J. Ecol. Field Biol. 32 (2): 83～86, 2009

Landscape Analysis of the Effects of Artificial Lighting around Wetland Habitats on the Giant Water Bug *Lethocerus deyrollei* in Jeju Island

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ABSTRACT: We conducted a landscape analysis to investigate the possibility of adverse effects of anthropogenic light sources, such as roads and residential buildings, on *Lethocerus deyrollei* on Jeju Island. Wetlands inhabited by *L. deyrollei* had fewer anthropogenic structures within a 3 km radius that had the potential to produce artificial light at night than wetlands not inhabited by *L. deyrollei*. In particular, the presence of artificial lights within a 1 km radius appears to reduce the probability of inhabitation by *L. deyrollei*. Our results suggest that artificial light sources may be critical determinants of *L. deyrollei* inhabitation patterns in a landscape, and that habitats that have a buffer area of at least 600～700 m radius free from residential buildings are the most appropriate habitats for *L. deyrollei*.

Key words: Artificial light, Jeju Island, Landscape analysis, *Lethocerus deyrollei*

INTRODUCTION

The giant water bug, *Lethocerus deyrollei* (Insecta: Hemiptera: Belostomatidae), one of the largest aquatic insects, is distributed in eastern Asia, including Japan, China, and Korea (Hashizume 1994). *L. deyrollei* inhabits mainly lentic freshwater habitats including natural wetlands such as pools, ditches, marshes, and swamps, and artificial wetlands such as water channels and rice fields (Jo 2003, Mukai et al. 2005). Like its congeners *L. americanus* and *L. medius* in North America, which mostly feed on tadpoles and frogs, *L. deyrollei* is carnivorous, and primarily feeds on small fish and anurans (Hirai and Hidaka 2002, Smith and Larsen 1993). Therefore, *L. deyrollei* requires access to sufficient food such as fish and anurans to maintain their populations, as well as access to emergent plants such as reeds or similar stalks, which serve as oviposition substrata (Ichikawa 1988). *L. deyrollei* is typically found in habitats that feature large, emergent plants such as *Phragmites communis*, *Typha angustifolia*, *Acorus calamus*, *Scirpus triangulatus*, *Scirpus lacustris* var. *creber,* and *Zizania latifolia* (Ministry of Environment 2007).

Populations of *L. deyrollei* have decreased dramatically in Korea, and the species is now just found in limited areas (Jo 2003). Accordingly, *L. deyrollei* has been designated as an endangered species by the Korean Ministry of Environment. The decrease in the *L. deyrollei* population has been attributed primarily to the loss and reduction of their wetland habitats. Population declines of prey populations, like frogs, may also negatively affect *L. deyrollei* (Hirai and Hidaka 2002).

Artificial lighting from anthropogenic sources such as street lamps and residential buildings can cause adverse effects on nocturnal insects (Frank 1988), including *L. deyrollei*' (Ono 1995). The flight-to-light behavior of insects often leads to high mortality in the presence of artificial lighting, which can cause a progressive decline of the population, and can result in local extinction in a short time (Rich and Longcore 2006). The effects of light can be particularly serious for rare species with specialized habitat requirements (Frank 1988, Killigs 2000). Insects of the genus *Lethocerus,* sometimes called "electric light bugs", are attracted in large numbers to street lights during night dispersion flights (Menke 1979). *L. deyrollei,* which need water for the survival and reproduction, are particularly vulnerable to artificial lights because landing in brightly lit areas without water can lead to mortality due to dehydration (Ohba and Takagi 2005).

Jeju Island contains some of the few remaining habitats of *L. deyrollei* in Korea, but the number of habitats where *L. deyrollei* are observed has declined. Although wetlands that appear to be appropriate habitat for *L. deyrollei* have been well investigated with regard to the availability of hydrophytes for oviposition and of prey fauna, there have been very few analyses of the local environments surrounding *L. deyrollei* habitats on Jeju Island in terms of landscape features that might influence night dispersion flight. In particular, no landscape analysis of anthropogenic light sources that may be harmful to *L. deyrollei* has yet been conducted on Jeju Island.

The aim of this study is to compare wetlands inhabited by *L. deyrollei* and wetlands that have appropriate biotic features, but are

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not inhabited by *L. deyrollei*, through landscape analysis of anthropogenic light sources, such as roads and residential buildings, to investigate the possibility that light sources have adverse effects on *L. deyrollei*' habitats and to provide landscape information to guide the conservation of existing habitats and the creation or restoration of additional appropriate habitats.

