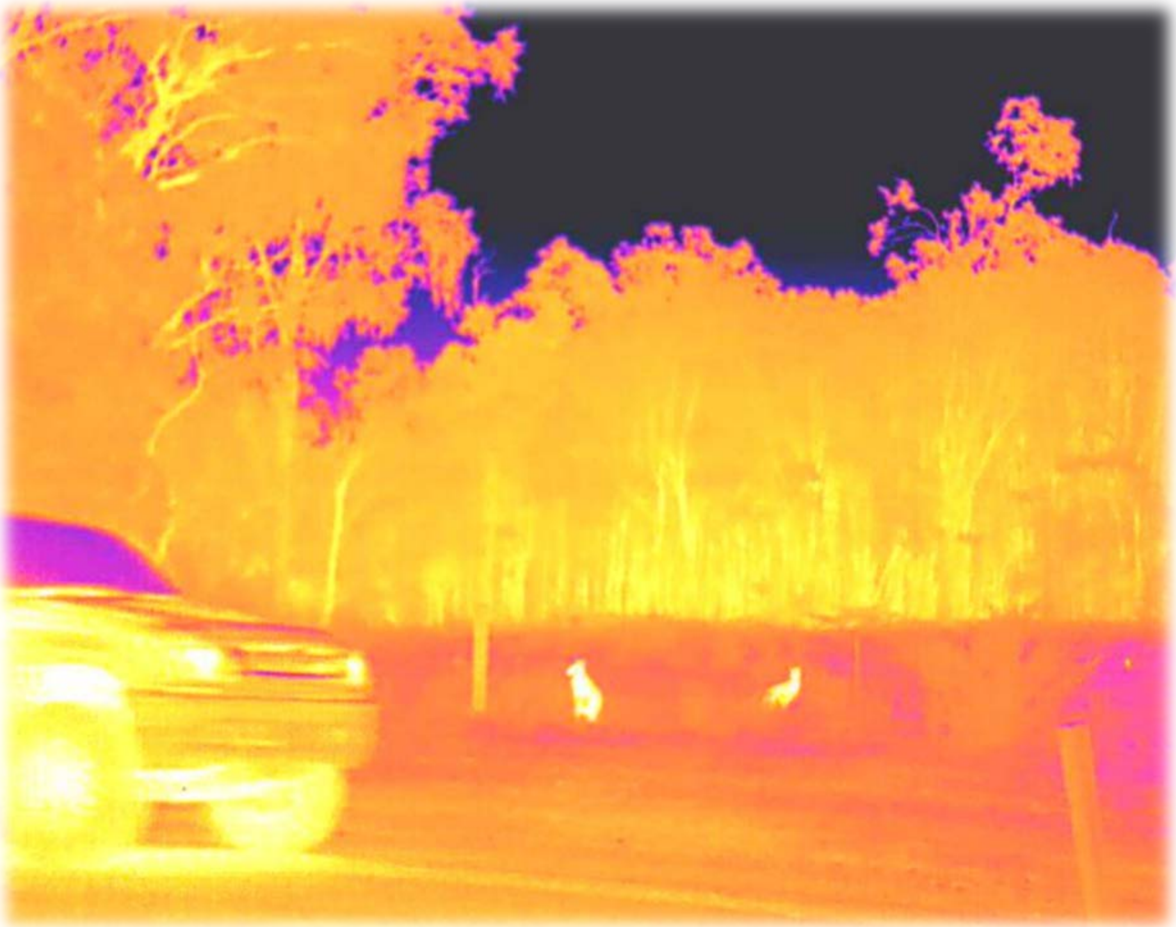
An Experimental Trial of 'Virtual Fence' Devices in an Effort to Reduce Vehicle Collisions with Wallabies on Heinemann Road, Mount Cotton.

Final Report, February 2020



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Cover photo shows a thermal image of two wallabies near the edge of Heinemann Road as a vehicle passes.

Executive Summary

Wallabies are commonly struck on Heinemann Road, Mount Cotton, and in an effort to reduce strikes, the Redland City Council initiated a two-year trial of a new system meant to discourage wallabies from crossing the road when vehicles approached at night. The system, known as a 'virtual fence' (VF), had been previously trialled in Tasmania, with seemingly promising results. However, a more recent study found devices were not as effective, and other researchers were critical of both the initial study's experimental design and conclusions. Exactly how VF devices are meant to work is also ambiguous, as they potentially operate as a conditioned secondary stimulus, warning animals that a vehicle is approaching (VF devices activate when car lights are detected), but they may also elicit escape responses because the warning stimuli themselves are in some way aversive. Demonstrably successful mitigation approaches such as fauna-specific crossing structures or wildlife barrier fencing, are often prohibitively expensive. There is therefore, a considerable need for viable alternative approaches that can cost-effectively be applied at the often enormous scales at which road strike occurs. This made exploration of the potential of VF devices worthwhile. Discouragingly, wallaby strikes did not appear to be reduced in two treatment years following the installation of VF devices, with 41 strikes in year 1, and 45 strikes in year 2, compared to 39 strikes in the pre-treatment year. Neither mean nor median monthly strikes appeared lower in treatment years versus the pre-treatment year. There appeared to be some seasonality to strike events, revealed by a moving average plot, and spatially, strikes appeared slightly more common in the northern half of the road, compared to the southern half, although strikes occurred along the entire road. A pilot investigation of wallaby behaviour near the road using thermal imaging revealed little to indicate any effect of active VF devices. A small number road crossings were observed, and included cases when VF devices were both inactive and active, suggesting, at least anecdotally, active devices failed to stop crossings. On one occasion, observers had to actively intervene (by beeping a car horn and flashing headlights) in stopping wallabies when it looked like they were about to cross the road into oncoming traffic, despite the VF devices being active. Opportunistic observations of wallaby responses to humans approaching on foot along the road (Redland City Council staff checking VF device operation) revealed a more obvious escape response and could serve as the basis for assessing responses to proposed deterrents. There were limitations in the experiment such as an inability to apply a more appropriate experimental design (e.g. before-after-control-impact and or crossover design). However, given results from both strike and observational data, we concluded that VF devices, in their current format at least, are not suitable in reducing wallaby strikes on Heinemann Road, and we recommended small-scale electric fencing, and/or, better street lighting could potentially be trialled, subject of course to the appropriate experimental design and ethical approvals.

Introduction

Wild animals being struck and killed by vehicles on roads, often called 'road kill', is a pervasive and ubiquitous problem throughout much of the world (van der Ree *et al.* 2015). It is clear that roads represent a major source of artificial mortality for many species, and in much of Australia, particularly for macropods (Klöcker et al. 2006). For instance, Matthews (2019) recently reported on six annual road kill surveys along a 390km segment of two major highways in south-east Queensland. Of the 612 vertebrate deaths recorded, the highest proportional representation of discernible species was for wallabies, at around 27.5%, with kangaroos a close second at 21.6% (derived from Table 1). Similarly, Brunton *et al.* (2018) found vehicle strike was the major source of decline in local populations of eastern grey kangaroo in the region, with 73% of all deaths arising from vehicle strike.

Wildlife strike mitigation usually involves major infrastructure investment, such as the installation of fauna crossing facilities (e.g. wildlife bridges, culverts and underpasses) and/or barrier fencing along problematic roads. Although often successful, such measures can be expensive and logistically challenging to implement at scale, reducing their utility. Alternative mitigation usually consists of measures that allow permeability in terms of animal crossings over the road directly, but, for instance, aim to modify driver behaviour and in turn, reduce strikes. An example is wildlife signage, which although applied at almost universal scales, tends to be widely considered as ineffective, although new approaches to signage remain a potentially fruitful endeavour in at least some cases (Bond and Jones, 2013).

