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Flash communication in *Luciola kuroiwae* (Coleoptera : Lampyridae)

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(With 4 text-figures, 3 tables and 1 plate)

クロイワボタル *Luciola kuroiwae* の発光交信

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クロイワボタル *Luciola kuroiwae* の発光パターンと習性については前報 (OHBA 1979, 1983) に報告したが本種の発光交信の全貌は不明であった。筆者はその後，沖縄県玉城村百名および名護市のクロイワボタルについて観察と実験を行ない雌雄間の発光交信を明らかにするとともに発光の色の生態的意義について検討した。野外の観察および実験方法は OHBA (1983) によった。ホタルの発光スペクトルは分光器により 400–660 nm まで連続的に記録した。クロイワボタルの発光交信は基本的にヒメボタル *Hotaria parvula* のそれ (HP system, OHBA, 1983) と一致するものの，詳細にみると以下の点が相違した。クロイワボタルは雌の応答発光直後に雄が強い光を放つ。この雄の発光はヒメボタルでは全く認められない雄の雌に対する特異な応答発光と考えられる。雌雄各々の応答発光は種や性の識別，更に性行動を解発させる役割を果していると考えられる。クロイワボタルは黄色光を放ち日没後に約30分間だけ飛翔発光し，LALL *et al.* (1980) の説に一致するが，ヒメボタルは黄色光を放つにもかかわらず深夜に活動する。日本産ホタルは発光の色と活動習性との間に相関が認められない種が含まれており，この点については今後より広い視点から観察や実験を継続して検討する必要があろう。

Introduction

Sexual signal of firefly involves species-specific flash patterns and coded time delay in female flash response (LLOYD, 1966). It is well known that the flashing of male fireflies varies from species to species. The light differs in color, peak intensity and kinetics of emission (HARVEY, 1952; BUCK and CASE, 1961; SELIGER *et al.*, 1964). Dark active North American fireflies emit green bioluminescence and dusk active species emit yellow (LALL *et al.*, 1980). Since the flash pattern and behavior of *Luciola kuroiwae* were discussed by OHBA (1979, 1983), additional observation, experiments and measurements of bioluminescence emission spectra of the firefly have been made. The present paper examines mating behavior and ecology of color of firefly bioluminescence.

Materials and methods

Observations and experiments were made on *Luciola kuroiwae* MATSUMURA, 1918 inhabiting the roadside at Hyakuna of Tamagusuku village, Okinawa Is.,

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southern Japan, on 4–6 May 1982. Recording and field techniques have been described in detail elsewhere (OHBA, 1983). The spectral emission of *L. kuroiwae* was measured with a spectrophotometer (Hitachi MPF-4) at the Yokohama Environmental Research Institute. For measurements a firefly was fixed on a plastic plate with a pin through its thorax so that the abdomen with the luminescent organ directly faced the sensor of the photometer. Scanning range and scanning times were 400 to 650 nm and 2 minutes, respectively. Fireflies were made syncopic by pressing their thorax firmly. Fireflies treated in this way emitted a stable and continuous luminescence lasting several minutes.

Observations and experiments

Field observations

Male—female flash interaction

Male flashing activity began 40 minutes after sunset and ended approximately at 20:00. Occasionally males could be seen later emitting their distinc-

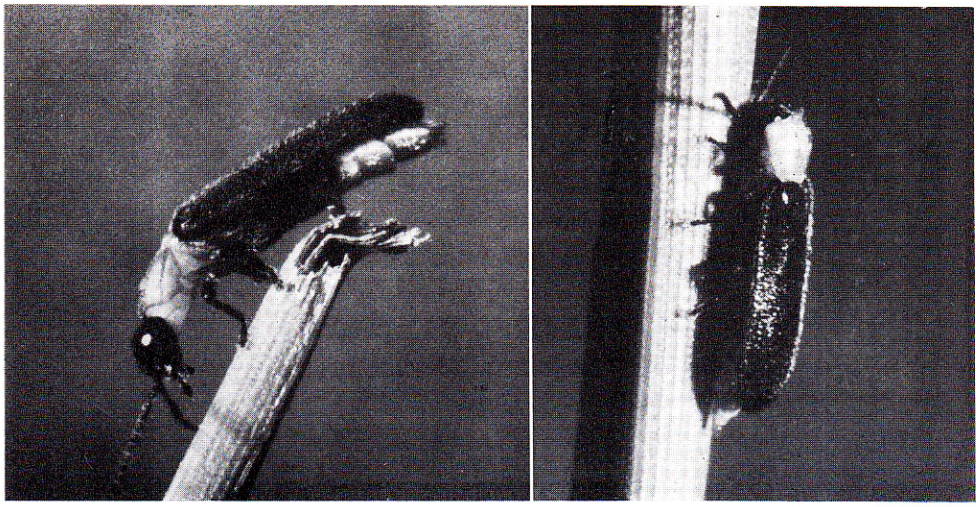

Fig. 1. Perched *Luciola kuroiwae*.
Left=male, Right=female.

