# Photopollution impacts on the nocturnal behaviour of the Sugar Glider (*Petaurus breviceps*)

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Night light pollution is an important environmental problem impacting on many animals including a variety of insects, amphibians, reptiles, birds, and mammals. While some impacts of night light pollution are well-known such as misorientation of sea turtle hatchlings and deaths of migratory birds, other less obvious impacts on reproduction, communication, competition, and predation have recently been reported. As some natural areas in New Guinea and Australia face agricultural and industrial development, conflicts between wildlife and photopollution will add to existing problems of habitat fragmentation and degradation. I report on the photopollution impacts on the nocturnal behaviour of the sugar glider (*Petaurus breviceps*). Captive sugar gliders were monitored using a "super nightshot" camcorder for baseline nocturnal behaviour following a 12 hour daylight/12 hour dark regime. Treatment consisted of 12 hour daylight/ 12 hour simulated ambient low and high luminosity street light photopollution (average 7.0 and 12.0 lux). Over 575 sugar glider-hours were analyzed. The results show marked behavioural impacts under high luminosity treatment, including almost total cessation of high level activity. Although impacts were reduced under the low luminosity treatment, even 7.0 lux reduced foraging time. This is the first report of photopollution impacts on sugar glider foraging and activity levels. Further research, particularly with wild populations, is needed to elucidate the extent of photopollution impacts on sugar gliders and their endangered and vulnerable relatives.

Key words: Photopollution, Night light pollution, Sugar gliders, *Petaurus breviceps*.

## INTRODUCTION

ECOLOGICAL light pollution is defined as "artificial light that alters the natural patterns of light and dark in ecosystems" (Longcore and Rich 2004). Night light pollution is known to be an important environmental problem (Outen 1998; Harder 2002; Longcore and Rich 2004) impacting on many animals including a variety of insects, amphibians, reptiles, birds, and mammals (Beier 1995; Adamany *et al.* 1997; Bergen and Abs 1997; Longcore and Rich 2004). While some impacts of night light pollution are well-known such as misorientation of sea turtle hatchlings and migratory bird deaths, other less obvious impacts on reproduction, communication, competition, and predation have recently been reported (for review see Longcore and Rich 2004). Approximately two-thirds of the world's population live in areas where night sky light levels exceed polluted status (Cinzano *et al.* 2001). Polluted status is reached when the artificial sky brightness is at least 10% greater than that of the natural background sky brightness above 45° elevation (Smith 1979).

Recent studies have found altered nocturnal feeding behaviour, including both prey detection and predator avoidance, resulting from artificial night lighting. For example, nocturnal frogs (*Hyla chrysoscelis*) have reduced foraging success under artificial lighting due to their diminished ability to detect prey in lighting conditions different from that under which their eyes evolved (Buchanan 1993). Likewise, coastal beach mice (*Peromyscus polionotus leucocephalus*) forage significantly less in food patches lit by artificial night lighting than in areas without artificial night lighting (Bird *et al.* 2004). This is probably a result of predator avoidance (Bird *et al.* 2004) since light levels are known to influence predation risk and success in a diverse group of species including various moths, fish, owls, and rodents (Clark 1983; Clark and Levy 1988; Frank 1988; Kotler *et al.* 1991; Rydell and Baagoe 1996; Lima 1998a). Also, night lighting can influence foraging among sympatric competitors where each species typically forages in different lighting conditions (e.g., the squirrel treefrog, *Hyla squirrela*, the western toad *Bufo boreas*, and the tailed frog, *Ascaphus truei*) (Hailman 1984; Buchanan 1998; Longcore and Rich 2004).