Another approach is to attempt to dissuade animals from roads either altogether, or at specific time. Methods include making verges less palatable (e.g. making sure wildlife aren't attracted to vegetation growing near or alongside roads), or using auditory and visual stimuli meant to alert or frighten animals (D'Angelo and van der Ree, 2015). Results involving the latter are often mixed or disappointing, with, for example, Benten *et al.* (2018) extensively reviewing studies involving so-called wildlife warning reflectors and finding little clear evidence of effectiveness. Another product on the market in a similar vein is the so-called 'virtual fence' (VF) device, described by Fox *et al.* (2018) as: "…an active electronic protection system that is activated by approaching vehicle headlights, which causes it to emit sound and light stimuli that alert animals that a vehicle is approaching." (p. B). Initial results suggested that VF devices represented a promising approach to minimising wildlife vehicle strike. Fox *et al.* (2018) carried out a three-year study of VF devices along a 3.2km section of a road in Tasmania, Australia. They reported that following installation of the devices, overall rates of road kill were significantly reduced compared to sites either concurrently or historically monitored without devices. For example, they found that Bennet's wallabies experienced a significantly reduced rate of strike in road sections where the devices were deployed (a rate of 0.25 wallabies struck per km), compared to road sections without devices (0.35 wallabies struck per km). Results were ever more marked for pademelons. A more recent comprehensive crossover and before-after-control-impact design employed by Engelfield *et al.* (2019) however, failed to show the same high level of reductions in strikes as reported by Fox *et al.* (2018), although there were consistent but non-significant reductions at most sites when VF devices were active.

Soon after the release of the study by Fox et al. (2019), Coulson and Bender (2019) responded critically in regard to the study design employed by Fox *et al.* (2018) as well as in relation to aspects of the purported efficacy of the VF devices themselves. One concern stemmed from a lack of available, peer-reviewed published reports about the VF devices, despite Fox *et al.* (2018) reporting their apparent availability and use across Europe since 2003. Coulson and Bender (2019) extensively commented on what they saw as some of the potential shortcomings of the device stimuli, such as the apparent incompatibility of some animals' visual and auditory systems to certain characteristics of the stimuli, and the very realistic prospect of habituation. Fox and Potts (2019) subsequently replied, rebutting some of the conclusions Coulson and Bender (2019) had reached, particularly in relation to the appropriateness of their analyses and subsequent interpretations, which they concluded remained valid. Engelfield *et al.* (2019) instituted an experimental design that overcame some of the limitations identified by Coulson and Bender (2019) albeit that again, such concerns were refuted by Fox and Potts (2019).

There is some ambiguity in relation to exactly what the VF devices are meant to do in attempting to reduce vehicle strike (Engelfield *et al.* 2019), and there is a good deal of complexity in trying to understand, and therefore manipulate, animal behaviour and learned or conditioned responses under such circumstances. For instance, the VF device supplier, Wildlife Safety Solutions, suggest on their Website (https://www.wildlifesafetysolutions.com.au/) that the devices acts as a 'warning' to animals, but also that they 'repel' animals from the roadside. Here, we expand on important aspects of learning theory and behaviour that inform on the potential efficacy of such devices/stimuli in a similar vein to St. Clair *et al.* (2019) did in relation a similar alerting system they designed to help reduce train collisions involving bears.

The aims of the VF devices as both a warning and a repellent potentially infer different learning pathways in animals. For instance, the notion of a 'warning' suggests that animals will learn to associate something inherently dangerous (in this case, presumably vehicles) with stimuli that themselves aren't initially dangerous or noxious (i.e. they are inherently benign, in this case, the flashing lights and sounds of the VF devices), such that these formerly benign stimuli come to produce the same escape or avoidance responses as the truly noxious stimuli. This is the foundation of classical conditioning. However, it relies not just on animals learning the association, but on recognising vehicles as a threat or danger in the first place, in a similar vein to their presumed recognition of a predator being an inherent threat in most circumstances.

Lima *et al.* (2015) conducted an extensive review of how and why animals do and do not respond to approaching vehicles and their results are informative. They suggested that three stages are involved: "vehicle detection, threat assessment, and evasive behaviour; [and that] failures can occur at any of these stages" (p. 60). Further, they added that animals may be overwhelmed by high vehicle speeds, probably do not perceive vehicles as a threat in many cases, and may generally habituate to passing vehicles. Some animals do exhibit some flight response immediately before being struck, however, often it is too late to avoid being hit. Reactions such as freezing (or what Lima *et al.* 2015 call "immobility" (p. 60)), which may in fact be an appropriate anti-predator strategy in many circumstances, clearly becomes very problematic in terms of vehicle strikes (Engelfield *et al.* 2019). Drivers too appear to generally lack an ability to avoid collisions at high speed, or in low visibility situations. Lima *et al.* (2015) acknowledge that a great deal more behavioural work is required in relation to better-understanding and therefore mitigating vehicle strikes.

More specifically, Blacker (2014) carried out observations of wallaby behaviour on road verges in relation to passing vehicles, as well as when crossing roads. One of her study roads was Heinemann Road, the same road as the current study (see Methods). Very few wallabies were reported to have taken flight in response to a vehicle passing by at the beginning of an observation, although fleeing was relatively common at some later point during an observation. Wallabies were also commonly alert as vehicles approached and passed, but some also continued to forage or exhibit other behaviours (e.g. grooming), and sex-level differences in such behaviour were observed (e.g. males appeared more alert). Thus, although vigilance behaviour and fleeing were often observed during observations, escape or avoidance responses were not clearly and consistently associated with any and all vehicles passing by, suggesting some degree of discrimination or habituation in responses. Wallabies most consistently fled when large vehicles (i.e. trucks) passed by, suggesting a potential threshold of vehicle size and/or associated stimuli triggering a flight response. In most cases, wallabies fled away from vehicles, but in a small number of cases, onto the road. On Heinemann

Road specifically, wallabies appeared to initiate a road crossing event further away from the edge of the road, and Blacker (2014) suspected this, in combination with the relatively large number of heavy vehicles, relatively high traffic volume and high speed the road featured was leading to the higher rate of strikes observed for that road. All observations were carried out during the day so it is unclear if differences in behaviour might occur at night.

Fox *et al.* (2018) suggested that due to there still being some strikes observed in sections of roads with active devices during their study, VF devices were more likely acting as a warning or alert to animals, rather than frightening them from roadways per se. But if vehicles do not consistently represent an unconditioned aversive stimulus, or if responses to some or most vehicle-related stimuli are subject to discrimination and/or habituation (Coulson and Bender, 2019), intended warning stimuli may not actually be warning animals about anything in particular most of the time. This differs from the situation explored by St. Clair *et al.* (2019) because they could more readily assume train-related stimuli were consistently aversive or threatening to bears. In contrast, a vehicle passing by an animal on a verge of a road is not, in and of itself, necessarily a threat and learning this might actually be rewarding, for example, because animals can access resources on verges (Engelfield *et al.* 2019). When an animal is already on, or rapidly about to cross a road, the very real threat of any oncoming vehicle may either not be clear until it is too late to respond, or is so overwhelming that it evokes a maladaptive response (e.g. freezing).

