



Optimising monitoring times for surveys of rūrū (*Ninox novaeseelandiae*)

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Abstract: Automatic recording devices (ARDs) are becoming increasingly popular as a monitoring tool, especially for cryptic or nocturnal bird species. We wanted to determine the optimal time(s) of night and month(s) of the year for monitoring rūrū (a small NZ owl) using ARDs, to enable development of a robust monitoring method that maximises probability of detection. Fourteen ARDs were placed at 500 m intervals throughout a 400-ha forest block in the Eglinton Valley, Fiordland, New Zealand, and the presence of rūrū recorded monthly from August 2011 to March 2012. Data from the Department of Conservation's national Tier 1 Monitoring Programme (2011–2016), gathered from multiple locations across public conservation land (PCL), were also analysed to provide broader context. Both at the Eglinton Valley and across New Zealand PCL, rūrū calls were detected in all months surveyed and during all periods of the night. Detection probability (derived from call activity) was generally higher in the North Island and the west coast of the South Island. At the Eglinton Valley the highest call activity occurred in December, with activity in spring generally higher than in summer. On PCL, calling activity was highest in spring and early summer and lowest in late summer. Patterns in how call activity changed throughout the night varied from month to month in the Eglinton Valley. Across New Zealand, PCL (for all months), the call activity peaked approximately 1 hour after sunset then steadily declined throughout the remainder of the night. Our results and those of previous studies indicate general patterns of calling activity but with local variation. We recommend that as a general rule, detection probability can be maximised by carrying out rūrū monitoring surveys in the spring or early summer, during the first few hours after sunset. However, we also recommend an initial study of the site(s) to investigate local variations in call activity before any long-term monitoring is initiated.

Keywords: morepork; automatic recording devices; owls; call detection.

Introduction

There is an increasing need to develop robust species monitoring methods for quantifying outcomes of pest management (Lee et al. 2005). For practical and financial reasons, it is unlikely that all species can be monitored at all times. It is, therefore, important to make informed decisions on the choice of appropriate indicator species and the optimal monitoring design. Internationally, owls have been shown to be useful indicators of ecosystem health (Olsen et al. 2002; Anthony et al. 2006). As birds of prey, they are at risk via secondary poisoning from any toxins within an ecosystem (Stephenson et al. 1999; Denny 2009). As cavity nesters they are vulnerable to nest predation (O'Donnell 1996) and are therefore a good indicator of the efficacy of predator management (Blackburn et al. 2001; Anthony et al. 2006). Methods used to monitor owl distribution or occupancy include assessing territories using mouse lures (Imboden 1975), mark-resight models (Blackburn et al. 2001) and acoustic call recognition from automatic

recording devices (ARDs; Gravia et al. 2008).

Rūrū (or morepork; *Ninox novaeseelandiae*) is New Zealand's only remaining native owl species (Heather & Robertson 2015). In New Zealand the rūrū is classified as Not Threatened (Robertson et al. 2016). It is relatively common and widespread, especially in forested parts of the North Island and western South Island (Robertson et al. 2007). Like many other owl species, rūrū usually nest in tree cavities (Stephenson & Minot 2006; Heather & Robertson 2015). Consequently, females are susceptible to predation from introduced mammals whilst nesting (O'Donnell 1996; Pohnke et al. 2015). The diet of rūrū is dominated by invertebrates, with the addition of vertebrate prey including birds and small rodents (Haw & Clout 1999; Haw et al. 2001; Denny 2009). The call repertoire includes a range of vocalisations, including the distinctive double-note call from which the vernacular names 'morepork' and indigenous 'rūrū' are derived.

As with many nocturnal species, the rūrū is cryptic and detection is highly dependent upon vocalisations. Frequency of

calling can vary due to various factors, including season, time of night and weather (Higgins 1999; Fraser & Hauber 2008). In a study of rūrū call frequency in Nelson, O'Donnell (1980) found that birds called most frequently on clear or overcast nights and rarely on frosty or rainy nights. Calling occurred at any time of night, from dusk until dawn. Call frequency peaked in April, with a secondary peak in August, and was lowest in July and October. Colbourne and Digby (2018) found that in northern New Zealand (Northland) there was no strong seasonal variation in calling activity but there were fewer calls from February to March with further declines of these calls from June to August. They found that calling peaked 3 hours after sunset with a secondary peak two hours before dawn. However, on Ponui Island near Auckland, Brighten (2015) found a peak in call rates around 5 hours after sunset followed by a second peak one hour before dawn. Rūrū on Ponui Island also called more often in the summer months compared to the winter months and number of calls was highest in November and January (Brighten 2015). These differences suggest the possibility of geographic variability in calling behaviour. As these previous studies had relatively small sample sizes, were somewhat contradictory and had no national overview, further investigation was warranted to help optimise sampling design for other monitoring programmes.

This paper explores in detail the effects of month and time of night on rūrū frequency of calling at the Eglinton Valley, Fiordland, New Zealand. Comparisons were made with national data, collected from public conservation land (PCL) through the National Biodiversity Monitoring and Reporting System (Department of Conservation 2018). This system is underpinned by the 'Tier 1' Monitoring Programme, which provides biodiversity data enabling the reporting of national status and trend for common and widespread species (Lee et al. 2005; MacLeod et al. 2012). Our study aims to provide recommendations for optimal timing of rūrū surveys, to inform method design for future rūrū monitoring programmes.

Methods

Study Site

The Eglinton Valley is located in the South Island of New Zealand (44°58' S, 168°01' E; Fig. 1), and consists of a wide, steep-sided, U-shaped valley of glacial origin. A grassland comprising of native and exotic species covers the valley floor at 250–500 m above sea level. Near the valley floor, the forest is dominated by red beech (*Fuscospora fusca*) and silver beech (*Lophozonia menziesii*), with mountain beech (*Fuscospora cliffortiodes*) becoming more common with increasing altitude. Terraces and outwash fans are covered with temperate beech (Nothofagaceae) forest to the treeline at 1000–1200 m above sea level (O'Donnell 2000). Rūrū were caught throughout the valley to examine nesting success and survival (MP, TG unpubl. data) and a small area of the valley was monitored using ARDs. The Tier 1 Monitoring Programme comprises multiple sampling locations (commonly referred to as 'plots'), throughout a wide range of habitat types on PCL (Fig. 1).

