A 10-year Ecological Monitoring Program for the Yellow-bellied Glider

Warrell Creek to Nambucca Heads Pacific Highway Upgrade Project

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Background

A proposal is required to develop a 10-year monitoring strategy for the yellow-bellied glider in relation to the operation phase of the Warrell Creek to Nambucca Heads Pacific Highway Upgrade Project. A baseline monitoring project is currently being conducted.

The NSW EPA has requested that the post-construction monitoring of the yellow-bellied glider be as comprehensive as the baseline monitoring. The EPA has requested that this monitoring be replicated over a 10 year period. The EPA also requires that the monitoring strategy be developed with consideration of future logging and fire operations conducted by the NSW Forestry Corporation in Nambucca State Forest (Nambucca SF).

The monitoring strategy proposed here will outline the baseline monitoring for the yellow-bellied glider at Nambucca SF and two reference locations. It will describe a 10-year monitoring strategy that is developed from the baseline survey. It will also describe a study to be activated in the event of logging or wildfire occurring within Nambucca SF. These forms of habitat disturbance could confound an examination of the influence of the Pacific Highway upgrade on the yellow-bellied glider within Nambucca SF. The disturbance study will allow any influence to be described. The 10-year monitoring can then be interpreted in that context.

Hypothesis to be tested

The hypothesis to be tested by this study is that the Pacific Highway Upgrade does not adversely affect the local population of the yellow-bellied glider in Nambucca SF. The new alignment of the Pacific Highway will extend through Nambucca SF where it occurs on the western side of the current highway and cut it approximately in two. This could have adverse consequences for the glider population if not adequately mitigated. The monitoring strategy proposed here is to determine how the local population responds over the 10 years post-construction.

Response to the highway upgrade could occur at the level of the individual glider and/or at the population level. An individual level response can be measured by comparing forest use adjacent to the highway upgrade before and after construction. A population level response can be measured by comparing the proportion of survey sites occupied by yellow-bellied gliders in Nambucca State Forest with that measured at reference locations before and after construction.

Individual glider response: Yellow-bellied gliders may alter their use of the forest in areas adjacent to the new highway due to the loss of foraging habitat or due to the loss of habitat connectivity. This response is one that may help to explain a subsequent population response or the response may be confined to a small number of animals living near the new highway location. The prediction is that the new highway will cause an individual response because local habitat availability will be reduced and the highway will at least initially pose a barrier to movement.

Population response: If the upgrade project is adequately mitigated then the abundance of yellow-bellied gliders in Nambucca SF should not decline relative to any control or reference sites. If mitigation is inadequate then glider abundance should decline relative to reference sites.

Methods to address the hypothesis

Individual glider response: Yellow-bellied glider activity or habitat use in the forest adjacent to the new highway can be measured by spotlighting. This may only provide a limited assessment of glider activity. The base-line survey will occur on only three nights spread over approximately six weeks. This is a very short period in which to characterise habitat use.

A much more detailed assessment of habitat use can be provided by Song Meters. These acoustic recording devices can be placed in the field to record for months at a time and provide a much more detailed record of activity for locations along the highway route. Specialised computer software is used to build a call signature for the yellow-bellied glider. This is then used to scan many thousands of hours of recordings to identify calls of the yellow-bellied glider. Song Meters can be used to generate indices of activity such as the number of nights the yellow-bellied glider was detected. Therefore, six Song Meters placed along the highway route (three each side) can reveal the use of the road-side habitat and how that changes over time. Song Meters placed at reference locations well away from the road route will enable any changes in activity to be put into context.

Population response: A population level response will be assessed by comparing the proportion of survey sites occupied by yellow-bellied gliders before and after highway construction. The surveys 'before and after' construction will take place in Nambucca State Forest where the highway will be constructed and at two reference locations, Yarriabini National Park and Ngambaa Nature Reserve. Spotlighting surveys will be conducted at independent sites dispersed across all three of these locations.

Trees incised by yellow-bellied gliders in sap feeding: Eucalypt sap comprises a significant component of the yellow-bellied glider diet at most locations (Wallis and Goldingay 2014). Initial surveys in Nambucca SF have revealed only a single tree that appears to have been incised by yellow-bellied gliders and with scars several years old. Examination of a tree identified by forestry workers as a glider-incised tree appears to be an incorrect. Monitoring of glider-incised trees may be used to index glider population levels (Goldingay and Kavanagh 1991). However, this approach shows no promise in Nambucca SF.

Baseline survey

Individual glider response: There are six survey transects located within 300 m of the highway route in Nambucca SF. These will each be surveyed three times before highway construction. This will provide limited assessment of changes in habitat use in the zone close to the new highway.

Six Song Meters have been installed in Nambucca SF within 250 m of the highway route. Two other Song Meters have been installed 600-1000 m from the highway route. These are likely to provide 3 months of data prior to highway construction. The Song Meters have been programed to record for a 3 h period after dark. This is the period in which yellow-bellied gliders are most vocal (Goldingay 1994) and recording for only part of the night enables long periods of continuous monitoring.

Population response: Forty survey transects have been installed within Nambucca SF to enable assessment of whether occupancy changes in response to the highway construction. The number of survey sites was increased from the number originally proposed to account for an expected low occupancy due to habitat being only of modest suitability arising from forest dominance by blackbutt (*Eucalyptus pilularis*) and a relative lack of old growth forest elements.

Assessment of whether a change in occupancy by gliders in Nambucca SF is a response to highway construction rather than a response to some other environmental factor such as annual rainfall requires comparison with several reference locations. The baseline survey has included 20 survey sites in Yarriabinni National Park and 30 in Ngambaa Nature Reserve. The number of sites reflects the size of the reserve.

Table 1. Summary of baseline surveys for yellow-bellied gliders. The 6 sites used in the habitat use spotlighting are a subset of the 40 population monitoring sites.

Survey type	Locations	Number of Sites	Description
Habitat use monitoring	Highway alignment	6	Transect spotlighting
	Nambucca SF	6	Song meter monitoring
Population monitoring	Nambucca SF	40	Transect spotlighting
	Yarriabini NP	20	Transect spotlighting
	Ngambaa NR	30	Transect spotlighting

Proposed 10 year monitoring strategy

General outline

The 10-year monitoring strategy is proposed to be as comprehensive in any year as the baseline survey. The extent of the baseline survey has been increased slightly from what was planned due to a low frequency of detections of yellow-bellied gliders in Nambucca SF in the initial round of surveys. The particularly low density of yellow-bellied gliders will be a consequence of low quality habitat. The Nambucca forest is dominated to a large extent by blackbutt and with a low density of hollow-bearing trees. These factors have also been suggested to explain the low use of blackbutt forest in south-east Queensland (Eyre 2007). Yellow-bellied gliders tend to prefer forest containing multiple tree species (Kavanagh 1987; Eyre 2007; Kambouris *et al.* 2013).

A novel component of the baseline monitoring is the inclusion of Song Meters (i.e. audio-recording devices) to provide a measure of relative habitat use and an index of continued occupancy of forest areas over time. The yellow-bellied glider is the most vocal of any marsupial in the world with calls given repeatedly throughout the night but predominantly in the first several hours after dark (Kavanagh and Rohan-Jones 1982; Goldingay 1994). Song Meters can detect gliders over a much longer continuous period of time compared to spotlighting (months compared to nights) so it is proposed that this element should be expanded from what is being done in the baseline monitoring.

10-year monitoring strategy

Annual monitoring across a 10-year period is not required. It is proposed that monitoring take place in 5 of the 10 years post highway construction (Table 2). The first two years post-construction is the period in which some disruption to the local population is expected, even if the population is able to adjust to the habitat disturbance over a longer period. So surveys are proposed for each of those years. Surveys could then be conducted two years later and then at two 3-year intervals.

Table 2. Summary of the 10-year monitoring strategy for yellow-bellied gliders.

Year	Locations
1	Nambucca SF, Yarriabini NP, Ngambaa NR
2	Nambucca SF, Yarriabini NP, Ngambaa NR
4	Nambucca SF, Yarriabini NP, Ngambaa NR
7	Nambucca SF, Yarriabini NP, Ngambaa NR
10	Nambucca SF, Yarriabini NP, Ngambaa NR

Survey details

The baseline survey was developed based on 30 years' experience of studying the yellow-bellied glider. This survey was fine-tuned during the initial baseline survey to accommodate low occupancy by yellow-bellied gliders across Nambucca SF.

Song Meters have been installed along the highway route to assess changes in habitat use post-construction. This method should be expanded so that all three large blocks of forest that comprise Nambucca SF are sampled (Figure 1). It is proposed that six Song Meters should be installed in each of the three forest blocks. This technique should be able to detect gliders even if they are rarely detected by spotlighting surveys due to the greater number of nights that can be sampled. This has the advantage that two data sets can be used to test the hypothesis that the Pacific Highway Upgrade does not adversely affect the local population of the yellow-bellied glider.

A further advantage of expanding the Song Meter monitoring is that the results of this technique could be compared directly to those of the spotlighting surveys during the first three survey periods (years 1, 2 & 4) and if it proves to be a more effective survey technique then it could be used as the only technique in subsequent years to assess population stability.

