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The impact of streetlights on an aquatic invasive species: Artificial light at night alters signal crayfish behaviour

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ABSTRACT

Artificial light at night (ALAN) can significantly alter the behaviour, communication and orientation of animals, and will potentially interact with other stressors to affect biodiversity. Invasive, non-native species are one of the largest threats to freshwater biodiversity; however, the impact of ALAN on such species is unknown. This study assessed the effects of ALAN at ecologically relevant levels on the behaviour of a globally widespread invasive species, the signal crayfish (*Pacifastacus leniusculus*). In experimental aquaria, crayfish were exposed to periods of daylight, control (<0.1 lx) and street-lit nights to test two hypotheses: (1) signal crayfish under natural conditions are nocturnal animals, spending more time in shelter during the day, whilst active and interacting during the night, and (2) ALAN reduces crayfish activity and intraspecific interactions, whilst increasing their propensity to use shelter. Our results confirm that signal crayfish are largely nocturnal, showing peak activity and interaction levels during control nights, whilst taking refuge during daylight hours. When exposed to short-term simulated light pollution from a streetlight at night however, activity and interactions with conspecifics were significantly reduced compared to control nights, whilst time spent in shelters increased. By altering crayfish behaviour, ALAN may change the ecosystem impacts of invasive crayfish in the wild. This study is the first to show an impact of ALAN on the behaviour of an invasive, non-native species, and provides information for the management of invasive crayfish in areas where ALAN is prevalent.

1. Introduction

Habitat degradation and invasive, non-native species can interact to significantly alter freshwater biodiversity (Dudgeon et al., 2006). An understudied form of habitat degradation is ecological light pollution caused by artificial light at night (ALAN) (Longcore and Rich, 2004; Gaston et al., 2014), which can significantly affect biodiversity by altering species interactions, orientation and activity, and causing behavioural and physiological changes (Navara and Nelson, 2007; Longcore and Rich, 2004). In aquatic ecosystems, the behaviour of invasive, non-native species can lead to significant economic and environmental damage (Mack et al., 2000) and the unknown effects of ALAN on invasive, non-native species could potentially both exacerbate or ameliorate their destructive impacts through altering their behaviour.

A large proportion of ALAN is caused by street lighting (Longcore and Rich, 2004) and there is a predicted 6% global increase per annum of streetlights (Hölker et al., 2010a). Within the UK, there are currently about 7.4 million streetlights in operation (Royal Commission on Environmental Pollution, 2009). In the absence of ALAN, nocturnal light intensity varies with the phase of the moon, but is typically below 0.1 lx (Perkin et al., 2011; Gaston et al., 2014). Nocturnal lighting conditions have been consistent over long geological time scales, and only as a result of recent anthropogenic activity has there been a drastic change in night light conditions (Gaston et al., 2014). Small variations in light intensity can alter the behaviour of aquatic animals, with some species sensitive to light intensities as low as 10^{-7} lx (Moore et al., 2006). The spectral composition of street lights can also influence which animals may be affected (Davies et al., 2013), with broad spectrum light sources becoming more common in the UK as older, narrow spectrum bulbs are replaced (Royal Commission on Environmental Pollution, 2009). Street lighting intensity recommendations in the UK currently indicate an average of 15 lx and minimum of 5 lx, whilst in North America an average intensity of 20 lx is used (Riley et al.,

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2013). These nocturnal light intensities are likely to be having profound, and as yet largely unidentified, effects on a wide range of species.

More than 30% of vertebrates and 60% of invertebrates are nocturnal, and these organisms are likely to be affected by altered light regimes (Hölker et al., 2010b) since ALAN may lead to a 'perpetual full moon' effect (Longcore and Rich, 2004). Nocturnal animals may become less active in the presence of artificial lighting; for example, male green frogs (*Rana clamitans*) call less during the breeding season (Bakker and Richardson, 2006) and bat activity along commuting routes is drastically reduced (Stone et al., 2009). Conversely, diurnal animals may extend their activity into the night, for example, songbirds sing earlier in the morning and throughout the night, resulting in physiological fitness costs (Miller, 2006; Dominoni et al., 2013, 2014). Predators may gain an advantage over prey as a result of ALAN, effectively exploiting a 'night light niche' (Longcore and Rich, 2004). Whether it is edificarian reptiles, such as geckos (Perry and Fisher, 2006), ground dwelling invertebrate communities (Davies et al., 2012) or various fish species (Becker et al., 2013), predators may increase their visual foraging success on prey attracted to the light source.

Compared to terrestrial ecosystems, there is a significant lack of research on the effects of ALAN in aquatic ecosystems (Longcore and Rich, 2004; Perkin et al., 2011; Gaston et al., 2014). Additionally, to our knowledge, no study to date has examined the effects of ALAN on invasive, non-native species. Existing studies of aquatic species, however, provide evidence that ALAN can induce behavioural changes. For example, streetlights disrupt Atlantic salmon (*Salmo salar*) fry dispersal from hatching sites (Riley et al., 2013, 2015) as well as the onset of smolt seaward migration (Riley et al., 2012). Riparian street lighting can also influence freshwater ecosystems by disrupting invertebrate exchange between the river and riparian edge (Meyer and Sullivan, 2013), reducing nocturnal drift rates (Holt and Waters, 1967; Perkin et al., 2014; Henn et al., 2014) and interfering with flying adult dispersal (Perkin et al., 2011, 2013). Given the known effects of ALAN on freshwater organisms, it is likely that aquatic, non-native species will respond to ALAN, though this has never been assessed.