Some natural areas in New Guinea and Australia face increased agricultural and industrial development. In addition to habitat fragmentation and degradation, wildlife is confronted with the impacts of artificial night lighting as forest canopies are thinned and residential/industrial lighting is erected. The sugar glider (*Petaurus breviceps*) — a member of the Petauridae family — is considered to be a secure species (Suckling 1983, 1995; Flannery 1995; Smith 1999) despite current levels of habitat loss and fragmentation. However, no information exists on the ability of species within the family Petauridae to cope with photopollution from decreased canopy cover and increased residential or industrial lighting. Potentially, photopollution may aid predators such as owls, kookaburras, goannas, and cats (Henry and Suckling 1984) in detecting sugar gliders. Further, photopollution may reduce sugar glider foraging success if the gliders spend less time foraging as has been noted in other

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marsupials (Laferrier 1997) and placental animals including lagomorphs (Glibert and Boutin 1991), bats (Rydell 1992), and small rodents (Lima 1998b). I examined the impacts of varying levels of light on the nocturnal behaviour (foraging, high and low level activity, and time in the nest cavity) of the sugar glider.

## METHODS

The study was conducted from 14 February-31 March 2005 with three captive sugar gliders. Two female sugar gliders were obtained from private individuals in Billings, MT, USA who had previously purchased the sugar gliders from an exotic pet store (approximate ages 1 year and ½ year). One male sugar glider was obtained from a breeder in Bozeman, MT, USA just after weaning. The sugar gliders lived 10 months together prior to the experiment and the older female was pregnant during the study. Ages at time of experiment were male, approximately 1 year; females, approximately 22 months and 16 months. Just prior to and during the experiment, the sugar gliders were housed in a separate room (~20°C) collectively in an approximately 1 m × 0.3 m × 0.5 m coated wire cage containing a nest cavity pouch, three activity wheels, one water bottle, and a variety of perching bars, shelves, and food dishes (Figs 1, 2). The cage was cleaned and food was transferred during the afternoon when the gliders were asleep. Each day gliders were collectively fed approximately 43.5 g chicken and 28.5 g of a mixture of nuts, yogurt chips, and dried papaya. The amount of food consumed was determined by subtracting the weight of food remaining in the morning from food offered the previous evening.

Gliders were maintained on a 12 hr light/12 hr approximately new moon dark regime, except during treatments. Twelve hour cycles were initiated at 0700 and 1900. Treatments consisted of 12 hr light/12 hr simulated ambient low or high luminosity street light photopollution (7.0 and 12.0 lux, respectively). Lux values were chosen as approximately minimum and average streetlighting levels (IDA 1996b). For reference, lux at twilight is approximately 10 lux, deep twilight is approximately 1 lux, full moon is approximately 0.1 lux, and quarter moon is approximately 0.01 lux. Experimental lux values were determined through conversion of foot-candles measured at the nest cavity entrance using an exposure meter (General Electric Type DW-68). I used a soft white 75W 120V incandescent light bulb (Osram Sylvania Products Inc, PA, USA) in one shaded lamp for the low luminosity treatment and in two shaded lamps for the high luminosity treatment. Lamps were arranged within the room behind cloth curtains until the desired lux was measured at the entrance to the nest cavity and a relatively overall even radiance was achieved throughout the room. Treatment nights were spaced by a minimum of three control (dark regime) nights because my previous observations indicated that gliders exposed to treatment conditions returned to normal behaviour following two nights of the dark regime. A total of eight dark control nights (four at the start of the study and four overlapping with the end) and four low and four

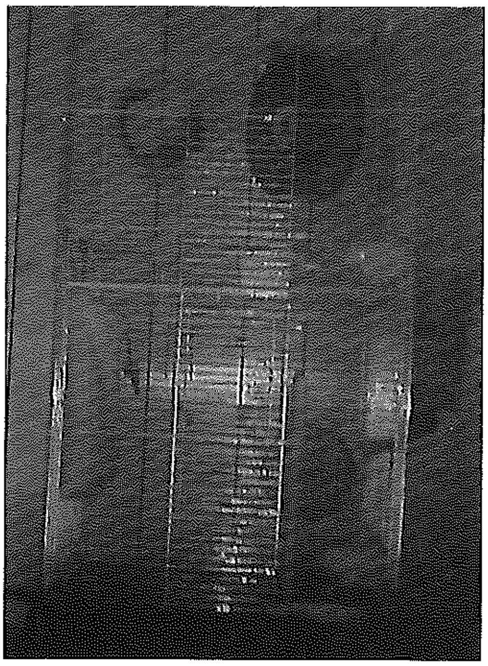

*Fig. 1.* Low luminosity treatment (7.0 lux) as seen through the enhanced vision "super nightshot" camera. Note the sugar glider in the activity wheel.

