The Herpetological Bulletin 143, 2018: 12-17

Changes in relative population size detection rates of great crested newts (*Triturus cristatus*) over time

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ABSTRACT - Amphibian populations have been shown to be in decline for the past four decades in part owing to habitat degradation and loss. In the United Kingdom, when faced by habitat works through development, consultant ecologists must undertake surveys for European protected species such as the great crested newt under licence following standardised guidance. However, previous studies and survey guidance present an unclear picture in reference to the ideal time of night to undertake sampling for this species. In this paper, an experimental review of the most effective times for detecting population sizes of great crested newts is presented. Sampling was undertaken at Scotland's largest great crested newt population during the peak breeding season repeatedly between sunset and sunrise a total of six times. The results show a significant non-linear relationship between the relative detection rate of great crested newt populations over time with a peak of detectability at 141 minutes after sunset, suggesting that between 60-180 minutes following sunset is the best time to undertake surveys for this species. These data also show a significant peak of great crested newt presence at an air temperature of 3.5 °C which is below the reported critical minimum. However, water temperature which corresponded to peak newt presence was 10.4 °C suggesting this may be a crucial component of accurate great crested newt surveillance.

INTRODUCTION

Since the 1970s, amphibians have been known to be declining worldwide (Alroy, 2015), with the chief threat being loss and fragmentation of habitats owing to changes in agricultural practices (Vié et al., 2009; Hartel et al., 2010). In Scotland, the great crested newt is protected under schedules 2 and 4 of the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended). More common in England and Wales, Scottish populations are typically smaller and more scattered (Wilkinson & Arnell, 2011; McInerny & Minting, 2016; O'Brien et al., 2017). Gartcosh Nature Reserve in North Lanarkshire is thought to have the largest single population of great crested newts in Scotland with a count of 1,012 adults achieved within the reserve during 2006 (McNeill, 2010). This core site is thought to support between 9 and 29% of the total population of great crested newts in Scotland (McNeill, 2010).

Scottish Natural Heritage licence holders are issued with the English Nature (2001) document entitled "Great Crested Newt Mitigation Guidelines" and must comply with the guidelines set out within. These guidelines do not make any suggestion of the best time of night to undertake surveys, instead stating only that nocturnal torchlight surveys are appropriate for the detection of great crested newts. However, there are a number of conflicting studies and documents, some of which propose that great crested newts are nocturnal (Steward, 1969; Himstdedt, 1971; Dolmen, 1983a; Griffiths, 1996; Kröpfli et al., 2010; Jehle et al., 2011) and others which state that great crested newts are crepuscular (Dolmen, 1983b; Griffiths & Inns, 2003; Kröpfli et al., 2010). Diel patterns of changes in behaviour have been noted amongst the Amphibia (Oishi et al., 2004) including for great crested newts (Himstdedt, 1971; Dolmen, 1983a & 1983b). Behavioural changes over time have been shown to be influenced by a number of factors including the diel rhythm of light and darkness, temperature, and prey availability (Noeske & Nickerson, 1979; Griffiths, 1985; Ranta et al., 1987). This has the potential to introduce errors in the survey of great crested newts, generating conservation concerns for the species. For example, if sample visits were undertaken at inappropriate times, surveyors may fail to detect newts or underestimate population size. If these samples were in support of development proposals, then habitat destruction works may impact newts fatally, or mitigation and compensation measures may fail to account for populations of underestimated size.

Maximising the detectability of great crested newt population sizes by means of determining an appropriate survey window is of chief importance for ensuring that accurate data are gathered. These data can then be collated as a measure of the status of the species to enable effective conservation strategy development and accurate reporting on the status of European protected species can then be undertaken (Wilkinson et al., 2011).

METHODS

Site Selection

As the University of Glasgow has been involved with the Gartcosh Nature Reserve in North Lanarkshire (NS 70 68), which is reported to hold Scotland's largest great crested newt population (McNeill, 2010; McNeill, 2012; Harper, 2015), this site was chosen as the sampling location. There is currently a development to the north-east of the site and an access road is due to be developed through the narrowest part of the reserve (McCrorie, L. 2016, pers. comm.). Owing to this, access was allowed to only one of the four distinct pond clusters present on site; the Bothlin Burn complex in the north-west of the reserve (Fig. 1).

