side of the riparian margin, where light levels will be less than 0.1 lux without additional planting. Therefore, the calculations for Amberfield presented in Appendix 4 (Table A1.1) represent the worst case (and highly unlikely) scenario and are only likely to be experienced by bats when vehicles lights illuminate the tops of mature vegetation close by a road. Even then, data shows that bats are active at light levels likely to be experienced 3 m into the BPA.

Results of the acoustic monitoring and light modelling at the BML and WSP Hamilton/Cambridge sites clearly shows that bats are active in the presence of vehicle headlights and when traffic volumes are higher than those expected at Amberfield. The presence of outliers in the light modelling data can make it difficult to compare levels across sites. However, the fact that 69% of Amberfield sites had maximum illumination levels lower than the mean for the WSP Cambridge sites, and 81% of Amberfield sites had illumination levels lower than the maximum predicted for all the WSP sites shows that bats are likely to persist 3 m into the BPA at Amberfield in the presence of headlights, and without further screening.

Bat activity in the presence of persistent static lighting at the BML and WSP Hamilton sites shows that long-tailed bats remain active at light levels far exceeding those modelled to be produced by vehicle headlights. LDP modelling shows that illumination from static persistent light from roadway lighting is much higher than those expected to be emitted by headlights (see Tables 5 and 6, Appendix 4). The potential effects of persistent artificial light are known for some species (Stone et al 2015) but not for long-tailed bats. While no studies of direct (e.g. delayed roost emergence) or indirect effects (e.g lower juvenile survival) have been conducted on New Zealand bats, it is clear that they remain active in the presence of persistent light levels far higher than those produced by vehicle headlights. The height at which illumination levels from these roadway lights drops below 0.1 lux is also above the treetops and so is very likely to be shining into the bats' preferred habitat. Control measures on static persistent lighting at Amberfield means that levels will not exceed 0.1 lux 3 m into the BPAs.

Bats' exposure to headlights, regardless of illumination intensity, will be relatively rare (compared with BML and WSP sites), and will last for only a few seconds. The number of vehicle movements per hour on Amberfield roads ranges from 0.7 to 12.5 per hour (see Figure 3 above, and Appendix 5). If I assume that a bat would be exposed to headlight illumination > 0.1 lux for 3.1 seconds[2] as a vehicle passes, then over 1 hour between 0.06 and 1.1% of available "bat time" is occupied by vehicle headlights shining on habitat. This information should also be considered within the context of bat activity at Amberfield. The highest bat activity reported during the summer 2020 surveys was 83.3 passes per night. Over an 11-hour night (between sunset and sunrise), this equates to 7.6 bats per hour or 0.12 bats per minute. For the point where Road 1 crosses the East-West Shelterbelt (site 8 in the TP Consulting Traffic Memo, Appendix 5), only 0.06 bats per minute were detected.

The above calculations represent a worst-case scenario as in many locations: 1) vehicles will not drive directly at bat habitat, 2) the data from the BML and WSP Hamilton/Cambridge reports show that the bats persist when maximum illumination levels exceed those expected 3 m into the BPAs, and 3) at the height that bats are flying the illumination levels will be considerably lower.

Long-tailed bats appear able to remain active despite the construction of a well-lit section of the Waikato Expressway. A detailed statistical analysis of bat acoustic activity over 4 years adjacent to, or near, the Cambridge Section of the Waikato Expressway showed no negative effect of the road either during its construction or while operational (WSP 2020). Modelling took into account acoustic activity as well as environmental conditions and habitat features, and compared activity with control areas not likely to be impacted by the road. Results showed that bat activity was stable or increasing with time, and despite the road being operational there was no effect of survey site distance to the road centreline on acoustic activity.

[2]Calculations made by LDP show that the exemplar vehicle's headlight intensity reduced to 0.1 lux at a distance of 43 m (at ground level with no screening). For a vehicle travelling at 50 km/h travels, BPA light spill will exceed 0.1 lux for 3.1 s.

In my opinion the results presented in this report are. The four studies presented used the same methods (time of year, acoustics monitoring, light modelling and source of traffic volumes) across all sites and so can be directly compared. As far as possible, the conditions under which bats at Amberfield would experience headlights, including the range of horizontal and vertical alignments of roads, were also matched with external sites (see Table 4, Appendix 4).

In conclusion, that data show that in the presence of headlights at an intensity of illumination similar to that predicted 3m into the BPAs at Amberfield, and with greater traffic activity (and therefore higher frequency of headlight sweep), long-tailed bats persist.

## 6. References

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## 7.0 Appendices

7.1 Appendix 1 - Boffa Miskell Bat Survey, February 2021.

7.2 Appendix 2 – Google Street View images of the 5 survey sites used in the BML Hamilton study.

7.3 Appendix 3 – Location of acoustic monitoring sites from the WSP Hamilton and Cambridge 2020 monitoring reports.

7.4 Appendix 4 - LDP Ltd Amberfield Headlight Sweep Effects, 26 February 2021.

7.5 Appendix 5 - TP Consulting Traffic Memo, February 2021.

## 7.1 Appendix 1

Memorandum

**Boffa Miskell**
Level 3, South Bloc, South Lobby, 140 Anglesea Street, Hamilton
PO Box 1094, Hamilton 3240
Telephone: +64 7 960 0006

Boffa Miskell

| | |
|---|---|
| Attention: | Steve Bond |
| Company: | Weston Lea Ltd |
| Date: | 4 February 2021 |
| From: | Tine Ulrich and Andrew Blayney |
| Message Ref: | Traffic bat survey for Amberfield - results |

## 1. Introduction

Previous bat monitoring surveys have shown that the rural-urban transitional area at the southern extent of Hamilton City is utilised by long-tailed bats. The Amberfield site, which Weston Lea Ltd has proposed to develop to facilitate a residential subdivision, is situated within this area. Previously, it has been shown that long-tailed bats utilise habitat features within the Amberfield site for commuting, foraging and opportunistic roosting (Boffa Miskell Ltd, 2018, 2020b, 2020a).

