Oxley Highway Upgrade – Port Macquarie

Monitoring of Wildlife Road Crossing Structures

June 2013 – September 2016

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Final Report

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Executive summary

This report describes three years (June 2013 – September 2016) of monitoring wildlife road-crossing-structures installed along the new alignment of the Oxley Highway at Port Macquarie. The primary target species in this study were threatened species: the yellow-bellied glider, the squirrel glider and the koala. Monitoring was conducted using motion-and-heat-activated cameras of two pairs of glide poles, one rope canopy-bridge, three underpasses and five or more wildlife road-escape ramps (drop-downs).

Two records were obtained of a yellow-bellied glider on one glide pole. There were 419 records of sugar gliders and squirrel gliders on poles. These species could not be readily distinguished in these images though a majority appear to be sugar gliders. There were 71 records of feathertail gliders on the poles. The rate of use of the poles was variable over time but in some periods there were nine or more nights per month with records. Despite the high rate of use only one pair of records could confirm a road crossing had occurred, and by a squirrel glider. The lack of synchrony in the records suggests that gliders were using the poles to glide to a tree on the other side of the road in close proximity to the glide poles. Monitoring of the rope-bridge over the three years produced nine records confirmed as sugar gliders, one confirmed as a squirrel glider, one sugar glider/squirrel glider record and two records of feathertail gliders. No crossings were confirmed but six records were in a single direction suggesting a crossing.

The three underpasses produced a large number of crossings by different species: swamp wallaby (1132), lace monitor (554), eastern grey kangaroo (459), red-necked wallaby (236), red fox (249), red-necked pademelon (136) and two species of bandicoot (122). There were nine records of koalas across the three underpasses. The rate of crossing showed that many species had areas of their home ranges on each side of the highway and used the underpasses to commute from one side to the other. The koala records suggest the underpasses allowed dispersal through the landscape. Targeted monitoring of a railing through one of the fauna underpasses revealed 89 crossings by the brown antechinus and 130 by the black rat. A female antechinus was recorded transporting four large young (1-2 at a time) in one direction through the underpass over a 48 minute period.

Monitoring of the road-escape ramps (drop-downs) revealed frequent activity of various species moving through the ramps. The swamp wallaby accounted for 58% of 740 movement records. Red-necked wallabies, eastern grey kangaroos and Rusa deer were other large species detected using the ramps to access the road-side vegetation. The frequent access to the road-side gained by these large mammals appears to undermine one value of the road-side exclusion fence which is to keep wildlife off the road to reduce traffic accidents. Despite this frequent incursion to the road-side by many species few records of road-killed wildlife were documented by the local wildlife carer organisation. Road-kills would be under-reported but few were seen while this study was being conducted. The risk posed by the escape-ramps should not be ignored.

This study has confirmed the potential value of glide poles to reconnect severed forest habitat for four species of gliding mammals. This study has convincingly demonstrated that underpasses have immense value in reconnecting habitat fragmented by a major road for a range of ground-dwelling wildlife species. This study calls into question the widespread installation of wildlife road-escape ramps along new sections of highways.

1. Introduction

Roads have the potential to disrupt the population processes of many species of wildlife. This may occur directly through the road-kill of wildlife which may deplete the size of local populations or indirectly by creating physical or psychological barriers that reduce or prevent dispersal movement. Collisions between vehicles and wildlife may also lead to wildlife being injured rather than killed outright. Thus, there is a strong justification for the installation of wildlife road-crossing structures to enable the safe passage of wildlife across roads. The provision of wildlife exclusion fencing assists in preventing animals gaining access to the road-way and funnels animals to the road-crossing structures.

When the Oxley Highway at Port Macquarie, New South Wales, was upgraded and realigned there was a recognised need to install a variety of wildlife road-crossing structures and wildlife exclusion fencing to minimise wildlife road-kill and injury, and to enable species to continue to move across the landscape. This led to the installation of the following structures to enable different species to traverse the road-way: two sets of tall wooden poles for gliding mammals; one rope-bridge for climbing and gliding arboreal mammals; seven fauna underpasses (three dedicated and four combined drainage/fauna) for a broad range of ground-moving species such as reptiles, bandicoots, wallabies, kangaroos and koalas; and 14 'koala drop-downs' that are one-way ramps through the exclusion fencing to allow animals, in particular koalas, to exit the roadway if they inadvertently found their way onto it.

This report describes the monitoring of the wildlife road-crossing structures installed on the Oxley Highway at Port Macquarie over a period of three years. The primary objective specified in the contractor brief was: "Development of an effective and robust monitoring plan for 2 pairs of glider poles, a rope ladder, five (5) koala drop-downs, two (2) dedicated fauna underpasses and one (1) combination fauna/drainage underpass over a 3 year period." Thus, the broad aim of this study was to determine the use of these structures by various wildlife species as a means of ultimately assessing their effectiveness to enable dispersal movement across the Oxley Highway. Of the structures installed on the Oxley Highway at Port Macquarie, monitoring was conducted of all of the glide poles, the only rope-bridge present, seven of 14 koala drop-downs (selecting an even spread along the highway), two of three dedicated fauna underpasses and one of four combination fauna/drainage underpasses.

2. Methods

2.1. Study Area

The Oxley Highway deviation at Port Macquarie extends for approximately 6 km east from the Pacific Highway. It traverses a large block of open sclerophyll forest for a length of approximately 2 km. The road consists of four lanes, is ~24 m wide and has a 5 m wide centre median. The median is vegetated with ground cover plants. The elevation of the study area varies from 14 to 40 m.

Road-crossing structures and drop-downs are largely located within the extent of the forest block. The extent of the study area is defined by the most eastern and western drop-downs (Figure 1). The road was officially opened to the public on 7 February 2012.

Traffic speed along this section of the highway is 90 km per hour. Average daily traffic volume has been measured at 14,300 vehicles per day (RMS, unpublished data).

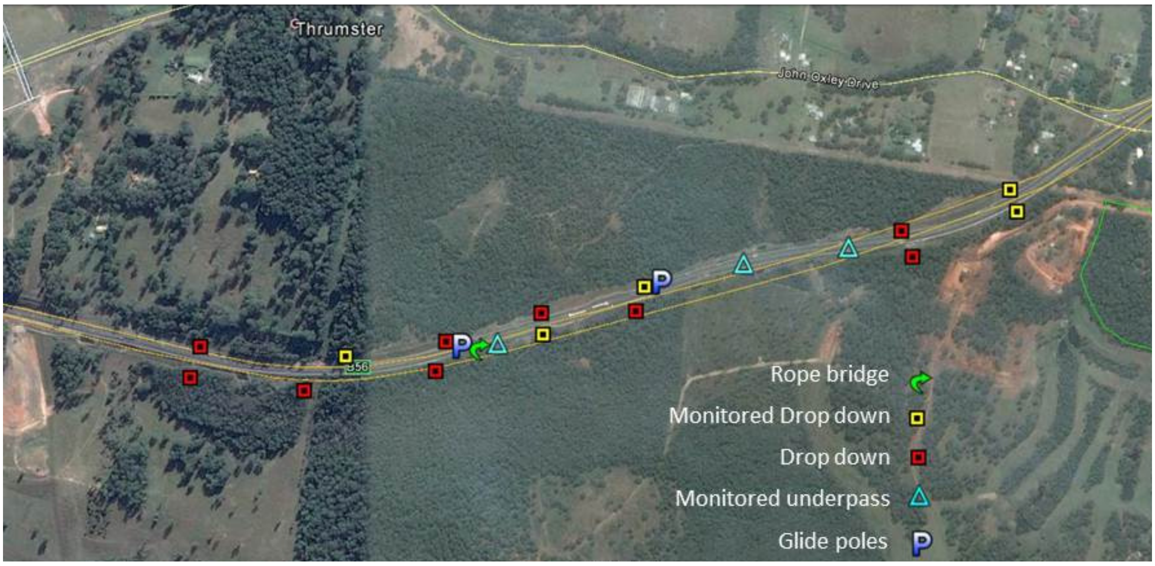

Figure 1. Aerial image of the Oxley Highway at Port Macquarie showing locations of road-crossing structures and koala drop-downs.

2.2. Monitoring of the Glide Poles

Two pairs of wooden glide poles (25-26 m high) were installed along the highway adjacent to the large block of open forest (Figure 2). The two pairs are located 460 m apart (Figure 3). The western pair is located 40 m from a rope-bridge.

Figure 2. Glide poles on the Oxley Highway. At left the western pole pair and at right the eastern pole pair.

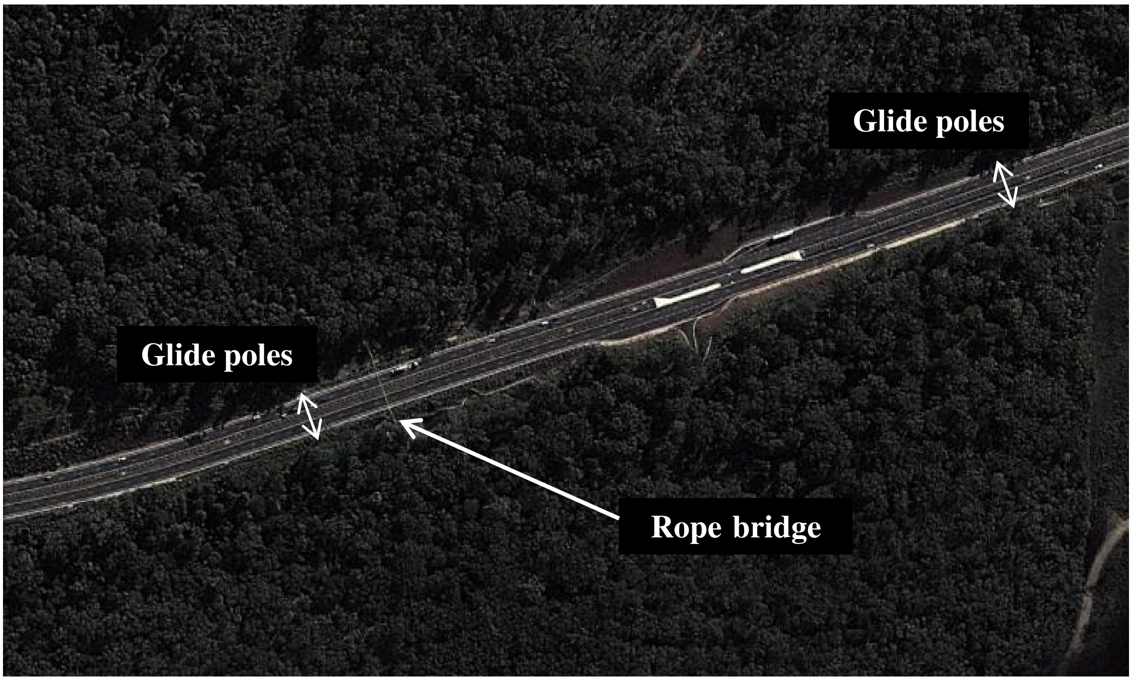

Figure 3. Aerial image showing the locations of glide poles and a rope-bridge on the Oxley Highway, Port Macquarie.

To detect arboreal animals on these poles a collar was fastened to each pole with a 15 cm wide gap. A Reconyx PIR (passive infra-red) camera was installed 2 m above the collar and directed at the collar gap. Any animal that climbed up through the gap would trigger the camera and be photographed (see Figure 4). Cameras were set to take 5 images 1 second apart when triggered and with a 1 minute delay between triggers.

