Odonatologica 32(1): 19-28 *February 24, 2003*

THE RESPONSE TO ROTATING OBJECTS BY *ANOTOGASTER SIEBOLDII* (SELYS) MALES (ANISOPTERA: CORDULEGASTRIDAE)

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Received April 15, 2002 / Revised and Accepted July 19, 2002

During their patrolling flight ♂ *A. sieboldii* responded to a rotating fan by hovering. The dragonflies did not respond to the playback sound of the fan. However, they did respond to the rotation of a mini desk fan which was observed through the window of a sound insulated box. The dragonflies responded to rotation of discs of various patterns, even when the ambient temperatures were low for summer; thus they did not respond due to thermoregulation. Only ♂♂ responded, and they did not respond to rotation of low velocity. – ♂♂ responded to a suspended ♂ or ♀ that was fluttering, but not when it was still. Therefore, it was concluded that the response to rotating objects by ♂♂ might be regarded as behaviour to ascertain whether a rotating object is a ♀ or not. The hovering rate (HVR) in relation to rotation velocity and colour patterns is discussed.

INTRODUCTION

Anotogaster sieboldii belongs to the Cordulegastridae, and is the largest dragonfly in Japan, its body size exceeding 10 cm in length. On the mainland of Japan, the adult appears in June and its flying season lasts until October. There have been a few reports on the ecology of this species, one made by ARAI (1985), the coauthor of this paper, who reported on the searching flight for females and the pursuit flight for conspecific males by males of *A. sieboldii*; the latter he regarded as antagonistic behaviour by males. Another was made by TAGUCHI (1990), who demonstrated the weak territoriality of males by a marking investigation. However, the report by ARAI (1986) that a male of *A. sieboldii* responded to the rotating fan of an air conditioner by hovering during its patrolling flight in hot summer has aroused interest. He suspected that such behaviour had originated in seemingly regarding a rotating object as another dragonfly.

It is not clear on what this behaviour is based. At a seminar presided by CORBET (2000) in Hamilton, New York in 1999, sound production by dragonflies was discussed. In view of this discussion, the behaviour of *A. sieboldii* may be assumed as a response to sound. On the other hand, considering the behaviour is seen only in hot weather, it may be due to thermoregulation, with the dragonfly orienting itself to the wind generated by the rotating fan, or in response to the actual rotation of the fan. We report the results of our experiments to investigate on what factor it is based.

STUDY SITES, MATERIAL AND METHODS

Experiments were made by Ishizawa at a small stream (Fig.1) adjacent to the bog in the campus of Waseda University, located on the hillside of the Sayama Hills, Mikajima-horinouchi, Tokorozawa City, Saitama prefecture, and by Arai at a stream in Dragonfly Park at Sueno, Yorii-machi, Osato-gun, Saitama prefecture.

The experimental period was from July 31 to September 2, 2001 at Tokorozawa, but only on one day, August 24, of the same year at Yorii-machi. About four or five hours a day, from 9:30 a.m. to 3:00 p.m. were allotted to the experiments.

Arai experimented on the responses of *A. sieboldii* to an electric fan powered by an engine generator and to a green disc of diameter 14 cm. All the other experiments were carried out by Ishizawa.

Experiment 1. — In order to verify whether *A. sieboldii* responds to sound or not, Ishizawa recorded the rotating sound of the fan of an air conditioner (Mitsubishi room air conditioner: Kirigamine MSZ-SFX28G-H; diameter of the fan: 45 cm; sound frequency of the fan rotation ranged between 63 and 4,000 Hz) and an electric fan (made by Matsushita Electric Industries Co., Ltd., F-C301J; diameter of the fan: 30 cm) using a tape recorder (SONY CFM-155, monophonic, the range of playback frequency: 100-8,000 Hz). The sound was played back several times in the presence of *A. sieboldii* for 10 min at time intervals of 10 min (rotation phase: RP). The behaviour during the 10-min interval of no sound (non rotation phase: NRP) was also observed, and the difference of the visiting frequency (VF) between both phases was investigated.

Experiment 2. — As an ovipositing female of *A. sieboldii* produces loud sounds of wing beating, lip vibration imitating the wing beating was recorded and played in the presence of *A. sieboldii* as mentioned above.

Experiment 3. — Two mini desk fans (Senju Co., Ltd, powered by four AM3 batteries; diameter: 14 cm) were operated at the site at the above intervals. The VF and the hovering frequency (HF), and the difference in HF between a pale green fan and a pink fan were investigated.

Experiment 4. — A mirror facing the oncoming flight course of *A. sieboldii* was suspended from a wooden bridge, and a mini fan was set facing the mirror, behind a paper

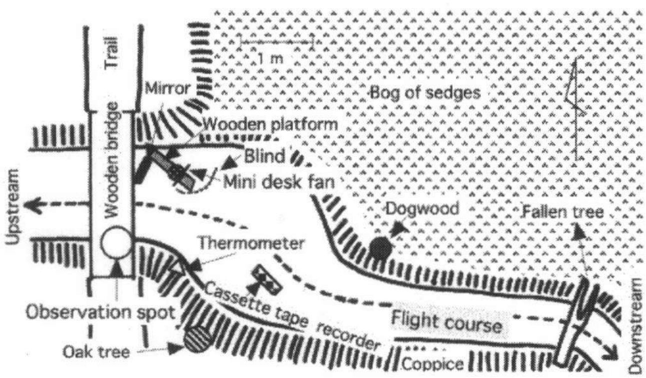

Fig. 1. Plan view of the study site.

blind, hiding the mini fan. The hovering rate (HVR is defined as hovering frequency divided by the visiting frequency: HF/VF) during RP was investigated.