The notion of VF devices acting as a potential repellent is presumably meant to infer that the light and sound stimuli produced by the VF devices are themselves noxious or aversive in some way (i.e. they are not initially benign, as might be supposed if they were a 'warning'). There is no suggestion from the supplier that VF devices are or are meant to be explicitly aversive however (for example, they state on the website that the audio and visual stimuli are 'non-invasive').We mentioned above that Fox et al. (2018) also considered devices to act as a warning rather than a frightening device per se. Further, Engelfield *et al.* (2019) measured the noise level of VF devices and concluded that sound from the device had a lower decibel level than background sounds from frogs and cicadas, making it highly unlikely that they are loud enough to be aversive or painful (Bomford and O'Brien, 2000).

Thus, if the stimuli are to be considered as noxious in some way, it is more likely that the intention would be to evoke something akin to a startle response. Related to this is idea of surprise, whereby a response is somewhat context-specific and in particular, is the result of a lack of warning or predictability about when/where exposure to stimuli will occur, even if there is some expectation of exposure in the first place. Alternatively, responses to VF stimuli as if they are noxious might be simply due to neophobia (Coulson and Bender, 2019). In both cases, habituation to such stimuli is very likely precisely because they are not overly aversive or otherwise biologically relevant (Conover, 2001; Appleby *et al.* 2017; Coulson and Bender, 2019; Engelfield *et al.* 2019).

A problem therefore is that if vehicles are not consistently understood as a threat, or vehicle-related stimuli are not consistently aversive, and neither are the VF device stimuli, then appropriate escape and avoidance learning will also fail to consistently develop. Thus, it is unclear exactly how VF devices might unambiguously operate to 'warn' or alternatively, 'repel' animals. And yet, the study by Fox *et al.* (2018) in particular suggested some potential in this regard, as did the study by Engelfield *et al.* (2019), albeit to a lesser degree, making additional explorations of the approach compelling.

Here, we provide the results of an experimental trial of VF devices in an attempt to mitigate wallaby vehicle strike along a road exhibiting a relatively high rate of strike events in the Redlands, Queensland. We used two main approaches in our assessment. The first was a comparison of annual strike events in a pre-trial period and a trial period. Additionally, we undertook preliminary observations of wallaby behaviour and responses in relation to active and inactive VF devices along the road, using thermal imaging equipment, a method Coulson and Bender (2019) recommended in their critique.

Previous Reports/Briefs

Two previous reports/briefs have been submitted in relation to this project. The first was an internal, general summary of results after a 6-month period of VF device operation (Watson, 2018). It highlighted the possibility of a seasonally-adjusted decrease in strike events, possibly attributable to VF devices, in the order of about a 30% reduction in strike events. However, the summary also noted a similar degree of reduction in two seasonally equivalent periods in which the VF devices had not been installed, suggesting that there was considerable variation possible in strike events regardless of the presence/absence of the VF devices.

A second report (Essex, 2018) was submitted after 12 months of treatment data had been collected, and it noted a reduction of only one wallaby being struck in first treatment year compared to the pre-treatment year. This report also took an in-depth look at a smaller wallaby strike dataset from Redlands Afterhours Wildlife Ambulance (RAWA) that included much greater details about strikes, including time classes of events, concluding that there did appear to be more strikes in the treatment year during the day compared to the pre-treatment year and correspondingly fewer at night. Given that VF devices only operate at night, this suggested the possibility that active VF devices had elicited avoidance in some wallabies when they were active, and maybe shifting road crossing attempts during the day, resulting in a greater number of strikes then. However, the numbers of records with this level of detail were minimal. Given the variation observed in the first report during periods when the VF devices were not deployed, it is also plausible that such an apparent anomaly was simply due to unaccounted for or random variation in strike data. Overall, Essex (2018) concluded that there was no noticeable reduction in strike events observed between the pre-treatment and first treatment years.

Differences in the datasets used between the current and previous reports are assumed to be the results of collation error correction on the part of Redlands City Council (RCC) or choices of which variables to examine. Whilst this makes direct comparisons between reports problematic, these differences are relatively minor and are not expected to impact the overall assessment of the VF devices in the current report.

Methods

Study Area

The study site consisted of the majority of Heinemann Road, which is approximately 3.8km long and located in the RCC area of south-east Queensland. Land use adjoining the road consists of mixed small acreage residential homes, livestock grazing paddocks and occasional stands of eucalypts and other mixed vegetation (see Figure 1 for an example of paddocks mixed with other vegetation). Residential development in the area has expanded in recent years. Wallaby strike on the road has historically been relatively high for some time, with, for example, Blacker (2014) recording approximately 40 wallabies a year as being struck along the road from 2010-2012. Two species of wallaby are common to the area: red-necked wallabies (*Macropus rufogriseus*) and swamp wallabies (*Wallabia bicolor*). Traffic volumes are estimated to be, approximately, 1380 vehicles per day, on average (Essex, 2018) and the posted speed limit on the road is 80km/hr.

Figure 1. A section of Heinemann Road captured from Google Street View. This section is at the junction of Giles St and Heinemann Road (where most thermal observations of wallabies took place – see section below) and is facing south.

Treatment

160 'virtual fence' (VF) devices (model DD430-B-E, Wildlife Safety Solutions – see Figure 2) were installed along the road on July 27, 2017 (approximately 3.8km in total). Devices were calibrated in-situ following supplier instructions. The devices have two volumes for audible stimuli, one comparatively quieter and one louder. If devices were relatively close to a residential dwelling, they were set to the lower volume setting, otherwise the higher volume setting was used.

Figure 2. Virtual fence device in-situ on Heinemann Road showing device itself and a green, plastic installation post.

Devices were initially spaced at approximately 50m intervals (on average), and placed on both sides of the road, covering almost the entire road. However, due to infestations of ants within the housing of the VF devices (see Figure 3), 26 devices required demounting and repair in November 2018.

Figure 3. Ants infesting a VF device and subsequently requiring offsite repair/maintenance

This left 134 devices and created some gaps in the original spacing. In March 2019, following an initial assessment by RCC, the decision was made to reduce the distances between the remaining devices to approximately 25m (on average). In turn, the length of the road section covered by devices was reduced to approximately 1.675km (25 x 134/2). Devices were exclusively removed from the most southern end of the road.

The problem of ant infestation was largely prevented from reoccurring by lanolin grease being applied liberally all around the mounting post on remaining devices, such that ants were deterred from climbing the poles to get to the devices. At conclusion of the study, all devices were retrieved and all but four (which had ant infestations) could be turned on/off and 'reprogrammed' via the recessed switches, suggesting that they were all in operational condition. And once the ants were allowed to escape the infested devices, they too could be switched on/off and reprogrammed. All devices also appeared to exhibit a correct 'tamper' alarm when moved (i.e. in a real world scenario where an unauthorised person might try to remove a device from the roadside, an alarm activates).

Data Sources

Wallaby vehicle strike data were collected and collated by RCC. Data were compiled from reports from the public about dead wallabies on the road which were then collected by RCC's mainland maintenance team from Roads, Drainage and Maintenance Unit, throughout the study period. Twelve months of data prior to installation of the VF devices was used as a 'pre-treatment' period (i.e. back to July 2016), with two 'treatment' years comprising strike events in the first (i.e. to July 2018) and second (i.e. to July 2019) years following installation. Wallaby species were not differentiated in available data.

Behavioural Observations

Observations were undertaken by one or two observers from within the confines of a stationary vehicle parked at various locations along the road verge. Observations were conducted between the hours of 5:30-9:00PM on three nights in June and July 2019. In order to observe wallabies, a thermal imaging camera (FLIR Vue Pro 640R) was connected to a portable 12V LCD television screen. This allowed observers to view wallabies at safe and unobtrusive distances. The camera was hand-held by observers (i.e. not mounted onto a tripod or other stabiliser) as this was the easiest way to allow scans of the viewable area by both observers. The camera had an in-built record facility, and relevant observations were recorded for later reviewing.