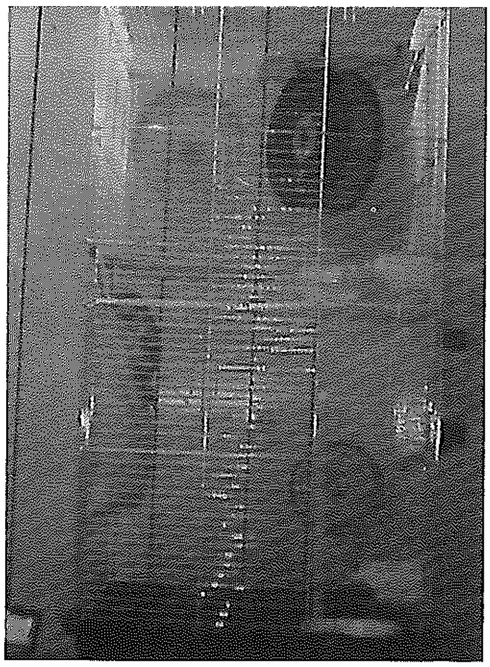

*Fig. 2.* High luminosity treatment (12.0 lux) as seen through the enhanced vision "super nightshot" camera. Note the sugar glider perching on the nest cavity pouch.

high luminosity treatment nights (randomly assigned throughout the study) were observed.

Nocturnal behaviour data were collected by monitoring gliders using a "super nightshot" camcorder (SONY Digital Handycam DCR-TRV33) for 12 hours each night. Tapes were changed every 1½ hours during the night. One of four behaviour categories was assigned to each glider summarizing every 30 sec of behaviour. Categories included 1) in the nest pouch, 2) foraging — eating, drinking, or travelling directly between feeding stations, 3) high level activity — running in the wheel, and 4) low level activity — perching, preening, or perusing the cage (see Figs 1, 2 for examples).

Over 575 hours of sugar glider behaviour were analyzed. Individual gliders could not be identified on tape, so glider behaviour was summed for statistical tests and averaged for Figures 1–4. One-way ANOVAs were used to determine differences between control and treatment conditions. I did not use repeated measures because the three gliders were not individually identifiable on tape.

## RESULTS

Following 12 hours of daylight, the mean time until the first glider exited the nest pouch was greatest for the low luminosity treatment (19.4 min, 17.4 SD), intermediate for the high luminosity treatment (12.5 min, 10.1 SD), and lowest for the dark control (6.4 min, 8.6 SD). Due to high standard deviations, none of the differences were significant at $\alpha = 0.05$. Mean time before 0700, when all three gliders returned to the nest pouch for the duration of the 12 hour night cycle, was 19.9 min (16.2 SD) for the high luminosity treatment, 17.8 min (17.2 SD) for the low luminosity treatment, and 2.5 min (3.5 SD) for the dark control. Compared to the dark control, both high luminosity and low luminosity treatment differences were significant ($P = 0.019$ and 0.043, respectively). There was no significant difference between high and low luminosity treatments ($P = 0.863$).

The low luminosity treatment resulted in similar food consumption compared to the dark regime ($P = 0.844$) (Table 1), decreased time spent foraging ($P = 0.100$) (Table 1 and Fig. 3), increased time spent in nest cavities ($P = 0.008$) (Table 1 and Fig. 4), and decreased high and low level activity ($P = 0.017$ and 0.031, respectively) (Table 1 and Figs 5, 6). Results for high luminosity treatment, compared to the dark regime, include decreased food consumption and time spent foraging ($P = 0.071$ and 0.009, respectively) (Table 1 and Fig. 3), increased time spent in nest cavities ($P = 0.000$) (Table 1 and Fig. 4), and decreased high and low level activity ($P = 0.001$ and 0.000, respectively) (Table 1 and Figs 5, 6). There was no significant difference in total food consumption between high and low luminosity treatments ($P = 0.193$) (Table 1). However, high luminosity treatment resulted in decreased time spent foraging ($P = 0.020$), increased time spent in nest cavities ($P = 0.000$), and decreased high and low level activity ($P = 0.005$ and 0.010, respectively) when compared to the low luminosity treatment (Table 1).