Table 1. Flash patterns of *Luciola kuroiwae*. Recorded by phototransistor system in the field. Recording temperature 25°C.

Sex	Flash pattern			
	Interval (sec.)		Duration (sec.)	
	Mean	Range	Mean	Range
Male	0.40	0.40–0.44	0.29	0.26–0.30
	0.80	0.70–0.90	0.30	0.28–0.31
Female	0.35	0.30–0.50	0.15	0.14–0.19
	0.78	0.72–0.80	0.15	0.14–0.18

tive flash patterns. Their peak activity time was approximately 19:45. Female flashing activity began with the male activity, and several female were found at the base of grass stem (Fig. 1). Female emissia were twinkles and flashes. Males flew 1–2 m above the ground. They flew toward female flashes, and perched near the females. Thereafter a male-female flash interactions occured (Table 1). The male emitted single short flashes with a short duration; females responded with a short delay time (Fig. 2.1). Immediately the male emitted bright flashes of long duration (approximately 1 sec.) when responding to the female (Fig. 2.2). Then males attempted to copulate with their females. The female response delay time was 0.18 to 0.24 second $\bar{x}$=0.21, Sd=0.02, n=11) at 25°C (Table 2), and the male response delay time was approximately 0.2 second (Table 3). A female emitting individual flashes was put in a plastic cage in the field. Flying males approached caged, flashing females and perched within 10 cm of them. Then their flash communication was as follows. First phase: the male emitted single short pulses of 0.7 second in interval and 0.2 second in duration and the female responded at a short delay time (Fig. 2.1). This male-female flash interaction continued for a short time (approximately 2 seconds). Second phase: the male responded to female flashes (Fig. 2.2 to 3). The male emitted bright flashes of long duration (approximately 1.0 second). The duration of the flashes was longer than that of female flashes. Then the male attempted to copulate with the female however she was in the plastic cage. Apparently because of circumstances, this flash interaction was repeated again and again between this male and female (Fig. 2.2).

Laboratory observations

Artificial flash—female flash interaction

Three males of *L. kuroiwae* were collected in the field, and released in the room of the laboratory (approximately 15 m^2). Thereafter perched on the ceiling and then were tested. Males of *L. kuroiwae* approached decoys that were brigter than normal female flashes (Plate 1, figs. 1–4). AF flash duration was 0.2 second, and intervals varied from 1.0 to 0.4 second. When the artificial flash (AF) interval was 1.0 second, the males were not attracted. The interval was 0.8 second, the males were attracted to within 20–60 cm of the AF, but the males flew away immediately (n=3) (Pl. 1, fig. 1). When the AF flash interval was 0.6 second, the males were also attracted to within 10–20 cm of the AF and flew around the AF for a while (2–3 seconds). Then they suddenly turned and flew away (n=3) (Pl. 1, figs. 2–3). When the AF flashes were 0.4 second in interval, the male directly flew down within 5–10 cm distance of the AF (n=3) (Pl. 1, fig. 4). This behavior was also released by green (500 nm) and red (650 nm) color light of AF.