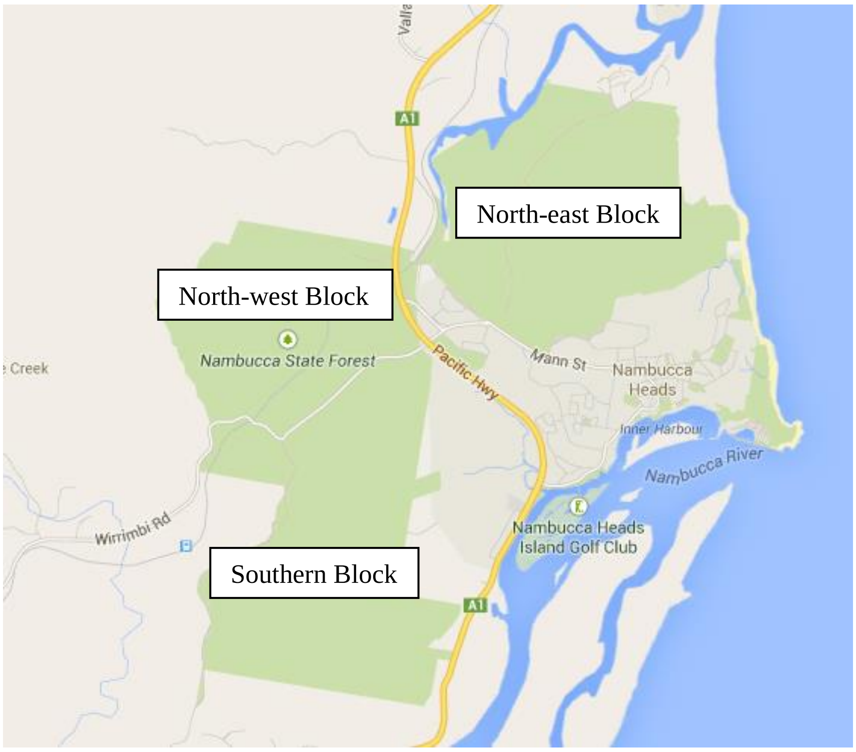

Figure 1. The three forest blocks comprising Nambucca State Forest. The southern block is that area south and east of the Old Coast Road.

Incorporating logging and fire into the 10 year monitoring strategy

Influence of logging and fire on the yellow-bellied glider

Several studies have suggested that the yellow-bellied glider is adversely affected by changes to forest structure associated with logging (Milledge *et al.* 1991; Eyre and Smith 1997; Lindenmayer *et al.* 1999; Incoll *et al.* 2001), whereas some studies have suggested otherwise (Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995). To some extent the influence of logging will depend on the severity of logging.

Nambucca SF is actively managed for timber production. Broad areas within the north-east portion of the forest surrounding Hyland Park Road and the north-west portion of the forest, west of the Pacific Highway, were logged in 2010 and 2012 (Figure 2). It is likely that logging will take place in other areas of Nambucca SF during the next 10 years. Due to the long history of logging in Nambucca SF the forest is dominated by tree age classes that have few hollow-bearing trees. Recent logging has excluded approximately 50% of the forest area from logging (Spencer 2012). It is expected that future operations will be similar. Nonetheless, it is expected that future logging will have some impact on the local yellow-bellied glider population. Therefore, this needs to be accommodated within the 10-year monitoring strategy.

The Forestry Corporation of NSW is likely to conduct hazard reduction burning in Nambucca SF to reduce the risk of wildfire. These fires are mostly confined to the understorey and are unlikely to have an impact on yellow-bellied gliders.

Wildfire could potentially occur during the next 10 years in Nambucca SF. This forest is close to the urban area of Nambucca Heads and burnt patches are evident in the forest in 2014 which appear to be the result of arson. The impact of wildfire on populations of yellow-bellied gliders is somewhat unknown. Recently, McLean (2012) suggested that recent fire had a negative influence on the presence of yellow-bellied gliders in forest on the northern tablelands of NSW whilst Kambouris *et al.* (2013) found that yellow-bellied gliders were frequency detected in 2010 in areas of Kosciuszko NP extensively burnt in 2003. The extent and severity of a wildfire will influence the impact it has on arboreal marsupials, though it appears many species are negatively affected to some extent (Lindenmayer *et al.* 2013). Therefore, it is predicted that an extensive wildfire within Nambucca SF could have an adverse influence on the distribution and abundance of the yellow-bellied glider.

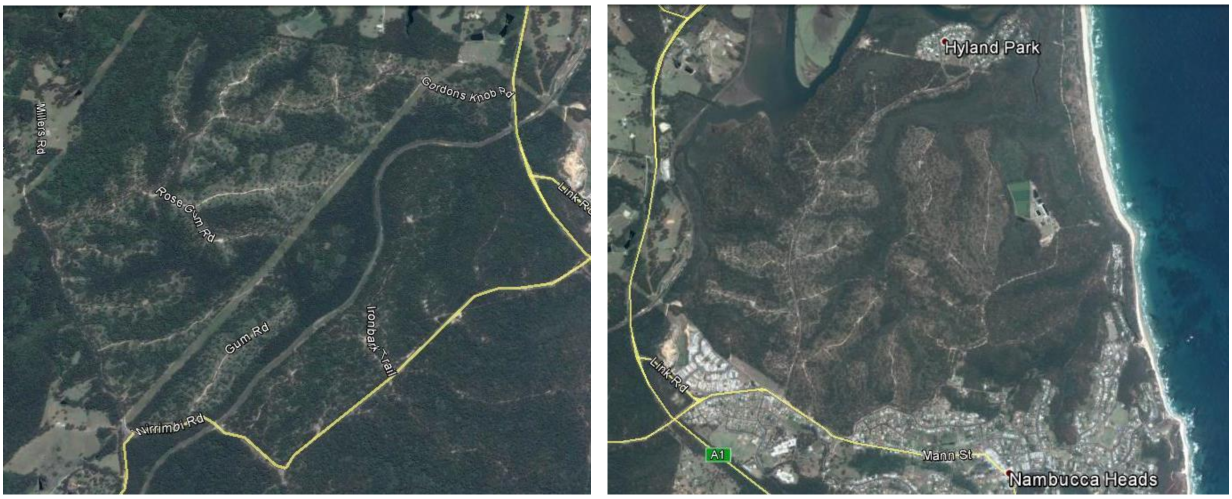

Figure 2. The north-west portion (*left*) and the north-east portion (*right*) of Nambucca State Forest showing evidence of recent logging (lighter areas surrounding the forest road network).

Incorporating logging and fire into the 10-year monitoring strategy

The 10-year monitoring strategy needs to anticipate that logging and wildfire will occur in this period. The baseline study has included 40 survey sites across Nambucca SF. This includes 10 sites in the north-east portion, 18 in the southern portion (south of the new highway route) and 12 in the north-west portion. Two of the three areas have been logged during the last four years so it is anticipated that only the southern portion will be subject to logging over the next 10 years. The three areas are separated by major roads which are likely to provide barriers to the passage of fire so it is expected that not all will be subject to fire in the same year. It is also expected that whilst the southern portion remains available for future harvest that it will be managed to exclude wildfire to the extent that it can be excluded.

In the event that logging and/or wildfire occurs within Nambucca SF, an additional study should be activated to determine whether these disturbance events affect the occurrence of the yellow-bellied glider so that this can inform the 10-year monitoring and determination of whether the Pacific Highway upgrade has negatively affected the local population of yellow-bellied gliders.

The separation of the three broad areas of forest and their recent logging history suggests that future disturbance from logging, and/or fire will not occur simultaneously in each forest block. Therefore, it is proposed that should logging or wildfire occur in any of the three areas that additional surveys should be conducted within 6 months of any event. This should entail a 3-counts per site spotlighting survey of baseline transects, as well as increasing the use of Song Meters to both detect and assess habitat use by yellow-bellied gliders (Table 3). This would involve the deployment of 6 Song Meters in each forest block. The areas not affected by disturbance would become reference sites to the block that is affected. In the unlikely event that several of the three forest blocks are affected simultaneously then forest blocks within Yarriabini NP and Ngambaa NR should also be included as reference locations.

Table 3. Summary of surveys for yellow-bellied gliders to be activated if logging or wildfire occurs within Nambucca SF.

Survey type	**Locations**	**Number of Sites**
Transect spotlighting	North-east block	10
	North-west block	12
	Southern Block	18
Song meter monitoring	North-east block	6
	North-west block	6
	Southern Block	6

Review of monitoring strategy

The yellow-bellied glider monitoring strategy should be reviewed after each year of surveys both in terms of what this reveals about how the local population is tracking post highway construction but also in terms of how effective the monitoring strategy is for monitoring populations of yellow-bellied gliders. Adjustments to the intensity of the survey should be made if required.

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Baseline Monitoring of the Yellow-bellied Glider Population in Nambucca State Forest –

Pacific Highway Upgrade:

Warrell Creek to Nambucca Heads

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Final Report

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Report Prepared for the NSW Roads & Maritime Services

Executive summary

The Warrell Creek to Nambucca Heads section of the Pacific Highway upgrade involves a new alignment of the Pacific Highway that extends through a major part of Nambucca State Forest. The yellow-bellied glider is a New South Wales-listed vulnerable species that occurs within Nambucca State Forest and may be affected by the highway upgrade. This report describes surveys conducted for the yellow-bellied glider in Nambucca State Forest with the aim of establishing a baseline of population abundance and distribution against which future surveys conducted post-construction can be compared. The post-construction surveys will enable an assessment of the success or otherwise of highway impact mitigation strategies. In order to identify fluctuations in population size due to environmental variation and unrelated to the highway upgrade, two control populations were also surveyed. One was in Yarriabini National Park to the south-east of Warrell Creek and the other was in Ngambaa Nature Reserve to the south-west of Warrell Creek. These reserves are located 12-22 km south of Nambucca State Forest.