The following outlines the results of an automated bat detector survey that was undertaken in January 2021 in the wider landscape surrounding the Amberfield site and investigating bat activity levels adjacent to public roads with different levels of traffic volume.

## 2. Survey methods

Automatic bat monitors (ABMs) were used that passively record both, long-tailed bat (at 40 kHz) and short-tailed bat (at 28 kHz) echolocation calls on two concurrently operating frequency channels. ABMs operate remotely by recording and storing each echolocation call (bat pass), along with the date and time of the bat pass occurrence.

Five automatic bat monitors (ABMs) were deployed next to roads in the wider landscape encompassing the Amberfield site within habitat features utilised by long-tailed bats such as vegetation edges and mature trees next to the road corridor (Appendix 1).

This survey was conducted from 22 January to 02 February 2021, for a total of eleven survey nights. ABMs were programmed to record from one hour before sunset to one hour after sunrise[1].

Long-tailed bat activity is influenced by overnight weather conditions such as temperatures, rainfall, wind speed, and moonlight (Ciechanowski et al., 2007; O'Donnell, 2000). Weather data from the survey period was analysed to ensure conditions were suitable for bats to be active and hence detectable via acoustic monitoring. Suitable conditions are henceforth referred to as 'fine weather nights; and are defined for the purpose of this survey report as follows:

- Air temperature does not drop below 10°C from sunset until four hours after sunset;
- Mean overnight wind speed does not exceed 20 km/h;
- Nightly wind gusts do not exceed 60 km/h;
- Rainfall of no more than 2.5 mm occurs in the first two hours after sunset; and
- No monitoring occurs during full moon or on one night either site of a full moon.

Hourly weather data was sourced from the nearest weather station available in New Zealand's National Climate database (Hamilton, Ruakura 2 Ews – approximately 4 km from the Amberfield site; https://cliflo.niwa.co.nz/) and included temperature, rainfall and wind speeds.

[1] Sunset and sunrise times were taken from the closest available location on the LINZ Sunrise/Sunset tables, see https://www.linz.govt.nz/sea/nautical-information/astronomical-information)

Acoustic data from fine weather nights was analysed using BatSearch version 3.12, a programme designed by the Department of Conservation for use with their ABMs. The software converts bat echolocation calls (bat passes) into spectrogram images enabling visual analysis including the occurrence of feeding buzzes[2].

## 3. Survey results

No adverse weather conditions were observed for the duration of this survey period (Appendix); however, a full moon occurred on 29 January 2021. Consequently, eight nights of data were analysed. A summary of the results for each survey site is provided in Appendix 3, and the mean number of bat passes recorded at each site is provided in Appendix 1.

### 3.1 Relative bat activity levels

Bat passes were recorded at four out of the five survey sites. No bat passes were recorded at site 3, while only one bat pass over the entire survey period was recording at site 4 (Appendix 1 and 3). The highest level of bat activity was recorded at survey sites 5 and 1, with 13.8 ± 2.7 and 11.5 ± 2.9 mean bat passes per night, respectively (Figure 1, Appendix 1 and 3).