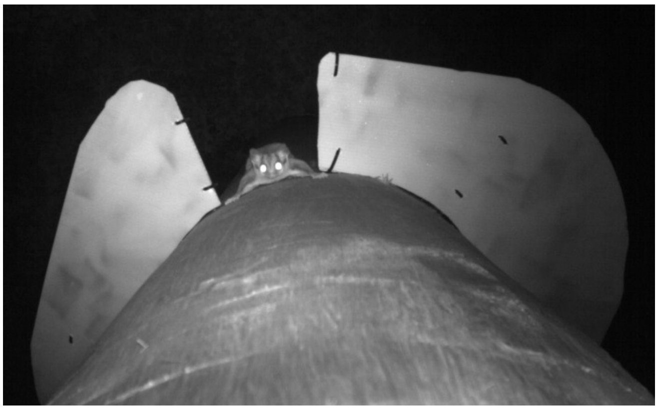

Figure 4. A sugar glider climbs through the gap in the pole collar.

When first installed on 19 June 2013, the collars were placed at 5 m above ground and the cameras at 7 m above ground and could be accessed via a ladder. In November 2013, the cameras and collars were raised to 21 m and 19 m, respectively, by a qualified tree-climber

(Figure 5). This was due to concern that animals may evade detection by gliding to a pole and landing above the cameras. The cameras were raised a further 1 m above the collars on 17 November 2015 to create a 3 m collar to camera spacing. An increase in the number of night images with no obvious cause of triggering suggested that gliders were triggering the cameras and ascending a pole faster than the reaction time of the camera and were not being photographed. Providing an additional metre above the collar should give a camera a slightly longer period in which to capture an image.

The poles were climbed by a tree climber approximately every second month from November 2013 to September 2016 in order to change SD cards and batteries in each camera. The SD cards were subsequently viewed on a computer and the date and time were recorded for all images of mammals on the poles. Date and time records were examined to assess potential road-crossing events.

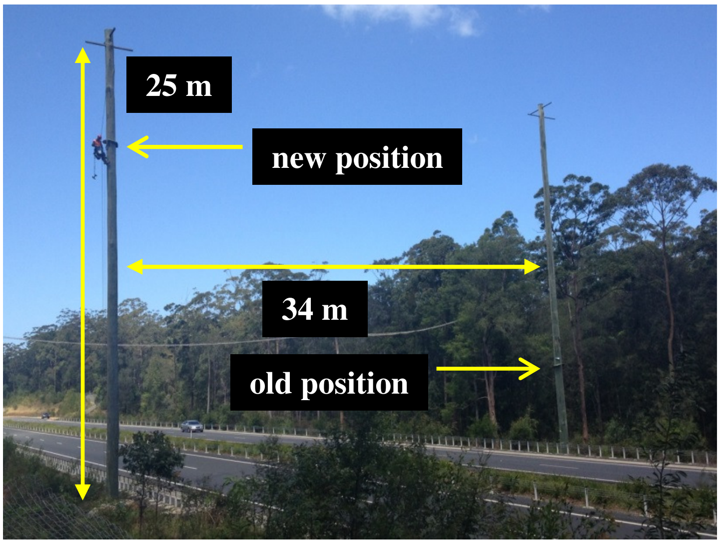

Figure 5. A close-up of the western pole array showing the initial position of the camera and collar and the new position used from November 2013 onwards.

2.3. Monitoring of the Rope-bridge

The rope-bridge is positioned approximately 12 m above the road-way and is held in position by two wooden poles (Figure 6). The pole to pole distance along the rope-bridge is 41 m. A single Reconyx camera mounted on a board was installed near each end of the rope-bridge on 18 June 2013 pointing back to the pole supporting the rope-bridge (Figure 6). Buckeye cameras that we intended to monitor the rope-bridge with did not become available from Faunatech until February 2014.

The Buckeye cameras installed relied on active infra-red sensor placed about 2 m in front of the camera. These sensors produced a beam that had to be cut by a passing animal to trigger the camera. A similar system (though with two sensor beams) was employed by Soanes et al. (2013) in their study on the Hume Highway in Victoria. In contrast the Reconyx cameras rely on a passive infra-red (PIR) sensor system which triggers the camera when a moving object whose temperature is sufficiently different to ambient moves in or out of the sensor's detection zone.

The Buckeye cameras were installed and were operational late on 5 February 2014. These cameras subsequently experienced continuing technical problems leading to their removal for repair in June 2014. A KeepGuard camera (using PIR) was placed in the position where the southern Buckeye had been. The Buckeye cameras were reinstated on 6 Dec 2014 and the KeepGuard camera removed. Camera 1 (southern side) commenced taking black images at night on 11 Dec 2014. On-going discussions with the supplier (Faunatech) and their discussions with the manufacturer (Buckeye) led to a resolution in July 2015 that there was a hardware problem requiring replacement of the camera unit. The Buckeye cameras were removed on 8 September 2015 and their position on the rope-bridge pole replaced by the Reconyx cameras.

Buckeye camera 2 was operational at night during year 2. Although it recorded many images during the day of Lewin's honeyeaters and a forest raven exploring the infra-red sensors (Figure 7), only a single image was obtained at night of a mammal.

Figure 6. Attachment of the rope-bridge to a supporting pole. There are two sections of the rope-bridge that allow access from trees in the forest (*Left*). Photograph taken at the south end of the rope-bridge. The Reconyx camera can be seen to the right of the rope-bridge (*Right*).

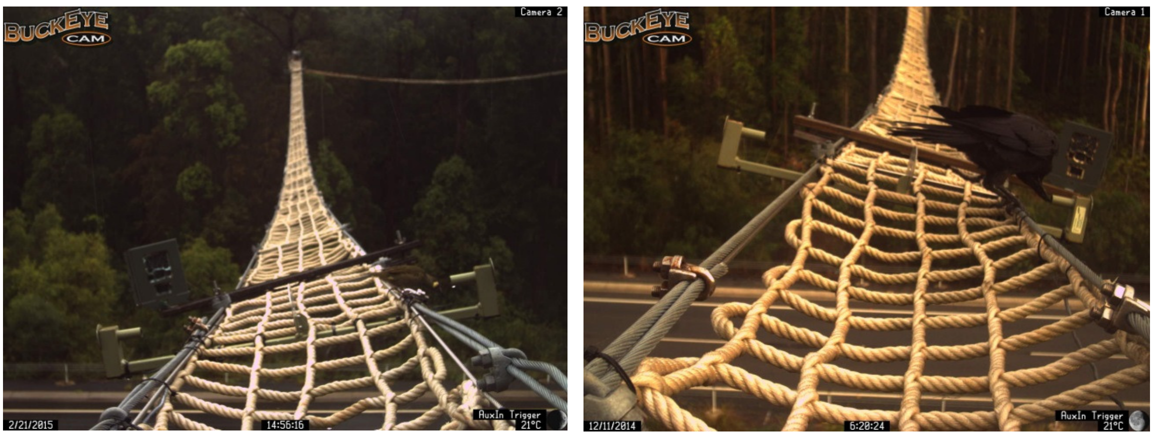

Figure 7. A Lewin's honeyeater examines the infra-red sensor on the northern camera on 21 February 2015 (*left*). A forest raven examines the infra-red sensor on the southern camera on 11 December 2014 (*right*).

The Reconyx cameras were operational on the rope-bridge from 18 June 2013 until 21 September 2016. From 18 June 2013 until 8 Sept 2015 they were positioned on the side of the rope-bridge pointing back to the pole supporting the rope-bridge (Figure 6). From 8 Sept 2015 until 21 September 2016 they were attached to the rope-bridge pole and directed forward from the pole.

The poles of the rope bridge were climbed by a hired tree climber approximately every second month from November 2013 in order to change SD cards and batteries in each camera, as well as other servicing of the cameras (see above). The SD cards were subsequently viewed on a computer and the date and time were recorded for all images of mammals on the rope-bridge.

2.4. Monitoring of the Fauna Underpasses

Three underpasses were monitored: a dedicated underpass with post and rail fauna furniture (1.8 m high by 3 m wide) located below the rope bridge (underpass west), a dedicated underpass with post and rail fauna furniture (3 m high by 3 m wide) located 600 m east of the rope bridge (underpass east), and a combined drainage/fauna underpass with no furniture (1.8 m high by 2.4 m wide) located a further 200 m east (combined underpass) (Figure 1). The actual underpasses to be monitored were specified by RMS. Hereafter the dedicated fauna underpasses are referred to as fauna underpasses and the drainage/fauna underpass referred to as the combined underpass.

Two Reconyx cameras were installed in the western fauna underpass and the combined underpass, ~5 m inside each end, mounted 1-1.5 m high and positioned to view the entrance. Two Reconyx cameras (both facing south) were mounted in the middle of the eastern fauna underpass at 1 m high and at 2.5 m high (to view along the fauna railing) (Figure 8). Cameras were set to take 5 images 1 second apart when triggered and with no delay between triggers.

Figure 8. (*Left*) Entrance to the eastern fauna underpass. (*Right*) This underpass had a camera installed 2.5 m high to record any animals using the fauna furniture.

Hair funnels were installed in the three underpasses from September 2013 until March 2014 with the hair collection wafers replaced every 2-3 months. One funnel was installed per underpass in the east fauna underpass (181 days) and the combined underpass (181 days) and two funnels in the west fauna underpass (131 and 181 days). These were baited with eucalypt leaves in an attempt to attract visits by koalas. Only a single record was obtained (common brushtail possum) so they are not referred to further.

The underpasses were visited approximately every second month from June 2013 in order to change SD cards and batteries in each camera. The two cameras in the western fauna underpass were stolen prior to the December 2014 site visit. Cameras were not replaced until two KeepGuard cameras were installed on 21 April 2015. The SD cards were subsequently viewed on a computer and the date and time were recorded for all images with animals as well as type and direction of movement.

The data presented here are the number of individuals per species per 24-h period that traversed (i.e. crossed) an underpass. Observations where animals stopped and turned around were not included. Multiple individuals of the same species were recorded only if >1 was seen in the same photo, or if different individual characteristics were evident (e.g. size differences; male & female; different markings), or if the direction of travel was the same (i.e. passes in opposite directions within 24 h could be the same individual so were recorded once only). Cameras installed at each end of an underpass did not always record an animal passing both cameras so relying on this measure to estimate crossings is likely to greatly underestimate the true crossing rate. There were many instances where an animal was recorded by one camera moving quickly (see Figure 9) (sometimes just a single image) with a very obvious direction of movement and apparent intent to traverse the underpass. Therefore, these records were counted as crossing records. Such observations were made in all three underpasses and included the swamp wallaby, eastern grey kangaroo, red-necked wallaby and red-necked pademelon. Lace monitors were also commonly observed moving in a straight direction but were only recorded by one camera. These records were also treated as crossings. Single camera traverses also allows crossing frequency to be determined for the eastern fauna underpass which had only a single camera to record ground-based species.