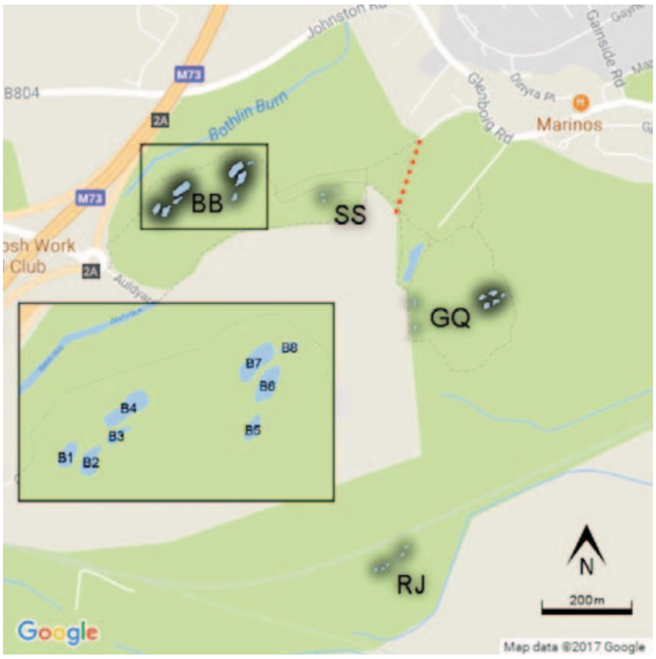

Figure 1. Gartcosh pond sets showing the six Railway Junction (RJ); seven Garnqueen (GQ); three Stepping Stone (SS); and eight Bothlin Burn (BB) pond cluster locations. Thick dotted line shows the approximate location of a road development which restricted access from the west to the GQ and RJ pond clusters. Inset: Bothlin Burn pond numbers

The Bothlin Burn complex of eight ponds was visited on the evening of the 17 March 2017 to identify the suitability of sampling ponds. This was determined in-field by counting the number of great crested newts present in the pond, assessment of the extent of accessible shoreline and by qualitative assessment of the clarity of the water. Ponds B1, B2, B3, B4, B5, B7, and B8 were chosen for sampling. Pond B6 had a thick ring of emergent macrophyte cover and no open water could be seen from the bank; as a result, this pond was excluded from the sampling effort.

Pond Sampling

At the beginning of every pond sample, the water temperature was read approximately 10 cm from the shore and at approximately 15 cm depth in consistently the same location utilising a TPI digital pocket thermometer. Air temperature was measured approximately 50 cm from the ground at a central location between pond B1 and B2 (Approx. NS 70575 68400) using a PeakMeter MS6508 digital thermometer. Cloud cover was estimated by the author as a percentage of visible sky obscured at the beginning of each individual pond sample, and moon % was read from the table given by astronomyknowhow.com (2017).

The seven sample ponds were surveyed by the author with a note taker annotating a recording form using the standard torching methodology given by Griffiths et al. (1996) whereby each pond was sampled at night utilising a high powered spotlight (Clulite Clubman CB3 LED, 1,000,000 candlepower). The accessible perimeter of the pond was traversed on foot from the same starting point and in the same direction for each sample. Torchlight searching was the only method utilised as this is the recommended least-disturbance methodology for sampling in SNH licence conditions and owing to its cost-effectiveness (Kröpfli et al., 2010). During nocturnal sampling key ID features are not always clear, if key features could not be seen during sampling, newts were placed into the category "unidentified newt". These records, which could not be split to sex or species were excluded from statistical analyses (n = 4).

Sample Repetition Rate

Six visits were undertaken at the site during the peak newt season as defined by English Nature (2001). Visits were made on the evenings of 25 March, 8 April, 22 April, 13 May, 26 May, and 17 June 2017. Sampling begun 30 minutes prior to sunset and continued until sunrise of the following day.

Ponds were sampled in a staggered manner repeatedly throughout the evening (Table 1). All seven sample ponds were sampled at differing repetition rates (hourly, two-hourly, and three-hourly) in order to control for the potential effects of repeated torchlight disturbance to newts. Sunset times were read from the table given on the website timeanddate.com (2017).

Ponds were sampled in the order: B1, B2, B3, B4, B5, B8, and B7 and subsets in the same order to ensure relatively consistent timing of visits per pond relative to sunset.

Table 1. Example sampling repetition rate for Bothlin Burn complex (visit 3 onwards). Example shown is the visits undertaken on 16th-17th June 2017.