Field protocols and analysis

At the Eglinton Valley, 14 ARDs were positioned on a grid at 500 m intervals within a 400 ha area, for 1–2 nights each month between August 2010 and March 2012 (Fig. 1). Although data were collected over the 18 month period, the time series was

incomplete, (missing 5 months) so we limited our analyses to a continuous 8 month period (August 2011 to March 2012 inclusive) that covered a single breeding season. Optimal spacing was determined using data from a previous study at the same site (Pryde & Greene 2016). To maximise probability of detecting rūrū, ARDs were deployed on nights that were likely to have relatively high levels of insect activity (O'Donnell 2000), i.e. little likelihood of rain or significant wind and where minimum temperatures were likely to be above 0°C. ARDs were attached to small trees (< 5 cm diameter), approximately 1.3 m off the ground. Any small leaves or small branches near the microphone were removed to minimise unwanted noise and signal interference. Efforts were also made to ensure ARDs were deployed at locations without significant environmental noise (e.g. near rivers or roads). ARDs were programmed to record between local sunset and sunrise times (New Zealand Standard Time).

ARDs were custom designed and developed by the Department of Conservation (DOC). Each device consisted of a water-resistant aluminium tube containing a programmable microprocessor, power source and digital data storage. Four water-resistant wm61a electrets microphones were covered with wind noise-dampening foam and housed within a protective wire-mesh cage. The microphones were linked to a low noise pre-amplifier with a DSP anti-aliasing filter. As most rūrū calls are discernible at low frequencies (Brighten 2015) the devices were set to record in the 0–4 kHz range. Operational life using four AA batteries (NiMh rechargeable) was approximately 100 hours. Sound files were recorded as 15 minute files (in .WAV format) on high capacity secure digital (SD) cards with a maximum storage capacity of 8 GB.

Resultant sound files were processed manually by four experienced ornithologists using the software Freebird version 1.2.5.1 (Freebird 2013). A subsample of the data was reassessed to check for consistency of processing between observers. The majority of the files were processed by one observer. Processing involved visual and aural examination for presence or absence of rūrū vocalisations within each 15 minute recording. We did not require a record of each individual call, as we were not attempting to calculate call rates or an index of abundance. Rather, we required an index of call activity, which could then be converted into probability of detection. Recording presence per time block provided a relatively efficient method of generating data for our purposes. Each record of rūrū presence was assigned to one of five time periods, hereafter referred to as 'night-time periods', which collectively spanned the hours of darkness from local sunset to sunrise (Table 1).

The Eglinton data consisted of ones (rūrū detected) and zeros (rūrū not detected) and were analysed using a generalised linear mixed model (GLMM) with a binomial distribution, using the statistical software R (version 3.2.1; R Core Team 2015). Four candidate models were specified, each with rūrū detection as the response variable ($\text{Logit}[\pi(y)]$: the probability that rūrū was detected, given fixed values of the explanatory variables) and various combinations of the fixed categorical explanatory variables month and night-time period (as additive and interaction terms; Table 2). We analysed the data to determine which months had the highest calling activity, and then subset the data into the separate months to investigate the optimal night-time period(s) to monitor for each month. We included the ARD stations as a random effect, as data from each station would not be independent. The preferred model was selected from a candidate set of models fitted, using the

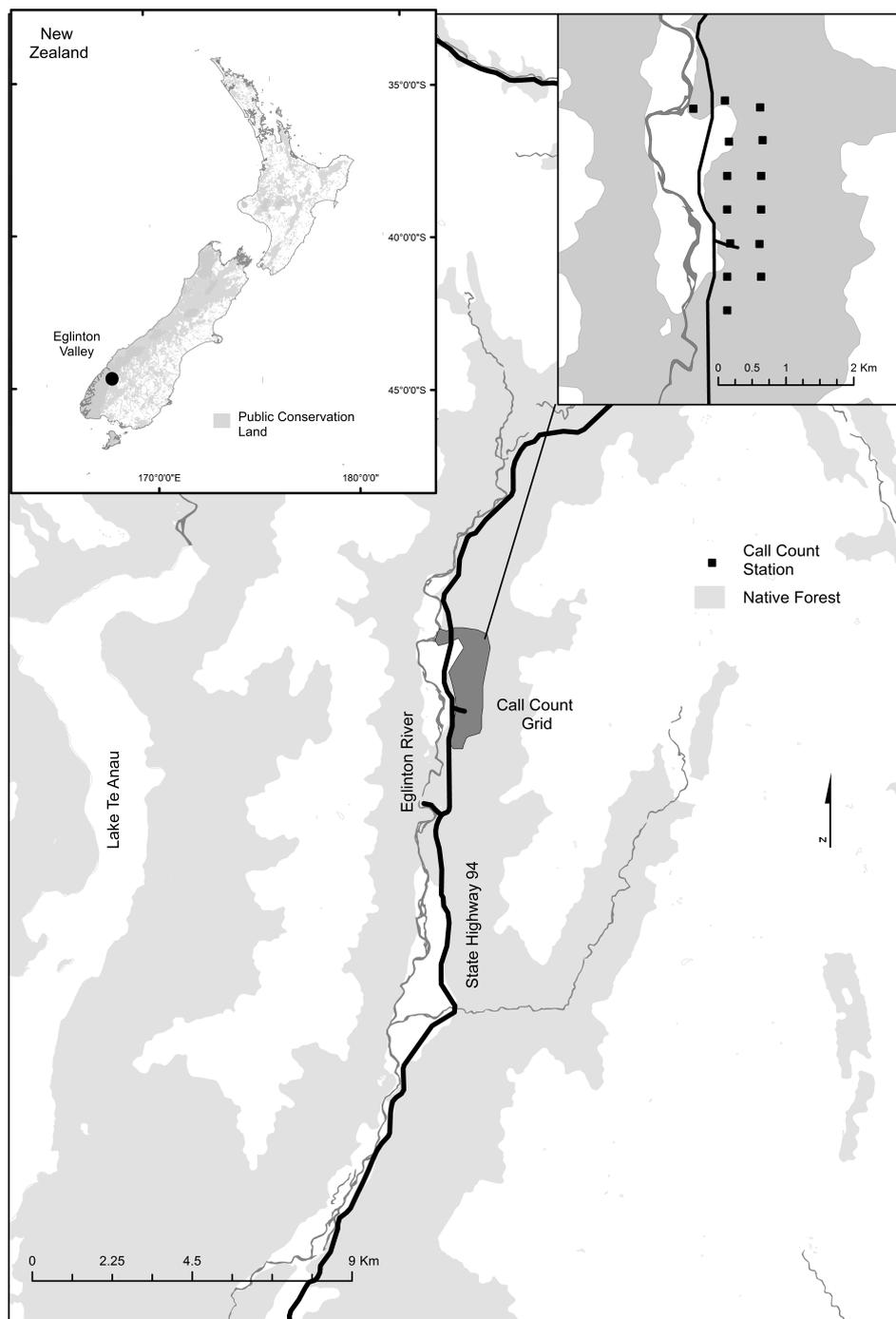


Figure 1. Location of the Eglinton Valley, Fiordland, New Zealand, and extent of PCL in New Zealand.