Wallabies that were close to the road were essentially treated as focal animals, although occasional, brief scans of the rest of the viewable area were also undertaken. On occasions when one or more wallabies were in close proximity to the road in different observable locations, observation time was split between each set of animals, usually for a few minutes at a time.

An attempt was made to examine naïve wallaby responses to newly installed VF devices at a different location. Three nights of observations were attempted but as no wallaby closely approached the section of road the devices were installed upon, no relevant data could be collected and as such, this element is not referred to again.

Results

Strike Data

Table 1 shows raw counts of wallaby strikes in the pre-treatment year (i.e. no VF devices deployed), as well as the first and second treatment years (i.e. VF devices deployed), with no decrease in strike events observed in the treatment years.

Table 1. Pre-treatment and treatment year frequency of wallaby strikes on Heinemann Road

Year	Strikes
1 (Pre-treatment)	39
2 (Treatment)	41
3 (Treatment)	45

Figure 4 shows a boxplot of these three years of data, grouped into monthly average strike events (here the median, illustrated as the solid black horizontal line within each box), showing no change between the pre-treatment and the first treatment years, and only a slight decrease in the second treatment year. There is a high degree of overlap in the boxes across years suggesting little overall difference.

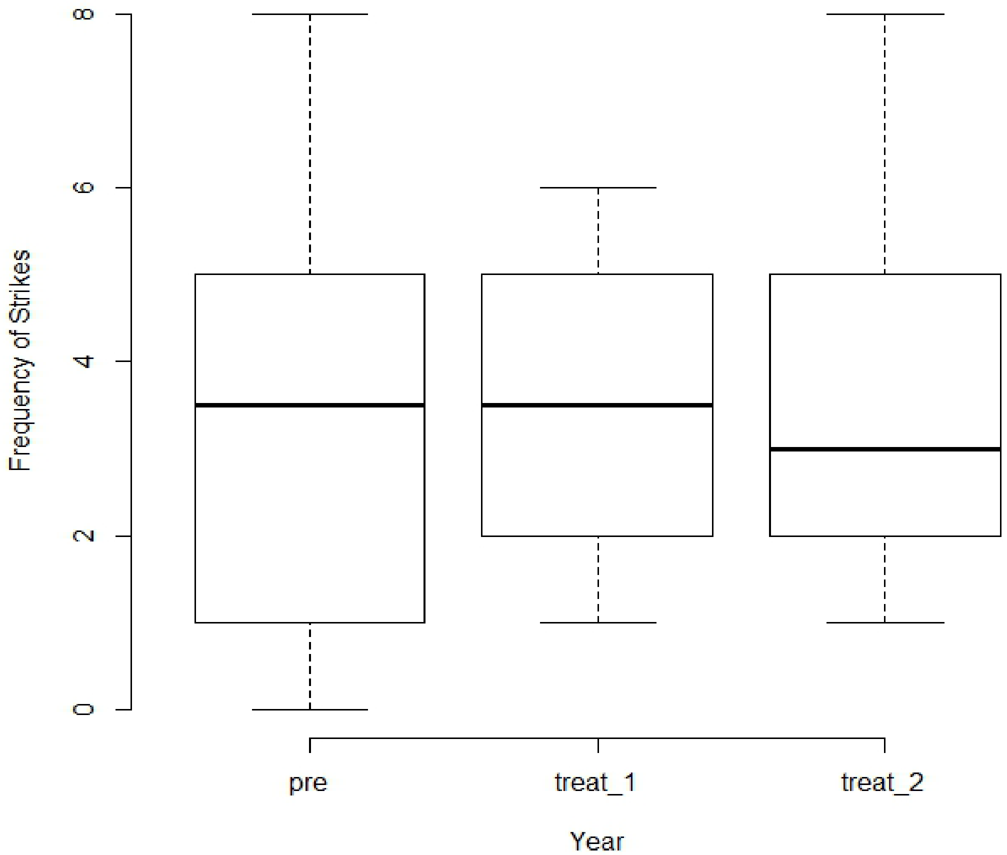

Figure 4. Boxplot of monthly strike events in pre-treatment ('pre') versus two treatment years ('treat_1'; 'treat_2').

Mean monthly strikes along with related statistics (e.g. variance) for pre-treatment and treatment years are given in Table 2.

Table 2. Mean, variance, standard deviation (SD), minimum and maximum monthly strikes grouped by year

	Year1 (Pre-treatment)	**Year2 (Treatment)**	**Year3 (Treatment)**
mean (monthly)	3.25	3.42	3.75
variance	6.39	3.17	6.02
SD	2.53	1.78	2.45
minimum	0	1	1
maximum	8	6	9

Here, neither mean in either of the treatment years is below the pre-treatment year. Variance however does appear to decrease in treatment years, particularly in the first treatment year.

Figure 5 shows line plots for monthly strike frequency in the pre-treatment and treatment years, highlighting that there was, apart from some hints of seasonality, relatively little consistency across years. Note, there were three months where the 'pre-treatment' strike frequency was higher than the corresponding month in one or both treatment years.

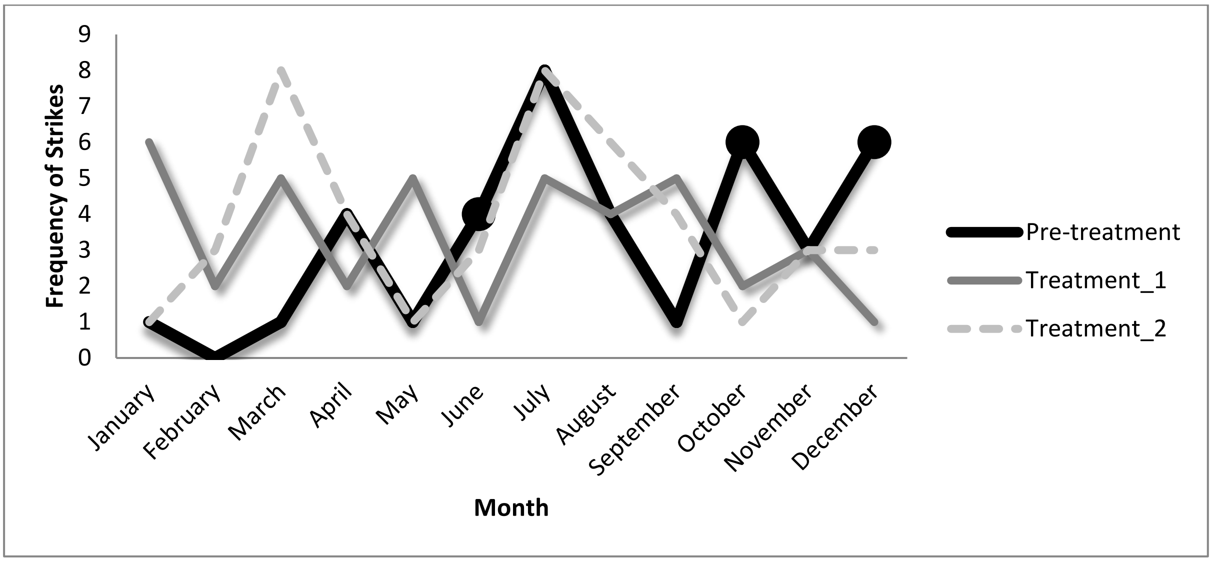

Figure 5. Line plots of frequency of wallaby strikes on Heinemann Road in pre-treatment (solid black line) and treatment years (solid grey and hashed grey respectively). Solid black circles show the three months where pre-treatment strike frequency was higher than corresponding treatment year months.