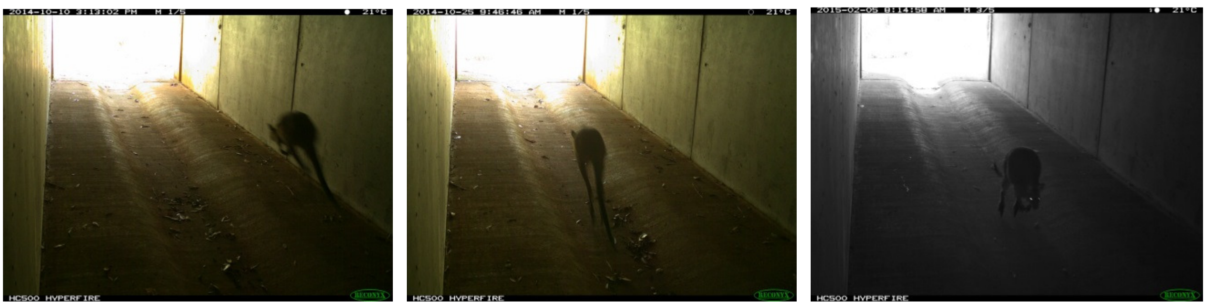

Figure 9. Images showing swamp wallabies moving quickly through the combined underpass.

2.5. Monitoring of the Koala Drop-downs (Road-escape Ramps)

Koala drop-downs are basically road-escape ramps that allow animals that might become trapped on the roadway to discover a break in the wildlife exclusion fence through which they can pass and exit the roadway. These escape ramps are designed for one-way passage and have been installed primarily to minimise koala road mortality. The entrance to the ramp is at ground level on the road side of the exclusion fence (Figure 10). The ground in the ramp is angled up so at the opening in the fence it is approximately 60-80 cm above ground level (Figure 11). This is intended to create a one-way passage. Any animals that somehow find their way onto the road side of the exclusion fence (e.g. by climbing over the floppy top fence) would not be trapped near the road but would eventually encounter an escape ramp and leave the road side. The ledge on the drop-down ramp is intended to be high enough that animals on the forest side of the exclusion fence should be prevented from gaining entry because they would need to jump up onto the ramp.

Figure 10. View looking down a drop-down ramp into the road-side vegetation for drop-downs 5S (left) and 7N (right). This shows the substantial amount of road-side vegetation that may be attractive to animals for foraging.

Figure 11. Motion-activated camera directed down the drop-down ramp.

Five to seven drop-downs were monitored using a Keepguard KG680v camera positioned on the refuge pole near the top end of the ramp and directed down the ramp (Figure 11). Cameras were set to take 3 images 1 second apart when triggered and with a 1 minute delay between triggers. Monitoring locations were spread along the road alignment and included five drop-downs in year 1 (Figure 1). The number of drop-downs monitored was seven in year 2 and six in year 3 due to the theft of several cameras and a reluctance to reinstall where theft had occurred. One drop-down at the eastern end of the study area became in close proximity to a new housing development and was considered vulnerable to further theft.

2.6. Analysis of Data and Hypotheses to be Tested

All camera images in this project were identified by Ross Goldingay. The images have generated data that have been collated to examine rates of use of the different wildlife structures. For the glide poles in which rates of use were relatively low, data have been collated in 2-month periods and expressed as the number of nights with records per month (30 day period). This allows comparison across a year as well as across poles. For the underpasses in which rates of use were relatively high, data have been collated on a weekly basis which allows comparison across years, underpasses and species.

The hypothesis to be tested is that the crossing structures enable safe passage of individuals of a species over or under a road. We do not have data on crossing rates of individuals at locations without these structures or for roads where traffic volumes are low and the road gap relatively small. However, there are published accounts from other locations for glide poles, rope-bridges and underpasses. These studies can generate predictions for various scenarios such as if animals have established their home ranges on both sides of a road and are using the structures to access other parts of their home range, or if dispersing individuals use the structures. If animals use road crossing structures to access different parts of their home range then the expectation is that rates of use of the structures will be high on a weekly basis whereas if they were only used in dispersal then use would be infrequent, perhaps only a few times per year. The other possibility is that the structures are unsuitable for use so one would expect to see zero use or almost zero use.

Taylor and Goldingay (2012) conducted radio-tracking of squirrel gliders at a site where glide poles were installed on the top of a wildlife land-bridge. They established that some individuals had parts of their home range on both sides of the road whereas others did not. They conducted camera trapping on the glide poles which suggested a crossing rate of once or twice per week. Taylor and Goldingay (2013) conducted camera-monitoring on glide poles at another location and suggested a crossing frequency of about once per week. Soanes et al. (2015) estimated crossing rates of squirrel gliders on rope canopy bridges and glide poles at a number of locations. The crossing rate for one rope-bridge was 29 crossings per week but zero at another three and 0.1 per week at a fifth. They monitored 15 glide poles at 10 locations. They made no detections on 4 poles. The crossing rate estimated from their cameras on other poles was 7-13 per week for four poles, once per week for two poles and negligible detections on 5 poles. Their data are confounded by poor installation design at five locations (i.e. a pole spacing requiring a glide ratio (distance glided/divided by height dropped) above the average glide ratio reported by

Goldingay and Taylor 2009). This problem was highlighted by Goldingay et al. (2011). In fact, an analysis conducted by Soanes et al. (2015) revealed that crossing rate was negatively influenced by canopy gap width and the number of poles installed to cross the gap.

The above data have been multiplied by 30 to convert to a value per month for comparison with the data collated in this study. This suggests if animals use the glide poles to access their home ranges the crossing rates should be 4 or more per month (4.8-7.9 crossings per month: Taylor and Goldingay 2012; 26.1-57.6 per month: Soanes et al. 2015). If animals are using the poles for dispersal (this is inferred) the rate may be of the order of 0.6-2 crossings per month. One would expect that if animals are using the poles for home range travel they could also be used by dispersing subadult individuals. However, use by dispersing individuals would occur but be indistinguishable from other use (i.e. records of use include regular home range movements and occasional dispersal movements). Detection values similar to those above could apply to the rope-bridges.

The same considerations described above apply to use of underpasses. High crossing rates (i.e. several per week) would indicate use of the underpass to access areas of the home range (Taylor and Goldingay 2003) whereas infrequent use would indicate either reluctance to use the structure or dispersal. Distinguishing the later may be difficult but can be informed by other studies that might suggest the willingness or otherwise to use a structure (see Goldingay and Taylor in press). Crossing rates by bandicoots where home ranges were on both sides of a highway (suggested from radio-tracking and trapping) were 2.1-16.8 crossings per week (Taylor and Goldingay 2003, 2014). Bond and Jones (2008) reported crossings by bandicoots of 2.8-5.6 per week (calculated from 40% of tracks per day that were crossings). In Western Australia, Chambers and Bencini (2015) recorded use by southern brown bandicoots at two underpasses of 2.4-6.6 records per week compared to 0.02-0.1 records per week at eight underpasses. Rates of use of 0.1-1.0 per week might suggest dispersal only, whereas rates of >2 per week might reflect home range use. Crossing rates by wallabies (mostly swamp wallabies) were of the order of 5.8-8.9 per week (Taylor and Goldingay 2003) and for western grey kangaroos at one underpass were 2.4 records per week (Chambers and Bencini 2015).

2.7. Target Species

Although the wildlife road-crossing structures are intended to be used by a range of species there are three target species in this study, which are listed as threatened species in NSW. One is the yellow-bellied glider which is the primary target of the glide poles and the rope-bridge. Based on records in the NSW Wildlife Atlas, this species has not been detected near the location of the Oxley Hwy realignment since 2002 (Figure 12). Another is the squirrel glider which might also benefit from glide poles and the rope-bridge. This species was detected to the east of the Oxley Hwy realignment in 2012. The koala is the third species. It has more than 50 records within 200 m of the Oxley Hwy realignment, including several since 2010.

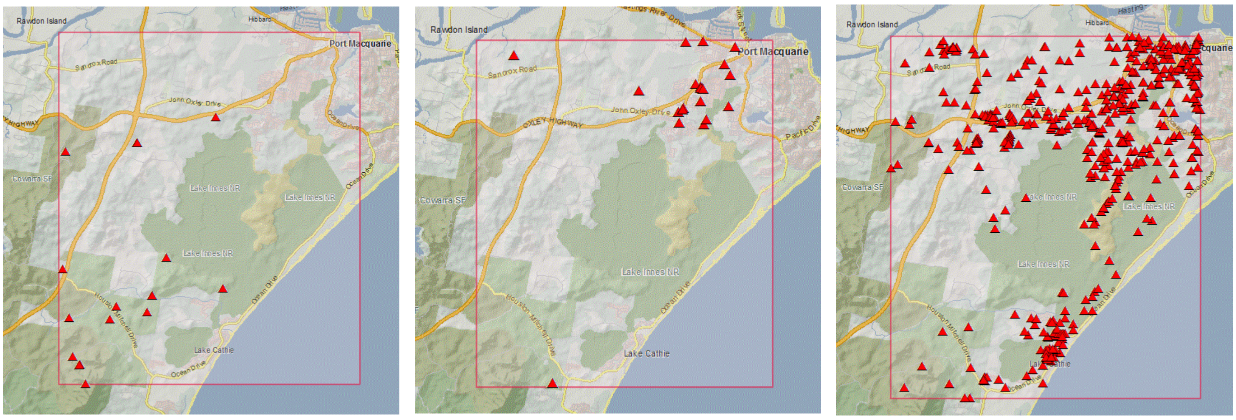

Figure 12. Records (red triangles) in the NSW Wildlife Atlas of the yellow-bellied glider (*left*), squirrel glider (*middle*) and koala (*right*) near the Oxley Hwy realignment.

2.8. Road-kill Data

Records of road-killed wildlife were obtained from FAWNA, a Port Macquaie based animal welfare group. Records were obtained for three roads: the stretch of the Oxley Highway that includes the monitored wildife road structures; John Oxley Drive which is the old Oxley Highway into Port Macquarie, and Hasting River Drive which is the other major arterial road that vehicles can take into Port Macquarie.

3. Results

3.1. Monitoring of the Glide Poles

Monitoring of the four glide poles (2 pairs) began on 19 June 2013. In years 1 and 2 one pole in each of the pairs did not meet its monitoring target (Table 1). Technical issues relating to excessive false triggering were a primary cause of this in year 1. In year 2 the northern camera of the western pole pair showed a night-time malfunction but could not be replaced until 10 February 2015. A setting error appears to have affected its functioning during Feb-April 2015. The cameras on the other three poles were functional for all of the 364 days in year 2 (Table 1). In year 3 the northern camera of the west pair became prone to false triggering and was again replaced. Monitoring in year 3 was extended beyond June 2016 to make up for the shortfall in years 1 and 2. Across the three years the poles were each monitored for an average of 319 days per year.

Table 1. Record of the number of days cameras were operational on different glide poles. Monitoring was conducted from 19 June 2013 to 21 September 2016. Monitoring years end on 31 May except in year 3. The monitoring target for all poles was at least 220 days each year. *This camera suffered a malfunction in year 2 and was replaced. It was prone to false triggering in year 3 and was again replaced.

Structure	**Camera**	**Days Operational (Target achieved)**					
		Year 1		**Year 2**		**Year 3**	
Glide poles – East pair	North	345	✓	364	✓	408	✓
	South	215	x	364	✓	378	✓
Glide poles – West pair	North	273	✓	61	x*	309	✓
	South	274	✓	364	✓	478	✓
Total monitoring days		1107		1153		1573	

Over the 3 years the pole cameras detected four species of gliders: sugar gliders, squirrel gliders, feathertail gliders, and yellow-bellied gliders. There were difficulties in distinguishing sugar gliders and squirrel gliders because many photos were of animals climbing towards the camera with an obscured view of the most diagnostic feature which is the width of the tail base. Therefore, all of these records are referred to simply as sugar gliders (specific identifications are given in images) while acknowledging that there were squirrel gliders in the mix of records (Figures 13, 14 and 15). Based on animals that could be distinguished it appears the squirrel glider is much less common in the study area compared to the sugar glider.