Table 1. Start and finish times of night-time periods, for each month surveyed in the Eglinton Valley.

Month	Time period				
	1	2	3	4	5
August	1757–2059	2100–2344	2345–0229	0230–0514	0515–0802
September	1834–2114	2115–2344	2345–0214	0215–0444	0445–0709
October	1912–2129	2130–2344	2345–0159	0200–0359	0400–0611
November	1955–2159	2200–2344	2345–0144	0145–0329	0330–0521
December	2035–2229	2230–2359	0000–0144	0145–0329	0330–0456
January	2047–2229	2230–0014	0015–0159	0200–0344	0345–0545
February	2018–2214	2215–0014	0015–0214	0215–0359	0400–0553
March	1930–2144	2145–2359	0000–0214	0215–0429	0430–0638

Table 2. Model definitions for analysis of rūrū detection at Eglinton Valley and across New Zealand PCL. In all models, rūrū detection was the response variable. For Eglinton Valley, explanatory variables were time of year (month), time of night (time period) and ARD location (station). For New Zealand PCL, explanatory variables included number of days after 1 September (daynum), time after sunset (timesun), latitude (lat) and longitude (long). The I() notation in model NZ3 has the effect that the product of longitude and latitude is incorporated as a single covariate. In combination with the main effects $s(\text{lat})$ and $s(\text{long})$, which are also in the model, this is equivalent to using $\text{lat}*\text{long}$ notation to incorporate the interaction effect. The I() notation is required to obtain diagnostic plots.

Area	Model type	Model ID	Model definition
Eglinton Valley	GLMM	EV1	$\text{Log}(\text{detection odds}) = \text{month}*\text{time period} + (1 \text{station})$
		EV2	$\text{Log}(\text{detection odds}) = \text{month} + (1 \text{station})$
		EV3	$\text{Log}(\text{detection odds}) = \text{month} + \text{time period} + (1 \text{station})$
		EV4	$\text{Log}(\text{detection odds}) = \text{time period} + (1 \text{station})$
New Zealand PCL	GAM	NZ1	$\text{Log}(\text{detection odds}) = s(\text{daynum}) + s(\text{timesun}) + s(\text{lat}) + s(\text{long}) + s(\text{lat}*\text{long})$
		NZ2	$\text{Log}(\text{detection odds}) = s(\text{daynum}) + s(\text{timesun}) + s(\text{lat}) + s(\text{long})$
		NZ3	$\text{Log}(\text{detection odds}) = s(\text{daynum}) + s(\text{timesun}) + s(\text{lat}) + s(\text{long}) + s(I(\text{lat}*\text{daynum}))$

minimum Akaike Information Criterion (AICc) value adapted for small sample sizes (Burnham & Anderson 2002). Model choice was determined by the difference in AICc (i.e. ΔAICc) between models and the best model. Models within two AIC units of the best model were deemed to have substantial support, differences between 4–7 units had considerably less support and where there was a difference of > 10 units there was essentially no support for the model (Burnham & Anderson 2002). Coefficient estimates and 95% confidence intervals were converted back from the log to the original scale, to provide the mean detection probability ($\pm 95\%$ confidence intervals) for each month and night-time period.

To establish a broader picture of rūrū call activity for comparison, ARD data from the Tier 1 Monitoring Programme were analysed. The Tier 1 Monitoring Programme was designed to monitor nationally common and widespread species and uses an 8 km grid overlaid across New Zealand PCL. DOC completes monitoring at c. 1354 randomly-selected grid intersection points ('plots') every 5 years (i.e. each plot is normally surveyed once every five years), with approximately 270 plots surveyed between September and April each year. Fewer plots were surveyed during the first two survey seasons, due to phased implementation of the programme. The programme began in 2011, and up to and including the 2015/16 survey season, processed ARD recordings were available from 554 plots. One hundred and thirty two (23.8%) of these plots were surveyed twice, in different survey seasons within the 5 year period analysed, resulting in a total of 686 plot locations completed. Four hundred and forty five plots were classified as forest, 40 were classified as shrubland and 69 were classified as non-forest. Plots from all habitat types were included in analyses, as rūrū inhabit open country with clumps of trees as well as forest (Heather & Robertson 2015). Even when there are no trees at a plot, suitable habitat may exist close enough for rūrū to be detected. Each plot was centred around a 20×20 m vegetation monitoring plot with transects radiating outwards from the four corners for monitoring brushtail possum (*Trichosurus vulpecula*), ungulates including deer (*Cervus* spp.), and goats (*Capra hircus*), and lagomorphs, i.e. rabbit (*Oryctolagus cuniculus*) and European hare (*Lepus europaeus*). Bird count stations were located at the ends of the mammal transects and in the centre of the plot (5 in total; Fig. 2). At

each bird count station, a single ARD was deployed and set to record between 2000 hrs and 0600 hrs for a single night, recording across a frequency range of 0–16 kHz. These ARDs were of the same design as those used in the Eglinton Valley.