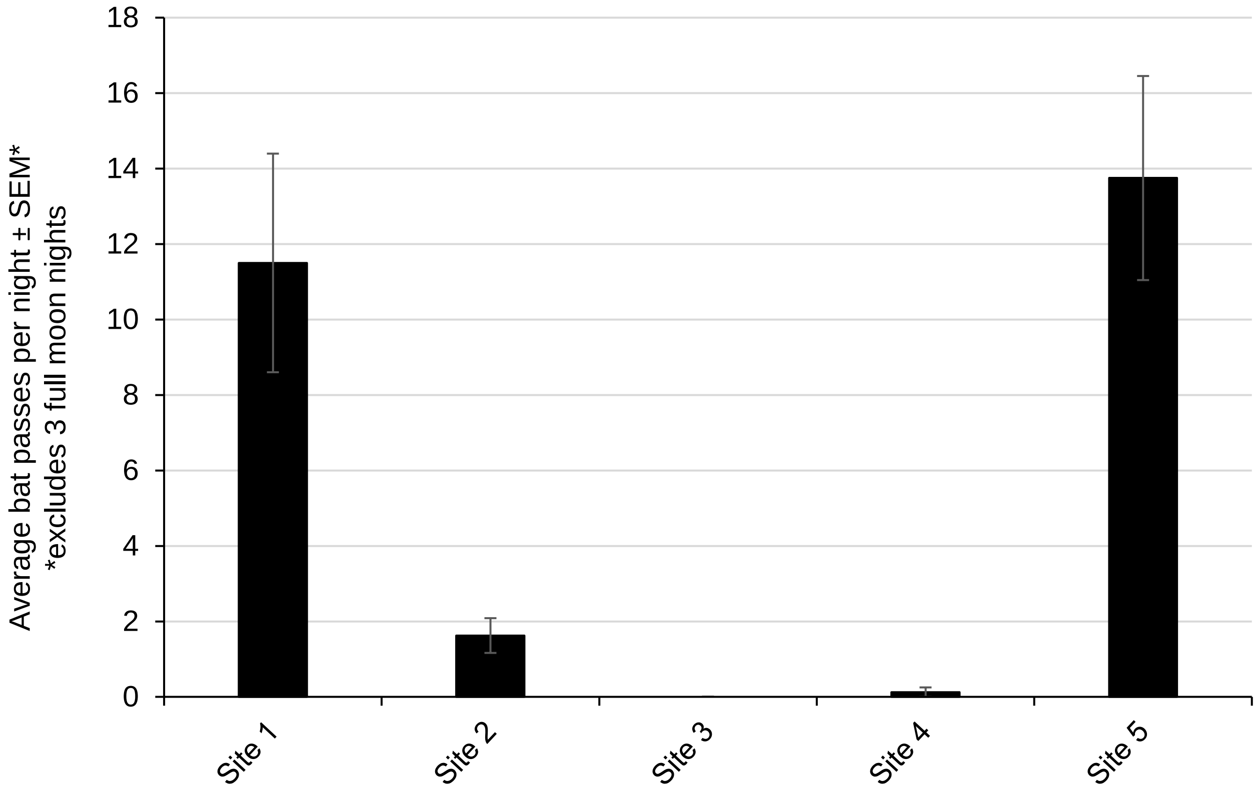



*Figure 1. Mean bat passes per night at each survey site.*

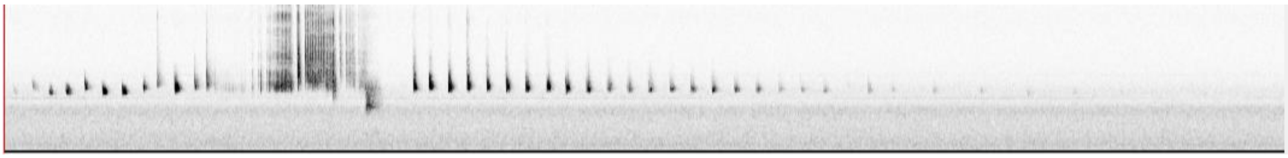
Bat activity at sites 1 and 5 was recorded during each night of the survey period, while bat activity was recorded on 87.5% of survey nights at site 2 and on 12.5% of survey nights on site 4 (Appendix 3).

### 3.2 Foraging activity

One feeding buzz (Figure 2 A) was recorded at Site 5; no other foraging activity was recorded at any other survey site (Appendix 3).

(A)

[2] When long-tailed bats capture flying insects on the wing, they increase the frequency of their echolocation 'clicks' as they home in on prey. This unique type of echolocation call can be identified on the spectrograms (Figure 2 A) and the relative frequency of feeding buzzes provides an indication of foraging habitat.



(B)

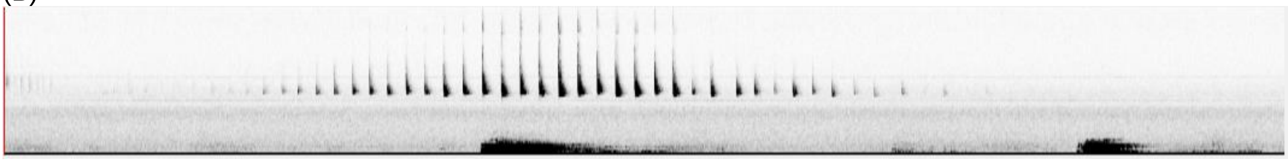


*Figure 2. A bat pass including a feeding buzz with an increase in click frequency as the bat is homing in on its prey (A) in contrast to a normal commuting bat pass with equally spaced echolocation clicks (B).*

### 3.3 Sunset and sunrise activity

Bat passes within one hour of sunset and one hour of sunrise were recorded at survey sites 1, 2 and 5; however, at none of these sites was sunrise activity immediately followed by sunset activity on the subsequent evening (Appendix 3)[3,4].

Concurrently, bat activity levels throughout the night was at its highest during the middle of the night at sites 1, 4 and 5. At site 2, bat activity levels close to sunrise were comparable, but not higher than those observed during the middle of the night[5] (Appendix 4).

## 4. Summary

The results from the January 2021 road traffic and lighting bat survey demonstrate that bats are utilising habitat features next to public roads in the wider landscape encompassing the Amberfield site for commuting and periodic foraging.

[3] Sunrise activity followed by sunset activity on the same day would indicate roosting bats arriving at a roost tree in the morning and leaving the roost in the subsequent evening.

[4] Three nights were excluded from analysis due to a full moon.

[5] A bi-modal bat activity pattern throughout the night with elevated levels of bat activity at the start and end of the night in comparison to the remainder of the night, indicates the presence of roosting bats with most activity recorded when bats are leaving and/or returning to a roost near the ABM location.