Figure 13. A female (*left*) and male (*right*) sugar glider detected on the south-west pole within 4 hours of each other (2423 h & 0344 h) on 29 June 2014. The male has a scent gland on the head that can be seen when this image is enlarged.

Figure 14. A male (*left*) and female (*right*) sugar glider detected on the south-west pole within 20 min of each other (0304 h & 0323 h) on 9 June 2016. The male's scent gland is obvious.

Figure 15. Squirrel gliders detected on the south pole of the east pole pair. The image on the right was taken after the camera was elevated by 1 m in November 2015 to improve detection.

Across the three years of the study there were 419 records of sugar gliders (including an unknown number of squirrel gliders) and 71 records of feathertail gliders (Figure 16). These amount to 318 records of sugar gliders (including an unknown number of squirrel gliders) on different nights and 65 records of feathertail gliders on different nights. The yellow-bellied glider was recorded on two occasions: on 17 Jan 2014 and 10 May 2015 (Figure 17). Surprisingly most records of individual species were on different nights for opposing poles. There was only a single instance when an image on one pole could be matched to an image on the opposing pole (Figure 18). Both images showed the same time suggesting the squirrel glider had landed on one pole, ascended and glided across the road to the other pole, and quickly ascended that pole. Presumably it then glided from that pole to the adjoining forest.

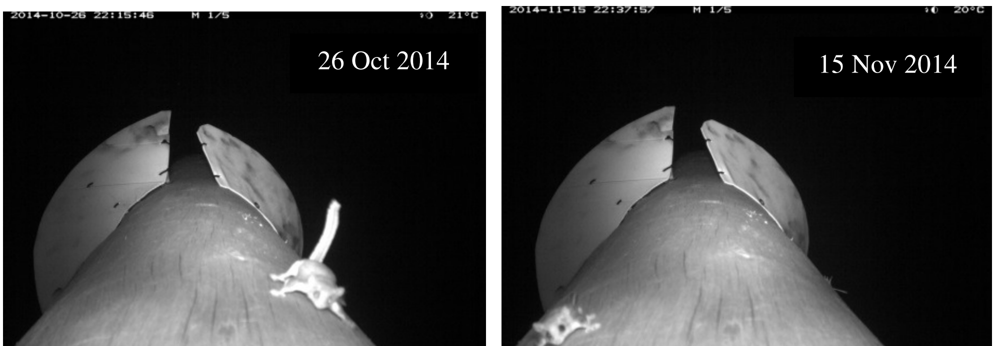

Figure 16. Feathertail gliders were detected on 60 different nights during the study.

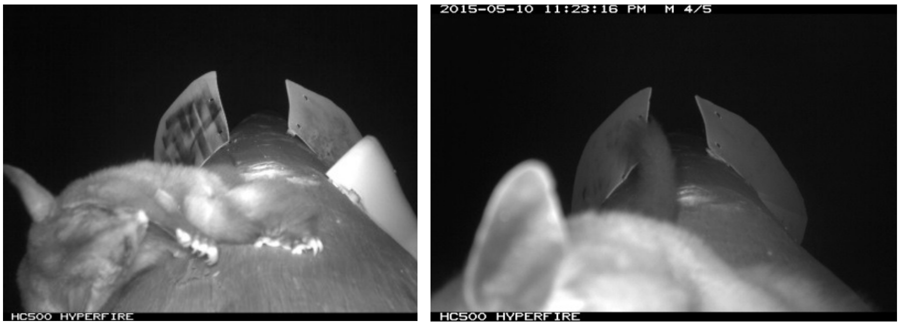

Figure 17. A yellow-bellied glider was detected on the north-east pole on 17 Jan 2014 (*left*) and on 10 May 2015 (*right*).

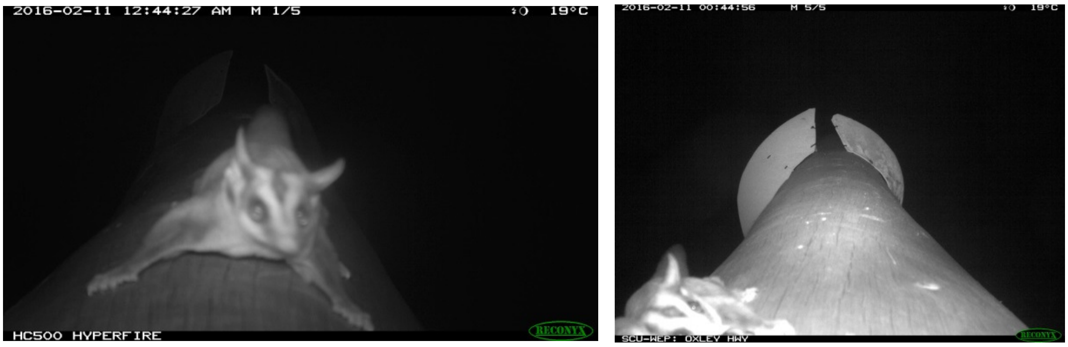

Figure 18. A male squirrel glider photographed at 0044 h on 11 Feb 2016 on each of the poles of the east pole pair.

Sugar gliders were detected relatively frequently on different poles across the 3 years (Figure 19). The number of nights with records varied from 0 to 20 nights per month. Feathertail gliders showed a consistent but low number of nights (0-2) with records across the 3 years (Figure 19). The south eastern pole showed a high number of records of feathertail gliders in Oct-Nov 2014 (Figure 19).

To further investigate whether the cameras were missing records of gliders on the poles we installed an additional Reconyx camera on each pole in late 2015 and early 2016. The camera was positioned at 7 m above ground and a collar extending around half the circumference of the pole was installed at 5 m above ground. All cameras were operational for 78 days from 18 Feb 2016 until 6 May 2016. The comparative data for high and low cameras in this period were west-north pole (high: 5 feathertail gliders; low: 0), west-south pole (high: 0; low: 2 sugar gliders), east-north pole (high: 4 sugar gliders and 2 feathertail gliders; low: 0) and east-south pole (high: 16 sugar gliders; low: 0).

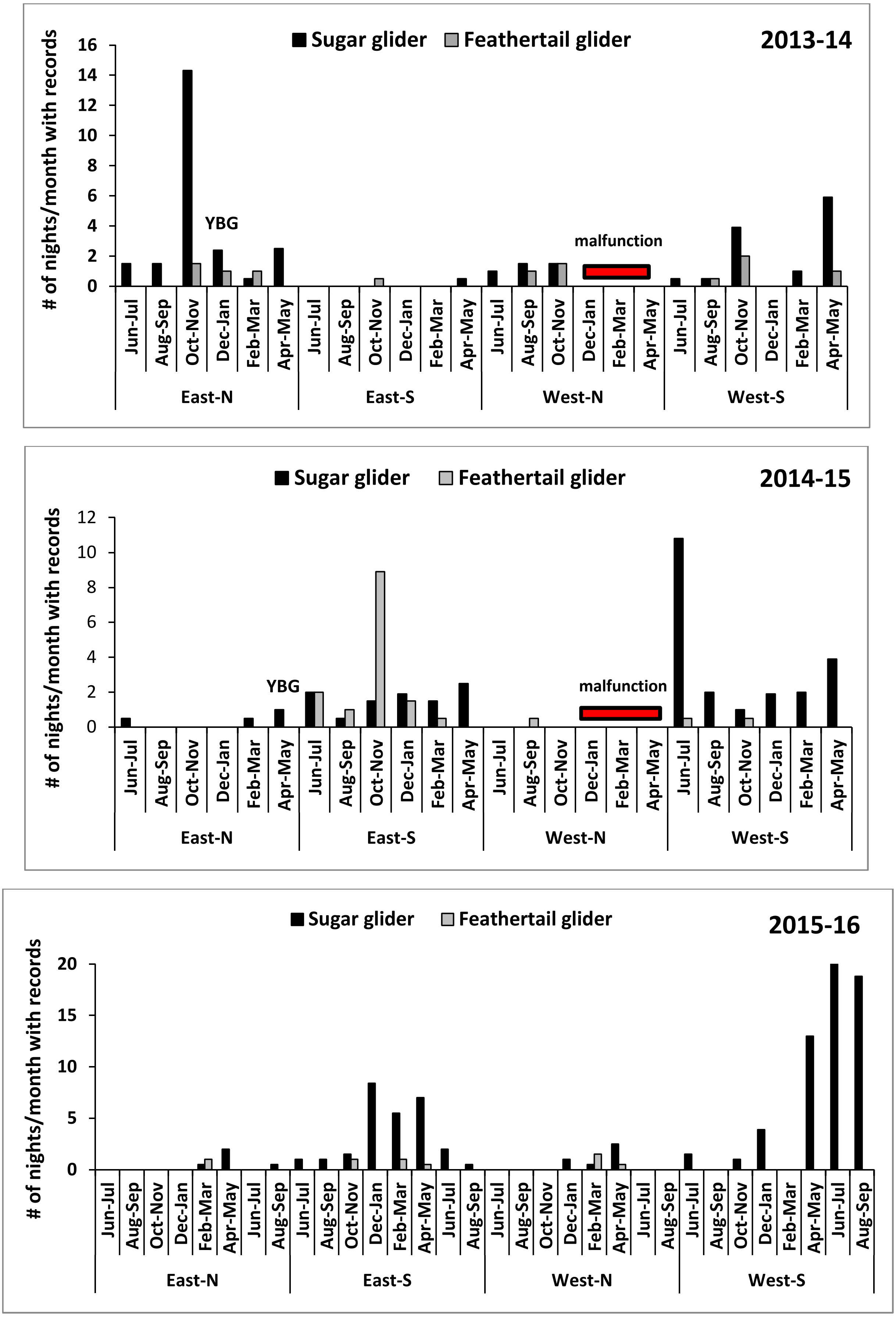

Figure 19. The number of nights per month in which sugar gliders and feathertail gliders were detected on the two glide pole pairs. The cameras were raised from 7 m above the ground to 21 m above the ground in November 2013. Cameras were raised 1 m, to be 3 m above the collar in November 2015.

3.2. Monitoring of the Rope-bridge

The Reconyx cameras were operational for 100% of the target monitoring period at both ends of the rope-bridge (Table 2). In year 1, three records of sugar gliders (10 January 2014 at 0210 h and 2308 h; 3 May 2014 at 2342 h) (Figure 20) and one record of a feathertail glider (31 Oct 2013) were obtained. All were obtained at the north end of the bridge. In year 2, a sugar glider was detected on 8 September 2014 (Figure 21) and one was detected at the south end on 27 April 2015 (Figure 22). On 17 May 2015 a blurry glider image was obtained at the north end. The Buckeye cameras also detected a sugar glider on 17 May 2015 (Figure 22). A feathertail glider was detected at the north end on 20 October 2014. A KeepGuard camera was put in place when the south Buckeye camera had been taken in for repair. This camera recorded a single sugar glider at the south end of the rope bridge on 26 November 2014 (Figure 21). In year 3, a sugar glider was detected on 11 January and a squirrel glider on 11 February 2016 (Figure 23), both at the north end. A sugar glider was detected on the south end on 16 January 2016. Another was recorded venturing out onto the rope-bridge on 1 July 2016 but turned back.