## DISCUSSION AND MANAGEMENT IMPLICATIONS

These data represent the first report of the impacts of photopollution on sugar gliders including reduced time spent foraging, increased time spent in the nest cavity, and reduced high and low activity levels. Sugar gliders under the dark control exhibited a crepuscular pattern with slight activity through the middle of the night (Fig. 4). However, under the high and low luminosity treatments the crepuscular pattern is either dampened or non-existent (Figs 3–6). Gliders foraging under the treatment light levels are perhaps hampered in their ability to distinguish dusk and dawn and are therefore, not foraging in their usual crepuscular pattern (Fig. 3). If light pollution impacts a glider's ability to distinguish dusk and dawn, they may exit too late from their nest cavity or return too early, effectively further reducing foraging (high level activity) opportunities (Figs 4 and 5). Gliders also scanned their surroundings less and preened less (low level activities) under treatment conditions (Fig. 6). Reduced scanning would likely negatively impact a glider's ability to avoid predators and detect prey, and possibly communicate with their colony. Reduced preening would likely negatively impact a glider's overall health.

*Table 1.* Mean (standard deviation) of food consumed and time spent foraging, in the nest cavity, and in high and low level activity for three gliders through 12 hours under three light conditions.

| Mean for three gliders through 12 hours | Dark control | Low luminosity treatment | High luminosity treatment |
|---|---|---|---|
| Food consumed (g) | 55.75 (1.55) | 56.29 (2.19) | 50.43 (2.15) |
| Foraging (min) | 394.13 (25.63) | 313.63 (36.25) | 250.25 (36.31) |
| Nest cavity (min) | 1 358.81 (45.58) | 1 616.88 (64.45) | 1 847.50 (63.13) |
| High level activity (min) | 176.56 (22.67) | 64.13 (32.06) | 0.13 (31.05) |
| Low level activity (min) | 230.50 (15.00) | 165.38 (21.21) | 62.13 (16.72) |

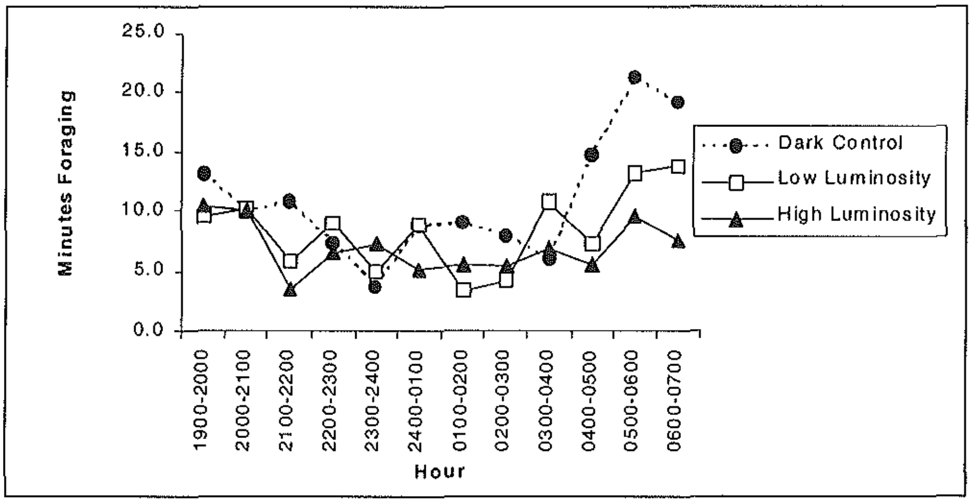


*Fig. 3.* Mean time in minutes per hour per glider spent foraging under three light conditions.