Up to ten 15 minute recordings were selected for processing (identification of bird calls) from each station, starting with the first complete 15 minute recording after official local New Zealand sunset time, followed by one recording per hour for every subsequent hour until local sunrise. This is the same protocol used for the collection of Tier 1 data and was

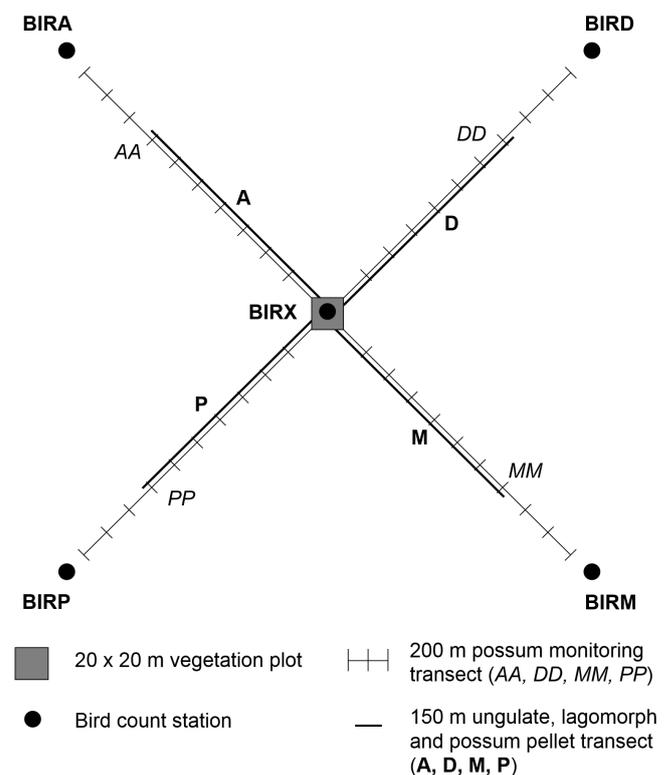


Figure 2. Tier 1 Monitoring Programme plot design. Black dots indicate locations of bird count stations (BIRA, BIRD, BIRM, BIRP, BIRX).

chosen for reasons of practicality, cost and time available for processing national data. Presence of rūrū was recorded in each of three five-minute time periods, for each 15 minute recording, by experienced ornithologists. Each identified call was tagged by drawing a box around the appropriate part of the sonogram and labelling it with the species name, using the Freebird software. A maximum of one rūrū call was tagged per 5 minute time period, giving detection per 5 minute period (1 = detected, 0 = not detected). Since measurements were made on different days in different locations, time of the year was treated as a continuous variable. Time of the night was converted to minutes after sunset, as this was thought to be the representation of time that most closely reflected how rūrū respond to the night cycle.

Data from Tier 1 were analysed using a logistic generalised additive model (GAM), in which the effects of time of year (daynum), time after sunset (timesun), latitude (lat), longitude (long) and a latitude:longitude interaction (lat*long) were modelled using splines(s), according to the formula:

$$\text{Log(detection odds)} \sim s(\text{daynum}) + s(\text{timesun}) + s(\text{lat}) + s(\text{long}) + s(\text{lat}*\text{long}) \quad (1)$$

An interaction effect between latitude and longitude was tested as well as an interaction between latitude and time of year (Table 2). A random effect was not required for plot locations, as the spatial trend (latitude and longitude) accounts for the location effect. For a more elaborate discussion of using

generalised additive models in ecological monitoring, refer to Ferguson et al. (2006).

To mitigate for observer bias we randomised the allocation of stations to operators so that for each plot the recordings from the five stations would go to five different operators. In order to investigate whether inter-observer variability affected the time and month trends, the GAM was fitted both with and without observer as a fixed effect and the results compared visually. Weather details were not collected for the Tier 1 nocturnal data and as such were not included as covariates in the analysis.

Results

A total of 7437 fifteen-minute recordings (100 station-nights over an 8-month period) were processed for the Eglinton Valley study area. A total of 70 585 5 minute periods were processed from the Tier 1 Monitoring Programme.

Geographic variation in detection probability and observer effects

Results from the GAM analysis of the Tier 1 Monitoring Programme data show that there was considerable variation in detection probability (based upon call activity) across PCL (Fig. 3). The highest detection probabilities (> 0.5) were from plots located in Northland, with moderate-high (0.3–0.5)

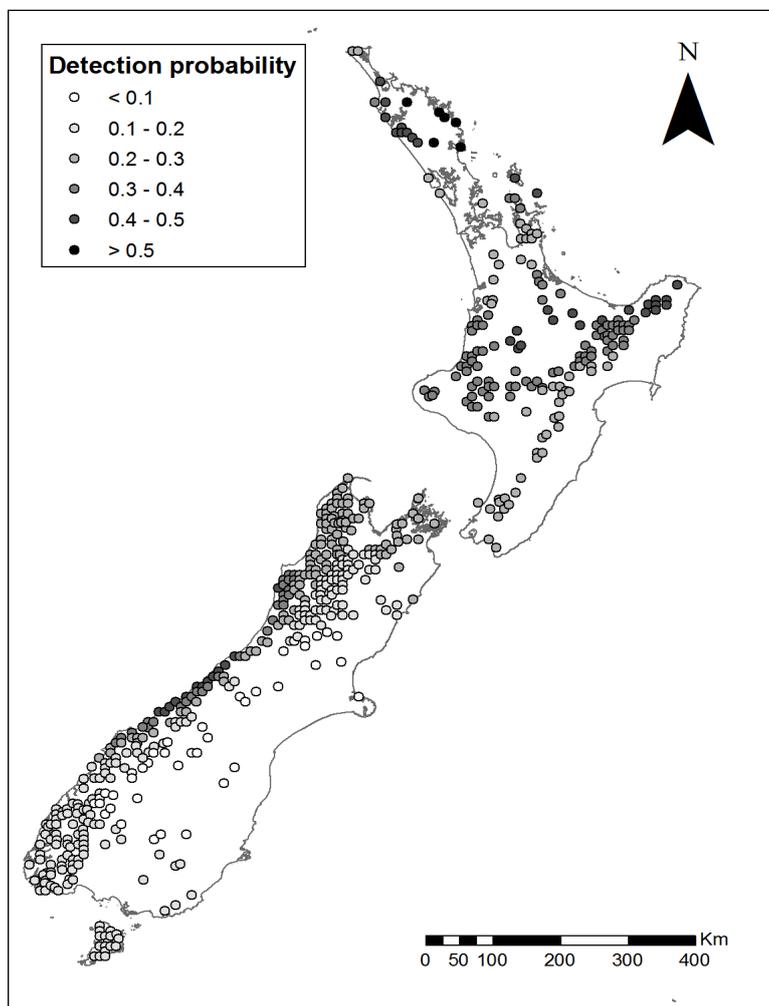


Figure 3. Detection probability (derived from call activity) for rūrū at monitored locations throughout New Zealand PCL.

Table 3. Akaike Information Criterion (AICc) values obtained for each candidate model describing the relationship between rūrū detection, time of year, time of night and geographic location at Eglinton Valley and New Zealand PCL. Where wt: Akaike’s weight, and K: number of parameters.