Spotlighting surveys were conducted on 40 transects in Nambucca State Forest, on 20 transects in Yarriabini National Park and on 32 transects in Ngambaa Nature Reserve. Each transect was spotlighted on three occasions with an interval of 3-4 weeks between repeat surveys. Acoustic recording devices were installed to gain insight into whether yellow-bellied gliders used forest habitat adjacent to the proposed new alignment of the highway through Nambucca State Forest. The yellow-bellied glider is a highly vocal species with individuals uttering 20 or more calls per night throughout the year which makes it amenable to using acoustic recording to document habitat use.

Yellow-bellied gliders were detected on five transects in Nambucca State Forest. This represents only four social groups because in one instance detections were from an area intermediate between two transects. Yellow-bellied glider social groups may occupy an exclusive area of 50-100 ha. When this is coupled with the spacing of the 40 transects in Nambucca State Forest it is likely that only 5-6 social groups were present during August to October 2014. Yellow-bellied gliders were detected on seven transects in Yarriabini National Park and on 10 transects in Ngambaa Nature Reserve with these representing individual social groups. Searches for yellow-bellied glider incised sap trees across vast areas of forest detected only a single old incised tree in Nambucca State Forest, while none were located in Yarriabini National Park or Ngambaa Nature Reserve.

Acoustic recording devices operated over two months at eight sites in Nambucca State Forest for 3-hours per night. Yellow-bellied glider calls were detected during only 2% of 580 site survey nights. Acoustic recording occurred at two locations in each of Yarriabini National Park and Ngambaa Nature Reserve for 3-hours per night for a total of 282 site survey nights. This produced detections of yellow-bellied glider calls on 25% of site nights. Acoustic recording in Nambucca State Forest detected glider calls at individual sites near the path of the Pacific Highway upgrade on 0 to 4% of nights. This compares to 16-28% of nights at the four sites along existing roads in Yarriabini National Park and Ngambaa Nature Reserve.

These results provide an adequate baseline of the yellow-bellied glider population in Nambucca State Forest and of two reference populations before the Pacific Highway Upgrade. This can be compared to that after the Pacific Highway Upgrade and ultimately allow a conclusion to be reached as to how the population in Nambucca State Forest has responded to the Pacific Highway Upgrade.

Table of Contents

1. Introduction

The Roads and Maritime Services (RMS) are upgrading the Pacific Highway between Warrell Creek and Nambucca Heads. The new alignment of the highway will extend through a large part of Nambucca State Forest where there is a population of the yellow-bellied glider (*Petaurus australis*). This species is listed under the New South Wales *Threatened Species Conservation Act* 1995 as a vulnerable species.

The RMS Environmental Assessment for this section of the Pacific Highway Upgrade requires:

A strategy would be developed … for monitoring the Yellow-bellied Glider population in the affected area of Nambucca State Forest as part of the flora and fauna management plan.

This requires the development and implementation of a monitoring program to provide baseline data for the yellow-bellied glider in Nambucca State Forest prior to the commencement of construction.

This report describes a project devised to meet this requirement. This project had three key aims: i) to collect baseline population data within Nambucca State Forest against which a comparison can be made to population surveys conducted some time later when the Pacific Highway through Nambucca State Forest has been completed, ii) to collect population data for two control populations concurrently with that in Nambucca State Forest, and iii) to provide a baseline of yellow-bellied glider activity along the highway footprint through Nambucca State Forest for future comparison. That is, so a future evaluation can be made of whether local habitat use by yellow-bellied gliders has been altered by the loss of habitat along the highway footprint.

The first aim will be addressed by conducting surveys throughout Nambucca State Forest. The proportion of survey sites occupied by yellow-bellied gliders will be used as an index of the size of this population. Repeating these surveys at a later date, during and after highway construction will allow an assessment of the trajectory of this population, whether it remains the same, increases or declines.

The second aim will be addressed by conducting surveys of two control populations located within the National Park estate. This allows any influence of environmental factors such as changes in rainfall on population dynamics to be identified because the control populations should not be under any influence of the highway upgrade. Each of the three populations will be compared over time against their baseline value. The proportion of survey sites occupied by yellow-bellied gliders will be used as an index of the size of these populations.

The third aim will be addressed in two different ways: i) by examining the surveys of those transects located along each side of the highway footprint in Nambucca State Forest, and ii) by using acoustic recording devices (Song Meters) to record patterns of activity and habitat use each side of the highway footprint.

Background on the yellow-bellied glider

To facilitate an understanding of the findings of this report the ecology of the yellow-bellied glider is briefly reviewed. The yellow-bellied glider feeds on a range of foods such as nectar and pollen, eucalypt sap, insect honeydew (i.e. secretions of sap-sucking insects), manna (dried sap that accumulates on leaves and small branches due to insect and other damage) and insects and spiders (Henry and Craig 1984; Goldingay 1986; Kavanagh 1987; Quin et al. 1996; Carthew et al. 1999). The yellow-bellied glider lives in family groups of 2-6 individuals, consisting of an adult male, 1-3 adult females and subadult individuals (Goldingay 1992; Goldingay et al. 2001). Only a single young is born per year which means that the size of individual social groups varies only slightly from year to year in response to breeding. Variation in group size can occur due to a reduction in food availability such as a prolonged period of poor flowering where nectar and pollen are staples in the diet (Goldingay 1992). Groups occupy exclusive territories that are typically about 50 ha in area, though they could be up to 100 ha in area (Goldingay and Kavanagh 1993; Goldingay and Quin 2004).

A consequence of a small group of individuals occupying a large area is that population monitoring needs to be conducted over a large area of forest to be inclusive of an adequate number of groups. This will be central to providing an index of the dynamics of a local population over time. The only way this can be done in a cost-effective way is through spotlighting surveys. These surveys actually rely on detecting the calls of gliders rather than observing gliders directly. The yellow-bellied glider is an extremely vocal animal, with individuals calling 5-15 times per hour for several hours after dark (Kavanagh and Rohan-Jones 1982; Goldingay 1994). These calls can be detected up to 500 m away by human observers. Gliders are also highly mobile, being able to cover 600 m in 20 min as they forage or >2 km across a night (Goldingay 1989; Goldingay and Kavanagh 1991). The combination of frequent calling and gliders frequently moving facilitates their detection even without direct observation. However, these factors can lead to overestimating how many individuals may be present in an area (Goldingay and Kavanagh 1993) so caution is required when attempting to estimate the number of individuals during surveys.

2. Methods

a. Study areas

Surveys were conducted in Nambucca State Forest (hereafter Nambucca), Yarriabini National Park (hereafter Yarriabini) and Ngambaa Nature Reserve (hereafter Ngambaa), on the north coast of New South Wales (Figure 1). Survey transects were located in each of these areas along the main management roads. Transects were placed a minimum of 500 m apart to increase the likelihood that yellow-bellied gliders detected on one transect were different to those detected on a neighbouring transect. There were 40 transects located in Nambucca (Figure 2), 20 transects in Yarriabini (Figure 3) and 32 transects in Ngambaa (Figure 4). The allocation of 40 transects within Nambucca meant that the whole State Forest was well covered and with the expectation that yellow-bellied glider home ranges were 50-100 ha in size and non-overlapping (Goldingay and Kavanagh 1993; Goldingay et al. 2001), then possibly no more than two glider groups might evade detection.

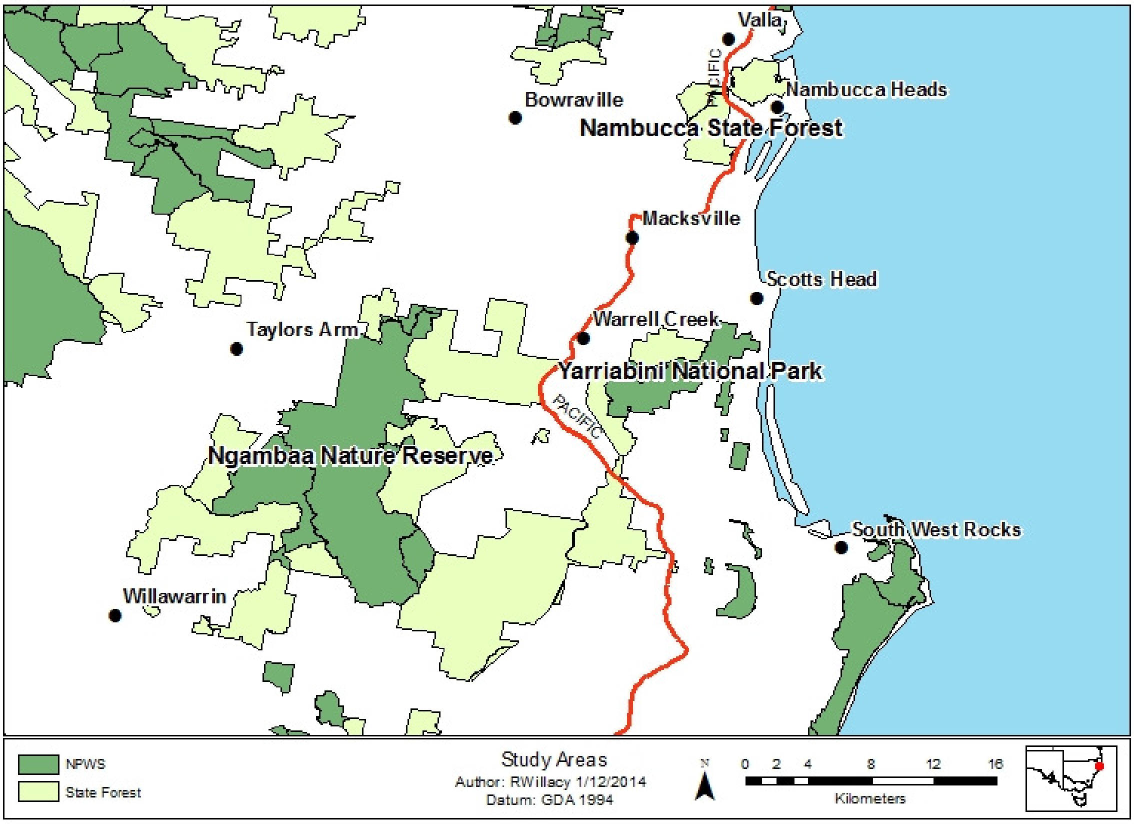

Figure 1. Location of the three study areas surveyed for yellow-bellied gliders. The red line shows the current path of the Pacific Highway.