MATERIALS AND METHODS

The Selection of Study Sites

The study focused on Jeju Island, an area that is known to contain many wetland areas inhabited by *L. deyrollei*. Ten wetlands were selected on the basis of field surveys, interview with residents, and literature study (Jeju Special Self-Governing Province et al. 2001) from June 2006 to September 2007. Seven wetlands were confirmed to be inhabitated (IS) by *L. deyrollei* and three wetlands were confirmed not to be inhabited (NIS) by *L. deyrollei* (Fig. 1). All of the natural wetlands selected share a set of features that suggest that they should be appropriate habitat for *L. deyrollei*. First, the vegetation in the wetland is well developed, and includes large emergent plants. Second, prey animals such as tadpoles and frogs are abundant. Finally, all the wetlands are inhabited by other common carnivorous aquatic insects including *Muljarus japonicus*, *Laccotrephes japonensis,* and *Gyrinus japonicus*.

Analysis of Artificial Light Sources in the Study Area

Duvirad (1974) suggested that Belostomatids are attracted to and able to fly to lights up to 3 km from their habitats. Therefore, areas within a radius of 3 km from each wetland were included in the zones for analysis; the zones were then subdivided into seven sectors according to their distance from the wetland (0～0.1 km, 0.1～0.5 km, 0.5～1.0 km, 1.0～1.5 km, 1.5～2.0 km, 2.0～2.5 km, 2.5～3.0 km; Fig. 2) for further analysis. For the landscape analysis, we used a 1:25,000 topographical map made by the National Geographic Information Institute, for which aerial photography was carried out from 2003 to 2004 and which was adjusted by field surveys from 2005 to 2007. Anthropogenic light reaching the study wetlands mostly originates from passing cars on roads and lighting from residential buildings in the surrounding areas. The length of all paved roads was measured, and the roads within the analysis zone were classified as > 11 m wide or < 11 m wide because traffic volume and the number of street lamps generally depend on road width and length. For residential buildings found in clusters of five or more buildings separated by distances of < 30 m, we drew a line connecting the outer walls of the buildings on the perimeter of the cluster and measured the area enclosed within this boundary. Individual buildings with areas of over 500 m^2 were also included in the analysis. We used AutoCAD 2008 to measure all road lengths and building areas within a zone of radius 3 km from the wetland, and the shortest distance from the wetland to adjacent roads and buildings, and calculated the density of the road length and the building area in each sector for each wetland.

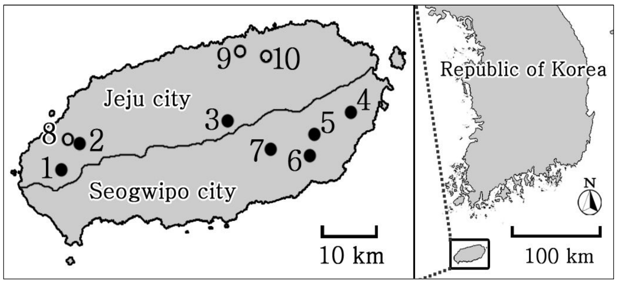

Fig. 1. Location of the study sites. Sites inhabited by *L. deyrollei* (IS) and sites not inhabited by *L. deyrollei* (NIS) are represented by black and white circles, respectively. Site 1; Gangjeongmot, 2: Georworimot, 3: Muljangori. 4: Hanmot, 5: Dadorimot, 6: Namseonmot, 7: Muryeongari, 8: Yeokgomot, 9: Namsaengimot, 10: Doreumot.

RESULTS AND DISCUSSION

The Density of Roads and Buildings within the Analysis Zones

Only one site, NIS 9, had a road with width >11 m. For roads < 11 m in width, the density of road length ranged from 4.48 to 28.03 m/ha in IS and from 22.01 to 32.73 m/ha in NIS (Fig. 3a).

The average density of road length in IS (16.87 m/ha) was lower than that in NIS (29.03 m/ha), although the difference was not statistically significant (p = 0.078).