Sample start time (minutes; relative to sunset)	Hourly Ponds	Two-Hourly Ponds	Three-Hourly Ponds
-30	B1, B2	-	-
+30	B1, B2	B3, B4	B5, B8
+90	B1, B2	B7	-
+150	B1, B2	B3, B4	-
+210	B1, B2	B7	B5, B8
+270	B1, B2	B3, B4	-
+330	B1, B2	B7	-
+390	B1, B2	B3, B4	B5, B8

Statistical Analyses

Data were scaled to be comparable across survey visits wherein the maximum count achieved of newts per pond per survey evening was assumed to be 100% of potentially detectable newts in that pond on that evening. All other counts at other sample times were then expressed as a percentage of that maximum to provide the proportion of the peak count achieved and acting as a measure of population detection rate. Detectability is used in the context of this work as a measure of the proportion of the maximum count of newts that can be found at a sampling location on a given evening rather than a binary positive or negative establishment of presence. As each individual pond sample lasted up to 20 minutes, the start time for each sample can be placed in the half hour period relative to sunset in which it occurred to provide the explanatory variable "half hour relative to sunset".

Generalised linear mixed models (GLMMs) were built using the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages in R v. 3.4.3 (R Core Team, 2017) with the dependent variable being the detected proportion of newts and the explanatory variables being the time relative to sunset in minutes, half hour relative to sunset, moon %, cloud %, air temperature, and water temperature. All models included the random variables of date and pond number. As the data showed distinct curves, polynomial models utilising the same variables were built to the 8th order. Models were nested and so stepwise backwards deletion of explanatory variables via likelihood ratio tests was utilised to choose the best fitted model. GLMMs to test the effects on proportion of newts detected against time since sunset with interaction terms between repetition rate, cloud %, air temperature, and water temperature were also built to ascertain if these explanatory variables interacted and impacted upon survey results.

RESULTS

Great Crested Newt Population Size of Study Site

In all six sample ponds, more male than female great crested newts were detected. Pond B4 consistently had the fewest great crested newts and pond B7 had the largest detected numbers of great crested newts (Table 2). Of the six visits undertaken, the survey beginning on the evening of the 9 April had the peak count of male great crested newts in pond B7, and the sample beginning evening of the 22 April had the highest individual count of female great crested newts in pond B2 (Fig. 2). Male great crested newts were already present in considerable, though unquantified numbers by the time of the first visit on 17 March.

Detection of Great Crested Newts

Figure 3a shows relative detection rates of adult great crested newt population sizes per half hour with a line of statistical best fit arising from a 4th order polynomial model peaking at 141 minutes after sunset (r^2= 0.65, $F_{(4,105)}$= 32.71, p= <0.001). This shows that there is a statistically significant change in the detection rate of great crested newt population sizes over the nocturnal period. The data also suggest that between c.60 and c.180 minutes after sunset, there is a 50% or greater chance that the detected proportion of great crested newts will be above 70% of the potentially detectable great crested newts during a sampling evening.

Male great crested newts had their statistical peak count period at 230 minutes after sunset (Fig. 3b) and were fit

Table 2. Peak counts of great crested newts (*T.c.*) in each of the sampled ponds

Pond No	*T.c.* Male	*T.c.* Female	*T.c.* Peak count
B1	45	9	51
B2	52	27	64
B3	25	9	34
B4	18	5	23
B5	48	4	51
B7	62	19	74
B8	25	6	30

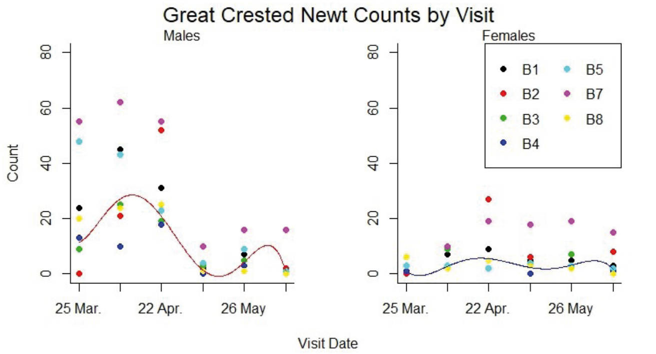

Figure 2. Peak counts of great crested newts in each pond per visit split by sex. The peak count for males was achieved on 9th April in pond B7, and for females the peak count was achieved in pond B2 on the 22nd April. Fitted curves show the statistical best-fit of 5th order polynomial models of detection by sex.

best with a 3rd order polynomial model (r^2= 0.55, $F_{(3,108)}$= 23.39, p= <0.001). In contrast, female great crested newts had a statistical peak count period at 168 minutes after sunset (Fig. 3c) and were also best fit with a 3rd order polynomial model (r^2= 0.38, $F_{(3,69)}$= 20.05, p= <0.001).