To examine any seasonality or trends, strike frequency data were collated into consecutive months (i.e. a time series) and raw data were overlayed with a moving average plot (Figure 6). As the moving average plot suggests, there is some degree of consistency in peaks (approximately 6-8 months apart) and troughs (approximately 4-7 months apart) in monthly strike events, suggesting the possibility of a seasonal component to strikes.

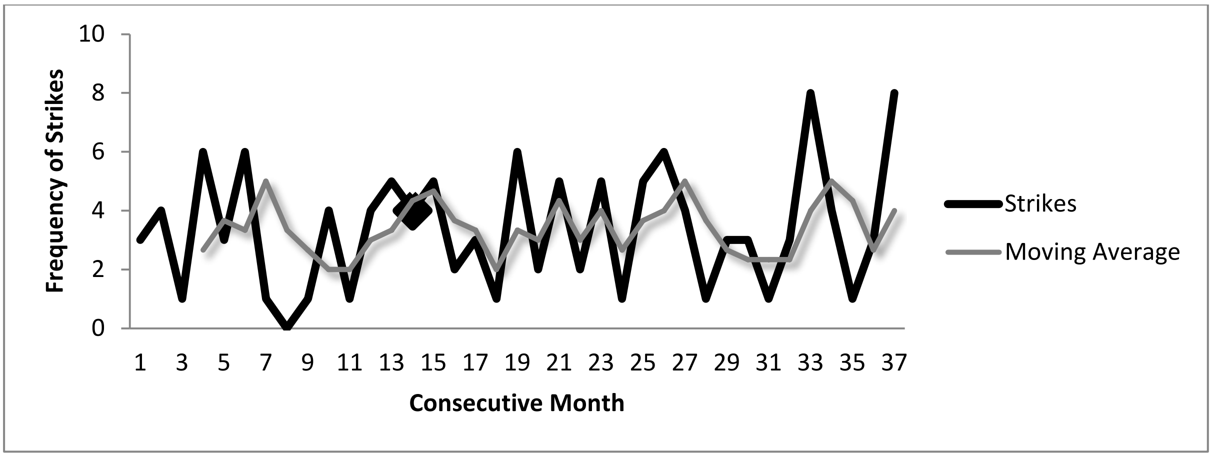

Figure 6. Time series of consecutive months of wallaby strike events on Heinemann Road with raw frequency data (solid black line) and a moving average plot (solid grey line) overlaid. Black, solid diamond (at Consecutive Month 14) indicates approximate installation date of VF devices.

Spatially, strike events appeared to occur across the majority of Heinemann Road, although some degree of clustering was observable, particularly at the level of 'block' (an set of seven divisions of the road divided into roughly equal portions derived from additional RAWA data – see Figures 7 and 8) when pooled across years. For instance, block 6 appears to have more overall strikes than any other block, although the majority of strikes occurred in the two treatment years, and block four had consistently high strikes in each year across the study period. Few strikes occurred in block 12.

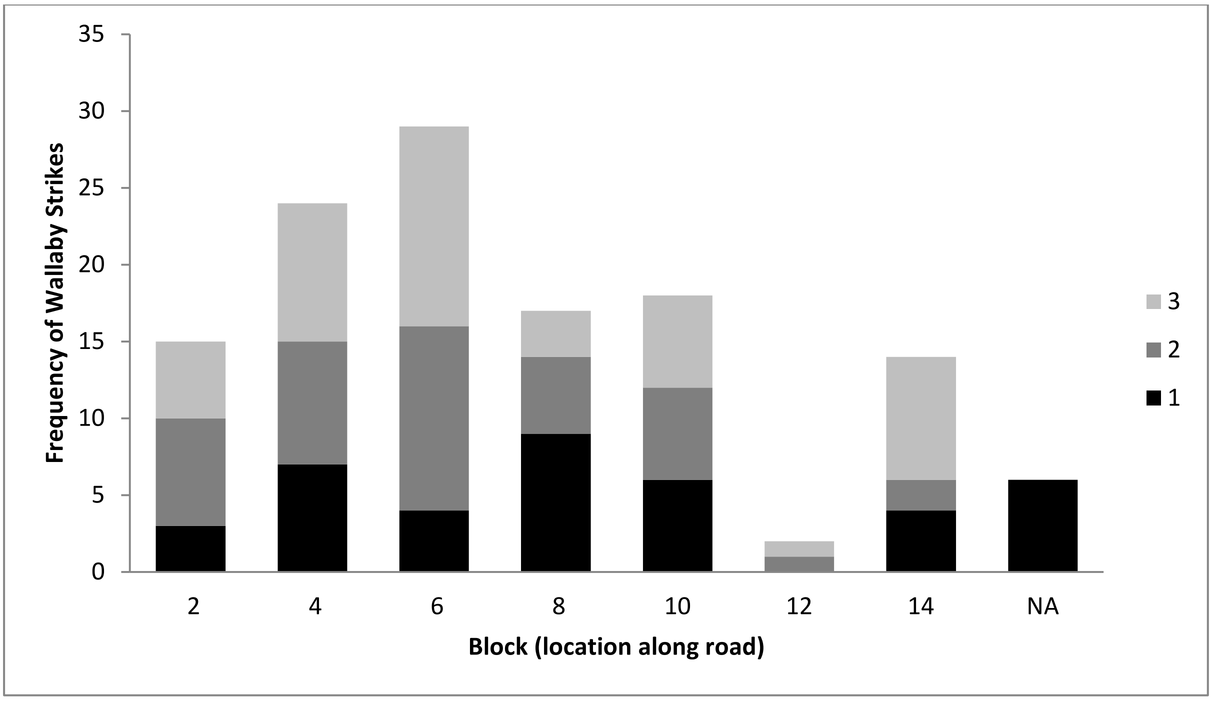

Figure 7. Strike events grouped into spatial 'blocks' or road sections along Heinemann Road in pre-treatment (1, black) and treatment (2, dark grey; 3, light grey) years