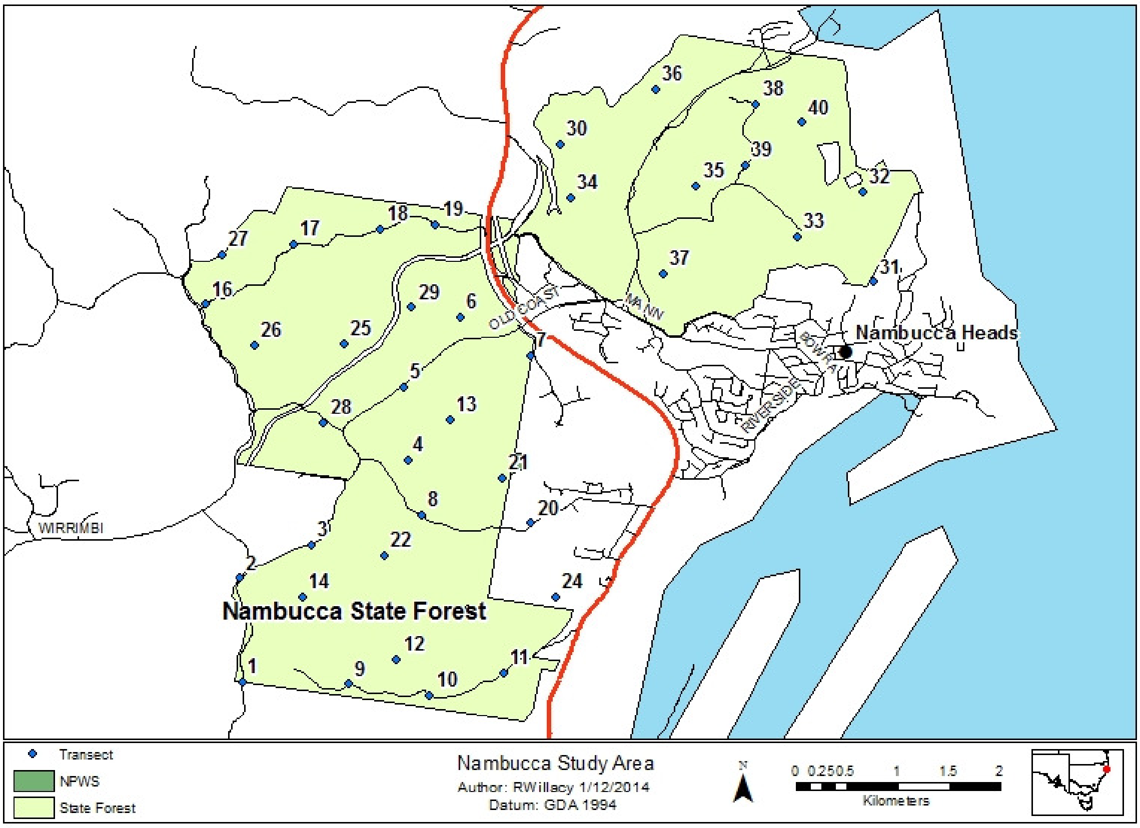

Figure 2. Location of the 40 survey transects in Nambucca State Forest. The red line shows the current path of the Pacific Highway.

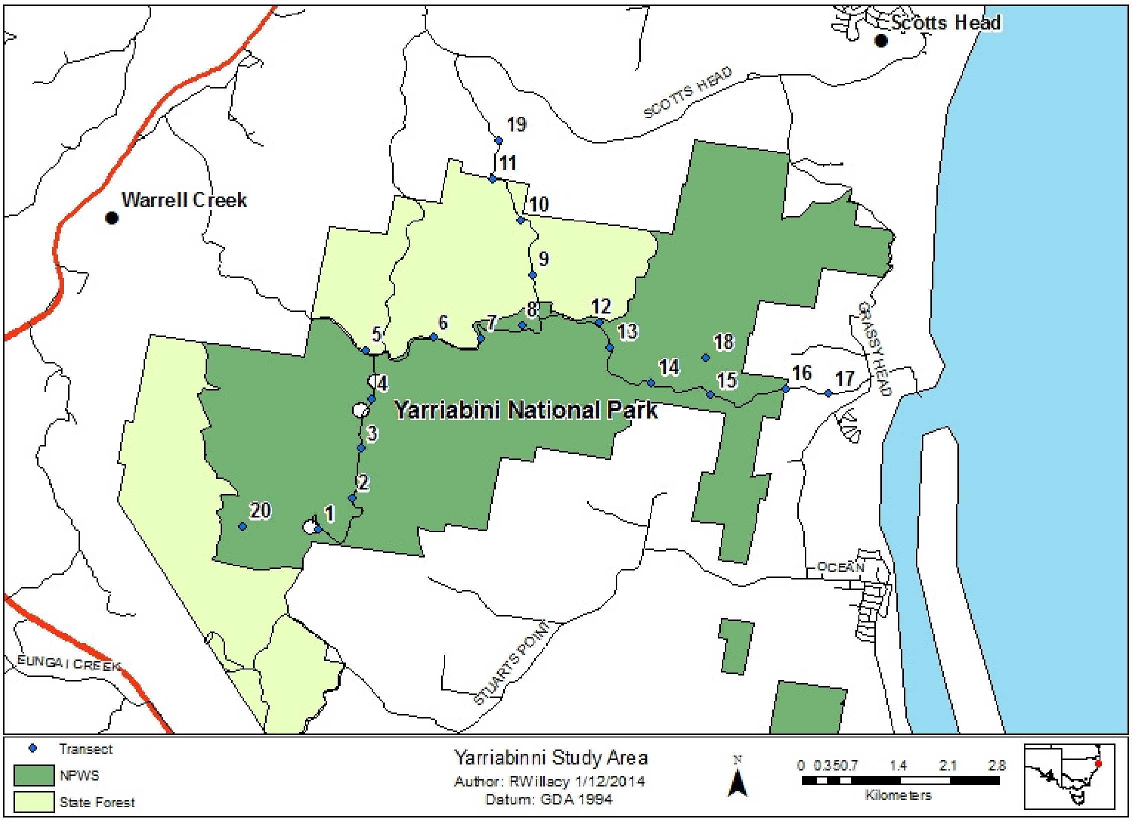

Figure 3. Location of the 20 survey transects in Yarriabini National Park. The red line shows the current path of the Pacific Highway.

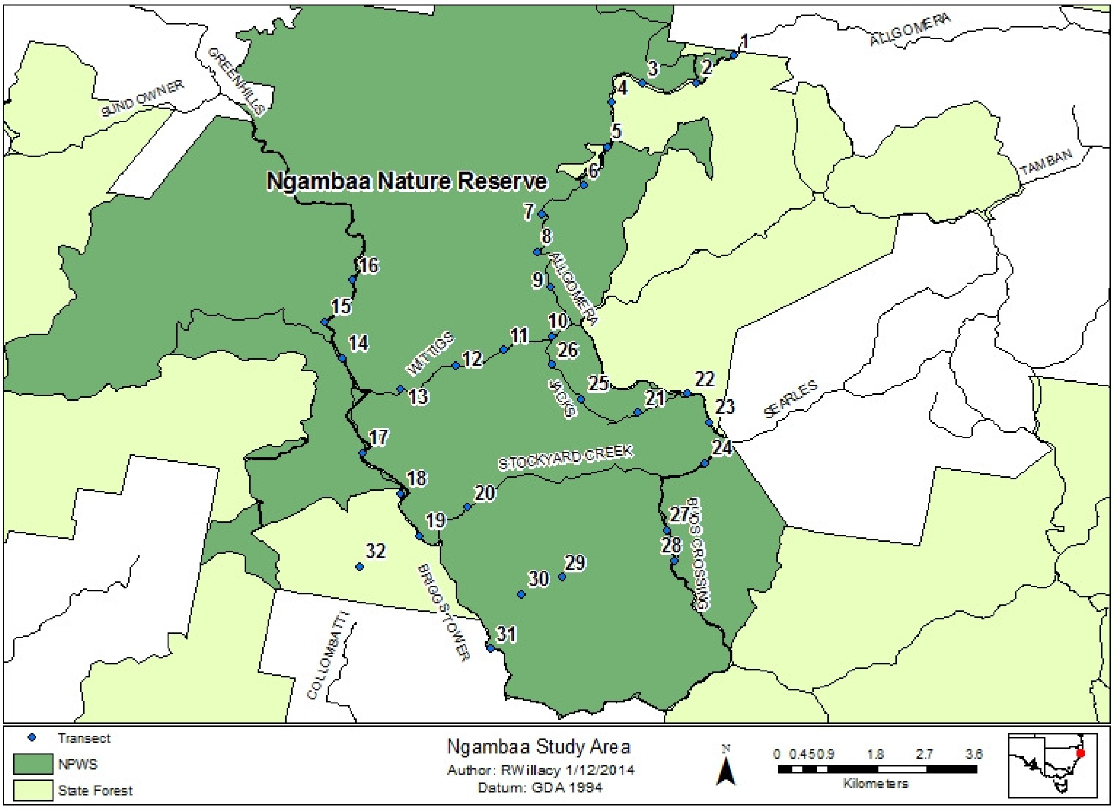

Figure 4. Location of the 32 survey transects in Ngambaa Nature Reserve.

b. Spotlighting surveys

The field survey team for this project consisted of Ross Goldingay, Darren McHugh, Jonathan Parkyn and Rosie Willacy. Surveys were conducted along each 200 m transect commencing after dark. Each transect was spotlighted using a M14 (225 lumens) or P14.2 (350 lumens) Led Lenser flashlight. Binoculars were used as required. Surveys were conducted for a period of at least 20 min per transect At the 10 min mark recorded calls of the yellow-bellied glider (4 calls) and the powerful owl (4 calls) were broadcast from a portable speaker that should have been loud enough for one of these species within at least 200 m of the transect to hear. Any animals detected were identified and the factor that enabled detection recorded for the gliders (i.e. call, eye-shine, movement of animal, sound of animal movement).