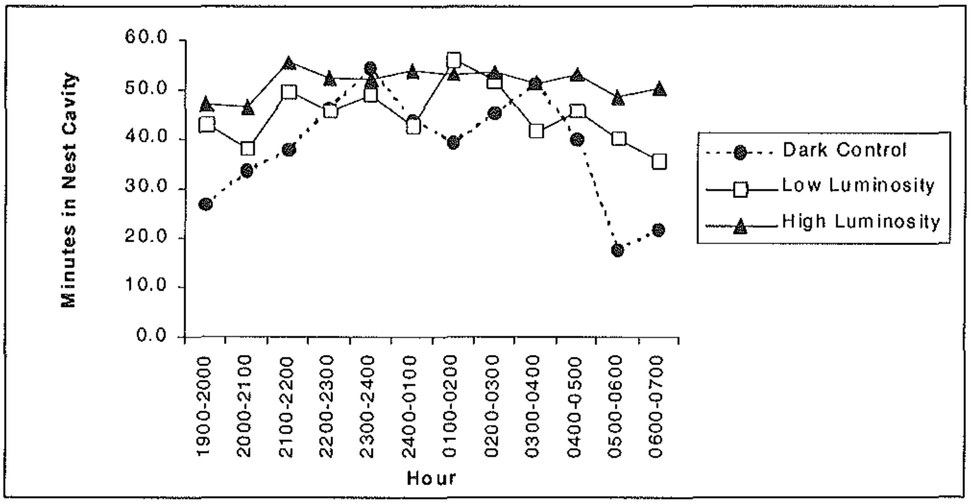


*Fig. 4.* Mean time in minutes per hour per glider spent in the nest cavity under three light conditions.

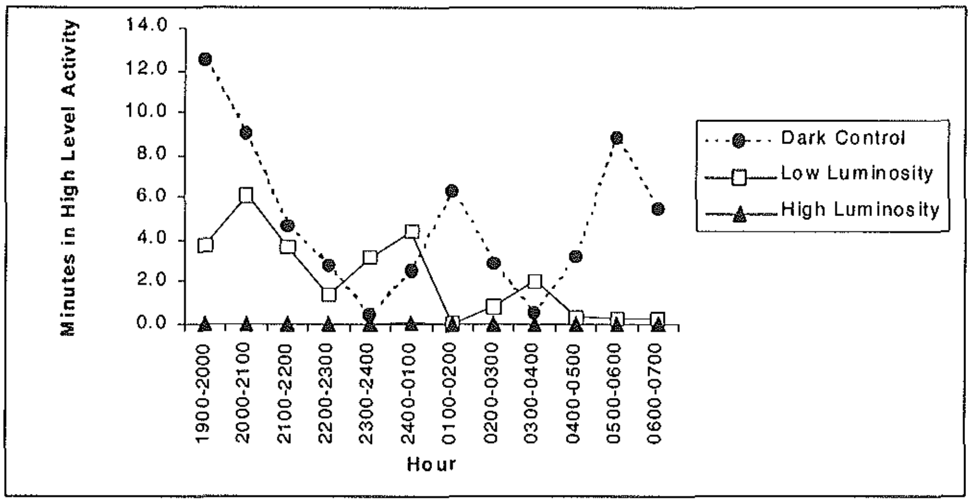


*Fig. 5.* Mean time in minutes per hour per glider spent in high level activity under three light conditions.