# 5. References

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Appendix 1 – Bat Survey Locations and Results Map

File Ref: A17134_Bat_Habitat.aprx/A17134_ABMSurvey2021


Boffa Miskell

www.boffamiskell.co.nz

0 1,000 m

1:25,000 @ A3

*Data Sources:* Boffa Miskell

*Projection:* NZGD 2000 New Zealand Transverse Mercator



**A17134 HAMILTON SOUTH DEVELOPMENT**

Bat Monitoring Results - January 2021

**Date: 4 February 2021 | Revision: B**

Plan prepared by Boffa Miskell Limited

*Project Manager:* **Rachel.deLambert@boffamiskell.co.nz** | *Drawn:* JWa | *Checked:* TUl

# Appendix 2 – Bat Survey Weather Summary

*Table 1. Weather data for the duration of the automatic bat survey.*

| Survey night | Date | Time | Minimum Temperature (°C) | Precipitation (mm) | Surface wind speed (km/hr) | Maximum wind gust (km/hr) |
|---|---|---|---|---|---|---|
| **Night 1** | 22.01.2021 | 20:00 | 16.3 | 0 | 11.5 | 28.1 |
| | | 21:00 | 15.5 | 0 | 10.8 | 23 |
| | | 22:00 | 14.7 | 0 | 7.2 | 15.8 |
| | | 23:00 | 13.7 | 0 | 5 | 9.4 |
| | 23.01.2020 | 0:00 | 12.3 | 0 | 3.6 | 7.6 |
| | | 1:00 | 10.4 | 0 | 1.8 | 4.3 |
| | | 2:00 | 9.7 | 0 | 1.8 | 5 |
| | | 3:00 | 9.2 | 0 | 2.2 | 7.2 |
| | | 4:00 | 8.6 | 0 | 1.8 | 5.4 |
| | | 5:00 | 8.1 | 0 | 2.2 | 5.4 |
| | | 6:00 | 8.4 | 0 | 2.9 | 7.2 |
| | | 7:00 | 10.5 | 0 | 2.5 | 6.5 |
| **Night 2** | 23.01.2020 | 20:00 | 17.4 | 0 | 14.8 | 29.5 |
| | | 21:00 | 17.1 | 0 | 10.8 | 19.4 |
| | | 22:00 | 16.9 | 0 | 10.8 | 17.3 |
| | | 23:00 | 16 | 0 | 5.4 | 11.5 |
| | 24.01.2021 | 0:00 | 15.5 | 0 | 6.8 | 13 |
| | | 1:00 | 15 | 0 | 6.1 | 16.6 |
| | | 2:00 | 15.5 | 0 | 6.1 | 13.7 |
| | | 3:00 | 13 | 0 | 3.6 | 7.9 |
| | | 4:00 | 13.1 | 0 | 8.6 | 17.3 |
| | | 5:00 | 15.6 | 0 | 7.2 | 15.1 |
| | | 6:00 | 16.3 | 0 | 6.8 | 12.2 |
| | | 7:00 | 16.5 | 0 | 10.4 | 22.3 |
| **Night 3** | 24.01.2021 | 20:00 | 18.2 | 0 | 14.8 | 29.2 |
| | | 21:00 | 17 | 0 | 8.3 | 18 |
| | | 22:00 | 15.9 | 0 | 6.8 | 13 |
| | | 23:00 | 15.6 | 0 | 7.2 | 11.9 |
| | 25.01.2021 | 0:00 | 15.3 | 0 | 8.3 | 16.9 |
| | | 1:00 | 15 | 0 | 7.6 | 16.6 |
| | | 2:00 | 14.9 | 0 | 8.6 | 15.1 |
| | | 3:00 | 14.3 | 0 | 4 | 9.4 |
| | | 4:00 | 13.9 | 0 | 9 | 23.8 |
| | | 5:00 | 15.5 | 0 | 11.9 | 23 |
| | | 6:00 | 15.5 | 0 | 10.4 | 23 |
| | | 7:00 | 15.7 | 0 | 10.4 | 20.2 |
| **Night 4** | 25.01.2021 | 20:00 | 18.8 | 0 | 15.5 | 28.4 |
| | | 21:00 | 17.8 | 0 | 9.4 | 25.9 |
| | | 22:00 | 17.2 | 0 | 9 | 17.6 |
| | | 23:00 | 16.8 | 0 | 10.4 | 18.4 |
| | 26.01.2021 | 0:00 | 16.9 | 0 | 8.3 | 20.2 |