Surveys in Nambucca were conducted in three periods: 14, 18 & 19 Aug 2014; 15 & 16 Sept 2014; and 20 & 21 Oct 2014. Surveys in Yarriabini were conducted in three periods: 1 Sept 2014; 22 Sept 2014; and 27 Oct 2014. Surveys in Ngambaa were conducted in three periods: 2 & 9 Sept 2014; 23 & 29 Sept 2014; and 28 & 29 Oct 2014. Weather conditions for spotlighting were dry except on 20 and 21 October 2014 during the third survey in Nambucca. It was dry during surveys on 19 transects. Light drizzle occurred sporadically during 18 transects, and more persistent rain during three transects. A yellow-bellied glider was detected on one of these three transects during rain.

Surveys commenced after dark by four people placed on different transects. The timing and direction of glider calls were compared by observers at completion to ensure double-counting did not occur when neighbouring transects were surveyed. Transect 40 in Nambucca was not marked out until the second round of spotlighting so this transect was surveyed twice but all others were surveyed three times. Surveys were conducted in the first 4 hours after dark for 86% of the 275 transect surveys.

c. Habitat analysis

We measured available habitat in two ways: by recording the forest types present along the 200 m spotlight transect (a forest type had to be intersected by at least 25 m of the transect to be counted); and by recording the number and diameter at breast height (DBH) of all trees (>10 cm DBH) within a circular plot of radius 10 m placed within the mid-point of each transect and randomly assigned to one side of the road. The first location where such a plot could be positioned was used.

Prior to analysis the habitat data were checked for colinearity by conducting a Pearson correlation analysis. If any variables showed high correlation with another then only one would be used. No two variables showed a correlation coefficient >0.5 so all were used in the analysis. All habitat variables were transformed by Ln(x+1) to improve normality.

The habitat and survey data were analysed using program PRESENCE (Version 5.7; USGS Patuxent Wildlife Research Center, Laurel, MD, 20708, USA) to estimate occupancy (ψ) and detection (p). Models were constructed using the habitat variables (covariates) in a series of steps. Initially, a series of models were built using each individual habitat variable (i.e. 19 models). Models were ranked by PRESENCE using Akaike's Information Criterion (AIC) to identify the most likely model (Burnham and Anderson 2002). This procedure ranks models from the lowest to the highest AIC value and the difference in AIC (ΔAIC) is calculated between each model and the top model. Where ΔAIC was <2, models were treated as being equivalent in their ability to explain the data (Burnham and Anderson 2002). Only those models in which the delta-AIC was <5 were retained. PRESENCE also generates a value of model weight (w) which gives an indication of how plausible a model is relative to other candidate models (Eyre 2007). In step 2, each model from step 1 in which w>0.1 was combined with the retained habitat variables and again ranked by AIC. Only models in which the combined variables improved model fit were retained.

Several variables were recorded at the time of each survey to include in models to examine what influence they had on the probability of detection. This included: hour after dark (1-6), moon brightness (0-3), rain (present or absent), and breeze (0-3). These were included in models in a similar way to that described for the habitat variables. Finally, models were run that included the top survey variables and the top habitat variables.

d. Song Meter surveys

We installed eight Song Meters (SM3; Wildlife Acoustics) within Nambucca, two each within Yarriabini and Ngambaa and one (SM2) at a site near Cockburn's Lane, approximately 1.5 km south of Warrell Creek (Figure 5). These were attached to trees approximately 6 m above the ground. They were programmed to record each day for 3 hours after dark. Those in Nambucca were established during 15-20 Aug 2014, those in the reserves during 9-10 Sept 2014 and that at Warrell Creek on 23 Sept 2014. Of those in Nambucca, six were installed along the new highway route (three each side), within 300 m of the route and 500-900 m apart along the route. Two were also installed within the forest 700-1200 m from the highway route.

Song Meters were powered by four 1.5 V D-cells and recorded audio data onto two 32 GB SD cards. Batteries and SD cards were replaced after approximately 2 months. Following a high rainfall event one Song Meter (#8) in Nambucca suffered a water leakage and had to be removed. A replacement Song Meter could not be installed until 27 October 2014.

Analysis of the audio recordings was by automatic detection using the sound recognition software Song Scope (Wildlife Acoustics). To create a signature vocalisation (referred to as a Recogniser) with which to detect yellow-bellied glider calls, calls were annotated from spectrograms of high quality recordings. These were sourced from: Nocturnal Bird & Mammal Calls of NE NSW – David Stewart; An Evening in the Australian Bush – Andrew Skeoch and Sarah Koschak; and field recordings specifically for this project from Cambridge Plateau in Richmond Range National Park, recorded on 11 August 2014 and during 8 to 30 September 2014.

A Recogniser was built from the gliding gurgle call type, as it is a feature of most of the vocalisation types and is frequently given by the yellow-bellied glider. The Recogniser was built using an iterative approach, including or excluding annotated vocalisations and changing model parameters based on the effect of the changes on the model statistics.

The Recogniser is characteristic of all of the annotated vocalisations (the training data) and model parameters. The model statistics (model average and standard deviation) therefore reflect the fit of the Recogniser to the training data and to training data that was excluded from the analysis for cross training purposes. A low score (e.g. < 50%) or large standard deviation (>15%) indicates that the generated model is not expected to perform well. Training data were included or excluded and parameters changed to maximise the score and standard deviation (indicating that the model is a highly accurate representation of the vocalisations). The strength of candidate models were tested further by searching both a high quality recording (David Stewart) and a field recording where the number of vocalisations was known and comparing the number and accuracy of vocalisations detected by each candidate Recogniser.

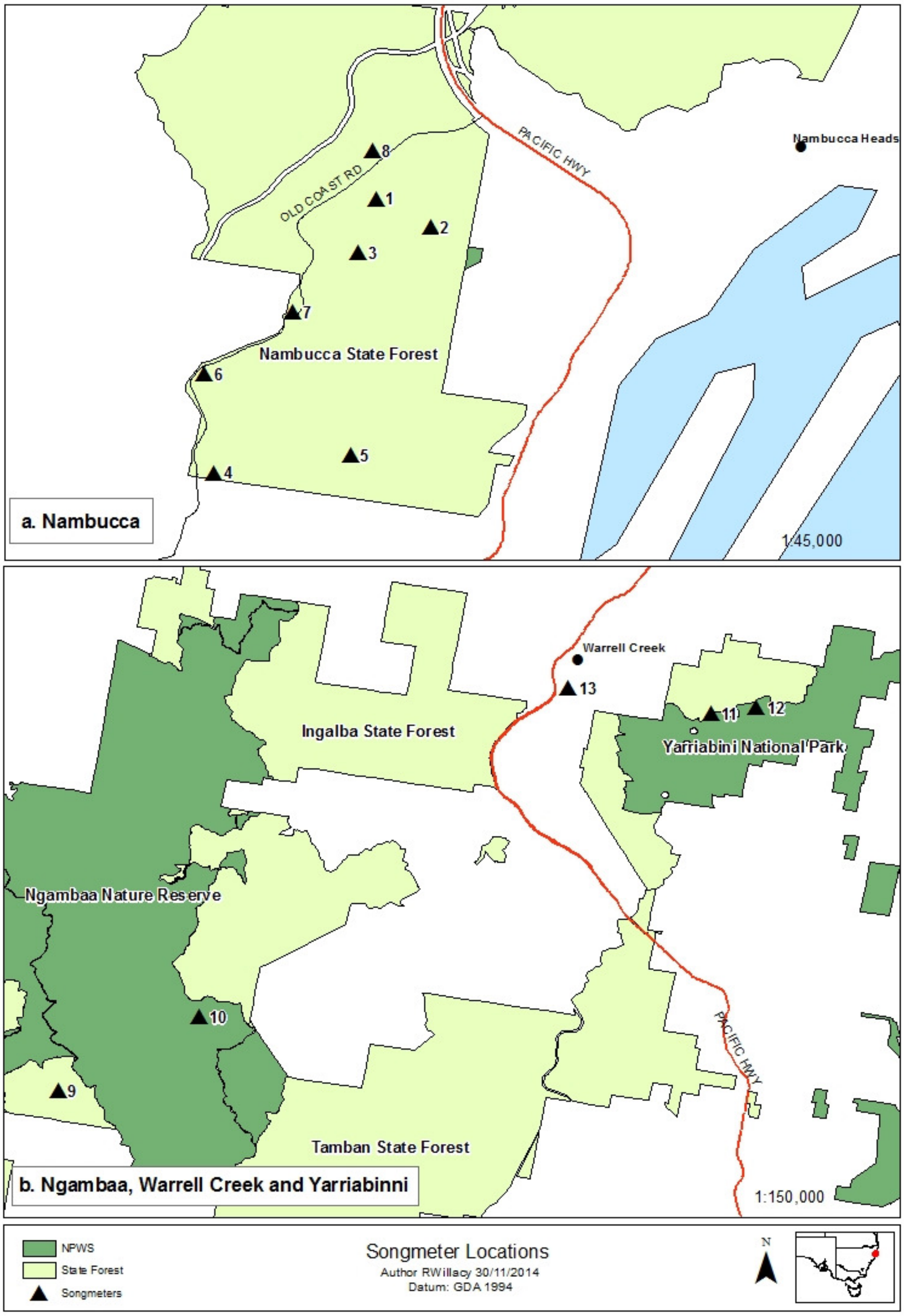

Figure 5. Location of 13 Song Meters across the study areas.