Bioluminescence emission spectra

The spectral emission of *L. kuroiwae* is shown in figure 3. Peak wave

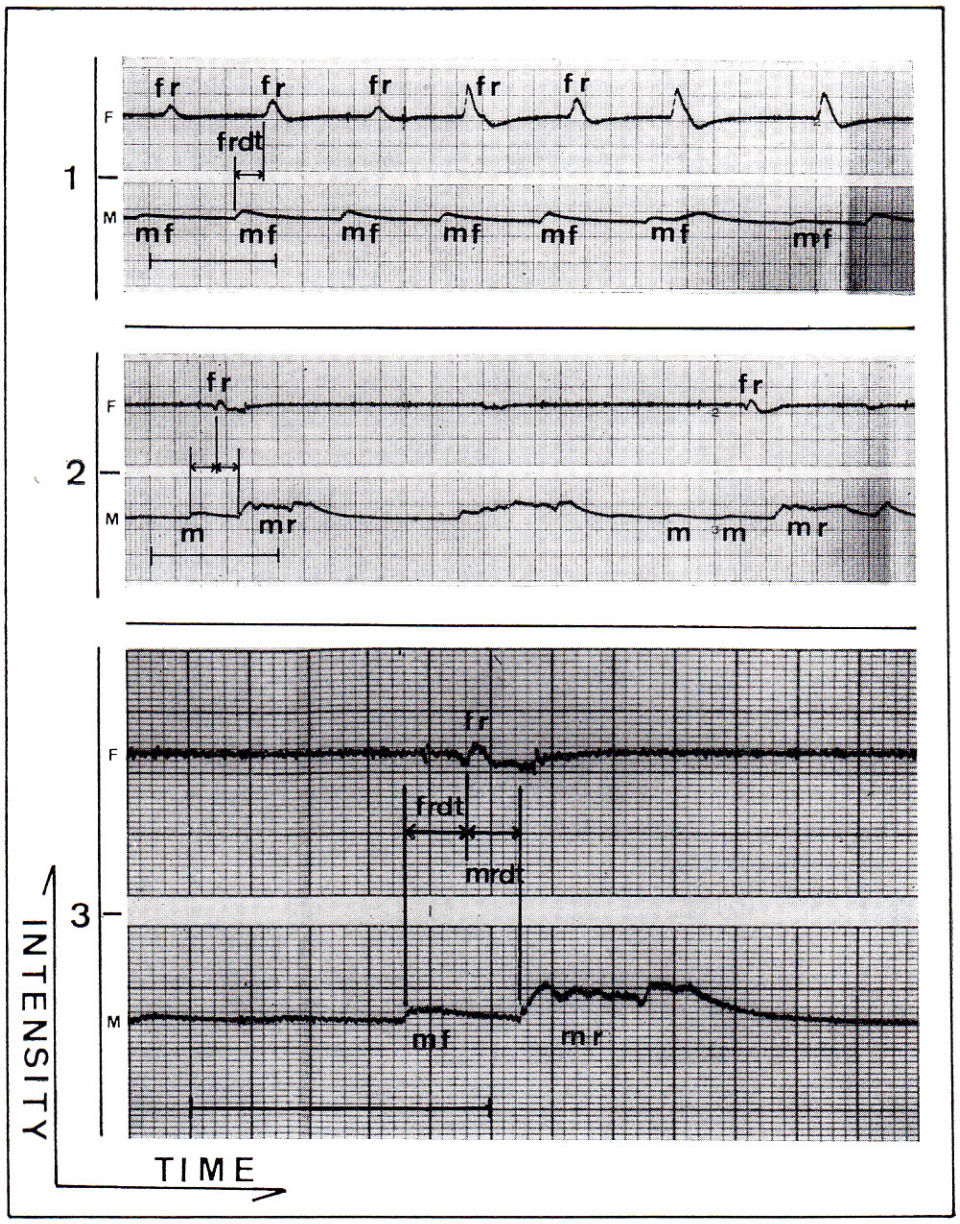

Fig. 2. Chart record of flashes of *Luciola kuroiwae* during male-female flash interaction.

Chart traces recorded with a phototransistor system in the field. Reading left to right. Ordinate: relative intensity, Abscissa: time, Scale indicating 1 second. M=male, F=female, mf, m=male flash, fr=female response flash, mr=male response flash, frdt=female response delay time, mrdt=male response delay time.

1. Female responds to male flashes with short delay time.

2–3. Male responds to female flashes with short delay time.

Table 2. Response delay time of a female *Luciola kuroiwae* during male—female flash interaction. Recording temperature 25°C. Sd=standard deviation.

Mean	Sd	Recorded value (sec.)					
0.21	0.02	0.22	0.24	0.24	0.19	0.24	0.18
		0.20	0.20	0.20	0.22	0.19	

Table 3. Response delay time of a male *Luciola kuroiwae* during male—female flash interaction. Recording temperature 25°C.