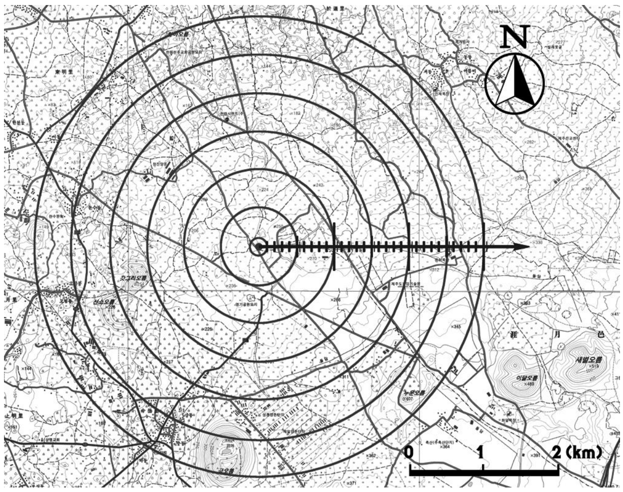

Fig. 2. An example of an analysis zone and its sectors on the topographical map (Site 2).

The density of building areas of coverage ranged from 1.57 to 303.73 m^2/ha in IS and from 226.01 to 680.33 m^2/ha in NIS (Fig. 3b). The average density of building area in IS (165.18 m^2/ha) was significantly lower than that in NIS (465.29 m^2/ha; $p < 0.05$).

The above results show that there were fewer anthropogenic structures that had the potential to be sources of artificial light within a 3 km radius of IS than NIS. A previous study suggested that street lamps near a stream may have caused a rapid local aquatic insect extinction (Rich and Longcore 2006), and our results similarly suggest that anthropogenic light sources within 3 km of wetlands may affect the ability of *L. deyrollei*' to survive in these wetlands.

The Effect of Artificial Light according to the Distance from the Wetland

We calculated ratios of the density of road length in IS to the density of road length in NIS for each distance sector in the analysis area. The ratio of IS to NIS was the highest (8.28) in the 0～0.1 km sector, and the ratio decreases until the 1.0～1.5 km sector, but leveled off in the range of 1.36 to 1.80 for the farthest sectors. Therefore, although the density of road length is consistently higher in NIS than in IS, the difference in road density is most evident in the distance sectors <1.0 km (Fig. 4a).

For building density, we could not calculate the ratio of IS to NIS for the distance sectors 0～0.5 km because there were no analyzable buildings within this range in IS, while the building density in the 0.1～0.5 km sector in NIS was 788.96 m^2/ha (Fig. 4b). For other distance sectors, the ratio was highest (25.62) in 0.5～1.0 km sector. The ratio was low and showed relatively little variation after the 1.0～1.5 km sector, ranging from 0.97 to 2.98. Overall, then, there were substantially more residential buildings emitting artificial light at night within a 1.0 km radius of wetlands in NIS than in IS. Light sources that are closer to insect habitats have a stronger influence on insect survival (Rich and Longcore 2006). Therefore, the anthropogenic structures, especially those within a radius of 1 km from wetland habitats, may be exerting an adverse influence on *L. deyrollei*, possibly leading to local extinctions in some areas.

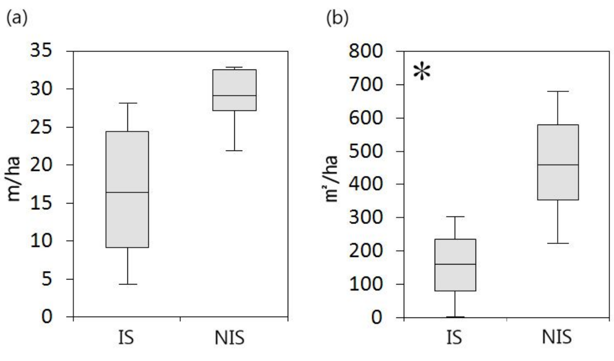

Fig. 3. The density of anthropogenic structures within a radius of 3 km from the wetlands: (a) road length, (b) building area (*: $p < 0.05$ by *T*-test).

The Distance from the Wetlands to the Nearest Roads and Buildings

The distances from IS wetlands to the nearest road < 11 m wide ranged from 31 to 1,147 m, with a mean value of 496.1 m, while the distances for NIS ranged from 20 to 280 m, averaging 110.4 m (Fig. 5a). The difference in the mean distance is not statistically significant ($p = 0.089$).

However, the shortest distance from each wetland to the nearest residential building around IS ranged from 614 to 2,029 m whereas for NIS, it ranged from 126 to 707 m, and the average least distance was significantly longer for IS (1,146 m) than for NIS (381 m in NIS; $p < 0.05$; Fig. 5b). That is, the areas within a radius of 600～700 m of most sites that are still inhabited by *L. deyrollei* had no residential buildings emitting artificial light, whereas all NIS had light-emitting buildings within 707 m of the wetland.