The final candidate Recogniser was used to run a test dataset that contained 23, 3-hour field recordings (Richmond Range). For each detected vocalisation, Song Scope produces quality and score values that are used to indicate the likelihood of a positive match with the recogniser. Twenty-two of the detected vocalisations were investigated and their score and quality averaged. These averages (Quality 45, Score 70) were used as the minimum levels for these parameters. A quality value of 5.0 indicates the statistical average values, with lower numbers indicating less, and higher numbers indicating greater confidence. The score value is a percentage and represents the statistical fit of the candidate vocalisation to the Recogniser's model. Therefore, for a candidate vocalisation to be counted, it must achieve both the minimum quality and the minimum score.

The effectiveness of the Recogniser to identify yellow-bellied glider calls from the audio recordings was assessed. The Recogniser may identify calls within the audio recordings that are not actually made by yellow-bellied gliders. These are referred to as *false positives*. These were controlled for by checking all identified calls. Conversely, the Recogniser may fail to identify calls actually present. This is referred to as *false negatives*. This may happen because yellow-bellied gliders are highly mobile and will be located at varying distances from the Song Meters, so the strength or loudness of different calls will vary. In addition, there may be background noise (planes, cars, calls of other animals) that may mask the yellow-bellied glider calls so they are not identified. The severity of the false negatives was assessed by listening to randomly chosen 10 min audio recordings from each Song Meter (i.e. each site). For each site, 10 (Nambucca sites) or 25 (Yarriabini and Ngambaa) nights were randomly chosen from a set of nights available (44-51 per site). Then for each night one 10 min period was chosen at random. The first 30 mins for a night were excluded because typically calls were not detected in this period. For each 10 min period the number of calls identified, and not identified, by the Recogniser were recorded. Essentially just the presence of identified and not identified calls was scored. We also scored those nights when calls were identified by the Recogniser outside that 10-min period. This was of interest because the Recogniser might fail to record a distant (i.e. low volume) call within a random 10 min period but record a call at another time on that night when that yellow-bellied glider was closer and the call louder.

3. Results

a. Spotlighting surveys

<u>Nambucca State Forest</u> – Yellow-bellied gliders were not detected during the first round of surveys in Nambucca. They were detected on three transects in round 2 (one was just after the actual transect traverse) and on three transects in round 3, representing five different transects overall. The spatial distribution of these records is such that these records may represent four different social groups. Detection of calling individuals from transects 20 and 21 on 16 September 2014 were from the same approximate area so it is assumed they were the same social group. These transects were located approximately 600 m apart.

<u>Yarriabini National Park and Ngambaa Nature Reserve</u> – In Yarriabini, yellow-bellied gliders were detected on three transects in round 1 (one was after the actual transect traverse), on five transects in round 2 and on seven transects in round 3, representing seven different transects overall. In

Ngambaa, yellow-bellied gliders were detected on 4 transects in round 1 (one after the actual transect traverse), on seven transects in round 2 and on one transect in round 3, representing 10 different transects overall.

Across all three locations yellow-bellied gliders were recorded on the survey transects on 31 occasions. All detections were initially by call though gliders were subsequently observed on several transects. Gliders were recorded by call before the call broadcast on 14 occasions (45%; average 3.7 min after survey commenced), only in response to call broadcast (response in <5 min after broadcast) on 11 occasions (36%), and well after call broadcast (>5 min; average 16.5 min after broadcast) on 6 occasions (19%). The frequency of response within a 2-min interval to glider call broadcast (n=7) was approximately equivalent to that of powerful owl call broadcast (n=5).

b. Surveys for sap-feeding trees

All transects were searched for trees incised by yellow-bellied gliders in sap feeding. No trees used in sap feeding were located on any of the survey transects across any of the three study locations. The forest was also searched for incised trees while repeatedly traversing forest tracks in a vehicle. This allowed for a vast area of forest to be searched at all three locations. Trees with any scars that resembled yellow-bellied glider incisions were carefully examined. One tree, a red bloodwood, with old incisions was found in Nambucca State Forest (Fig. 5).

Three trees that were recorded by personnel of the Forests Corporation as glider incised trees in 2001 were located based on GPS data. None were sap-feeding trees and it is doubtful that they ever were.

Figure 5. Yellow-bellied glider incised red bloodwood (*Corymbia gummifera*) within Nambucca State Forest.

c. Habitat analysis

A model that included the abundance of Rainforest species (this included brushbox) had the greatest support (Table 1). In subsequent steps of the analysis this model was combined with other top ranking variables. This revealed that there was also strong support for models in which rainforest was included with Blue/Flooded Gum, Spotted Gum, Blackbutt or Grey Gum. Rainforest and Blue/Flooded Gum had a positive influence while Spotted Gum, Blackbutt and Grey Gum had a negative influence on occupancy. A further step that produced models with three variables did not improve the fit of the model. The best of the 3-variable models had a ΔAIC that was >2, suggesting that these models had only modest support.

Among the variables that were measured at the time of the survey and therefore potentially had an influence on detection, Breeze had the strongest support (Table 1). The model weight showed that this model had >6 times more support than a model in which detection probability was constant across the three survey occasions. Breeze had a negative influence on detection. When the habitat and the survey variables were combined a model that combined rainforest abundance and breeze intensity had twice as much support (based on model weight) as one that also included the abundance of Blue/Flooded Gum.

Table 1. Model selection output for the top six models from an analysis of the influence of habitat variables on yellow-bellied glider occupancy (psi or ψ). Variables included in a model are shown in brackets and may relate to occupancy (psi) or detection probability (*p*). A constant model with no variables included is indicated by (.). AIC = Akaike information criterion, ΔAIC = difference in AIC between one model and the top model, w_i =model weight, k=number of parameters. Note that rainforest is the sum of rainforest and brushbox basal area.

Model	AIC	ΔAIC	w_i	Likelihood	K
Habitat variables					
psi(Rainforest),*p*(.)	188.73	0.00	0. 287	1.000	3
psi(Rainforest + Blue/Flooded Gum),*p*(.)	189.57	0.84	0.189	0.657	4
psi(Rainforest + Spotted Gum),*p*(.)	189.72	0.99	0.175	0.610	4
psi(Rainforest + Blackbutt),*p*(.)	190.23	1.50	0.136	0.472	4
psi(Rainforest + Grey Gum),*p*(.)	190.44	1.71	0.122	0.425	4
psi(Rainforest + Blue/Flooded Gum + Blackbutt),*p*(.)	191.04	2.31	0.091	0.315	5
Detection variables					
psi(.),*p*(Breeze)	189.14	0.00	0.705	1.000	3
psi(.),*p*(.)	192.86	3.72	0.110	0.156	2
psi(.),*p*(Dark)	194.31	5.17	0.053	0.075	3
psi(.),*p*(Survey)	194.39	5.25	0.051	0 .072	4
psi(.),*p*(Moon)	194.83	5.69	0.041	0.058	3
psi(.),*p*(Rain)	194.84	5.70	0.041	0.058	3
Detection and Habitat variables					
psi(Rainforest),*p*(Breeze)	185.99	0.00	0.574	1.000	4
psi(Rainforest + Blue Gum),*p*(Breeze)	187.43	1.44	0.280	0.487	5
psi(Rainforest),*p*(.)	188.73	2.74	0.146	0.254	3

d. Song Meter surveys

Song Meters were established within Yarriabini and Ngambaa where gliders were known to be present to gain an understanding of calling frequency at occupied sites and to assess the frequency of false negatives (calls not detected by the Song Meters but where calls were present in a random subset of 10-min periods). Calls by yellow-bellied gliders were detected on 16-28% of 70-71 nights within Yarriabini and Ngambaa with 2-5 calls per calling night (Table 1). The percentage of the random periods that contained false negatives ranged from 0% to 24%. However, on only one of 11 nights for these Song Meters (sites 9-12) with a false negative in the random period was a call not detected by the Recogniser on that night. There was also one missed in Nambucca at Song Meters 3 & 7 and two missed at Song Meter 13 at Warrell Creek. Call loudness varies with distance from the Song Meter to the calling individual. It appears calls that were not detected by the Song Meters were those where calls were of low volume, with calling individuals possibly >200 m away.

Table 1. Analysis of audio recordings for yellow-bellied glider calls at different locations. Song Meters recorded audio for a 3 h period commencing at civil sunset on each night they operated. Values show the percentage of nights in which the recogniser identified a call and the calls per night. The effectiveness of the Song Meter recogniser was scored for each site for one random 10 min period on either 10 (Nambucca & Warrell Ck: sites 1-8, 13) or 25 (Reserves: sites 9-12) randomly selected nights. A true positive occurred when a call was detected by the recogniser in a random 10-min period. A false negative was when calls were present in the 10-min period but not detected by the recogniser. A true positive was when the recogniser detected a call on the night of the 10-min period.