The air temperature which statistically corresponded to peak counts was 3.5 °C (Fig. 4a, b) and the data were best fitted with a 6th order polynomial model (r^2= 0.71 $F_{(6,18)}$= 22.62, p= <0.001). All maximum counts with the exception of pond B4 were achieved at an air temperature below 5 °C (Fig. 4b). However, water temperature showed a peak of great crested newt counts at 10.4 °C and best fitted with a 3rd order polynomial model (r^2= 0.71, $F_{(3,26)}$= 6.25, p= <0.01). Figure 4c shows that as water temperature drops to 5 °C, detection rates of newts fall, and Fig. 4(d) shows that all peak counts with the exception of ponds B5 and B8 occurred above 10 °C water temperature.

The percentage of visible sky obscured by cloud had a significant, negative effect on the proportional counts of great crested newts (r^2= 0.60, $F_{(1,30)}$= 8.56, p= <0.01). However, moon % did not show any significant relation with proportional counts of great crested newts (r^2= 0.61, $F_{(1,10)}$= 0.03, p= 0.86).

No significant interaction was found between the repetition rate treatment and the relative detected proportion of great crested newts over time (r^2= 0.83, $F_{(1,138)}$= 1.4915, p= 0.21). However, a significant interaction was found between detection rate of great crested newts over time

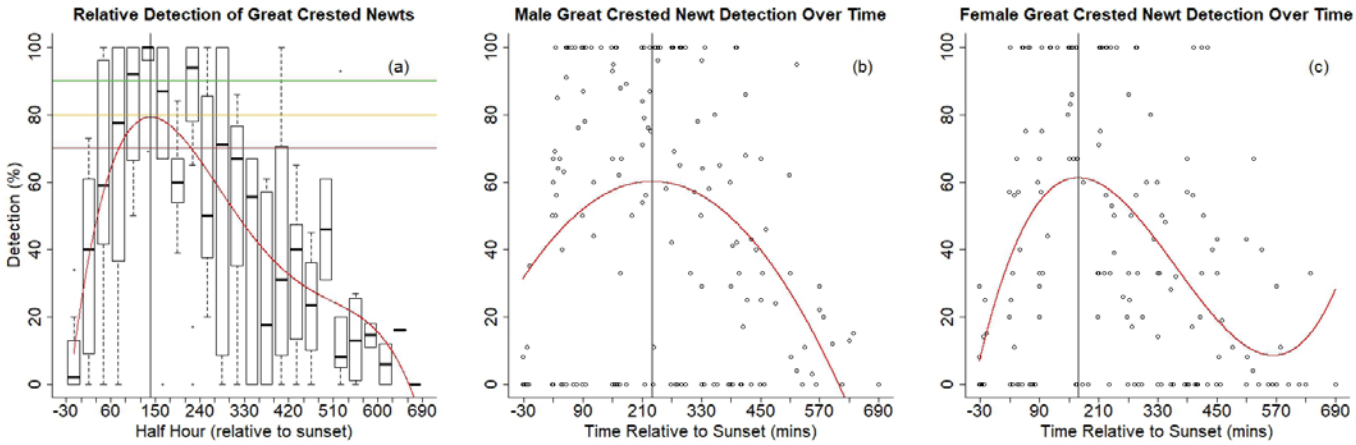

Figure 3. (a) Great crested newt detections expressed as a percentage of the maximum count achieved per pond per evening shown as boxplots splitting the detection rates in to quartiles with the thick black horizontal line at each serving as the marker of the median with boxes either side showing the range of the core 50% of data. Dotted lines represent the outer 50% of data and clear dots represent outlying data points. This plot shows great crested newt detection by half hour period relative to sunset. Data show a strong non-linear relation best fitted with a 4th order polynomial (curve) peaking at 141 minutes after sunset. These data suggest that between c.60 and c.180 minutes following sunset, the relative detection rates are at least 50% likely to be c. 70% of the maximum detectable newts per pond per evening. Lower horizontal line corresponds to 70%, middle to 80%, and upper to 90% detection rate. **(b)** Male GCN expressed as proportion of newts detected per pond per evening plotted against time in minutes relative to sunset. Data show a statistically significant non-linear relation best fitted by a 3rd order polynomial (curve) peaking at 230 mins after sunset. **(c)** Female GCN expressed as proportion of newts detected per pond per evening plotted against time in minutes relative to sunset. Data show a statistically significant non-linear relation best fitted by a 3rd order polynomial (curve) peaking at 168 mins following sunset.