None of these records over the three years were obtained at both ends of the rope bridge on the same night. Some images were of sugar gliders that appeared to be preparing to glide from the bridge (Figure 21). Three records of sugar gliders (Figures 20 *left*, 22 *right*, 23 *left*) and the one of a squirrel glider (Figure 23 *right*) suggested movement towards the other end of the rope-bridge and may represent crossings. The two records of the feathertail glider showed movement in a single direction away from the camera that suggested a crossing.

Table 2. Record of number of days cameras were operational at each end of the rope bridge and the number of detections (SG/SqG = sugar glider or squirrel glider; FTG = feathertail glider). Monitoring was conducted from 19 June 2013 to 21 September 2016. The monitoring target for the rope-bridge was at least 220 days per year. Monitoring years end on 31 May except in year 3.

Structure	Camera	Days Operational (✓ Target achieved)					
		Year 1		Year 2		Year 3	
Rope-bridge	North side	346	✓	365	✓	420	✓
	South side	309	✓	365	✓	478	✓
Detections	SG/SqG	3		4		4	
	FTG	1		1		0	
Total days		655		730		898	

Figure 20. Sugar gliders detected on the rope-bridge in January (*left*) and May 2014 (*right*).

Figure 21. A sugar glider detected by the Reconyx camera on the rope-bridge in September 2014 (*left*) and by the KeepGuard camera in November 2014 (*right*).

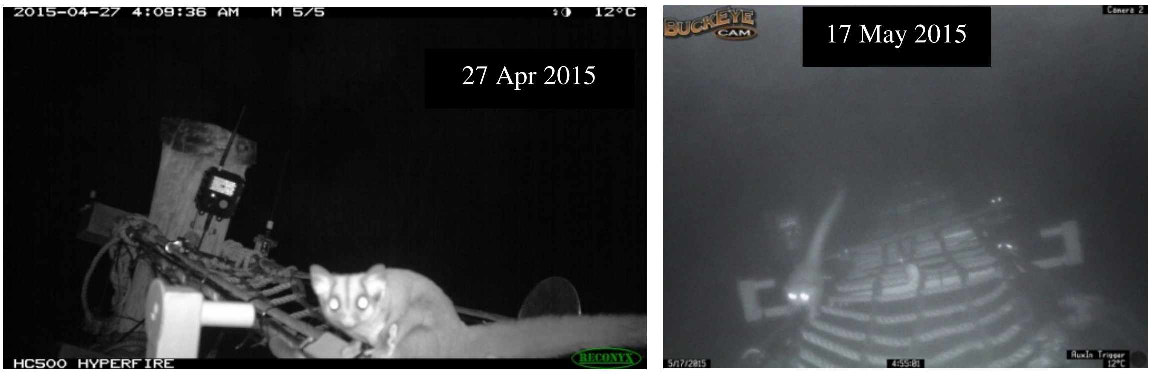

Figure 22. Sugar gliders detected on the rope-bridge in 2014 including once by the Buckeye camera suggesting a crossing (*right*).

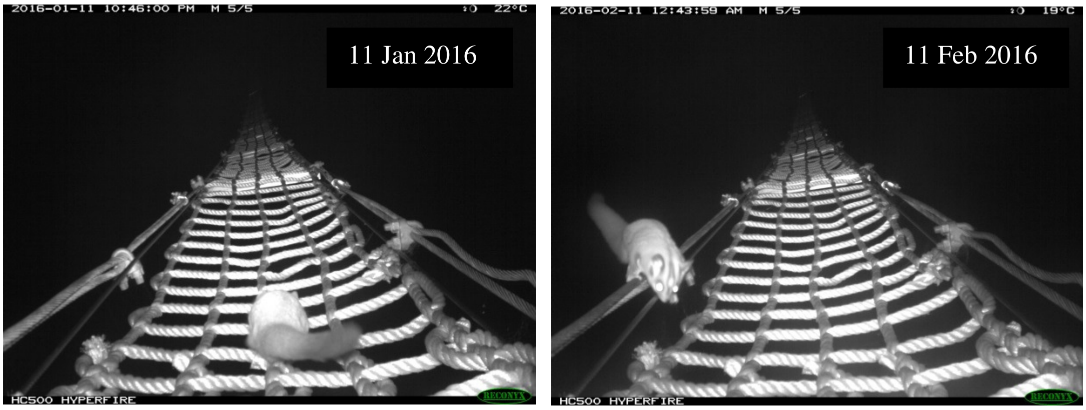

Figure 23. Directional movement by a sugar glider (*left*) and a squirrel glider (*right*) suggesting a crossing of the road.

3.3. Monitoring of the Fauna Underpasses

The cameras in the three underpasses achieved the monitoring targets for each of the three years (Table 3). The species commonly recorded in the underpasses were the swamp wallaby, the lace monitor, northern brown bandicoot, red-necked pademelon, red-necked wallaby, eastern grey kangaroo, red fox (Figure 24) and long-nosed bandicoot. There were four koala traverses detected in year 1, none in year 2 and 5 in year 3 (Table 3) (Figure 25).

Table 3. Record of the number of days cameras were operational within underpasses. Monitoring was conducted from 18 June 2013 to 6 May 2016. The monitoring target for the underpasses is 7 months (i.e. 210 days). *The two cameras in the western fauna underpass were stolen which led to no coverage between 2 December 2014 and 21 April 2015. The number of koala traverses is shown for each year in each of the underpasses.

Structure	**Camera**	**Days Operational (✓ Target achieved)**						**Koala crossings**		
	Position	**Year 1**		**Year 2**		**Year 3**		**1**	**2**	**3**
West fauna underpass*	North side	349	✓	225	✓	340	✓			
	South side	349	✓	225	✓	340	✓			
								0	0	2
East fauna underpass	Middle-high	349	✓	364	✓	340	✓			
	Middle-low	349	✓	364	✓	340	✓			
								1	0	0
Combined underpass	North side	349	✓	364	✓	340	✓			
	South side	349	✓	364	✓	340	✓			
								3	0	3
Totals		2094		1906		2040		4	0	5

The swamp wallaby was the species that conducted the largest number of passes in all underpasses, exceeding >250 in each underpass (Table 4). The lace monitor was another species that showed a high level of use of all three underpasses with >100 traverses per underpass. Other species such as the red-necked wallaby, eastern grey kangaroo, red fox and red-necked pademelon showed >100 passes in at least one underpass over the three years (Table 4). Traverses of the underpasses by dogs and cats were rare events. Two of the 4 dog records were of two collared dogs that traverse the combined underpass together.

Table 4. The number of passes by species detected in the three underpasses.

Species	Fauna west	Fauna east	Combined	Total
Swamp wallaby	285	570	277	1132
Lace monitor	116	202	236	554
Eastern grey kangaroo	29	382	48	459
Red-necked wallaby	4	227	5	236
Red fox	23	2	224	249
Red-necked pademelon	122	11	3	136
Bandicoots	27	82	13	122
Deer	0	4	1	5
Brushtail possums	8	0	0	8
Koala	2	1	6	9
Echidna	0	3	0	3
Cat	0	1	0	1
Dog	0	2	2	4
Hare	1	0	1	2

Figure 24. The species commonly recorded in the underpasses. *Upper row*: lace monitor (*Left*), northern brown bandicoot (*Middle – close-up*), and red-necked pademelon (*Right*). *Lower row*: red-necked wallaby (*Left*), eastern grey kangaroo (*Middle*), and red fox (*Right*).

Figure 25. Koalas were detected in all underpasses: combined (*left*), east fauna (*middle*) and west fauna (*right*).

The crossing data have been collated on a weekly basis and averages determined for each of the years in which monitoring has taken place (from 18 June 2013 to 6 May 2016). This has revealed some patterns in the data for the six most commonly detected species. The swamp wallaby traversed all three underpasses at a rate of at least 1-2 crossings per week (Figure 26). Traverses of the east underpass were consistently higher than in the other two underpasses. The eastern grey kangaroo showed high crossing frequency in the eastern underpass in three of the years but there was an obvious decreasing trend (Figure 27). The red-necked pademelon was rare in all three underpasses in the first 18 months of the study but then started using the west fauna underpass frequently in 2015 and 2016 (Figure 28). The lace monitor showed a high frequency of crossing in all three underpasses (Figure 29). Its activity was mostly confined to the period of September through to April. The two species of bandicoot were not particularly abundant individually so they have been pooled. They crossed in the east fauna underpass more than once per week in 2014 and 2015 (Figure 30). The red fox showed a very high crossing frequency in 2013 in the combined underpass but the rate declined to a very low level in that underpass in 2016 which matched the low levels in the other two underpasses (Figure 31).

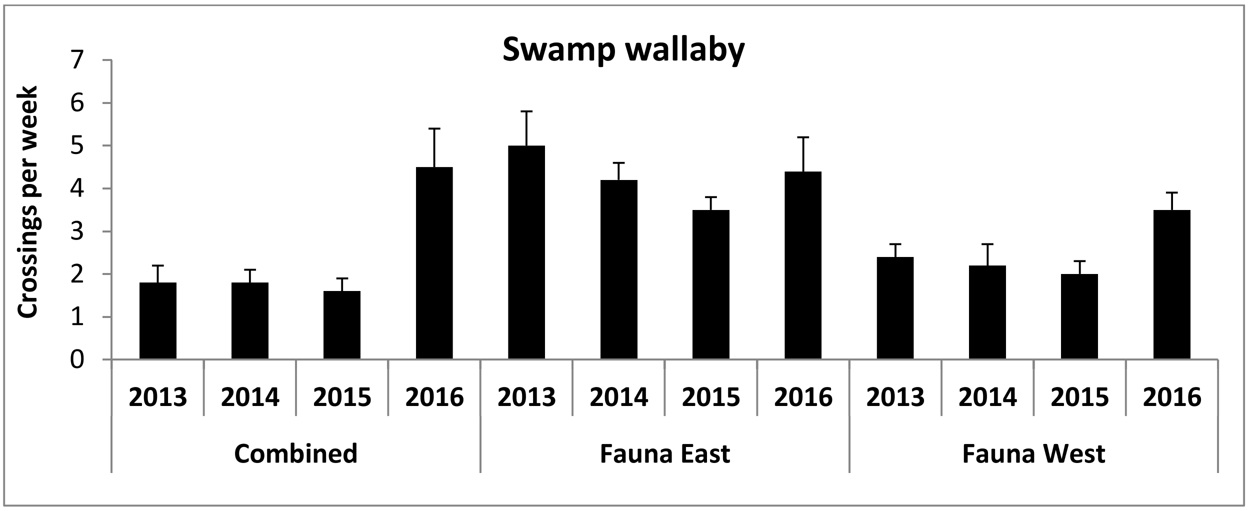

Figure 26. The mean number of passes per week (+Standard Error) by the swamp wallaby.