| Survey night | Date | Time | Minimum Temperature (°C) | Precipitation (mm) | Surface wind speed (km/hr) | Maximum wind gust (km/hr) |
|---|---|---|---|---|---|---|
| | | 1:00 | 17.6 | 0 | 5.8 | 15.5 |
| | | 2:00 | 15.5 | 0 | 5 | 9.4 |
| | | 3:00 | 15 | 0 | 3.6 | 10.4 |
| | | 4:00 | 14.2 | 0 | 2.9 | 7.9 |
| | | 5:00 | 13.6 | 0 | 4.3 | 15.1 |
| | | 6:00 | 13.5 | 0 | 3.2 | 8.6 |
| | | 7:00 | 14.6 | 0 | 4.3 | 10.1 |
| Night 5 | 26.01.2021 | 20:00 | 19.6 | 0 | 11.5 | 26.6 |
| | | 21:00 | 18.7 | 0 | 8.6 | 16.2 |
| | | 22:00 | 17.7 | 0 | 5.8 | 12.6 |
| | | 23:00 | 16.5 | 0 | 4 | 8.6 |
| | 27.01.2021 | 0:00 | 15.8 | 0 | 2.9 | 6.8 |
| | | 1:00 | 14.9 | 0 | 2.2 | 4 |
| | | 2:00 | 14.4 | 0 | 1.8 | 4.7 |
| | | 3:00 | 14 | 0 | 2.2 | 5 |
| | | 4:00 | 13.5 | 0 | 1.4 | 3.6 |
| | | 5:00 | 13.2 | 0 | 0.7 | 2.5 |
| | | 6:00 | 13.1 | 0 | 1.4 | 4.7 |
| | | 7:00 | 13.8 | 0 | 3.6 | 10.4 |
| Night 6 | 27.01.2021 | 20:00 | 19.2 | 0 | 12.2 | 27 |
| | | 21:00 | 18.2 | 0 | 7.9 | 15.1 |
| | | 22:00 | 17.3 | 0 | 6.5 | 10.4 |
| | | 23:00 | 16.5 | 0 | 6.1 | 10.4 |
| | 28.01.2021 | 0:00 | 15.9 | 0 | 4.3 | 8.6 |
| | | 1:00 | 15.1 | 0 | 4.7 | 7.9 |
| | | 2:00 | 14.4 | 0 | 3.6 | 10.4 |
| | | 3:00 | 14.6 | 0 | 4 | 10.1 |
| | | 4:00 | 15.3 | 0 | 2.2 | 5.8 |
| | | 5:00 | 15.7 | 0 | 2.5 | 6.5 |
| | | 6:00 | 16.3 | 0 | 2.5 | 5 |
| | | 7:00 | 16.6 | 0 | 2.5 | 6.1 |
| Night 7 | 28.01.2021 | 20:00 | 17 | 0 | 23 | 43.2 |
| | | 21:00 | 16.6 | 0 | 18 | 40.7 |
| | | 22:00 | 15.7 | 0 | 18.4 | 31.7 |
| | | 23:00 | 14.8 | 0 | 13.7 | 28.1 |
| | 29.01.2021 | 0:00 | 14.1 | 0 | 11.9 | 22.3 |
| | | 1:00 | 13.1 | 0 | 9 | 18.4 |
| | | 2:00 | 12.2 | 0 | 6.1 | 18.4 |
| | | 3:00 | 10.2 | 0 | 3.6 | 9.4 |
| | | 4:00 | 9.6 | 0 | 3.2 | 5.8 |
| | | 5:00 | 8.3 | 0 | 2.5 | 8.3 |
| | | 6:00 | 8.3 | 0 | 4.3 | 8.6 |
| | | 7:00 | 9.1 | 0 | 4 | 8.6 |
| Night 8 | 29.01.2021 | 20:00 | 18.1 | 0 | 11.2 | 23 |
| | | 21:00 | 17.3 | 0 | 10.4 | 22.3 |

| Survey night | Date | Time | Minimum Temperature (°C) | Precipitation (mm) | Surface wind speed (km/hr) | Maximum wind gust (km/hr) |
|---|---|---|---|---|---|---|
| | | 22:00 | 17.3 | 0 | 7.9 | 18 |
| | | 23:00 | 15.8 | 0 | 9.7 | 26.6 |
| | 30.01.2021 | 0:00 | 14.9 | 0 | 9.4 | 22.7 |
| | | 1:00 | 14.6 | 0 | 6.5 | 22.3 |
| | | 2:00 | 13.6 | 0 | 6.8 | 15.8 |
| | | 3:00 | 12.8 | 0 | 8.3 | 21.6 |
| | | 4:00 | 12.6 | 0 | 6.1 | 16.6 |
| | | 5:00 | 11.4 | 0 | 3.2 | 9.4 |
| | | 6:00 | 10.7 | 0 | 2.2 | 6.1 |
| | | 7:00 | 10.5 | 0 | 3.6 | 10.1 |
| **Night 9** | 30.01.2021 | 20:00 | 17.2 | 0 | 6.8 | 15.8 |
| | | 21:00 | 15.5 | 0 | 5 | 10.1 |
| | | 22:00 | 13.7 | 0 | 3.2 | 5.8 |
| | | 23:00 | 12.2 | 0 | 2.5 | 6.5 |
| | 31.01.2021 | 0:00 | 12.1 | 0 | 2.9 | 10.1 |
| | | 1:00 | 12.9 | 0 | 3.6 | 11.9 |
| | | 2:00 | 11.5 | 0 | 2.9 | 8.3 |
| | | 3:00 | 11.5 | 0 | 5.8 | 17.3 |
| | | 4:00 | 11.4 | 0 | 4.7 | 13.3 |
| | | 5:00 | 10.5 | 0 | 4 | 8.6 |
| | | 6:00 | 9.9 | 0 | 5.4 | 10.4 |
| | | 7:00 | 10 | 0 | 4.7 | 10.8 |
| **Night 10** | 31.01.2021 | 20:00 | 18.3 | 0 | 13.7 | 27 |
| | | 21:00 | 17.1 | 0 | 7.2 | 16.6 |
| | | 22:00 | 14.7 | 0 | 3.2 | 9.4 |
| | | 23:00 | 13 | 0 | 2.5 | 6.5 |
| | 01.02.2021 | 0:00 | 12.5 | 0 | 1.4 | 5 |
| | | 1:00 | 11.5 | 0 | 2.2 | 8.3 |
| | | 2:00 | 10.6 | 0 | 2.2 | 4.3 |
| | | 3:00 | 10.3 | 0 | 0.4 | 2.2 |
| | | 4:00 | 9.8 | 0 | 1.4 | 4.3 |
| | | 5:00 | 9 | 0 | 2.2 | 5.8 |
| | | 6:00 | 9 | 0 | 1.1 | 3.6 |
| | | 7:00 | 9.3 | 0 | 2.2 | 4.3 |
| **Night 11** | 01.02.2021 | 20:00 | 19.8 | 0 | 9.4 | 20.9 |
| | | 21:00 | 17.4 | 0 | 5 | 10.4 |
| | | 22:00 | 15.9 | 0 | 4.7 | 10.8 |
| | | 23:00 | 14.5 | 0 | 5.8 | 11.2 |
| | 02.02.2021 | 0:00 | 14 | 0 | 4.3 | 10.8 |
| | | 1:00 | 13.4 | 0 | 2.5 | 6.5 |
| | | 2:00 | 13.8 | 0 | 5 | 9 |
| | | 3:00 | 13.9 | 0 | 5.8 | 11.2 |
| | | 4:00 | 13.5 | 0 | 4.3 | 7.2 |
| | | 5:00 | 13.4 | 0 | 2.9 | 7.6 |
| | | 6:00 | 12.5 | 0 | 2.2 | 6.5 |