Locations & sites		**Calls Detected**		**Random Periods**		
(Distance & direction from new road alignment)	Nights sampled	Nights with calls	Calls per night on calling nights	True positive	False negative	True positive nights
Nambucca SF						
Road edge						
1 (S<200 m)	73	3%	2.0	0	0	10%
3 (S300 m)	74	4%	2.0	0	10%	10%
4 (S<200 m)	67	0	–	0	0	0
6 (N300 m)	70	0	–	0	0	0
7 (N100 m)	74	3%	2.0	0	10%	0
8 (N150 m)	55	0	–	0	0	0
Forest sites						
2 (S700 m)	85	4%	1.7	0	0	0
5 (S1200 m)	82	0	–	0	0	0
Yarriabini NP						
9	71	27%	3.3	0	24%	36%
10	71	28%	3.3	4%	8%	32%
Ngambaa NR						
11	70	27%	2.1	4%	12%	44%
12	70	16%	5.0	0	0%	12%
Warrell Creek						
13	35	9%	1.7	0	20%	10%
Total	897					

The Song Meters detected calls in Nambucca SF at sites SM1, SM2, SM3 and SM7 on 3-4% of nights (Table 1). These sites are clustered around survey site 4, though up to 780 m away (Figure 6). Detections at these sites all occurred on different nights (SM1: 14 Aug, 3 Nov; SM2: 15 Oct, 28 Oct, 29 Oct; SM3: 13 Sept, 19 Sept, 25 Sept; SM7: 21 Aug, 13 Oct). Three of these sites occurred within 300 m of the new highway alignment. The Song Meter placed at Warrell Creek off Cockburn's Lane detected calls on 9% of nights, though only 35 nights were sampled at this location.

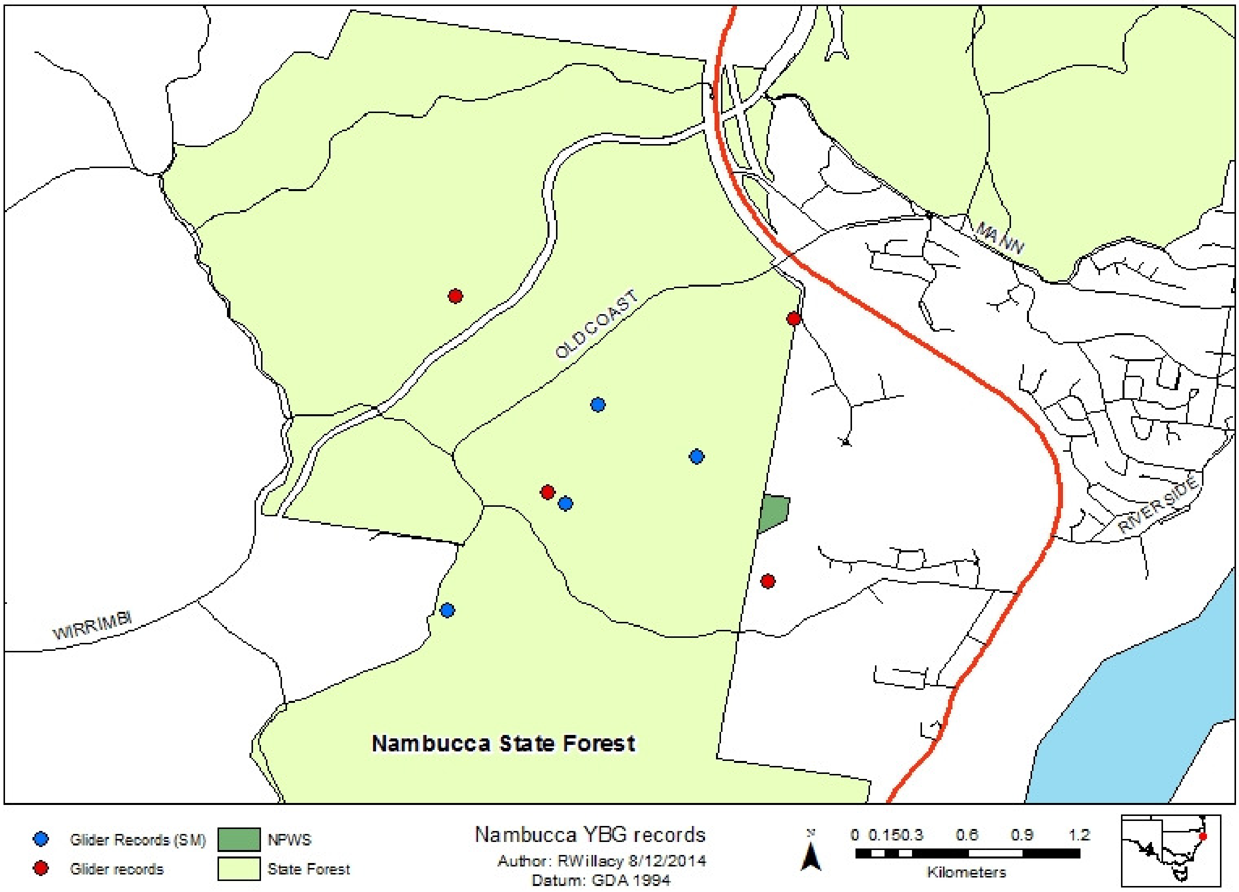

Figure 6. Location of the yellow-bellied glider detections in Nambucca State Forest by spotlighting survey (red spot) and by Song Meter detection (blue spot). The spotlight detections show the location of gliders rather than the transect locations.

4. Discussion

a. Population surveys

The principal aim of this project was to provide a baseline estimate of the size of the yellow-bellied glider population in Nambucca to enable the trajectory of the population to be followed over time in response to the construction of the dual carriageway Pacific Highway which will bisect the western portion of Nambucca. Spotlighting surveys were conducted across 40 survey transects in Nambucca on three different occasions over a 2-month period. Only four social groups were detected.

Although the survey transects provided a very comprehensive coverage of Nambucca State Forest it is possible that up to two further social groups evaded detection.

Yellow-bellied glider social groups in habitats of average productivity typically contain an adult pair and one subadult offspring (Goldingay and Kavanagh 1990). This means that the adult population in Nambucca may number only 8-12 individuals. Monitoring by Song Meters over periods of approximately two months at eight sites scattered through Nambucca confirms that yellow-bellied gliders were in low abundance; they were detected at four sites and detected on only 3-4% of nights.

In contrast, yellow-bellied gliders were relatively abundant in Yarriabini and Ngambaa. There were 8 social groups detected from only 20 transects in Yarriabini and 10 social groups detected from 32 transects in Ngambaa (Figure 7). Song Meters detected gliders on 16-28% of nights across two months of sampling in these reserves.

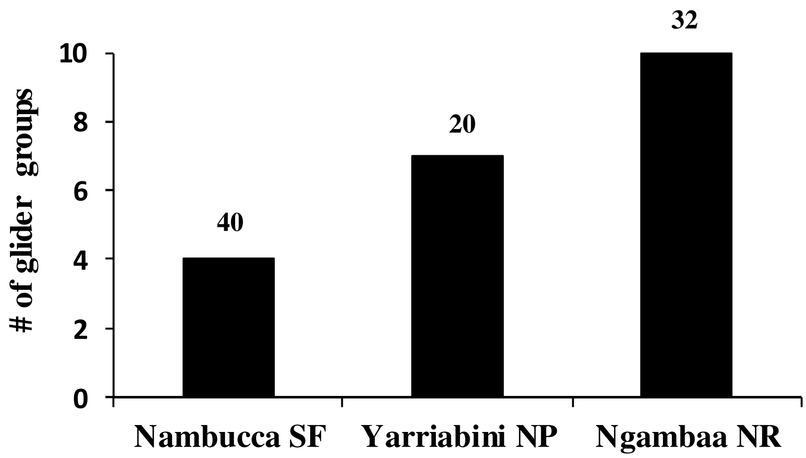

Figure 7. The number of yellow-bellied glider social (family) groups recorded across the three study areas. The number of survey transects is shown above each bar.

Yellow-bellied gliders are highly vocal and territorial (Kavanagh and Rohan-Jones 1982; Henry and Craig 1984; Goldingay and Kavanagh 1993; Goldingay 1994) so a failure to detect them at many sites over two months of sampling suggests there are few there. Yellow-bellied gliders have very large territories of approximately 50-100 ha (Goldingay and Quin 2004). The size varies in response to food availability and productivity. Given the low incidence of glider records in Nambucca it is likely that glider territories are at the upper end of the size range. This is suggested by the cluster of Song Meter records to the south-east of Old Coast Road (see Figure 6).

The reason for the low number of yellow-bellied glider groups in Nambucca is due to low habitat suitability and intensive logging. The habitat analysis conducted suggested that an increase in the abundance of rainforest and brushbox basal area increased the probability of a site being occupied by yellow-bellied gliders. Although the addition of blue gum (a composite with flooded gum) also had a positive influence on yellow-bellied glider occupancy it did not provide any better discrimination among sites. Yellow-bellied gliders rarely feed in rainforest habitat (Quin et al.