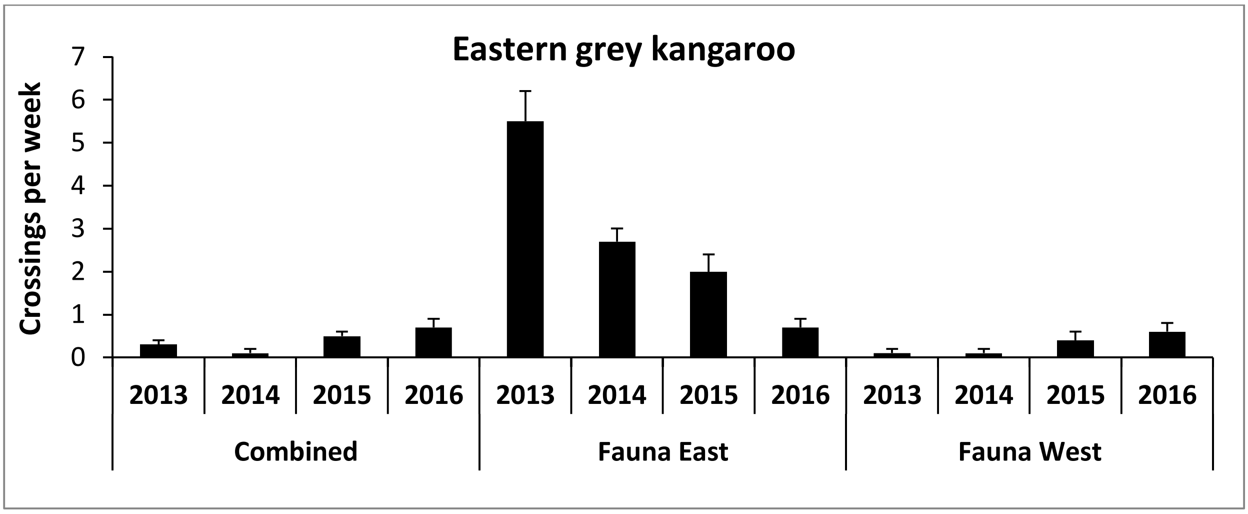

Figure 27. The mean number of passes per week (+SE) by the eastern grey kangaroo.

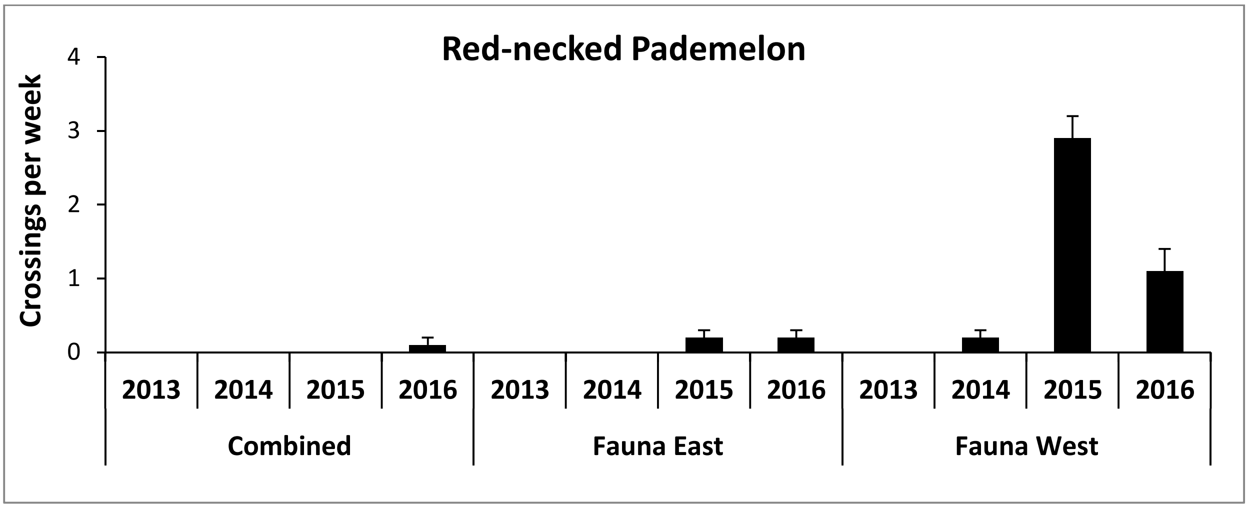

Figure 28. The mean number of passes per week (+SE) by the red-necked pademelon.

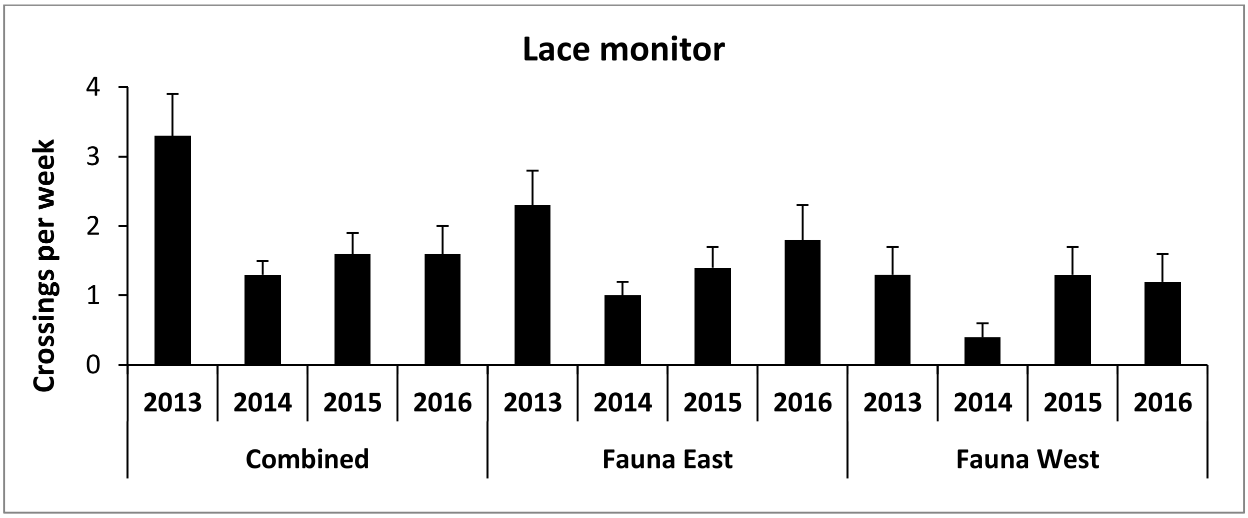

Figure 29. The mean number of passes per week (+SE) by the lace monitor.

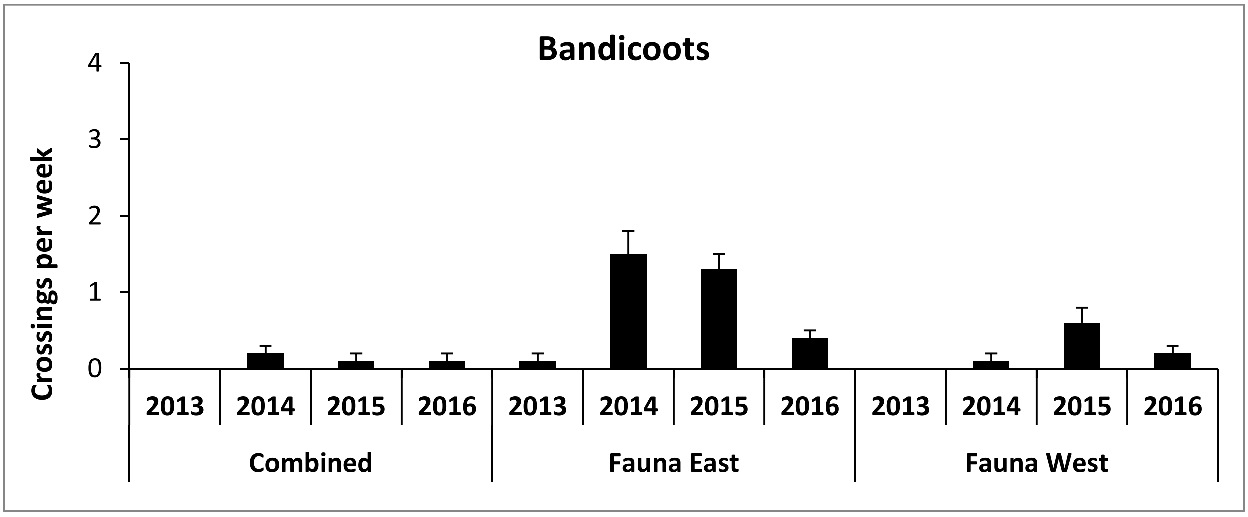

Figure 30. The mean number of passes per week (+SE) by bandicoots (pooling long-nosed bandicoots and northern brown bandicoots).

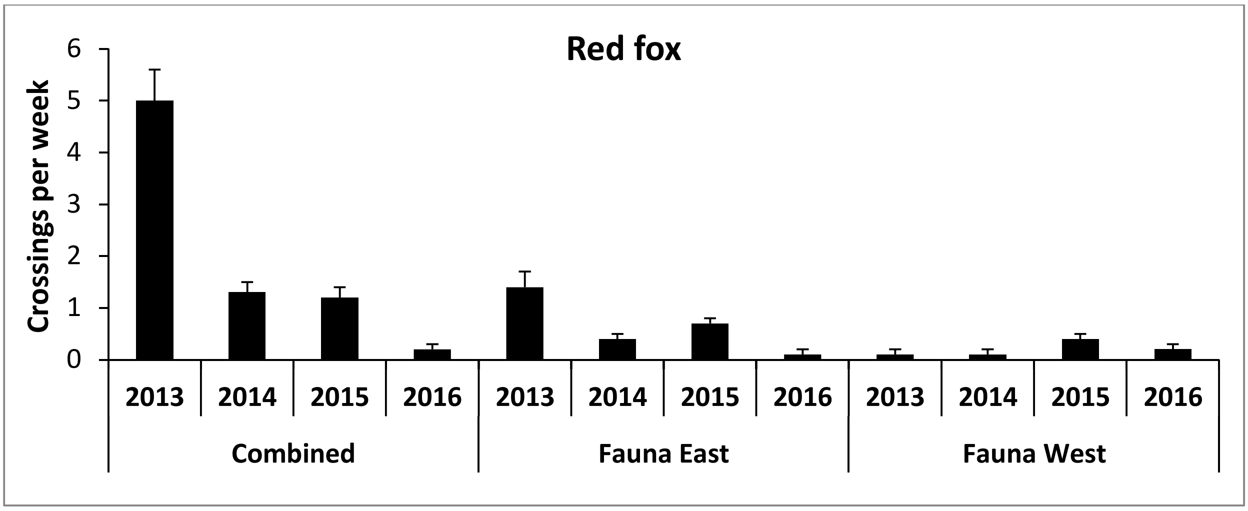

Figure 31. The mean number of passes per week (+SE) by the red fox.

Monitoring the fauna furniture in the eastern fauna underpass

The camera monitoring of the railing in the eastern fauna underpass revealed 89 crossings by the brown antechinus, 130 by the black rat and two by the lace monitor (Figure 32). The antechinus showed a relatively even crossing rate over the four calendar years of 0.4-0.8 per week (Figure 33). In contrast, the black rat showed a high level of crossing activity in 2013 which declined dramatically in 2014 (Figure 33). There were no records by this species in 2015. In 2016 the crossing rate was 1.5 per week.

One interesting observation was made on 6 January 2015 (Figure 32, *lower right*) when an antechinus mother was recorded carrying 4 large nestlings (two, then one, then another) across the railing over a 48 min period; each crossing past the camera with back-young taking approximately 3-8 sec.

Figure 32. Three species were detected on the fauna railing in the eastern fauna underpass. The lace monitor (*upper left*), black rat (*upper right*), and antechinus (*lower left*). One antechinus carried back young across on 6 Jan 2015 in one direction only (*lower right*).