Area	Model ID	AIC	Δ AIC	wt	K
Eglinton Valley	EV1	5366.15	0.00	1.00	41
	EV2	5473.48	107.33	0.00	9
	EV3	5477.77	111.62	0.00	13
	EV4	5658.22	292.07	0.00	6
New Zealand PCL	NZ1	62962.56	0	1.00	45
	NZ3	63052.46	99.90	0.00	45
	NZ2	63317.41	354.85	0.00	36

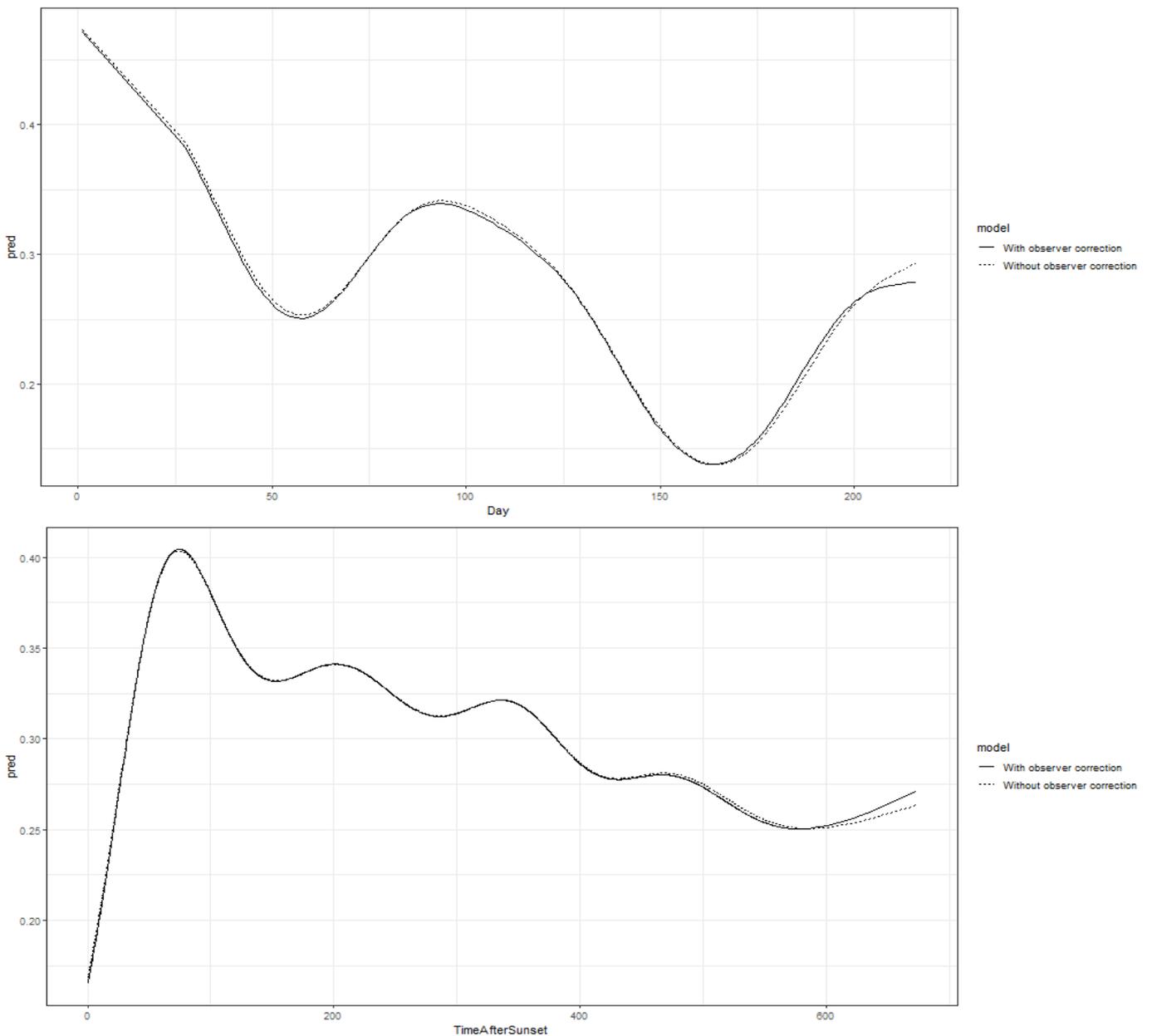


Figure 4. The detection probability in the GAM model in the Tier 1 data where the primary model (without observer effect correction) is compared to a model in which observer was included as a fixed effect for a) with the monthly trend and b) the hours after sunset.

detection probabilities from plots in the central and eastern North Island and west coast of the South Island. Lowest detection probabilities were obtained from plots in the central, eastern and southern South Island. The selected model (with the lowest AIC) included an interaction effect between latitude and longitude (Table 3), suggesting that geographic location had a significant effect on detection probability. Although there was considerable interobserver variability with respect to detection rates, the randomisation of the work allocation ensured that the observer bias did not influence the time and month trends (Figure 4a,b).

Seasonal variations in call activity

In the Eglinton Valley, rūrū calls were recorded during all 8 months analysed. Frequency of calling varied between months (Fig. 5) and was relatively high in August, dropped in September and then increased through October and November to a maximum in December. Frequency of calling declined in January and February, increasing again in March. On New Zealand PCL, call activity was relatively high in September, declined in October, then increased throughout November and into early December (Fig. 5). Call activity then steadily declined through the remainder of December and January, to a low point in early-mid February. As with the Eglinton Valley, call activity increased again in March (Fig. 5). It is important to note that, due to differences in collection

and analysis methods for Eglinton Valley and New Zealand PCL, the positions of data points on the y-axis scale of Fig. 5 are not directly comparable. However, plotting these data on a single graph enables easy comparison of trends in detection probability.

Night-time variations in call activity

In the Eglinton Valley, frequency of calling was quite variable between night-time periods in some months (August, November and December) and less variable in others (September, October, January, February and March; Fig. 6). In November and December, call activity was highest in the 2nd, 3rd and 4th night-time periods and considerably lower during the 1st and 5th periods. Conversely, in August call activity was higher during the 1st and 5th periods and lowest in the 3rd period. For the other months there was relatively little difference in call activity between night-time periods. GLMM analysis of the Eglinton Valley data confirmed, however, that the frequency of calling was dependent on an interaction between the month and night-time period (Table 3; see Appendix S1 in Supplementary Materials). Across New Zealand PCL, for all months, the average detection probability (derived from call activity) was lowest at sunset then rose sharply to a peak approximately 1 hour later (Fig. 7). Thereafter detection probability steadily declined through the night. This presented a somewhat different pattern to that observed at Eglinton Valley (Fig 6).