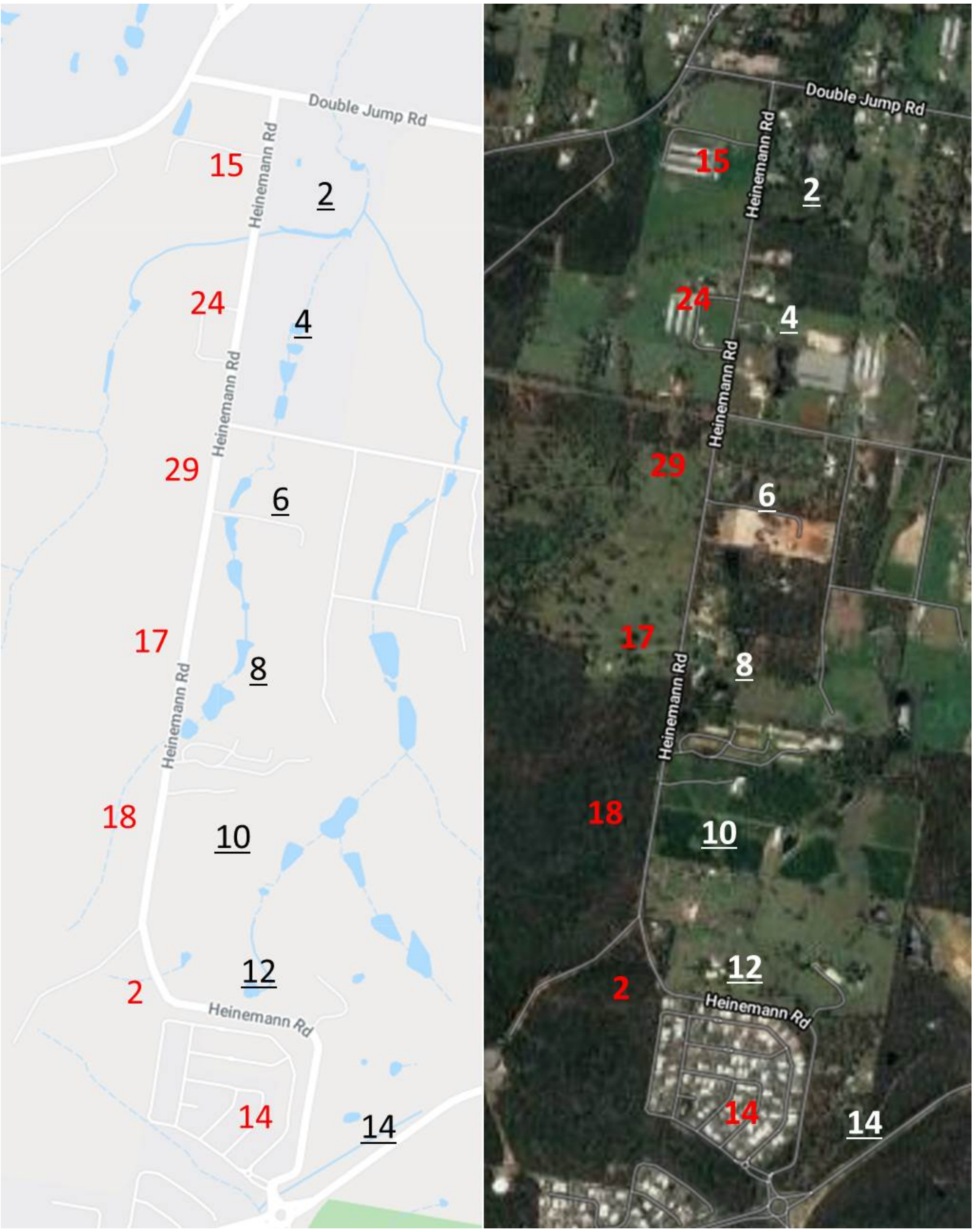

Figure 8. A basic Google map (left hand side) and satellite map (right hand side) of Heinemann Road showing the blocks (black and white numbers 2-14) and the number of wallaby strikes within each block (red). Source modified after Google Earth.

Finally, strike events were, where possible, mapped using available GPS coordinates, for the pre-treatment and first treatment years only, as no GPS data were available for the second treatment year (Figure 9). Again, strike events occurred along most of the road in both years, although some relatively small sections are devoid of strikes, particularly towards the southern end of the road. A note that the number of strike events that contained GPS data differed from the main dataset used for the bulk of analysis presented above, so maps (Figure 8) are provided for illustrative purposes only.

Figure 9. GPS plotted wallaby strike events for pre-treatment (LHS black points) and first treatment (RHS grey points) years on Heinemann Road. Source modified after Google Maps using GPS Visualizer.

One potential confounding element that Figure 9 adequately dispels is the so-called ‘fence end’ problem described by Coulson and Bender (2019), which suggests that in some circumstances where fences prevent road kill along the fenced section, animals move to fence ends and road kill rates become highly aggregated. Fewer strikes appear on the southern ‘curve’ in the road.

Thermal Camera Observations

Overt (highly obvious) movements were examined in approximately 37 observable wallabies (roughly estimated from counts in thermal images) to passing vehicles/activated VF devices (supplemental data file - https://www.wildspy.com.au/TEMP/Heinemann_Rd_Virtual_Fence_Monitoring_Data.xlsx). These observations equated to 37 independent events (those where passing vehicles were >19sec apart meaning VF devices were not continuously active) over an approximately 55min period in which only one obvious flight response was observed (see further below). Many of the observable wallabies were almost certainly too far away from the road/active VF devices to be reasonably considered as representative, but there were approximately 8-10 individuals that were considerably closer to the road (<~11m). However, even these wallabies appeared to show no overt escape/flight response across this brief observation period.

It is possible however, that even wallabies that were relatively close to active VF devices were not representative, for example, because they were still far enough from the road or passing vehicles to have learned not to react to active VF devices. Here, some additional observations are potentially instructive. Two observations of 'startle' or 'flight' responses by wallabies were observed when vehicles passed very close by them and when the VF devices were also activated (including the one case mentioned above as part of 37 consecutive observations across a 55min period – see videos: https://www.wildspy.com.au/TEMP/startle_vehicle_2.mp4 and https://www.wildspy.com.au/TEMP/startle_vehicle.mp4).

Importantly however, both examples occurred when vehicles had already (just) passed by wallabies, and not when the VF devices were first activated. Put another way, if these wallabies had been on the road at the time, they would have been able to be struck regardless of their eventual flight response, which appeared to be more related to the vehicles themselves, rather than VF devices per se.

We observed (or in one case, could reliably infer) three road crossing events by wallabies when VF devices were not active (see video: https://www.wildspy.com.au/TEMP/cross_eg_ULR.mp4 for an example). Although these may simply have been random events, it at least suggests the possibility that some wallabies might have learned only to cross the road when the VF devices are not active. It is worth noting that this would require quite a sophisticated degree of discrimination learning in wallabies, such that they have learned not to overtly respond to active VF devices unless they are intending to cross a road. To this end, we did have one additional observation of a wallaby crossing a road while VF devices were active and a vehicle was approaching (video: https://www.wildspy.com.au/TEMP/cross_while_VFactive_ULR.mp4). This serves, albeit as an anecdote, that at least this wallaby had not learned to specifically avoid crossing a road when VF devices were active. Figure 10 shows screenshot examples of a wallaby crossing when the VF devices are inactive (10A) and active (10B).

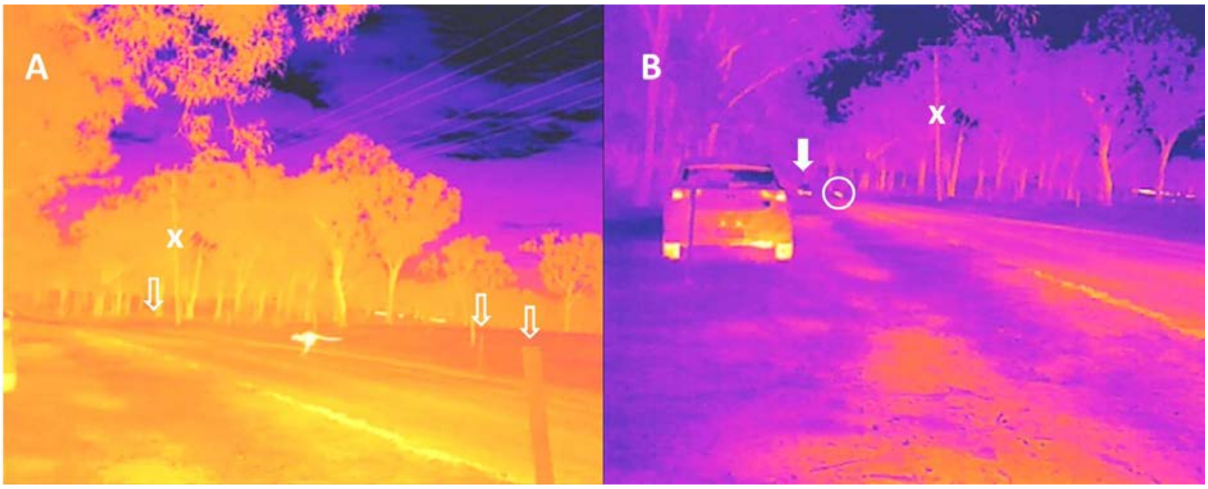

Figure 10. Screenshots of thermal imaging videos taken of wallabies when crossing Heinemann Road, once when the VF devices were inactive (A) and active (B) noting in the latter, the wallaby (highlighted by a white circle), is crossing as a vehicle (indicated by a solid white arrow) is approaching. In figure A, the white outline arrows indicate the positions of some VF devices. The white 'x' in each image is the same telephone pole.