| Survey night | Date | Time | Minimum Temperature (°C) | Precipitation (mm) | Surface wind speed (km/hr) | Maximum wind gust (km/hr) |
|---|---|---|---|---|---|---|
| | | 7:00 | 12.6 | 0 | 0.7 | 2.2 |

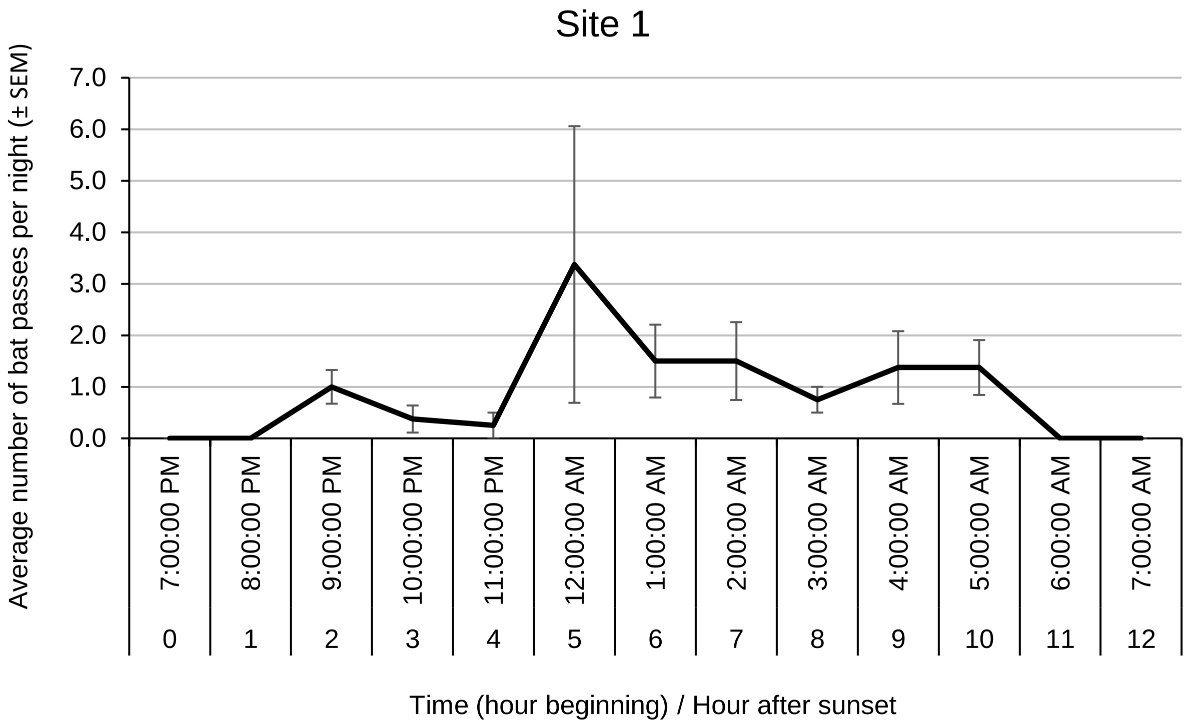
# Appendix 3 – January 2021 Road Lighting and Traffic Bat Survey Summary