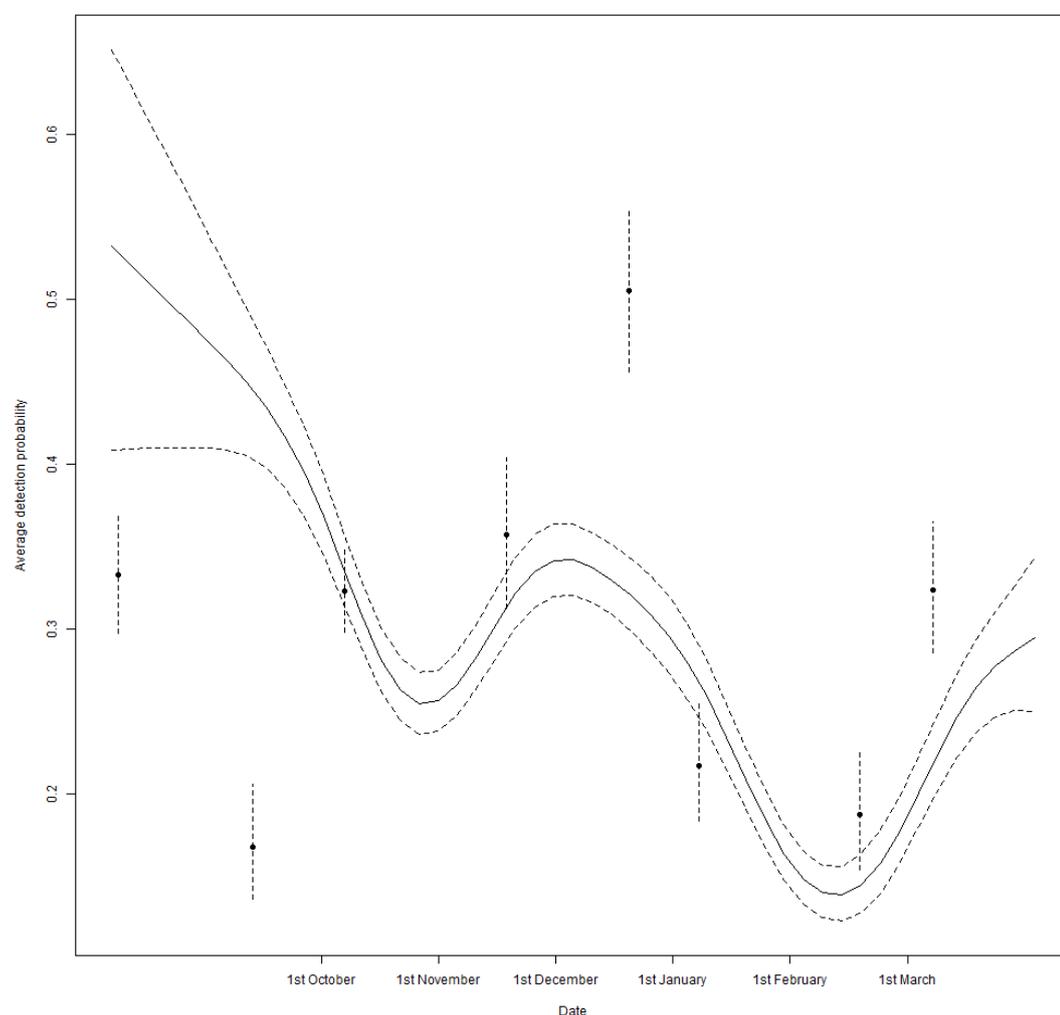


Figure 5. Fitted mean rūrū detection probability (derived from call activity, \pm 95% CI) from GLMM analysis of detections at Eglinton Valley (EV; August 2011–March 2012; black dots) and from GAM analysis of detections on New Zealand PCL (2011–2012 to 2014–2015 survey seasons; solid line). The latter was based on the averaged geographic location (latitude and longitude), at 30 minutes after sunset.