Among the most prolific, ecologically and economically costly aquatic invaders are freshwater crayfish (Holdich et al., 2009; Strayer, 2010). Crayfish are keystone species (Geiger et al., 2005) and ecosystem engineers (Johnson et al., 2011; Statzner et al., 2000) that can alter the structure and function of aquatic ecosystems by interacting with organisms on multiple trophic levels and changing habitat topography (James et al., 2014). In addition, the impacts of crayfish on aquatic ecosystems are predicted to be greater for invasive, non-native than for native species (James et al., 2014). Crayfish are largely regarded as nocturnal animals, though they may also show a degree of activity during the day (e.g. Edmonds et al., 2011; Miranda-Anaya, 2004; Miguel and Aréchiga, 1994). They are likely to be affected by ALAN, particularly as the light detection sensitivity of crayfish peaks at 570 mμ (Kennedy and Bruno, 1961), which is within the spectra of light emitted from commonly used high-pressure sodium streetlights (Royal Commission on Environmental Pollution, 2009). The impact of ALAN from streetlights on both native and invasive crayfish however is unknown.

Here, we investigated the effects of ALAN on the behaviour of signal crayfish (*Pacifastacus leniusculus*). By exposing crayfish to daylight, control (<0.1 lx) and artificially lit nights, this study tested the following hypotheses: (1) signal crayfish are nocturnal, spending more time in shelter during daylight, whilst active and engaged in intraspecific interactions during the night, and (2) ALAN reduces signal crayfish activity and intraspecific interactions but increases their propensity to shelter.

2. Materials and methods

2.1. Animal origin and maintenance

Signal crayfish (*P. leniusculus*) were caught using baited cylindrical crayfish traps ('Trappy Traps', Collins Nets Ltd., Dorset, UK) over a period of two weeks during spring 2014 from Dderw Farm pond, Llyswen, Brecon, South Wales (52°01′47.3″N 3°15′24.1″W) where ALAN is not present (<0.1 lx at the water surface at night). Traps were checked on a daily basis under trapping license number: CE068-N-315. Crayfish were transported to the Cardiff University aquarium facility and maintained in 100 L holding tanks (approx. 30 crayfish per tank) filled with dechlorinated water. Photoperiod was set at a 16 h light/8 h dark cycle. A desk lamp enclosed by neutral density filters (LEE Filters, Hampshire, UK) provided continuous, low night-time illumination at <0.1 lx (equivalent to a clear night at the trapping site) when the main aquarium lights were switched off. Daytime lighting at a similar intensity to that experienced at the trapping site on an overcast day was provided using full spectrum daylight mimicking bulbs (Sylvania T5 F13W/54-765 G5 Luxline Standard Daylight bulb) giving an intensity of 1000 ± 50 lx at the water surface. Crayfish in holding tanks were provided with a 2 cm pea gravel substrate, plant pot refugia and were fed daily with Tetra Crusta crayfish food pellets. Weekly 50% water changes were performed to maintain water quality. Animals were maintained under these conditions for at least two weeks to acclimatise to the laboratory conditions before the experiment began and any crayfish that showed signs of moulting, disease or lost appendages were excluded from the study. Blackout material was used to separate stock crayfish tanks from experimental aquaria. All applicable institutional and national guidelines for the care and use of animals were followed.

2.2. Influence of ALAN on crayfish behaviour

The effect of ALAN on signal crayfish behaviour was tested using a high-pressure sodium streetlight bulb (Phillips SON-T Pro 70w) in a luminaire with neutral density filter sheets (LEE Filters, Hampshire, UK), which provided a light intensity of 12 ± 5 lx at the water surface (similar to levels experienced in urban areas with street lighting; Riley et al., 2013). Infrared LED security cameras (3.6 mm SONY Hi-Res Super HAD, Waterproof IP68, Model: VN37CSHR-W36IR-25; RF-Concepts, Dundonald, UK) were installed above each experimental aquarium (tank measurements: L60 cm × W30 cm × D30 cm). Crayfish behaviour was recorded using a digital video recorder (embedded DVR-Video/LAN/USB. Model: LS8004MA-KGB Cameras; Innovative Technology, Wellingborough, UK). Each aquarium contained a pair of male signal crayfish and included a 2 cm pea gravel substrate as well as two plant pot refuges. Crayfish pairs were size matched to within 10% carapace length following Martin and Moore (2008) and one crayfish per pair was marked using yellow nail polish for individual identification.

Four pairs of crayfish were observed simultaneously (i.e. in four separate aquaria) and the experiment consisted of six trials ($n = 24$ pairs). During each trial, 32 h of video was recorded per pair of crayfish. The timing of trials were as follows: on day one, crayfish were introduced to experimental aquaria on the opposite side to the shelters at 15:00 h, allowing the animals time to acclimatise to the tanks before video recording began at 18:00 h. Crayfish were recorded during daylight (1000 ± 50 lx) from 18:00 h to 22:00 h (daylight PM), followed by a night-time period 22:00–06:00 h and then another daylight period from 06:00 h to 10:00 h (daylight AM) on day two (1000 ± 50 lx). The crayfish then remained in their tanks until the recordings were repeated at the same time on day two. In half of the trials, crayfish were exposed to control lighting (<0.1 lx)