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Photons and foraging: Artificial light at night generates avoidance behaviour in male, but not female, New Zealand weta[☆]



Bridgette Farnworth^{a,*}, John Innes^b, Catherine Kelly^a, Ray Littler^c, Joseph R. Waas^a

^a Biological Sciences, School of Science, University of Waikato, Private Bag 3105, Hamilton, New Zealand

^b Manaaki Whenua - Landcare Research, Private Bag 3127, Waikato Mail Centre, Hamilton 3240, New Zealand

^c Mathematics and Statistics Department, University of Waikato, Private Bag 3105, Hamilton, New Zealand

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ABSTRACT

Avoiding foraging under increased predation risk is a common anti-predator behaviour. Using artificial light to amplify predation risk at ecologically valuable sites has been proposed to deter introduced mice (*Mus musculus*) and ship rats (*Rattus rattus*) from degrading biodiversity in island ecosystems. However, light may adversely affect native species; in particular, little is known about invertebrate responses to altered lighting regimes. We investigated how endemic orthopterans responded to artificial light at Maungatautari Ecological Island (Waikato, New Zealand). We predicted that based on their nocturnal behaviour, ecology and evolutionary history, tree weta (*Hemideina thoracica*) and cave weta (*Rhaphidophoridae*) would reduce their activity under illumination. Experimental stations (n = 15) experienced three evenings under each treatment (order randomised): (a) light (illuminated LED fixture), (b) dark (unilluminated LED fixture) and (c) baseline (no lighting fixture). Weta visitation rates were analysed from images captured on infra-red trail cameras set up at each station. Light significantly reduced the number of observations of cave (71.7% reduction) and tree weta (87.5% reduction). In observations where sex was distinguishable (53% of all visits), male tree weta were observed significantly more often (85% of visits) than females (15% of visits) and while males avoided illuminated sites, no detectable difference was observed across treatments for females. Sex could not be distinguished for cave weta. Our findings have implications for the use of light as a novel pest management strategy, and for the conservation of invertebrate diversity and abundance within natural and urban ecosystems worldwide that may be affected by light pollution.

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1. Introduction

Non-commensal wild house mice (*Mus musculus*) in New Zealand are influenced by ambient light and reduce activity at both artificially lit foraging patches within forests (Farnworth et al., 2016) and foraging patches exposed to bright moonlight (Shapira et al., 2013). As New Zealand's native biodiversity experiences significant damage caused by introduced mice and rats (*Rattus rattus*; *R. norvegicus*) (Innes et al., 1995; Watts et al., 2017), we recently proposed that light may be an untapped conservation tool for protecting partially fenced peninsula sanctuaries in New

Zealand or deterring rodents from landing on the docks of protected islands (Farnworth et al., 2016). Rodent activity could also be reduced near or on the outer surfaces of pest-proof fences that completely surround forest fragments (Farnworth et al., 2016), particularly along the elevated curled hood of pest-fencing, where rodents frequently travel (Connolly et al., 2009).

Although illuminating structures or surfaces might assist conservationists with rodent control, artificial light may negatively impact native biodiversity. Ecological light pollution occurs from either: (a) periodic increases in illumination; (b) fluctuations in light levels that occur unexpectedly; or (c) direct glare from light sources (Longcore and Rich, 2004). Artificial light is well known for affecting the navigation responses of charismatic vertebrates such as sea turtles (Peters and Verhoeven, 1994), sea birds (Le Corre et al., 2002) and bats (Stone et al., 2009). Nearly two-thirds of invertebrates are nocturnal (Holker et al., 2010) and, in comparison to vertebrates, illumination elicits more subtle responses. For

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* Corresponding author.

E-mail addresses: bridgette.farnworth@outlook.com (B. Farnworth), innesj@landcareresearch.co.nz (J. Innes), catherine.kelly@my.jcu.edu.au (C. Kelly), ray.littler@waikato.ac.nz (R. Littler), waasur@waikato.ac.nz (J.R. Waas).

example, although insect attraction to lighting is a well-known phenomenon, their population sizes decrease if insects continually congregate at lighting until mortality occurs (Holker et al., 2010). Prolonged light exposure also changes community composition towards systems dominated by predatory and scavenging invertebrates (Davies et al., 2012) and extends the circadian activity periods of diurnal feeders (Frank, 2009), while facilitating vertebrate predators, such as bats, to detect nocturnally feeding invertebrates (Rydell, 1992). Furthermore ecosystem services may be affected by artificial illumination if, for example, nocturnal invertebrate pollinators that preferentially forage under dim lighting are lost, thus uncoupling relationships between plant and animal species (Macgregor et al., 2015).

Understanding the impact of light pollution is valuable if conservation managers from New Zealand and abroad exploit artificial light to protect ecosystems surrounded by exclusion fencing or to create 'virtual barriers' (e.g. lit corridors separating managed from unmanaged land) to control rodent movement. Although many international studies demonstrate negative impacts of light (reviewed in Longcore and Rich, 2004), the effect of artificial lighting on New Zealand's native vertebrates and invertebrates has not been studied in detail. Understanding how nocturnal species respond towards illumination is essential when considering light as a rodent deterrent, especially for endemic fauna such as the weta (*Anostomatidae*; *Raphidophoridae*) that are already threatened by rodent predation. Weta are flightless orthopterans with genera containing some of the largest insects in the world (Larsen and Burns, 2012) but weta populations rapidly declined after the introduction of mammals to New Zealand; the Norway rat and the ship rat are now considered their most significant predators (Gibbs, 1998).