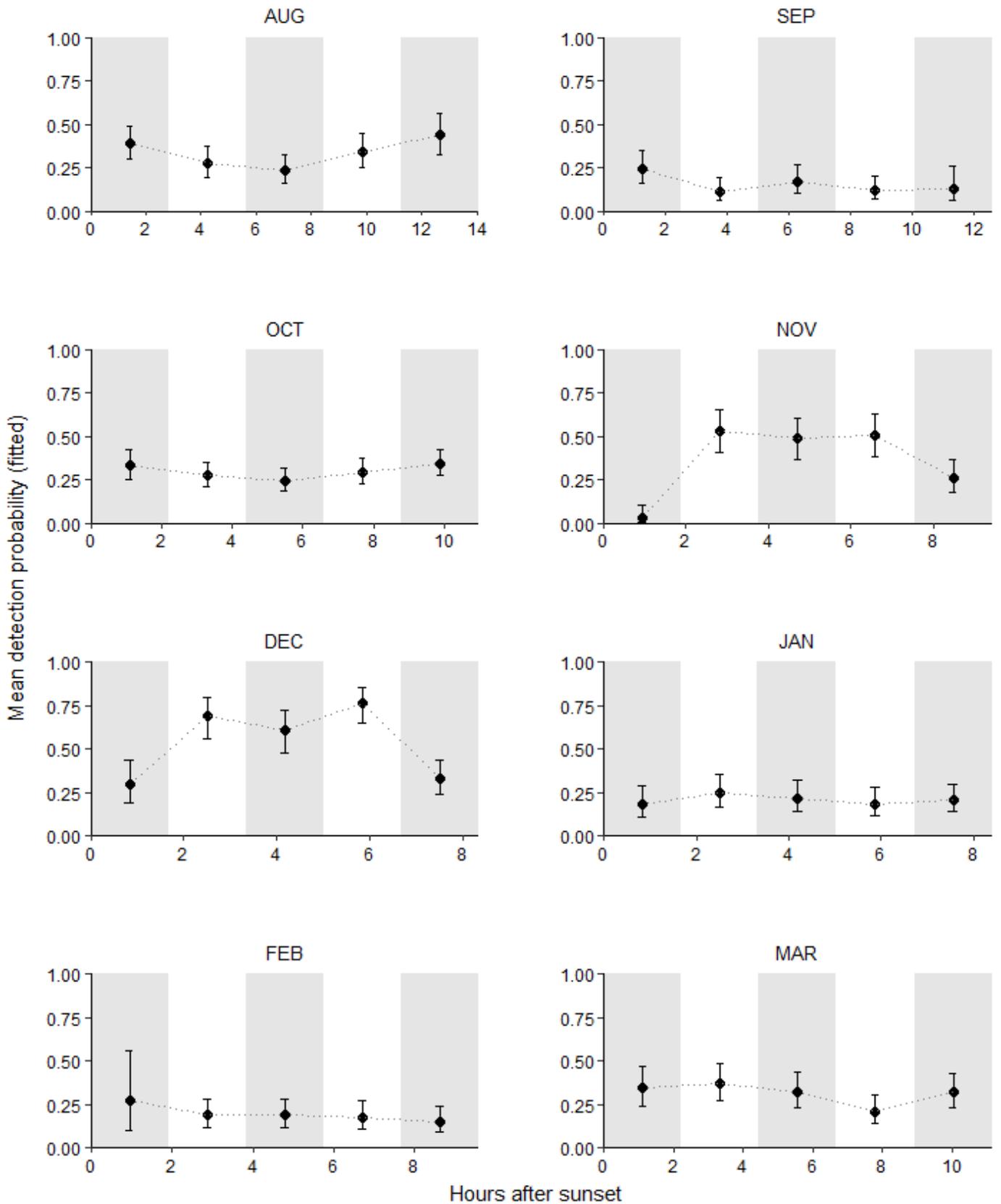


Figure 6. Fitted mean rūrū detection probability (derived from call activity; \pm 95% CI) from GLMM analysis Eglinton Valley data, for each night-time period (represented by alternating shaded and unshaded areas), within each month.

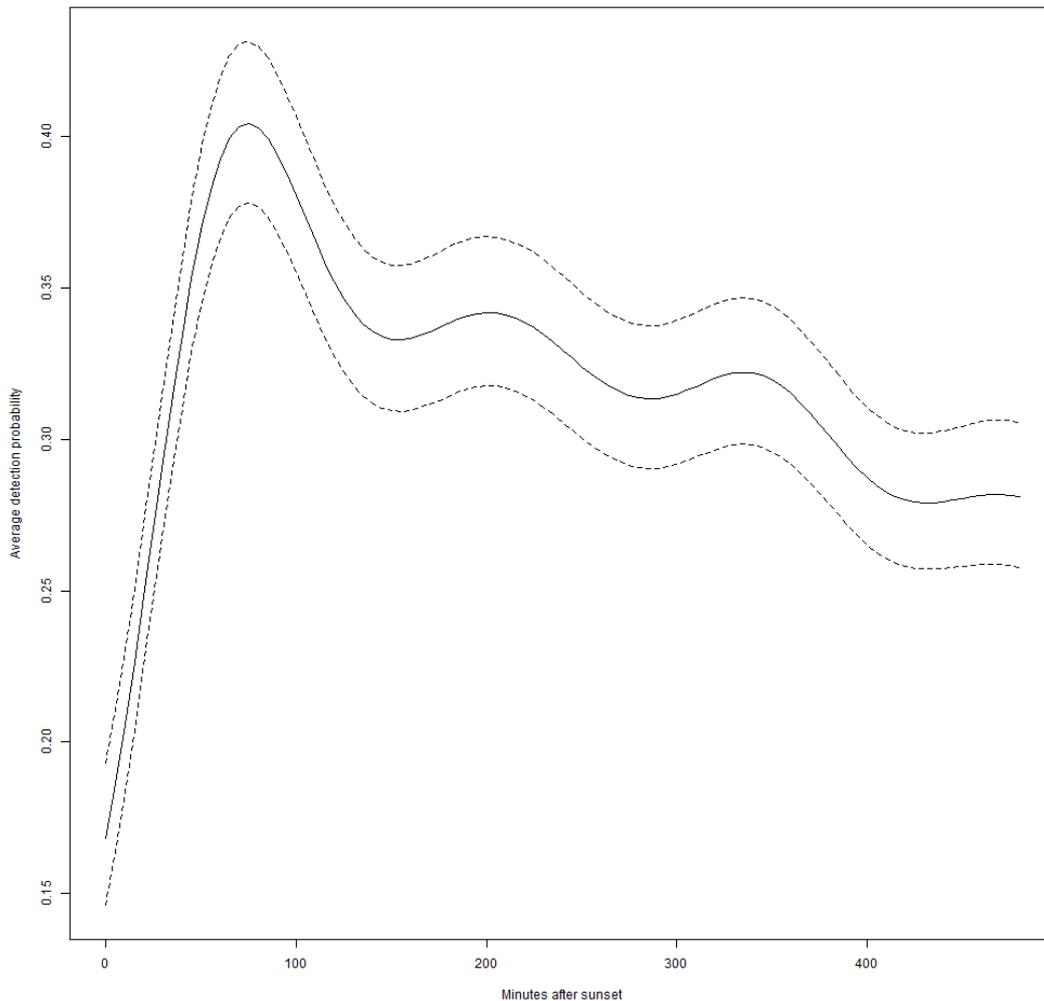


Figure 7. Fitted mean rūrū detection probability (derived from call activity; \pm 95% CI) from GAM analysis of New Zealand PCL data. This is based on averaged geographic location (latitude and longitude), adjusted for the 1st day of January. Due to differing lengths of nighttime at different times of the year, only data from the first 8 hours after sunset were included.

Discussion

Geographic variation in detection probability

There was considerable variation in detection probability (derived from call activity) across New Zealand PCL. One possible explanation for this variation is that the detection probability is proportional to density of rūrū in a given area; however, the relationship between detection probability and population density has not been investigated as part of this study. The data indicate that probability of detection was highest in Northland, the central and eastern North Island and the west coast of the South Island, and lowest in the eastern and southern South Island. This pattern is at least partially reflected in findings of previous studies that report rūrū distribution and/or abundance (Imboden 1975; O'Donnell 1980; Saint Girons et al. 1986; Stephenson 1998; Robertson et al. 2007; Pohnke et al. 2015). Other factors which may result in variable detection probabilities could include local variation in calling behaviour and differences in habitat composition and structure. In areas where detection probability is high, less survey effort will be required to detect presence of rūrū, compared to those areas where detection probability is low. It may, therefore, be appropriate to adjust the amount of survey effort accordingly. Where there is no existing information on rūrū abundance for a given location, an initial study would help inform the researcher regarding the appropriate level of effort.