Further to above, a fourth set of observations related to two wallabies very close to the road (one right at the road's edge) as well as being relatively close to observers (directly in front of our observation vehicle). As well as not appearing to overtly respond to active VF devices (video: https://www.wildspy.com.au/TEMP/2_wallabies_6_vehicles+vfactive_ULR.mp4), we chose to actively intervene at a point where the wallaby closest to the road appeared to be about to attempt to cross into incoming traffic (we beeped our vehicle horn and flashed our lights), after which the wallaby fled a short distance away from the road (video: https://www.wildspy.com.au/TEMP/intevention_ULR.mp4). Although we can't be certain that this wallaby did indeed intend to cross, we suggest that this is at least another potential example of a wallaby that had not learned to avoid crossing a road when VF devices were active.

Finally, an impromptu assessment of VF devices by two Council staff members during part of an observation night provided an opportunity to observe wallaby responses to humans approaching nearby to them on foot. In contrast to the general lack of response to passing vehicles/active VF devices, several wallabies were observed moving reasonable distances rapidly away from approaching people (video: https://www.wildspy.com.au/TEMP/human_disturbance_ULR.mp4), and at distances further away then was observed for flight responses involving vehicles. Wallabies closest to approaching people also appeared to trigger a similar flight response in some (but not all) wallabies even further away. Flight response distance did appear to vary between individual wallabies to some degree, although this could not be accurately determined. Engelfield *et al.* (2019) reported a similar observation of a possum feeding directly underneath an active VF device, with the possum only moving when approached by observers.

Although species could not be reliably determined in most cases, all wallabies that could be identified to species level were red-necked wallabies.

Discussion

Our results suggest that there is no clear evidence that the installation of VF devices prevented meaningful numbers of wallaby strikes on Heinemann Road. Nor do our preliminary behavioural observations of wallabies nearby active VF devices appear to suggest that the devices unambiguously operate as either a repellent or warning stimulus complex per se. Taken together, it suggests that VF devices are not suitable for reducing wallaby strikes on Heinemann Road, at least in their current format, as Engelfield *et al.* (2019) concluded. However, we recognise that there are some critical issues relating to aspects of our results, and thus, caution is required in any subsequent interpretations. For instance, due to budget and logistical constraints, we were unable to implement a robust experimental design in our examination of strike data, such as that undertaken by Engelfield *et al.* (2019). Further, a reduction in the length of road outfitted with VF devices in March 2019 makes direct comparisons between pre-treatment and treatment years more problematic. Another major impediment is the absence of population abundance data from which to draw inferences relating to the proportion of the population being struck. For example, it is not clear if, or to what degree density dependence influences strike frequency, which as Coulson and Bender (2019) recognised can have an impact on results and the validity and interpretation of particular statistical tests, or comparisons between studies (Englefield *et al.* 2019).

Our data suggest the potential for a modest seasonal component to strikes with, for example, a fairly consistent peak in strike events in July, particularly in the pre-treatment and second treatment years. Both species of wallaby within the Redland Coast area are capable of breeding all year round, although partial seasonality in births has been observed in red-necked wallabies, around spring each year (Higginbottom & Johnson, 2000). Yet, our data showed no clear relationship between strike frequency and this time of year. However, it is possible that movement patterns leading to higher strikes relate to seasonal changes in rainfall or the availability of food. This suggests at least some prospect for employing temporary mitigation measures with a higher beneficial outcome at certain times of the year, such as in winter.

Location too may play a role in strikes, and therefore a role in mitigation, particularly when viewed in 'blocks'. For instance, if budgetary constraints limit options, mitigation that focussed on the area encompassed by blocks 4 and 6, which account for approximately 42% of all recorded strikes, might yield useful reductions. Similarly, it would be important to determine the potential factors involved in the markedly lower frequency of strikes observed in block 12. One possibility in this regard is the presence of bends/corners along this section of road, which might translate into slower vehicle speeds and/or great vigilance. Traffic 'calming' measures might therefore represent a reasonable approach to reducing wallaby strikes.

Differences in land use along the road are also likely to influence wallaby activity and therefore strike frequency. For instance, sections with large paddocks are well-suited to grazing by wallabies, and where each side of the road features paddocks, it is logical to expect wallabies may try and cross the road. This may be less common where one side with paddocks has an opposing side with dense residential dwellings, particularly if coupled with high or impassable fencing. During the attempt to examine naïve wallaby responses to VF devices, the location featured exactly such conditions, and in three nights of observations, no wallaby appeared to come close to the road or the devices. In contrast, observation locations along Heinemann Road featured paddocks or more open habitat on both sides of the road. An assessment of any such potential 'barrier' effects, or those that might encourage crossings, on Heinemann Road could help prioritise mitigation decisions based upon the highest probability of wallabies crossing. In turn, we recommend a further observational study using the thermal camera approach we used to properly determine 'hot spots' for crossing activity, and therefore, priorities for mitigation. This would also be a good opportunity to attempt to determine population abundance/density of wallabies, and their distribution along the road.

Engelfield *et al.* (2019) reported that the VF device manufacturer suggested devices were most effective for low and medium traffic densities and would not be as effective in almost continuous traffic. However, estimates of traffic volume on Heinemann Road are lower than the traffic volume reported in Engelfield *et al.* (2019), as are posted speed limits, suggesting these also are not the source of any differences. Perhaps there are critical differences in the ecology and/or behaviour of the wallaby species in the studies.

We did observe two wallabies cross roads when devices weren't active, but also observed one wallaby cross when devices were active and actively intervened in another case when devices were active and a crossing into oncoming traffic appeared imminent. Our sample size is too small to draw any conclusions, but coupled with the slightly larger sample of wallabies' responses observed between active and inactive devices (i.e. no discernible difference) wallabies in our study did not appear perturbed being in relatively close proximity to active VF devices. The two startle responses we observed seemed more related to passing vehicles then VF devices, and in both cases, wallabies were also very close to the edge of the road, providing some confirmation that vehicles might have to be very close to wallabies to actually register as a threat to escape from, just as Lima *et al.* (2015) reported for other species elsewhere. Therefore, we strongly suspect that the light and sound stimuli that the VF devices produce are not aversive, in keeping with the conclusions of Fox *et al.* (2018), Coulson and Bender (2019) and Engelfield *et al.* (2019) as well as the device supplier.

Further, if some wallabies have learned to use VF devices as a warning about when or when not to cross Heinemann Road, others plainly have not. Given how close vehicles might have to be to actually be perceived as a threat, an association between this and the VF devices would require the latter to only activate when wallabies are very close to the road edge when vehicles pass by, at least initially. This might be possible with the addition of motion sensors or a 'break-the-beam' sensor that conditionally activates VF devices only when both a vehicle is present and a wallaby is detected very close to the road, but would require modification of the VF devices.