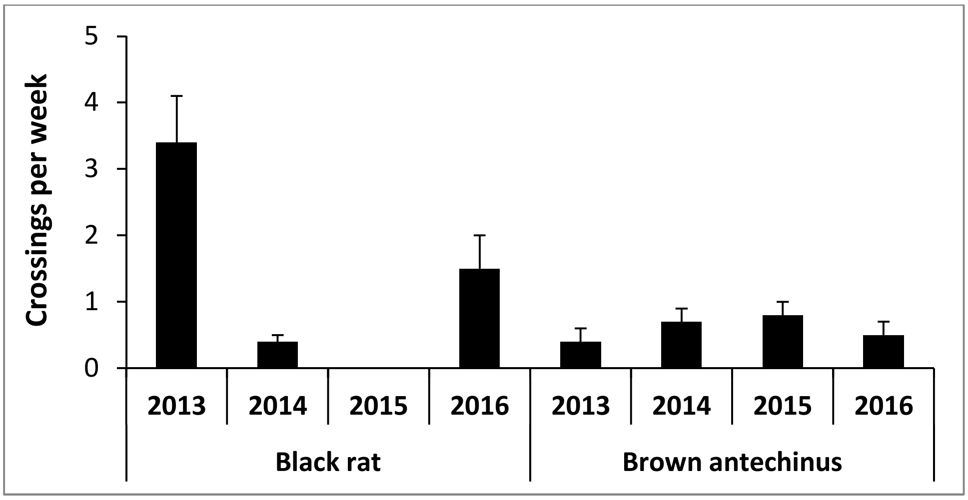

Figure 33. The number of passes per week (+SE) by rats and antechinuses on the fauna railing in the eastern fauna underpass.

3.4. Monitoring of the Koala Drop-downs (Road-escape Ramps)

The monitoring target of 210 days for each of five drop-downs was exceeded in each year of the survey (Table 5). In year 2 the target was achieved for three individual drop-downs but two targets were achieved by summing across pairs of cameras due to the theft of two cameras, some camera malfunctions and installation at different drop-downs. In year 3 the monitoring period was extended through to 21 September 2016 due to the theft of four of the cameras. Some cameras were repositioned over the three years in an attempt to gain a better insight into what was happening at the drop-downs more broadly across the study area and due to camera theft.

This led to individual drop-downs being monitored for different periods. Concern over the visibility of two cameras after the road-side vegetation was slashed meant cameras were not re-installed at those locations. This led to up to 6-7 different drop-downs being monitored in years 2 and 3 for varying lengths of time. Overall, the total period of drop-down monitoring per year was 52.6 months, compared to 35 months required (five drop-downs for seven months).

Table 5. Record of the number of days cameras were operational on different drop-downs. Monitoring was conducted from 16 July 2013 to 21 September 2016. Drop-downs are numbered from the western end of the Oxley Highway. North and south indicate the side of the highway. The monitoring target was for 5 drop-downs monitored for 7 months (i.e. 210 days) each year. In year 2 the target for two drop-downs has been reached by summing the monitoring of individual drop-downs (shown with the same colour and with the summed value in the same colour).

Camera (ID)	Days Operational (Target achieved)					
	Year 1		Year 2		Year 3	
3 South (3S)					172	
4 North (4N)			57		216	✓1
4 South (4S)	319	✓1	186		243	✓2
sum			243	✓1		
5 North (5N)	319	✓2	326	✓2	336	✓3
5 South (5S)			236	✓3	478	✓4
7 North (7N)	319	✓3	326	✓4	336	✓5
7 South (7S)	242	✓4	177			
2 North (2N)	319	✓5	127			
sum			304	✓5		
Total days	1518		1513		1781	

Animals were recorded at all drop-downs monitored. The focus of the records collected was on medium to large-sized animals that passed through the drop-downs to move between the forest and the road-side habitat (Table 6). Small mammals were not specifically recorded because they could pass directly through the fences surrounding the drop-downs. Black rats were the most frequently detected animal, being abundant at each drop-down (Figure 34) and being detected on a majority of nights in which cameras were operational. Swamp rats and antechinuses were also detected climbing around many of the drop downs.

Table 6. Records of movements by wildlife species through the drop-downs. The values are the sum of movements in either direction. The drop-downs monitored each year are arbitrarily numbered but are identified by their ID code (N=north, S=south).

Drop-downs (DD)																			
	Year 1					**Year 2**							**Year 3**						**Total**
DD #	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	
DD ID	2N	4S	5N	7N	7S	2N	4S	5N	7N	7S	5S	4N	3S	4S	5N	7N	4N	5S	
Days monitored	319	319	319	319	242	127	186	326	326	177	236	57	172	243	336	336	216	478	4734
Species																			
Bandicoots	7	2	6	20	3	5	13	20	5	1	1	1		6	3	22	3	30	148
Swamp wallaby		2	127			2	1	115	17		18	21		6	129		49	15	502
Red-necked wallaby				35	3					1							1		40
Red fox	1		3	8	4	2	1	2	20		4		3	3	3	1		25	80
Lace monitor	2	3	3		1						3			1	4	4		2	23
Brushtail possum			2		1			1	1		1		2		6				14
Rusa deer				1									1						2
Eastern grey kangaroo					1					1									2
Cat						2													2
Ringtail possum																1			1

A black cat was recorded twice (12 days apart) moving through drop-down 2N (Figure 34), whilst lace monitors (Figure 34) were detected occasionally at most drop-downs. Long-nosed and northern brown bandicoots (Figure 35) were detected at most drop-downs whereas two species of brushtailed possum, the common ringtailed possum and the eastern grey kangaroo (Figure 36) were detected infrequently. The red fox was a frequent user of some drop-downs (Figure 37; Table 6).

Those species detected frequently were observed to move up and down, through the drop-down in both directions. Images showed animals stretching out (Figures 35 and 37, *middle*) and disappearing over the edge of the drop-down ledge (Figures 34 and 37, *right*) as well as appearing at the edge with their back to the camera (Figure 36, *left*) before moving away from the camera (Figure 34, *middle*; Figure 37, *left*).

Figure 34. Black rats (*left*) were present at all of the drop-downs and produced records almost every night. A cat was detected on two occasions (*middle*). Lace monitors used the drop-downs in both directions (*right*).

Figure 35. Bandicoots were frequently detected on the drop-downs and going up and down the drop. This included long-nosed bandicoots (*left*) and (*middle*), and the northern brown bandicoot (*right*).

Figure 36. Occasionally detected at the drop-downs were the common brushtail possum (*left*), the northern mountain brushtail possum (*middle*), and the eastern grey kangaroo (*right*).

Figure 37. A red fox moving through a drop-down towards the road-way (*left*). A red fox using a drop-down (*middle and right*) to exit the road-side.

The swamp wallaby was the most frequently detected species commuting through the drop-downs, with images showing definitively that wallabies moved in both directions. Swamp wallabies could be seen leaping from the ledge of the drop-down in one image and then they were gone or only their tail was visible (Figure 38). When moving in the other direction they appeared at the top of the drop-down ledge and then were photographed moving down the ramp and in some cases bounding away.

Figure 38. Swamp wallabies are frequent users of the drop-downs. These three images show individuals departing the road-side of the drop-down.

Overall, there were 814 movements by animals recorded through the drop-downs over the 3-year monitoring period (Table 6). The swamp wallaby acounted for 62% of these records while the two species of bandicoots acounted for 18% of records. Because different drop-downs were monitored in different years it is not practical to examine variation in the use of individual drop-downs over the three years. However, the totals for each year have been summed across individual drop-downs and standardised by the monitoring periods in a given year. This shows an increase in the movement of swamp wallabies through the drop-downs in year 2 (Figure 39). Swamp wallabies showed variable use across different drop-downs (Table 6). Drop-down 5N was the most frequently used of all drop-downs by swamp wallabies. Movement per 30 days through this drop-down was consistently high over the three years (yr1: 11.9; yr 2: 10.6; yr 3: 11.3). The monthly rate for bandicoots and the red fox showed an increase after year 1. Lace monitors and possums showed low rates.

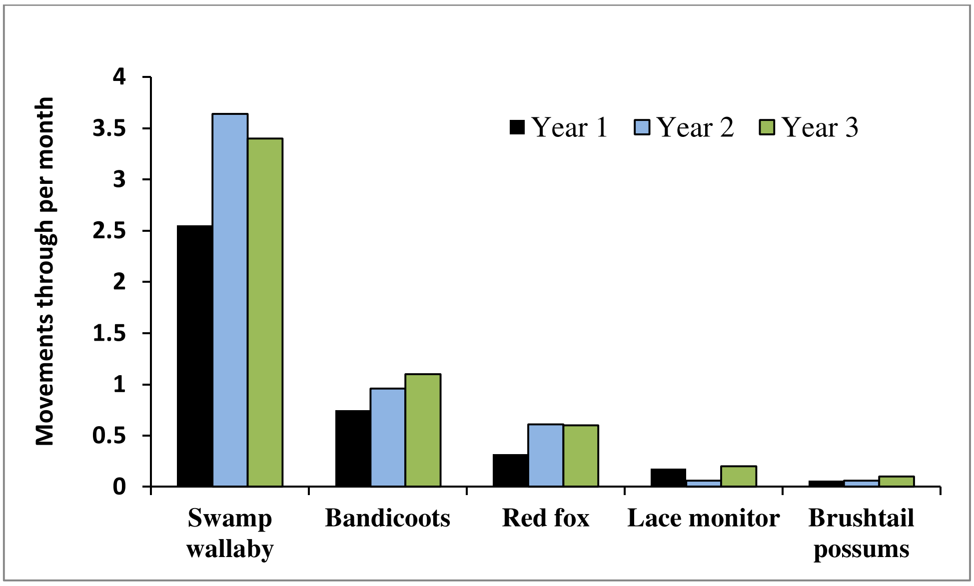

Figure 39. Movements per month (30-day period) through the drop-downs by the species most commonly recorded using the drop-downs.

3.5. Road-kill Data

Fawna reported just four road-kills on the Oxley Highway going into Port Macquarie in the 3 years of this study (Table 7). Higher numbers of road-kills were detected in John Oxley Drive in each year, mostly comprising grey kangaroos and red-neck wallabies.

Table 7. Road-killed mammals reported for three major roads in the study area (records to 6/6/16).

Species	**Oxley Hwy**			**John Oxley Dr**			**Hastings River Dr**		
	13/14	14/15	15/16	13/14	14/15	15/16	13/14	14/15	15/16
Long-nosed bandicoot						3			
Eastern grey kangaroo		2		2	3	4	1	1	2
Red-neck wallaby			1			2		1	
Common brushtail possum					1	1			
Mountain brushtail possum		1							
Eastern pygmy-possum							1		
Totals	0	3	1	2	4	10	2	2	2

4. Discussion

4.1. Effective Monitoring of Wildlife Crossing Structures

Our camera monitoring of the various crossing structures was highly effective in terms of the periods over which our cameras were operational. This includes monitoring for a period of 3.1 years on two of the glide poles (each of the pairs), 3.1 years on the rope-bridge, 2.9 years on two of the three underpasses and 2.7 years on two of the drop-downs. This monitoring detected previously undocumented species using the glide poles (feathertail glider and yellow-bellied glider) and the underpasses (red-necked pademelon). It has also documented large numbers of records for some species using the underpasses: 1132 records of the swamp wallaby, 554 records of the lace monitor and 459 records of the eastern grey kangaroo. This study also provides the first monitoring study of koala drop-down structures (road-escape ramps).