Mean	Sd	Recorded value (sec.)					
0.21	0.02	0.20	0.20	0.22	0.20	0.23	0.21

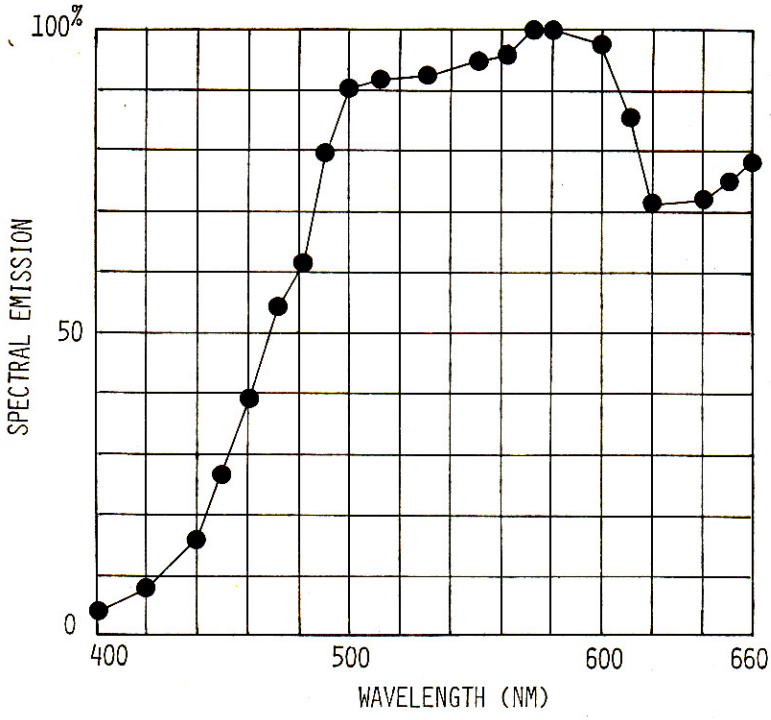

Fig. 3. Emission spectram of *Luciola kuroiwae*. Recorded with photometer (Hitachi MPF-4) scanning from 400 to 660 nm.

length of this species is approximately 550 nm, but 500 to 600 nm wave lengths (green to red color) were present.

Discussion

The flash communication of *L. kuroiwae* is summarized in figure 4. As mentioned before, its flash communication system corresponds to HP system (OHBA,

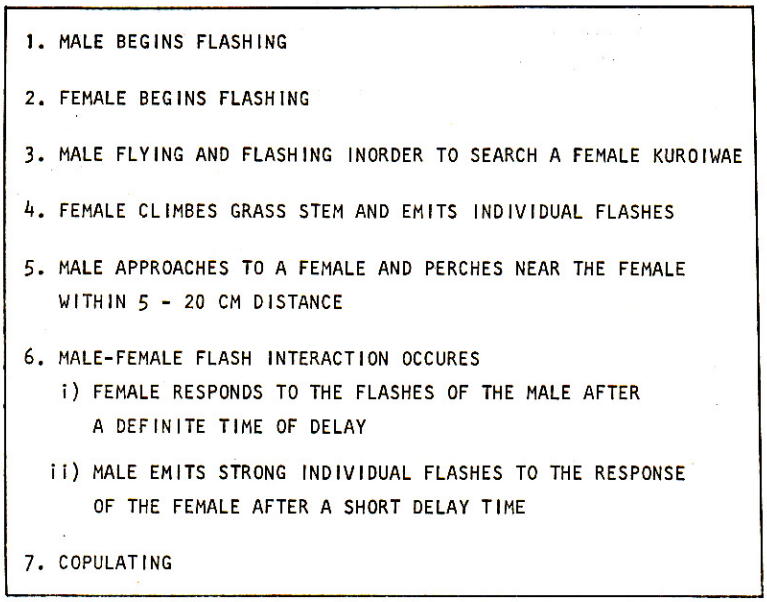

Fig. 4. Flash communication in *Luciola kuroiwae*.

1983). A similar communication system has been observed in American *Photinus* fireflies (LLOYD, 1966). One difference between the communication of *L. kuroiwae* and *Hotaria parvula* is that the male of *L. kuroiwae* emits bright flashes of long duration with a short delay time after a phase in which the female responded to male flashes. This male response phase is very important role in the mating behavior of *L. kuroiwae*, and never appears in *H. parvula*. However, the male of *H. parvula* discriminates the shape of luminous organ of female *parvula* (OHBA, 1983). This was not observed in *L. kuroiwae*. Flying and flashing activity of *L. kuroiwae* continues only 30 minutes, from twilight time to 20:00, thereafter the activity nearly ceases. On the other hand, *H. parvula* begins flashing at 20:00 and continues until 3:00 (OHBA, 1980). Peak activity of this species is approximately at 0:00 in Nagoya City (OHBA, 1979, 1980). Flashing and flying activity of these species are very different. However, their emissia are similar and extend from red to green. Generally, their light appears yellow to the naked eye. The relationship between time of activity and color of light emissia of American fireflies are discused by LALL *et al.* (1980). Their study indicates that late-active species emit greenish light, while twilight active species emit yellowish light. As compared with *H. parvula* and *L. kuroiwae* is cotrary to the results of this study. The parameter of color of light emission is uncertain in Japanese fireflies. It should be considered from a wider viewpoint.