The above results suggest that the minimum acceptable distance between *L. deyrollei* habitats and artificial light sources is 700 m

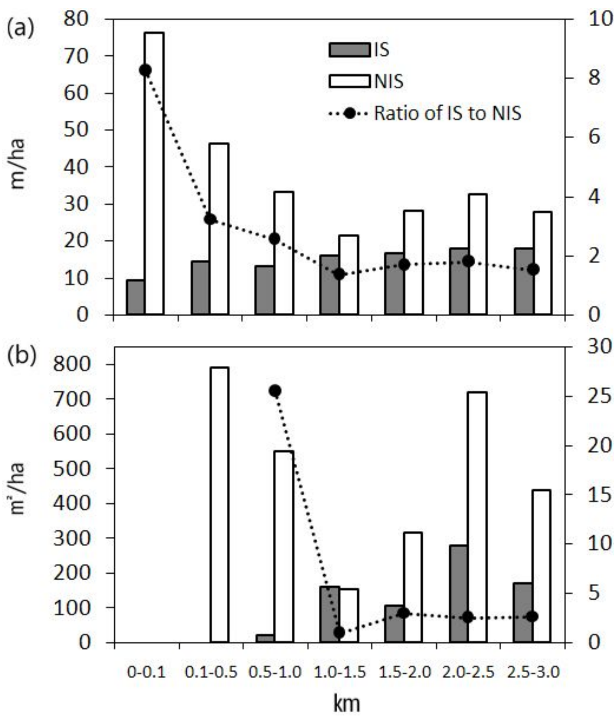

Fig. 4. Mean density of anthropogenic structure (the left vertical axis) and the ratio of IS to NIS (the right vertical axis) according to the distance from the wetlands: (a) road length, (b) building area.

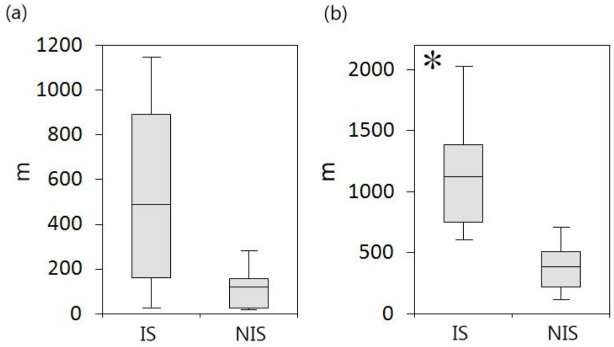

Fig. 5. The distance from the wetlands to anthropogenic structures: (a) roads, (b) buildings (*: $p < 0.05$ by T-test).

or more. Similarly, a minimum distance of > 300 m between anthropogenic structures and important habitats is suggested for the conservation of diverse avifaunas including marsh- and grassland-dependent species (Maeda 2005).

CONCLUSION

Landscape approaches of human effects on animal habitats, such as the current analysis of artificial light sources, are clearly needed to inform management plans for the conservation of habitats for *L. deyrollei* and other declining species. Our results suggest that anthropogenic light-emitting structures near wetlands might affect local populations of *L. deyrollei* in Jeju Island. The existence of artificial lights, especially within a 1 km radius might be critical factor affecting the probability that a local population will be able to persist in a wetland area. Moreover, considering that roads <11 m in width on Jeju Island have low traffic flow and few street lamps, it seems likely that the most critical issue affecting the habitability of wetlands may be the presence of a buffer area of at least 600～700 m radius without residential buildings. Therefore, the results of this study show a significance of anthropogenic lightening sources in terms of landscape environment of *L. deyrollei* habitats. The effects of artificial lighting on the landscape should be considered prior to the initiation of new developments around existing habitats or the creation of alternative habitats.

ACKNOWLEDGMENTS

This work was supported by the Korean Ministry of Environment as "The Eco-technopia 21 project" entitled "Development of preservation, restoration, and propagation techniques on two endangered wetland insects, *Lethocerus deyrollei* and *Nannophya pigmaea*, in Korea," a Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2007-313-C00735) and the Brain Korea 21 Project of Seoul National University in 2007～2008.

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(Received February 10, 2009; Accepted February 18, 2009)