New Zealand's tusked (*Anisoura* and *Motuweta*), giant (*Deinacrida*), tree (*Hemideina*) and ground (*Hemiandrus*) weta belong to the *Anostomatidae* family (Watts et al., 2011a), while the *Raphidophoridae* family includes the cave weta, which are more speciose but less well described (Cook et al., 2010). Both families are nocturnal, a lifestyle that is entrained by environmental light when weta emerge from their roosting cavities at dusk (Lewis and York, 2001). It is likely this circadian pattern coincides with wetas' evolutionary history alongside native diurnal predators (e.g. huia (*Heteralocha acutirostris* – species extinct but diet known), North Island kokako (*Callaeas wilsoni*), tieke (or saddleback; *Philesturnus carunculatus*), kaka (*Nestor meridionalis*), weka (or woodhen; *Gallirallus australis*) and kahu (or swamp harrier; *Circus approximans*) (Gibbs, 1998). Detecting changes in illumination regulates the onset of a weta's active phase (i.e. when light intensity reaches 5 lux; Lewis and York, 2001) but also offers a degree of protection against native nocturnal predators of weta, such as the whekau (or laughing owl; *Sceloglaux albifacies* – species extinct but diet known), ruru (or morepork owl; *Ninox novaeseelandiae*) and the tuatara (*Sphenodon punctatus*) (Gibbs, 1998). For example, tuatara predation on Mercury Island causes the Mercury Island tusked weta (*Motuweta isolata*) to suppress their activity under the full moon and emerge in dark periods between moonrise and moonset (McIntyre, 2001).

Artificial light may have a similar impact to moonlight on weta behaviour. For example, Watts et al (2011b) gained the subjective impression that fewer Cook Strait giant weta (*Deinacrida rugosa*) were found on cloudy nights that reflected lighting from a nearby city (Wellington, New Zealand; 7.5 km away) and Wehi et al. (2015) suggested that artificial light reduced tree weta cavity occupancy. Artificial illumination may alter the reliability of information that environmental cues usually provide about predation risk for weta. Further, unnecessary anti-predator behaviour, such as avoiding an illuminated area in the absence of predators, may be costly to weta

and the communities weta are part of.

Based on their nocturnal behaviour, ecology and evolutionary life history, we predict the Auckland tree weta (*Hemideina thoracica*) and cave weta (*Raphidophoridae*) at Maungatautari Ecological Island (Waikato, New Zealand 38°03'S, 175°33'W) will reduce their activity if sections of pest-fencing surrounding the reserve are illuminated to assist conservationists with rodent control. To assess the effects of using light as a conservation tool on non-target species, we experimentally examined how native weta species used pest fencing in the presence and absence of artificial light. Our findings not only have implications for light as a novel pest management strategy but also for the conservation of invertebrate diversity within natural and urban ecosystems and for restoration techniques that use weta and other light sensitive invertebrates as indicator species at city parks and reserves.

2. Method

2.1. Study site

Maungatautari Ecological Island is an eroded andesitic volcanic cone that supports a dense mix of podocarp-broadleaved species and forest types, ranging from lowland to montane forest (Clarkson, 2002). A 47-km pest-proof exclusion fence (Xcluder™ Pest Proof Fencing Ltd, Rotorua, New Zealand) surrounds 3363 ha of forest area on the mountain and contains two smaller enclosures: the 35 ha 'Northern Enclosure' and the 65 ha 'Southern Enclosure' (Speedy et al., 2007). Aerial poisoning and trapping were used to kill all introduced mammals present within the reserve (Speedy et al., 2007). Although the smaller enclosures have generally remained free of all mammalian pests since April 2005 (Northern Enclosure) and July 2006 (Southern Enclosure) (Speedy et al., 2007), mice remain the only mammalian predator in the main sanctuary (Watts et al., 2017). We created 15 stations within the hood of the fence that divides the Southern Enclosure from the Main Sanctuary, where mammalian predation would be restricted to mice alone. Stations were spaced approximately 150 m apart along the fence and accessed daily using a vehicle track that runs parallel to the fence.

2.2. Procedures

Each station was systematically allocated three lighting treatments within the hood: (a) light (an illuminated lighting fixture), (b) dark (a unilluminated lighting fixture), and (c) baseline (no lighting fixture present). Artificial illumination was supplied by an LED lamp (Senyoo, SY-CL02; 1.6 W; 5700 k; 100 lumen; cool white light). The lamp had a magnetic base which allowed it to be attached vertically to the underside of the metal pest-fence hood (Fig. 1). Lamps were fixed at an 8 cm distance so that the light intensity within the gutter of the hood, where rodents travelled, would reach 1000 lux, as measured by an Iso-Tech 1335 digital light meter. The lamp had four modes of brightness (2%; 50%; 75%; and 100%). The second mode was selected for our experiment to ensure the lamp would have enough battery capacity to run overnight without significant dimming. We measured lux readings (starting at 1000 lux) over a 10 h period in the lab and found light intensity decreased linearly by an average of 37 lux per hour.

On test evenings, infra-red trail cameras (Reconyx HC600 Hyperfire Covert IR Cameras; Wisconsin) were attached with cable ties to the steel brackets holding up the curved steel hood (Fig. 1). Cameras were positioned to enable a view of the underside of the hood and set to take pictures at 5 s intervals. The lighting fixtures were attached to a marked point underneath the fence hood that was located 1 m to the left of the camera and 8 cm back from the lip

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