Seasonal variations in call activity

At the Eglinton Valley, rūrū call activity varied considerably between months and was highest in December, followed by November. Call activity was lowest in September, January and February. Data from the Tier 1 Monitoring Programme (for New Zealand PCL) also indicated that call activity was highest during spring and early summer months (particularly September and mid-November to mid-December) and lowest during mid-late summer (January and February). These patterns were most likely the result of behavioural changes associated with the breeding cycle. Rūrū typically establish breeding territories in the spring, during which there is an increase in call production. At the Eglinton Valley in 2011, incubation of nests started in mid-September and fledging took place between November and December (MP, unpubl. data). Later in the summer when they are with nestlings or fledglings, adults call much less frequently (Higgins 1999). The relatively low level of call activity in September at Eglinton Valley was contrary to expectations, however this could be an anomaly caused by failure of several ARDs, resulting in a much smaller sample size for this month. The lower levels of call activity during January and February may relate to the period when the adults remain relatively quiet when the fledglings are persistently begging for food, whilst the increase in March recorded in the Eglinton Valley is likely the result of fledged juveniles attempting to establish their own territories. In

Nelson, New Zealand, O'Donnell (1980) recorded relatively high frequencies of calling in August and March, which is consistent with our results for Eglinton Valley. Call activity in Nelson was higher still in April; however, this month was out of scope for the current study and therefore comparisons could not be made. On Ponui Island there were two peaks in call rate: the first occurred in November, which was reasonably consistent with our results, whilst the second occurred in January (Brighten 2015). The explanation for this later peak in call activity is not obvious, although differences between sites may be a function of temporal or geographic variations in the breeding cycle, other variations in behaviour or simply the result of small sample sizes. Colbourne and Digby (2018), in a similar study in Northland, found no strong seasonal variation at one site but declines in call activity from June to August at a second site. In Australia, a study of southern boobook in New South Wales by Debus (1997) recorded a similar pattern, with increased call activity in late winter or spring, followed by a decline through February into autumn to a low in winter. Similarly, in a study in Canberra, Olsen et al. (2002) detected a greater amount of call activity in spring compared to summer/autumn and low activity in winter. Overall, this and previous studies generally agree that there is a pattern of relatively high rūrū call activity in the spring followed by low call activity in the summer. There are, however, some variations in the timing of these highs and lows.

A further consideration when monitoring rūrū populations over multiple years, is the effect of breeding success. For measurement of annual trends, it is essential to perform monitoring surveys, particularly those based on indices of relative abundance unadjusted for detection probability, at the same time each year (Ralph et al. 1995; Thompson et al. 1998). Rūrū successfully bred at Eglinton Valley in the 2011–2012 season, however they do not breed every year at this site (MP, unpublished data). The increase in call activity in autumn is probably due to juvenile birds establishing their own territories, and if so, would be heavily influenced by breeding success for that year. Results from one season to another could therefore vary considerably, depending upon the number of juveniles fledged. Monitoring of call activity during the spring months, when behaviour is focussed on establishing territories, would be independent of breeding success and thus provide data that are more comparable between years.

Night-time variations in call activity

Across New Zealand PCL, call activity reached a peak approximately one hour after sunset, then steadily declined throughout the remainder of the night. Results from the Eglinton Valley were variable, with some months showing distinct differences in call activity between periods of the night and others showing little difference. However, there was a significant interaction effect between month and night-time period, indicating that generally speaking, time of night had an important influence on call activity. Observations of southern boobook in Australia (Debus 1997) were consistent with our results for New Zealand PCL, recording a peak in call activity during the first half of the night. Colbourne and Digby (2018) found that probability of rūrū calling reached a peak after 20% of the night at Hodges Bush and after 30% of the night at Trounson Kauri Park, and thereafter remained relatively constant at both sites. This suggests that whilst rūrū call activity is usually at a peak in the earlier part of the night, there may be geographic and seasonal variations. Our study

agreed with previous studies in reporting that rūrū calls can be detected throughout the hours of darkness.

Study limitations

For nocturnal species such as rūrū, ARDs provide an effective and relatively efficient alternative to traditional observer-based monitoring techniques. The ability to collect data from multiple locations simultaneously from dusk until dawn is an obvious advantage of these devices. At present, however, a major limitation is the time it takes to convert audio recordings into usable data. Currently this is achieved by manually processing recordings by visually scanning sonograms and listening to potential bird vocalisations. Within the Eglinton Valley, one or two nights of data for each ARD station per month was considered sufficient to generate presence/absence data. However, rūrū are relatively common at this site, and at sites where they are less common additional nights may be required to determine the actual presence of this species (Sanderlin et al. 2014). This could result in many additional processing hours which may be beyond the financial budget of some monitoring programmes. There has been much recent research into automated species identification to improve processing efficiency (Frommolt et al. 2008, Steer 2010; Frick 2013; Priyadarshani et al. 2018). Complete or even partial automation, would allow a larger number of recordings to be processed more quickly, producing a larger sample and improved confidence in results of analyses. Unfortunately, at the time of our study such techniques were not sufficiently developed.

Recommendations

Decisions regarding timing of monitoring surveys will depend upon the study objectives. However, we believe monitoring in spring or early summer would maximise detection probability and provide a reasonably robust assessment of rūrū population status and trend that can be usefully compared between years. This and other studies have shown that call activity was often higher in the first half of the night, although call activity can also remain relatively constant throughout the night. Ideally, to allow for geographic and seasonal variation in call activity, rūrū monitoring would entail processing of recordings from the entire night. However, where budget constraints preclude this, we recommend monitoring is carried out during the first few hours of darkness, as this is likely to maximise the probability of detection. Any monitoring programme design should consider the amount of survey effort likely to be required to detect rūrū, which will be influenced by the local population density. An initial study would be invaluable prior to full implementation, to ascertain the appropriate level of survey effort required on a local scale.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Coefficient estimates for Model EV1 (GLMM analysis of Eglinton Valley data).

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