A major limitation with the current model of VF device is that they are only able to operate at night, meaning roads are effectively left unmitigated during daylight hours. Thus, even if VF devices did work well at night, the potential for strikes during the day means there could still be substantial impacts on populations if road crossings occur during the day. Blacker (2014) observed wallabies crossing roads on many occasions during the day, including on Heinemann Road, making night-time only operation of VF devices problematic. This might be one reason for differences between the current study and previous studies involving other species that might be more nocturnal, although both species of wallaby in the current study are also clearly active at night. Presumably, a reason for VF devices being limited in this way is that the ability to detect vehicles at night is more straightforward than during the day, because a light-sensitive sensor of some kind can be used.

Something like a pneumatic traffic counting sensor strip across roads at each end of a treatment road might allow for the limitation to be overcome, provided such a sensor could communicate with VF devices.

Similarly, there may already be other technologies/approaches that could enhance or replace VF devices. For example, VF devices could be paired with 'small-scale' battery and solar powered electric fencing such that both the VF devices and the electric fence turn on/off in the presence/absence of approaching vehicles. The VF devices would therefore serve as a true warning to wallabies, not of approaching cars necessarily, but that they will get a shock if they touch the fence while VF devices are active. In turn, this would mean devising a method to activate the electric fence when VF devices activate. We estimate that it would cost approximately $500-$2000 per km to deploy a battery and solar powered electric fence, depending upon factors such as the existence of another fence, the size of the battery and solar panel required, the degree of anti-vandalism strategies required and the sophistication of activation procedures.

An example of a simple electric fence system is the 'Solar Energizer 70' (Obrien's - https://www.obriensplastics.com/energizers/solar-energizer-70). Ideally, the electric fence would only operate when vehicles are present just as the VF devices do so that a conditioned association between the two sets of stimuli would occur, and wallabies could still cross the road when vehicles aren't present. However, if this was not possible or practical (e.g. high traffic volumes), an electric fence with a sufficient solar panel and battery could likely operate for considerable periods of time autonomously, and other warning stimuli could be applied, such as bunting/fladry, or audible and/or visual stimuli placed at regular intervals along the fence to help wallabies learn to avoid electric fences.

Additionally, vehicle and/or wallaby-activated street lights could be considered, as they might serve a dual purpose of providing an additional stimulus to animals, but also importantly, increase driver and animal visibility. Such approaches could offer greater immediate potential in reducing wallaby strikes on Heinemann Road than it appears has been the case for VF devices.

Recommendations

1. Implement additional studies of wallaby behaviour near to roads whenever any mitigation approach is trialled (include control roads), and obtain information about wallaby numbers, using thermal imaging as described here.
2. Consider trialling small-scale electric fencing as a deterrent to wallabies entering roads. This could range from a simple treatment of the fence always being on, to only being on at dawn, dusk and at night, or, attempting to link fence activation with wallaby and vehicle presence.
3. Consider trialling brighter street lighting, and if possible, either making it contingent on vehicle presence, or vehicle and wallaby presence.
4. If proposed mitigation is expensive (e.g. wildlife barrier fencing; street lighting), examine roads for potential factors such as suitable habitat type for wallabies on both sides of the road (e.g. paddocks or grassy areas) in an effort to determine the best places for mitigation.
5. Attempt to consolidate wallaby strike data sources such that available data are consistent and include important spatial and temporal information whenever possible.

References

Appleby, R., Smith, B., Bernede, L., & Jones, D. (2018). Utilising aversive conditioning to manage the behaviour of K'gari (Fraser Island) dingoes (Canis dingo). *Pacific Conservation Biology*, *23*(4), 335-358.

Benten, A., Annighöfer, P., & Vor, T. (2018). Wildlife Warning Reflectors' Potential to Mitigate Wildlife-Vehicle Collisions—A Review on the Evaluation Methods. *Frontiers in Ecology and Evolution*, *6*, 37.

Bomford, M., & O'Brien, P. H. (1990). Sonic deterrents in animal damage control: a review of device tests and effectiveness. *Wildlife Society Bulletin (1973-2006)*, *18*(4), 411-422.

Blacker, A. R. (2014). *Wallabies and Roads: Interactions and Management in an Urbanising Landscape* (Doctoral dissertation, Griffith University, Queensland, Australia).

Bond, A., & Jones, D. (2013). Wildlife warning signs: public assessment of components, placement and designs to optimise driver response. *Animals*, *3*(4), 1142-1161.

Brunton, E. A., Srivastava, S. K., & Burnett, S. (2019). Spatial ecology of an urban eastern grey kangaroo (Macropus giganteus) population: local decline driven by kangaroo–vehicle collisions. *Wildlife research*, *45*(8), 685-695.

Conover, M. R. (2001). *Resolving human-wildlife conflicts: the science of wildlife damage management*. CRC press.

Coulson, G., & Bender, H. Roadkill mitigation is paved with good intentions: a critique of Fox et al.(2019). *Australian Mammalogy*. 42(1) 122-130 https://doi.org/10.1071/AM19009

D'Angelo, G., & van der Ree, R. (2015). Use of reflectors and auditory deterrents to prevent wildlife-vehicle collisions. *Handbook of road ecology*, 213-218.

Englefield, B., Candy, S. G., Starling, M., & McGreevy, P. D. (2019). A Trial of a Solar-Powered, Cooperative Sensor/Actuator, Opto-Acoustical, Virtual Road-Fence to Mitigate Roadkill in Tasmania, Australia. *Animals*, *9*(10), 752.

Essex, B. (2018) Preliminary Report on the Virtual Fence Trial Project on Heinemann Road, Redland Bay, Internal Report, July, Redland City Council

Fox, S., Potts, J. M., Pemberton, D., & Crosswell, D. (2019). Roadkill mitigation: trialing virtual fence devices on the west coast of Tasmania. *Australian Mammalogy*. 41(2) 205-211 https://doi.org/10.1071/AM18012

Fox, S., & Potts, J. (2019) Virtual fence devices–a promising innovation: a response to Coulson and Bender. *Australian Mammalogy*. 42(1) 131-133 https://doi.org/10.1071/AM19031

Higginbottom, K., & Johnson, C.N. (2000), Partial seasonality of breeding in red-necked wallabies (*Macropus rufogriseus banksianus*. Journal of Zoology, 251: 71-77. doi:10.1111/j.1469-7998.2000.tb00594.x

Klöcker, U., Croft, D. B., & Ramp, D. (2006). Frequency and causes of kangaroo–vehicle collisions on an Australian outback highway. *Wildlife Research*, *33*(1), 5-15.

Lima, S. L., Blackwell, B. F., DeVault, T. L., & Fernández-Juricic, E. (2015). Animal reactions to oncoming vehicles: a conceptual review. *Biological Reviews*, *90*(1), 60-76.

Matthews, R. W. (2019) Patterns and composition of medium and large vertebrate roadkill, based on six annual surveys along two adjoining highways in south-eastern Queensland, Australia. *Australian Mammalogy*.[online early] https://doi.org/10.1071/AM19044

St. Clair, C. C., Backs, J., Friesen, A., Gangadharan, A., Gilhooly, P., Murray, M., & Pollock, S. (2019). Animal learning may contribute to both problems and solutions for wildlife–train collisions. *Philosophical Transactions of the Royal Society B*, *374*(1781), 20180050.

van der Ree, R., Smith, D. J., and Grilo, C. (2015). 'Handbook of Road Ecology.' (John Wiley and Sons: New York.)

Watson, D. (2018) Virtual fence 6 month data report, Internal Report, February, Redland City Council