best-fit 4th order polynomial and air temperature (r^2= 0.83, $F_{(4,138)}$ = 4.92, p= <0.001) as well as water temperature (r^2= 0.61, $F_{(4,143)}$= 5.05, p= <0.001).

DISCUSSION

The data presented here show a significant non-linear relationship between the relative detection rates of great crested newts and time (Figs. 2-3). The peak time of detection of great crested newts was 141 minutes after sunset dropping gradually to sunrise (Fig. 3a), suggesting that there is a nocturnal pattern of presence in the water column. This pattern of detectability, tending to be more nocturnal, confirms observations by other authors (Steward, 1969; Himstdedt, 1971; Dolmen, 1983a; Griffiths, 1996; Kröpfli et al., 2010; Jehle et al., 2011) and does not conform to a crepuscular pattern of detection wherein newts would be more active at sunset and sunrise with a low point of activity during the core part of the night (Dolmen, 1983b; Griffiths & Inns, 2003; Kröpfli et al., 2010).

The observations of differential detection rates over the nocturnal period suggest that there is a two hour window between c.60 to c.180 minutes after sunset where the chance of achieving a peak count of greater than 70% the available population is more than a half (Fig. 3). The best-fit polynomial curve presented by this data shows broad similarity to that reported by Himstdedt (1971). The guidance for great crested newt surveys determines that great crested newts are most detectable between mid-March and mid-June (English Nature, 2001). The data presented here suggest that in Scotland, great crested newts may be active in large numbers earlier in the season (Fig. 2), and indeed the author has noted great crested newts active at Gartcosh nature reserve in February. A more thorough review of survey methodologies from a Scottish perspective may find that the situation is different here at the northern fringe of the range of great crested newts. This trend is known to occur amongst other amphibian species where environmental conditions at the fringe of ranges can lead to plastic developmental responses and ecology that is different to core range populations (Brattstrom, 1968; Orizaola & Laurila, 2009; Orizaola et al., 2010, Muir et al., 2014a; Muir et al., 2014b).

The differential detection peak for males and females (168 and 230 minutes after sunset respectively; Fig. 3b,c) may be due to the breeding ecology of this species. As the breeding system is that of a lek, the males will generally be non-randomly distributed in the open areas of the pond for a prolonged time period as they display and await females for mating. The females spend less time in the lekking arena and following mating they venture in to surrounding vegetation to lay eggs, at which point they can become obscured and detection becomes inherently more difficult (Hedlund & Robertson, 1989). The peak detection time for all adults being earlier than that for males or females at 141 minutes after sunset (Fig. 3a) is counter-intuitive and may be an artifact of modelling. However, this issue remains functionally unexplained and requires further work.

Though the system of peak counts has been shown to be a poor proxy of population size (Griffiths et al., 2015) they are still required by the British statutory nature conservation organisations when designing mitigation and compensation measures at the licensing stage of developments. The data presented here suggest that time relative to sunset will potentially impact not only on the detection of occupied ponds with small populations but also on the assessment of the population size at all occupied ponds. Standardisation of a sampling window for great crested newts, which I propose to be between 60 and 180 minutes following sunset, coupled with the population