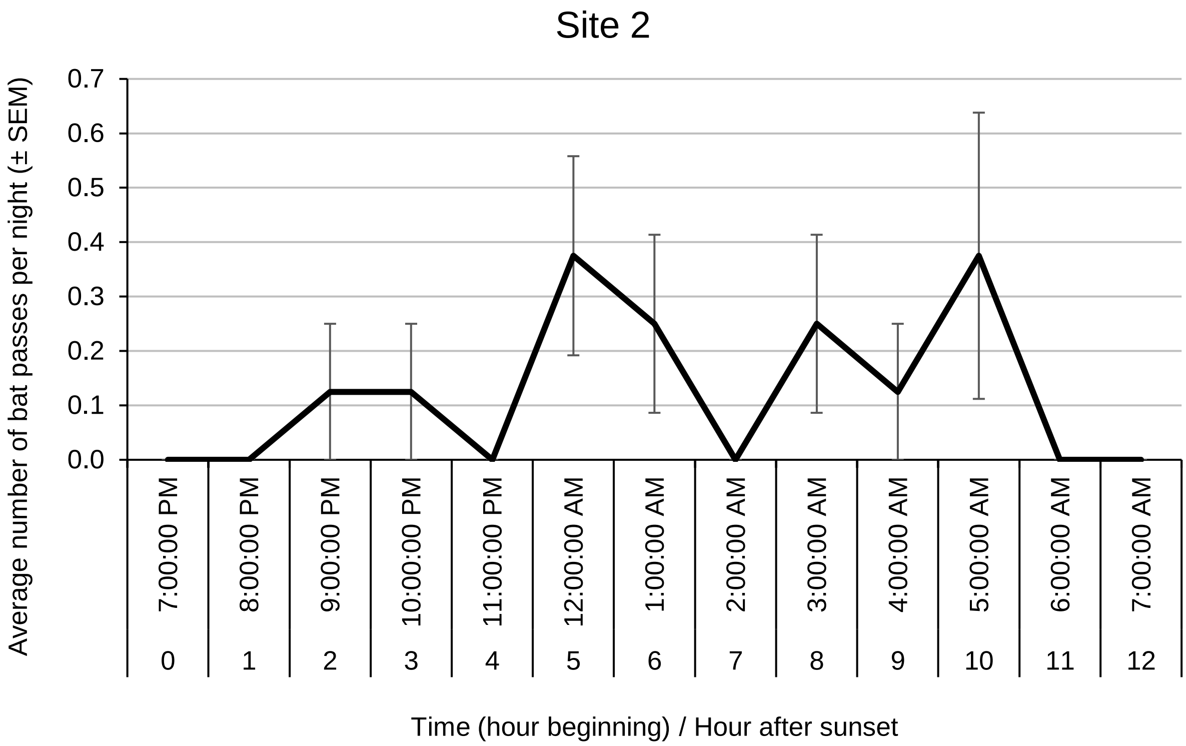
*Table 2. January 2021 road lighting and traffic bat survey information and results summary.*

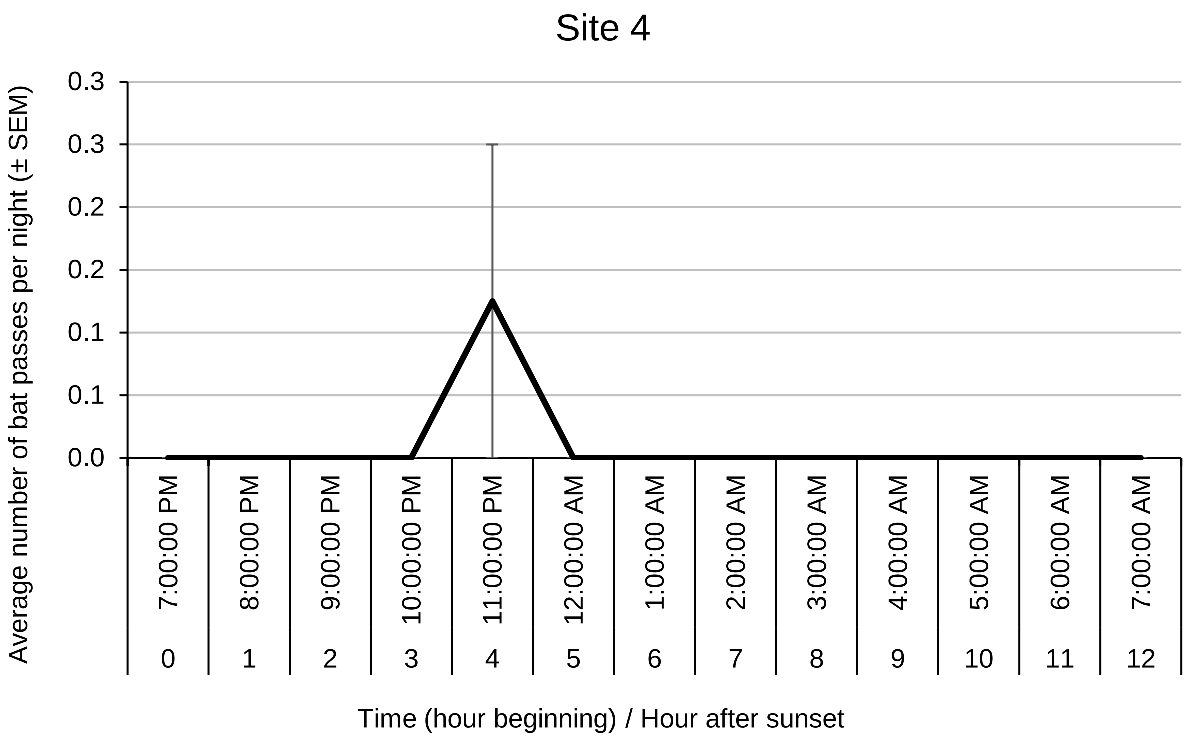
| Survey Location | ABM ID | Date ABM set | Nights deployed | Nights analysed | Total No. of Bat Passes | Mean No. of Bat Passes per Night (± SEM) | % of Nights with Bat Passes | Total No. of Feeding Buzzes | % of Bat Passes that were Feeding Buzzes | No. passes within 1 hour of sunset | No. passes within 1 hour of sunrise | % passes within 1 hour of sunset | % passes within 1 hour of sunrise | Activity within 1 hour of sunset AND sunrise (Yes/No) | Sunrise activity followed by sunset activity the next evening (Yes/No) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site 1** | Ham_AR_5 | 22.01.2021 | 11 | 8 | 92 | 11.5 ± 2.9 | 100.0 | 0 | 0.0 | 8 | 4 | 8.7 | 4.3 | Yes | No[6] |
| **Site 2** | Ham_AR_11 | | | | 13 | 1.6 ± 0.5 | 87.5 | 0 | 0.0 | 1 | 2 | 7.7 | 15.4 | Yes | No[6] |
| **Site 3** | Ham_AR_13 | | | | 0 | 0.0 ± 0.0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0.0 | No | No |
| **Site 4** | Ham_AR_17 | | | | 1 | 0.1 ± 0.1 | 12.5 | 0 | 0.0 | 0 | 0 | 0.0 | 0.0 | No | No |
| **Site 5** | Ham_AR_10 | | | | 110 | 13.8 ± 2.7 | 100.0 | 1 | 0.9 | 1 | 11 | 0.9 | 10.0 | Yes | No |