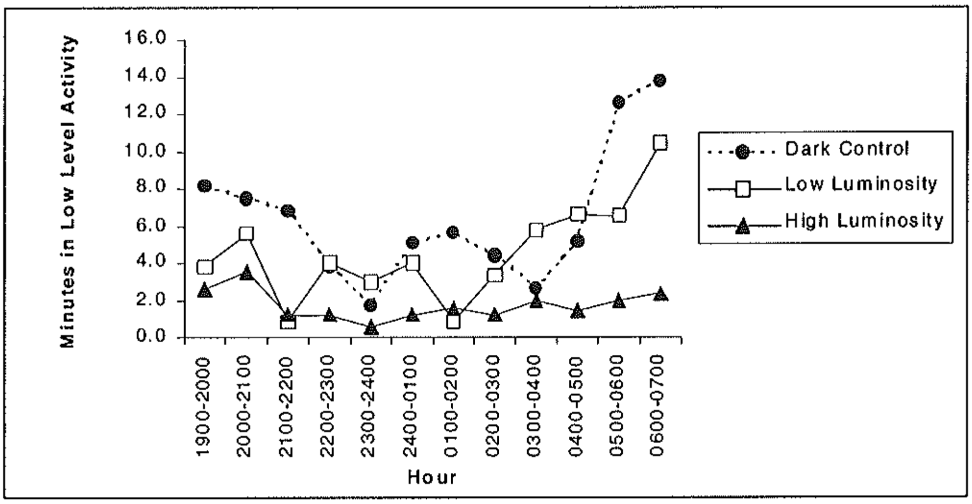


*Fig. 6.* Mean time in minutes per hour per glider spent in low level activity under three light conditions.

Sugar glider behaviour was most noticeably impacted by the high luminosity treatment, where high level activity was almost non-existent. Under the low luminosity treatment (7.0 lux) gliders showed no overall decrease in the amount of food consumed. However, they did show decreases in time spent foraging and overall activity levels. This indicates that wild sugar gliders experiencing similar photopollution conditions (7.0 lux) will likely be negatively affected while foraging since food will not be as readily available as it was in this experiment and gliders must search for food. This information is important when selecting the lux and type of night lighting for residential, agricultural, and industrial areas where sugar gliders and their relatives are found. Although sugar gliders are able to cross pastures as large as 200 m (Henry 1996), they nevertheless require areas of forest and woodland habitat sufficiently connected (Suckling 1983, 1995). Further, sugar glider relatives that depend on mature trees for nest hollows may be much more negatively affected when habitats are severely fragmented and cleared (e.g., Mahogany Glider, *Petaurus gracilis*; MGRP 2001 and Leadbeater's Possum, *Gymnobelideus leadbeateri*; Smith 1983). Maintaining canopy cover sufficient to restrict excess light is recommended, especially if no information exists on the species' ability to thrive in fragmented habitats.

While maintaining canopy cover and appropriate understorey is ideal, photopollution impacts (where artificial light is required) can be reduced by properly managing light emissions. Proper light management includes replacing those light fixtures that emit light directly upward with efficient full, cut-off shielded fixtures (no light is emitted horizontally or upward) that require less wattage, provide more light to the ground, and reduce light waste. Cut-off shield fixtures can reduce the problem of decreased habitat connectivity experienced by those nocturnal foragers that avoid artificially lit areas. The use of diffuse, coated ("frosted") bulbs in place of clear bulbs will also reduce lumen output (IDA 1996a). Additionally, low pressure, sodium (LPS) lamps could be used in place of most street, parking, and security lights. LPS lamps emit light in the yellow spectrum while other lights (such as bug lights) emit a greater range of wavelengths. Broader spectrum lights can disrupt prey detection and predator avoidance behaviour in nocturnal foragers (Buchanan 1993; Bird *et al.* 2004). In summary, low wattage and lumen output, narrow spectrum, and shielded light fixtures are the least environmentally disruptive. However, there is no ideal spectrum since varying light spectrums can impact on animals differently (Longcore and Rich 2004).

Some cautions in interpreting these results include the use of captive sugar gliders which may or may not behave as wild sugar gliders, the degree of behavioural similarity between sugar gliders and their endangered and vulnerable relatives, endogenous changes throughout the study (although the study design largely accounted for this), the ability of sugar gliders to adapt to consistent photopollution over time, and the actual photopollution levels (lux) in Oceania areas where sugar gliders reside remains unmeasured. Nevertheless, this study indicates that, while sugar gliders are considered to be a secure species, their foraging success and ability to avoid detection by predators may be compromised by photopollution in those Oceania areas experiencing habitat fragmentation and destruction and increased artificial lighting (Suckling 1983, 1995). Information on sugar glider behaviour may prove to be vital in managing populations of their endangered and vulnerable relatives. Since glider behaviour in this experiment was negatively impacted by the low luminosity treatment of 7.0 lux, the maximum lux at which glider behaviour is not impacted remains unknown. Further research — particularly with wild populations — is needed to elucidate the extent of photopollution impacts on sugar gliders and their endangered and vulnerable relatives.

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