1996) and were not detected in it in this study but rainforest can be indicative of productive sites that are favoured by gliders (e.g. Goldingay and Quin 2004). Nambucca is dominated by extensive areas of blackbutt habitat. This habitat is one that is not favoured by yellow-bellied gliders (Mackowski 1986; Eyre 2007) although they will feed within this tree species (Goldingay 1990). Furthermore, Nambucca is a timber production forest and has been logged quite heavily over the last 20 years. This adds to a low overall suitability of this area to yellow-bellied gliders.

b. Population variation over time

Yellow-bellied glider abundance is known to vary over time due to climate induced variation in food availability (Goldingay 1992). This has been described in more detail in the closely related squirrel glider (*Petaurus norfolcensis*) which confirms that population fluctuations can be severe and also prolonged (Sharpe and Goldingay 2010). This implies that variation in the abundance of gliders at Nambucca and the control populations is to be expected over a period of several years. Rainfall is likely to be the environmental variable that drives population dynamics over time. Given that annual rainfall on the Nambucca part of the north coast has been 8-35% above average over the last four years (Coffs Harbour rainfall station, Bureau of Meteorology) it is likely that population levels of yellow-bellied gliders in this region are at or above their long-term average. This means that any decline in rainfall over the next several years is likely to be associated with lower population indices. Variation in yellow-bellied glider abundance on the New South Wales south coast arose through change in the number of individuals per social group (Goldingay 1992). However, this occurred in highly productive habitat. It is unclear how glider groups will respond in low or average productive habitat. On the New South Wales southern tablelands glider groups remained at a similar level over a 6-year period (Goldingay and Kavanagh 1990) when annual rainfall averaged 13% above the annual average (Bombala rainfall station, Bureau of Meteorology). It is possible that a loss in local food availability may lead to expansion in territory size which may be possible at Nambucca given that there seems to be many areas of forest that are currently unoccupied by yellow-bellied gliders. This does not appear to have been an option for glider groups in southern New South Wales because adjoining areas were occupied by other yellow-bellied glider groups.

c. Song Meter surveys as population indices

The Song Meters enabled 8 sites in Nambucca to be surveyed across an overall total of 580 nights for 3 hours each night (i.e. 1740 h of audio recording). This sampling detected calling by yellow-bellied gliders on only 10 nights (2%). In contrast, a total of 282 nights (846 h) of Song Meter sampling within Yarriabini and Ngambaa produced detections on 69 (25%) nights. Spotlighting surveys in Nambucca covered the equivalent of 119 nights and detected gliders on 6 nights (5%) but with considerable person effort. Spotlighting surveys in Yarriabini and Ngambaa covered the equivalent of 156 nights and detected gliders on 28 nights (18%) and again with considerable person effort. An overall comparison of detection by Song Meters versus spotlighting (call detection) for the three study areas gives somewhat similar results although only two sites were surveyed by Song Meters in each of Yarriabini and Ngambaa, and these sites were known to contain yellow-bellied gliders before installation. Not all recorded calls were detected by the

Recogniser because call volume may vary considerably depending on how distant a calling individual is from the Song Meter. Nonetheless, the Recogniser performed reasonably well with a relatively low rate of false negatives. This suggests the number of calling nights might be a good index of glider activity in the vicinity of the Song Meter (possibly sampling within a 100 m radius).

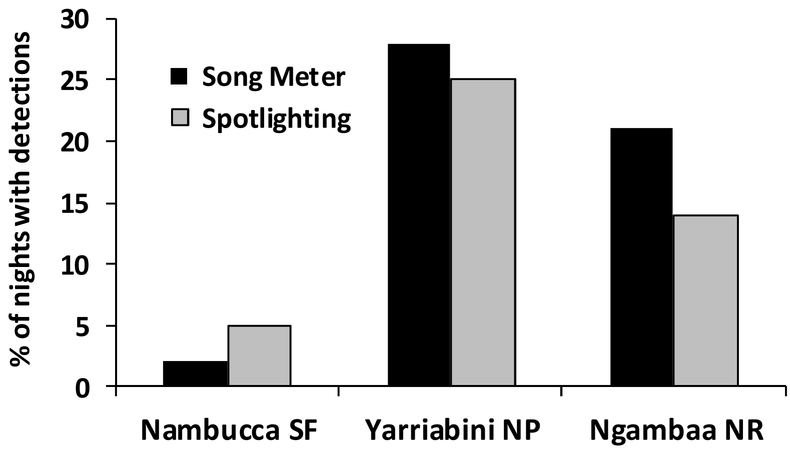

Figure 8. Percentage of survey site nights (sites times nights) in which yellow-bellied gliders were detected across the three study areas. Song Meter detections are based on eight sites in Nambucca State Forest and two in each of Yarriabini National Park and Ngambaa Nature Reserve. Spotlighting (call) detections are based on 40 sites in Nambucca, 20 in Yarriabini and 32 in Ngambaa.

d. Song Meter surveys as indices of habitat use

One of the aims of this project was to provide a baseline of yellow-bellied glider activity along the highway footprint through Nambucca to enable an assessment of whether gliders in the vicinity of the highway are affected by highway construction. An adverse impact could arise due to: i) the loss of foraging habitat directly where the highway has been constructed, ii) the loss of access to foraging habitat due to segregation of habitat types by highway construction, iii) aversion of the forest adjoining the new highway due to traffic noise and other road-related disturbances, and iv) loss of dispersal pathways. These scenarios are not mutually exclusive and it may be difficult to distinguish which factor gliders have responded to if they show an adverse response. However, the more important issue for this project is whether a response can be measured to enable a conclusion of whether there has been no change, a decline in glider activity or even an increase in glider activity. Song Meter analysis revealed low levels of activity north and south of the highway alignment and at sites deeper into the forest (Figure 9). No detections were made at some sites in each of these three categories of site. Although the data are relatively scant they do provide a basis against which future changes can be compared.

The sampling conducted during this project with Song Meters has revealed enormous potential in using this method to monitor populations of yellow-bellied gliders.

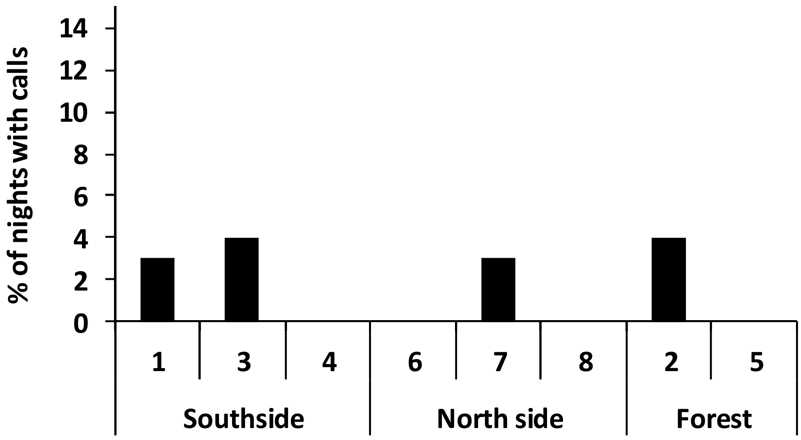

Figure 9. Percentage of nights in which yellow-bellied glider calls were detected by Song Meters (numbered 1-8) along the new highway alignment (within 100-300 m) through Nambucca State Forest and deeper within the forest (700-1200 m away). Audio recordings were made on 55-85 nights.

5. Acknowledgements

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Appendix 1. Yellow-bellied glider detections across all survey sites. Numbers for each survey are the number of individuals detected.

Location/survey site	UTM		Survey 1	Survey 2	Survey 3
Nambucca State Forest					
1	495470	6606766			
2	495411	6607706			
3	495839	6608162			
4	496642	6609002			1
5	496622	6609656			
6	497327	6610295			
7	497872	6610101			1
8	497157	6608436			
9	496135	6606829			
10	496820	6606755			
11	497514	6606908			
12	496737	6607121			
13	497186	6609475			
14	495933	6607733			
15	495226	6606142			
16	495113	6610603			
17	495858	6611195			
18	496599	6611338			
19	497279	6611321			
20	497683	6608430		2	
21	497450	6608868			1
22	496631	6608142			
23	497196	6607491			
24	497931	6607645			
25	496134	6610067		3	
26	495314	6610187			
27	495250	6611094			
28	496120	6609438			
29	496798	6610348			
30	500774	6610823			
31	500687	6611704			
32	500126	6611265			
33	500122	6611083			
34	498206	6611649			
35	499172	6611811			
36	498932	6612717			
37	499118	6610803			
38	499781	6612569			
39	499690	6611973			
40	500183	6612175			

Location/survey site	UTM		Survey 1	Survey 2	Survey 3
Yarriabini National Park					
1	492437	6591031			
2	492972	6591325			
3	492919	6591990			
4	492987	6592708		1	1
5	493118	6593424			
6	493591	6593735	3	1	1
7	494296	6593632			
8	494942	6593945			2
9	495110	6594456			
10	495072	6595277			
11	494752	6595944			
12	495679	6594039		3	1
13	496028	6593632		1	1
14	496538	6593125			
15	497256	6592948			
16	497978	6592996			1
17	498724	6592968	1	1	3
18	497217	6593489			
19	494658	6596586			
20	491718	6591012			

Location/survey site	UTM		Survey 1	Survey 2	Survey 3
Ngambaa Nature Reserve					
1	480892	6590388		1	
2	480306	6589901			
3	479602	6589798			
4	478980	6589535			
5	478906	6588730	2	2	
6	478542	6588028			1
7	477878	6587523		3	
8	477817	6586832			
9	478024	6586179			
10	478055	6585297			
11	477291	6585038			
12	476548	6584758			
13	475689	6584321			
14	474855	6584682			
15	474645	6585414			
16	474956	6586077			
17	475091	6583175			
18	475692	6582438			
19	475985	6581669			
20	476563	6582040			
21	479207	6583858	1		
22	479971	6584222		1	
23	480519	6583749		1	
24	480459	6583000			
25	478637	6583984			
26	478195	6584644			
27	479740	6582152			
28	479968	6581223			
29	478233	6580931			
30	477592	6580613			
31	477102	6579626		1	
32	475050	6581109	2	2	