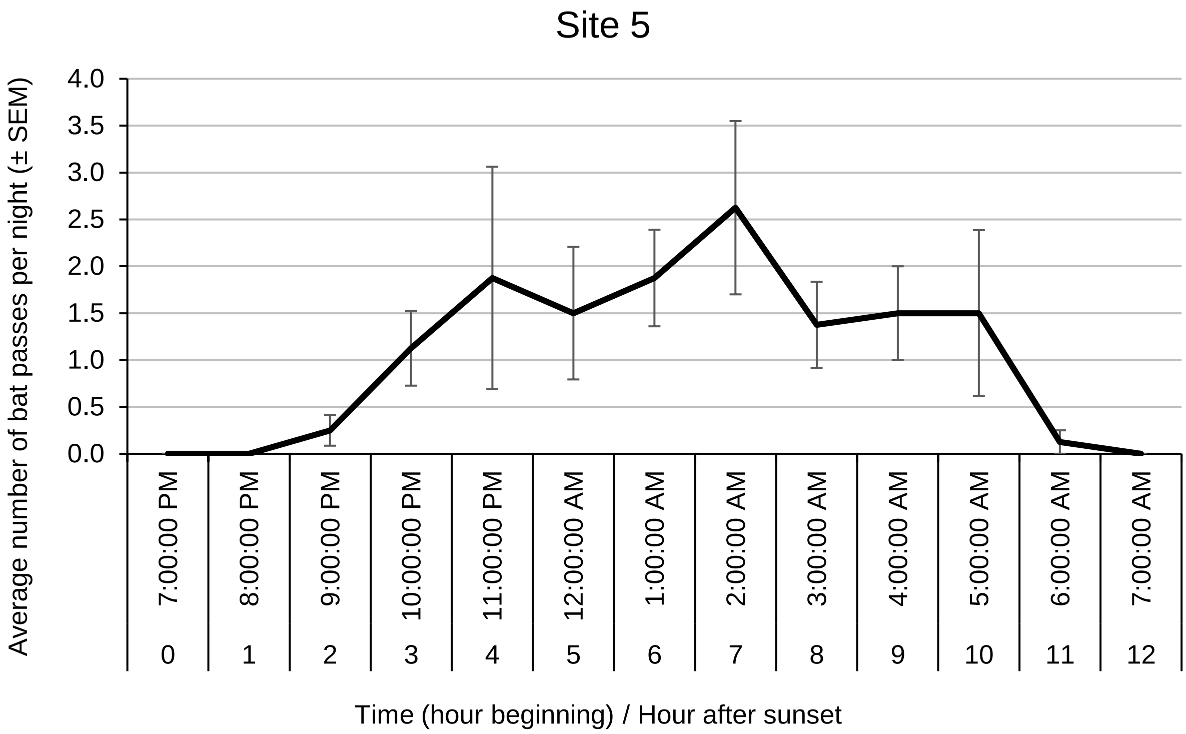
[6] Three nights excluded from analysis due to full moon.

## Appendix 4 – Mean bat activity throughout the night




Site 4
Average number of bat passes per night (± SEM)
0.3
0.3
0.2
0.2
0.1
0.1
0.0
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM
12:00:00 AM
1:00:00 AM
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (hour beginning) / Hour after sunset


Site 5
Average number of bat passes per night (± SEM)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM
12:00:00 AM
1:00:00 AM
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (hour beginning) / Hour after sunset

### 7.2 Appendix 2

Yellow dot shows approximate location where ABMs were deployed along the roadside in the BML Hamilton study. The site number is in the top left corner of each Google Street View image. Location maps are given in Appendix 1.


Site 2
Google Earth
1.88 m


Site 3
Google Earth
1.87 m


Site 4
Northbound
Google Earth
© 2021 Google
1.28 m


Site 4
Southbound
Google Earth
© 2021 Google
1.77 m


Site 5
Google Earth
1.84 m

## 7.3 Appendix 3


Figure A3a: Acoustic monitoring and light modelling sites taken from the Waka Kotahi New Zealand Transport Agency 2020 monitoring report for the Hamilton Section of the Waikato Expressway.


Figure A3b


Figure A3c


Figure A3d

Figure A3b-d: Acoustic monitoring and light modelling sites taken from the Waka Kotahi New Zealand Transport Agency 2020 monitoring report for the Cambridge Section of the Waikato Expressway. A2b - Oaklea Lane, A2c - Lloyd Propery, A2d - Karapiro Bridge.

## 7.4 Appendix 4

## 7.5 Appendix 5