4.2. Detections on the Glide Poles and Rope-bridge

Our cameras detected sugar gliders and squirrel gliders (mostly they could not be distinguished) 419 times and feathertail gliders 71 times on the four glide poles during the study (i.e. 104.8 and 17.8 per pole for these species, respectively). Our monitoring of the glide poles was only able to confirm a single pole to pole crossing of the Oxley Hwy, which was by a squirrel glider (Figure 18). The lack of confirmed crossings does not indicate that crossings did not occur but could be due to several factors. These are: 1) the pole locations enabled gliders to glide onto a pole (from a tree) or from a pole (to a tree) so that they were only detected once, 2) gliders used the poles to glide to other trees on the same side of the road, and 3) our cameras were not consistently reliable so only one of a pair of cameras detected a glider when a crossing occurred. All three scenarios are likely to have occurred.

In the first scenario our detection represents detecting gliders ascending a pole before gliding across the road. Our cameras were installed at 21 m above ground so based on their position were unlikely to miss a glider that glided onto a pole with the intention of gliding from that pole (i.e. it ascended that pole up to the cross-beam). The glide height (25 m) would allow a glide of 46 m (Goldingay and Taylor 2009; Goldingay 2014). The pole to pole gap was 34 m but the close location of the forest behind the poles meant a pole to tree gap was about 40-45 m. So gliders could use the poles to cross the road but glided directly to a tree on the other side of the road.

The second scenario is likely to explain some of the detections. Gliders often use specific trees that may be taller or in more open locations to travel through their home ranges (R. Goldingay, personal observations). However, due to the location of the poles on the road side and slightly outside the forest, suggests that the location may not be ideal because gliders often use trees to forage in as they travel through their home ranges. Therefore, the poles provide some opportunity to access parts of the home range but the peripheral location suggests the poles might only provide occasional benefit in this regard.

The third scenario is also likely given that we did encounter numerous technical problems with some of our cameras. Over several months in two of the years one camera was not reliable. There was also some indication that the cameras did not always detect gliders that triggered the camera with blank images or just the tail of a glider being detected. In the last year of the study it appeared that gliders were accustomed to the cameras and moved quickly or moved behind the pole to pass the camera. Many images were obtained of gliders just above the collar climbing at an angle to then disappear behind the pole. Possibly they were avoiding the infra-red flash. Although this scenario is likely to account for many missed records it seems unlikely to account for why only a single crossing record was obtained over three years. It seems more plausible that gliders were using the poles to glide to a tree on the other side of the road.

Despite this limitation in relation to confirmed crossings the poles were subject to relatively high levels of use by gliders in some months. The detection rates can be compared to those described as crossing rates in section 2.6. Our detection rates are conservative because they represent only a single detection per night. In year 1 there were 14.3 detections of sugar gliders per month in October-November 2013 on the north-east pole which suggests the pole was being used for home range travel. The south-west pole had rates of detection of 3.9-5.9 per month which also suggests use in home range travel. Rates of detection on the other two poles were lower but this may suggest inconsistent detection. In year 2 the rate of detection was 10.8 per month in June-July 2014 on the south-west pole indicating home range travel. In year 3 it was particularly high (up to 8.4 per month) on the south-east pole, whilst the south-west pole had use of 13-20 nights per month for six months. This suggests home range travel across the road. So across the three years the detection data suggest that at least 3 of the 4 poles were being used in some months for home range travel. This may suggest seasonal use of the home range by sugar gliders, which is to be expected. The key point here is that the glide poles appear to have functioned well for sugar gliders and squirrel gliders, with a confirmed road crossing by a squirrel glider.

Feathertail glider rates of detection were 1-2 per month on 3 of the 4 poles in year 1. It is unclear whether these would represent home range travel or dispersal. However, the rate for this species was 8.9 per month on the south-east pole in year 2, suggesting home range travel. It was low and sporadic in year 3. This species is very fast moving (Goldingay personal observation) so detection on poles may not be consistent. The high detection rate recorded in one period is consistent with home range travel so it is plausible the periodic detections recorded reflect home range travel more broadly.

Two records were obtained of a yellow-bellied glider on the north-east pole over the 3 years. These may represent dispersal movements. There are no data available on the relative abundance of this species in the forest so no conclusion can be reached as to whether the few detections represent avoidance of the glide poles. Given the frequent use by other glider species of glide poles in this study and other studies (Taylor and Goldingay 2012, 2013; Soanes et al. 2015) it seems implausible that the yellow-bellied glider would show an avoidance of the glide poles.

Over the three years on the rope-bridge there were nine detections of sugar gliders, one of a squirrel glider, one of an unidentified sugar glider/squirrel glider and two detections of feathertail gliders. Three records of the sugar glider, one of the squirrel glider, and two of the feathertail glider were of animals moving in a single direction with no later detection, suggesting a crossing had occurred (Goldingay et al. 2013; Soanes et al. 2015). The low overall number of detections over three years for two cameras (11 sugar glider/squirrel glider, and two feathertail glider) compares to the average on a glide pole pair (i.e. two cameras) of 209.5 sugar glider/squirrel glider detections and 35.5 feathertail glider detections. This difference suggests that gliders were favouring the glide poles over the rope-bridge to cross the road. The very low rate of detection on the rope-bridge may suggest occasional dispersal movements across the rope-bridge. Soanes et al. (2015) studied rope-bridges and glide poles. One site where they frequently detected squirrel gliders on a rope-bridge did not have glide poles. At one site with a rope-bridge and glide pole they recorded a crossing rate of 36 per month on a glide pole but no detections on a rope-bridge despite a longer monitoring period on the rope-bridge. More research is needed before any conclusion can be reached about the relative merits of glide poles and rope-bridges.

4.3. Detections in the Underpasses

We detected a range of species within the underpasses from the large eastern grey kangaroo down to bandicoots and brushtail possums. The most frequent user was the swamp wallaby with >1100 crossings detected over the three years. The species that was the next most frequent in crossing through the underpasses was the lace monitor. Of particular significance was the large number of crossings by the red-necked pademelon. This species has not been documented using underpasses before. Also of significance was the large number of crossings by the red fox. A small number of traverses by koalas occurred across the three underpasses.

Some species showed a greater use of one underpass compared to the others. The red fox favoured the combined underpass (90% of records), the eastern grey kangaroo the eastern fauna underpass (83% of records), the red-necked wallaby the eastern fauna underpass (96% of records), the red-necked pademelon the western fauna underpass (90% of records), and the combined bandicoot species the eastern fauna underpass (67% of records).

The published literature on species (bandicoots, swamp wallabies, kangaroos) with home ranges on each side of a road suggest crossing rates through underpasses of >2 crossings per week (Taylor and Goldingay 2003, 2014; Bond and Jones 2008; Chambers and Bencini 2015). This is what was seen for the swamp wallaby across all three underpasses, for the eastern grey kangaroo for the eastern fauna underpass, the red-necked pademelon in the western fauna underpass, the lace monitor in the combined and eastern fauna underpass, and at the combined underpass for the red fox.

Although it is of concern that there was a high level of activity by the red fox at the combined underpass, the activity by this species declined over the 3-year period. The reason for this is unclear but may have arisen from baiting that may have been conducted by neighbouring property owners, though we have no knowledge of this.

The species of particular significance for the underpasses in the study area is the koala. This species was detected using all three underpasses although the number of records was low. However, this low frequency is consistent with what would be expected if koalas were using the underpasses to disperse through the landscape.

We conducted targeted monitoring of the wooden railing in the eastern underpass. This revealed a relatively high frequency of crossings by the black rat and the brown antechinus. Inexplicably the black rat showed a high level of crossings in 2013 (>3 crossing per week) and a complete absence in 2015. The brown antechinus showed a consistent crossing frequency of about 0.5 per week. These species were detected rarely on the ground in the underpasses. The frequent use of the railing by these semi-arboreal species provides support for this measure having value in facilitating the movement of some species across roads that otherwise might rarely cross.

4.4. Detections at the Drop-downs (Road-escape Ramps)

Monitoring of the drop-downs revealed a high frequency of use by various wildlife species. Our data suggest that the drop-downs were actually providing access for a number of species (swamp wallaby, long-nosed and northern brown bandicoots, red fox and lace monitor) to the road reserve where otherwise they would not have access. The swamp wallaby accounted for 62% of records. It did not use all monitored drop-downs but showed very high use of some which probably aligned with important elements of habitat in the surrounding landscape. Drop-down 5 North was monitored for over 200 days in each of the three years. Swamp wallabies moved through this drop-down approximately once every third day in each year.

The high frequency of movement through the drop-downs potentially poses a risk that these animals will find their way onto the road-way and cause a traffic accident. The swamp wallaby accounted for 502 recorded movements over the three years. Our cameras would not have detected every movement and we did not monitor all drop-downs for every day of the year so the frequency of these animals being in the road-side vegetation would be very high. We also detected two passages of a Rusa deer and two by eastern grey kangaroos and 40 by red-necked wallabies. Overall, this shows that the benefit of the exclusion fence keeping animals off the road-side has been severely compromised by the installation of the drop-downs. Surprisingly this did not lead to a high level of road-kill through the study area (see Table 7) but it poses a risk that should not be ignored.

4.5. Type of Use Recorded for the Various Wildlife Structures

Detection of animals on road-crossing structures could represent exploratory use, regular use associated with animals moving around their home range, or irregular use associated with road crossing where a structure has enabled dispersal. Sugar gliders and feathertail gliders were detected on the glide poles relatively frequently but we were unable to demonstrate that crossings had occurred based on an alignment of the time stamp on the images. This may reflect the possibility that animals are gliding back to where they originated, or that the poles are enabling gliding to trees on the opposite side of the road, so animals are only detected on one pole and not two, if pole-to-pole road crossing had occurred. There was one record obtained of a squirrel glider recorded on both poles at the same time, reflecting a pole-to-pole crossing.

Despite the lack of confirmed road-crossings by gliders the rate of use of the poles does suggest that sugar gliders and feathertail gliders were using the poles for home range movements at least periodically. Two records of the yellow-bellied glider suggest the poles were used in dispersal movement by this species. In contrast, only 13 records were obtained of gliders (sugar gliders, squirrel gliders and feathertail gliders) on the rope-bridge and potentially six represented a crossing. The relative lack of use of the rope-bridge compared to the glide poles suggest the possibility of avoidance of this structure compared to the glide poles. Further study is needed to confirm whether this is the case.

Our monitoring of the underpasses has revealed that complete crossings of the road through the underpasses occurred by wallabies, bandicoots, kangaroos, lace monitors, red foxes and pademelons. Usage was particularly frequent for wallabies, kangaroos and lace monitors. These movements were associated with home range movements because these animals were regularly using both sides of the highway. Only nine traverses of the underpasses were recorded for the koala. However, this level of use is consistent with dispersal movement so the underpasses may be effective in this regard.

Monitoring of the drop-down escape ramps revealed frequent use by the swamp wallaby and bandicoots, as well as less frequent use by other large mammals such as the red-necked wallaby, eastern grey kangaroo and Rusa deer. These records reveal that these structures have enabled these species to include areas of the road verge inside the exclusion fence within their home ranges. This suggests that these structures are being used for purposes beyond their intended use (occasional escape ramps) and that many species now have a two-way passage onto the road-side which may lead to traffic hazards and road-kill.

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