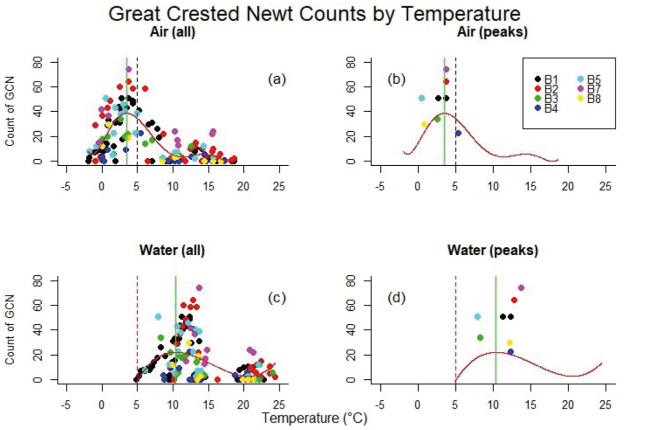

Figure 4. Counts of great crested newts over all visits split by pond and plotted against temperatures of air and water with the vertical hashed lines representing the 5 °C idealised detection rate air temperature previously reported. **(a)** Counts of GCN plotted against air temperature showing a significant non-linear trend best fitted by a 6th order polynomial (curve) with a peak at 3.5 °C (vertical solid line). 66 samples were taken below 5 °C and 97 were taken above 5 °C; **(b)** shows the peak count achieved for each pond plotted against temperature; only the peak count for pond B4 was achieved above 5 °C. The polynomial from (a) is shown for comparison; **(c)** shows a significant non-linear relation between GCN detection and water temperature best fitted with a 3rd order polynomial (curve) and peaking at 10.4 °C (solid vertical line); and **(d)** shows peak counts plotted against water temperature; for all ponds except B5 and B8, the peak count was achieved above 10 °C and the polynomial fit from (c) is shown for comparison.

density system given by Griffiths et al., (1996), would help to ensure that data collected on population sizes across the species range would be comparable. Collation of such data throughout a species range would enable interpretation of the relative importance at both local and national scales of great crested newt populations.

The guidance for surveys of great crested newts and previous literature on the topic suggests that great crested newts become most active above 5 °C air temperature (Verrell & Halliday, 1985; English Nature, 2001; Sewell et al., 2010; Harper, 2015). This study could only be undertaken on specific agreed dates with the land owner and so the temperatures were not always above 5 °C (Fig. 4). However, the results showed that a peak detection of great crested newts was achieved at 3.5 °C air temperature and almost all peak counts per pond were achieved below an air temperature of 5 °C (Fig. 4a,b). This contrasts with observations from prior surveyors (Verrell & Halliday, 1985; English Nature, 2001; Sewell et al., 2010; Harper, 2015), and provides a potentially interesting future research aspect from a Scottish perspective. Indeed, the temperature which seemed to be most relevant to great crested newt activity was the water temperature. This conformed to previous studies where great crested newt presence in the water column reduced as the water temperature dropped towards 5 °C, with a peak of detection at 10.4 °C (Fig. 4c,d). It would be prudent for ecological practitioners to measure water temperature as a regular component of great crested newt surveillance and reporting.

The phase of the lunar cycle has been shown to have a significant impact on the relative detection rates of newts, wherein detection of newts is significantly lower at a full moon and for up to 10 days following (Deeming, 2008). However, in this study the absolute percentage of visible moon surface was utilised as an explanatory variable and showed no significant effect on detectability. Percentage of visible sky covered by cloud as estimated by the author in the field did show a negative correlation with newt detection rate. This may be related to some aspect of natural light cues and could warrant further exploration.

Though these data present an insight into the relative detection rates of great crested newts over time, there are some areas where the experimental design could be improved. Repeated nocturnal sampling of ponds throughout an evening at different pond clusters on consecutive nights would provide a more statistically robust measurement of newt population detection. In addition, there were no measurements of the light levels at which newts were detected; further studies should seek to measure the ambient light levels at the survey site at each sampling time to ascertain whether this has any impact on the relative abundance of newts in the water column of their breeding ponds. Differences in visibility of and accessibility to the water column on different visits due to growth of algae or macrophytes can introduce differences to the relative detection of newts via torchlight throughout a season (Griffiths et al., 1996). Further work should incorporate these variables during modelling. Finally, third-party verification of identification in-field would be beneficial to ensure that fatigue from prolonged nocturnal surveying did not impact upon the quality of the data being collected.

ACKNOWLEDGEMENTS

I would like to thank my project supervisor Prof. Roger Downie for support and constructive review throughout this project; to Debbie McNeill for review and commentary of my project proposal and methodology; Nosrat Mirzai for calibration of equipment; Steven Allain and Victoria Muir for manuscript review; Daniel Haydon and Sofie Spatharis for assistance with data analysis; and to Graham Sennhauser, Struan Candlish, Hannah Williams, Rosanna Mooney, Bradley Fairclough, and Aisling Gribbin for their assistance with my field work. Thanks also to anonymous reviewers for comments that greatly improved the submitted version of the manuscript.

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Accepted: 17 February 2018