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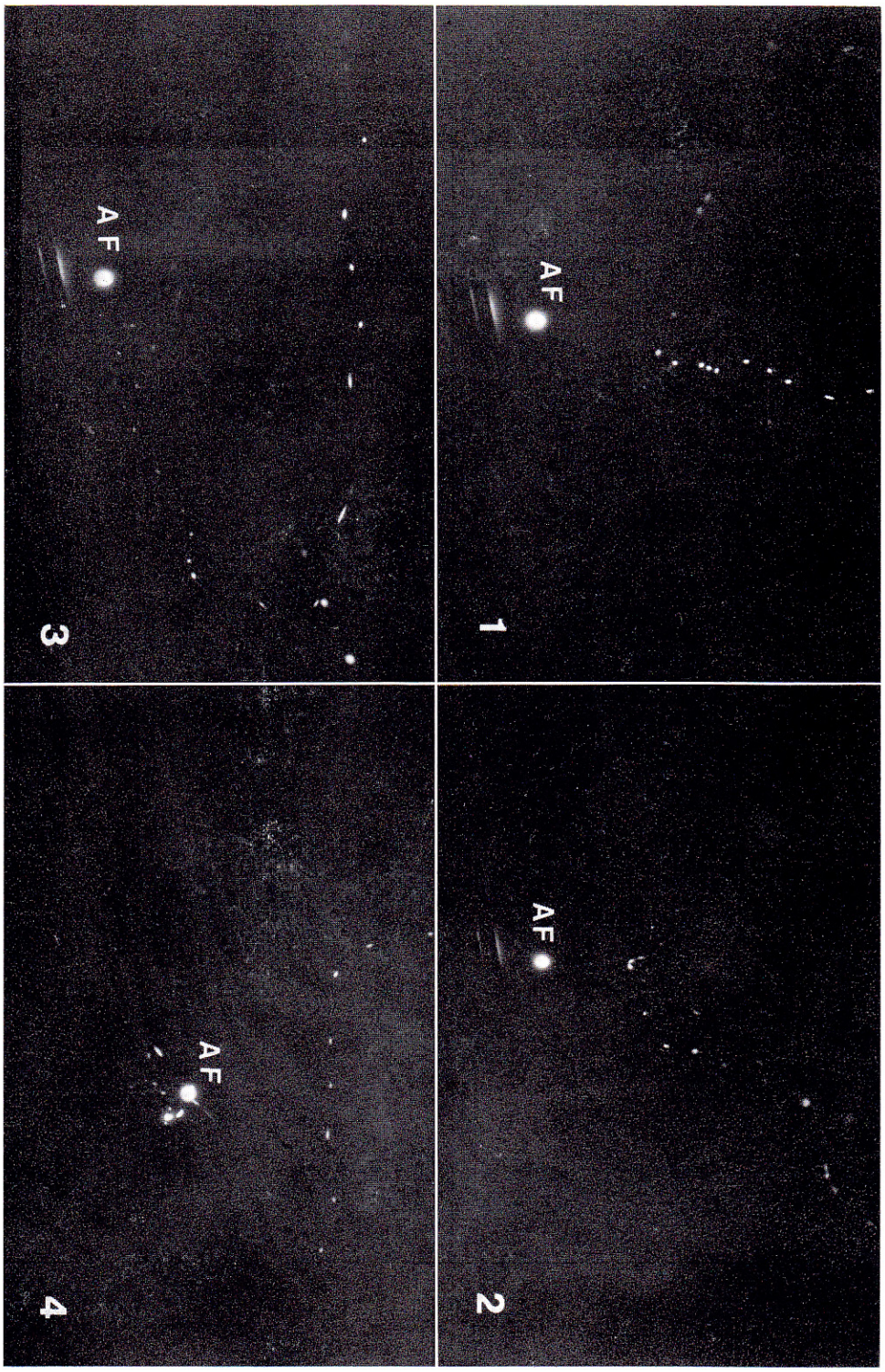
Explanation of plate 1

Figs. 1–4. Behavior of a male *Luciola kuroiwae* to artificial flashes.

1. Male attracted by variable artificial flashes. When the interval is 0.8 second and duration is 0.2 second, the male approaches within 10 cm, thereafter the male turn buck and flew away.

2–3. Male approaches to artificial flashes (interval=0.6 second) the male confirm to artificial flashes after a while he buck and flew away.

4. Male approaches to the artificial flashes and perches near the one. Flash interval is 0.4 second, and duration is 0.2 second.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