Experiment 5. – To clarify more precisely the response to the fan by *A. sieboldii*, Ishizawa made a sound insulated box (24W-27D-33.5H cm) with a triple structure of a 5.5 mm thick wooden board, sealed by a 1.5 mm rubber sheet and a 20 mm thick Styrofoam inner layer, and 3 pieces of acrylic resin for a window. It was placed on a wooden platform with a rotating fan inside, with the window facing the oncoming flight course of the dragonflies. The sound of the rotating fan inside the box was barely audible without approaching close to the box, and HF was compared with RP of the fan in the box and RP of the fan outside of the box.

Experiment 6. – In order to exclude the effect of wind generated by the fan, discs of various sizes (diameter: 6, 9, 12, 13, 14 cm), of various colours and patterns and tapered blades cut out from a blue disc were inserted onto the shaft of the mini fan instead of the fan blades, and the hovering rate (HVR) of the discs was investigated.

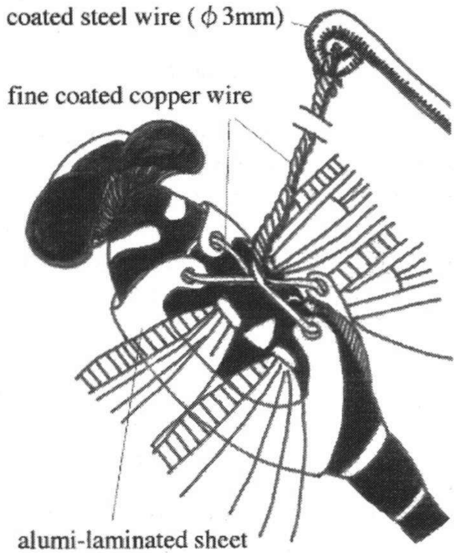

Fig. 2. Mechanism for suspending male and female *Anotogaster sieboldii*. Living specimens were suspended with a fine-coated copper wire from the tip of a coated steel wire with their thoraces wrapped by a sheet of aluminum-laminated film.

Experiment 7. – Response to photographs of an ovipositing female placed along the stream, or to swinging a photograph of it attached to the tip of a bamboo stick, was investigated.

Experiment 8. – One male and one female of *A. sieboldii* were caught and suspended 20 cm above the water surface with a fine coated copper wire connected to the tip of a coated steel wire (diameter 3 mm) with their thoraces wrapped by a sheet of alumni-laminated film (Fig. 2). Response (HF) of visiting *A. sieboldii* to the suspended dragonflies was investigated. Suspended dragonflies were stimulated to flutter by swinging the steel wire.

The ambient temperatures (Ta) were measured with a digital thermistor thermometer (made by A&D, AD-5624, probe: 3 mm in diameter) at the start and end of each phase of the experiments. The body temperatures (Tb) of *A. sieboldii* were estimated by the above-mentioned Ta and regression analysis of the data of Tb and Ta collected on August 19, 1990 at the same site as the experiments.

Rotation velocity (Hz) of the mini fan was variable at 4 levels by changing the voltage (from 1.5 to 6 V). Each phase of the experiments was normally tried for 10 min; however, in some cases it was for 5 min

Rotation velocity (Hz) of the mini fan and discs were measured with a non-contact tachometer (CUSTOM, RM-2000; measuring range: 30.0-30000.0 rpm, sampling time: 1.0-2.0 sec.). Wing beat frequency (Hz) was measured with the tachometer, using light reflected from the silver marked wing tips after Experiment 8 was completed.

As the rotational objects were set facing downstream, it was mostly dragonflies that visited the experiment site flying upstream that were counted as VF. However, some that came from upstream and turned back were also counted. Hovering for more than two seconds was defined as hovering (HF). The significance of the data was analyzed with a chi-square test.

RESULTS

RESPONSE TO PLAYBACK SOUNDS (Exps 1+2)

A. sieboldii did not respond to the playback sound of the fan of an air conditioner, nor that of an electric fan. The difference of VF between RP and NRP was not significant, (RP: n=38, NRP: n=35, p>0.7).

Except for momentary hovering, no dragonfly responded to lip vibrations or to their playback. The difference of the mean value of HVR (hereafter HVR is shown as the mean value) between sound phase and no sound phase was not significant (P>0.05), 46.5%: 30.4%, respectively.

RESPONSE TO FANS (Exp. 3)

The HVR at RP of the mini fan was 57.6% (HF, n=53/60 min); significantly greater (p<0.001, Fig. 3) than that at NRP: 11.5% (HF, n=12/60 min). However, at NRP some momentary hovering was observed similar to the hovering at NRP in Experiment 2 but, as the rotation velocity decreased (to less than 30 Hz) all hovering ceased.

In ARAI's experiment using an electric fan, *A. sieboldii* responded to it by hovering (HF: n=8) or by circling around it (n=15) at the rotation velocity of the fan (greater than 16 Hz). It responded from both the front and the rear. However, when the rotation of the fan was stopped, *A. sieboldii* did not respond. However, only males responded to rotation of the fans by hovering. Females either passed the site without response or were seen ovipositing in front of the fans. HVR of total VF (n=29) was 27.6%, and including the circulating frequency the total HVR increased to 79.3%. However, in the case where the rotation velocity decreased to less than 11 Hz, none was seen to respond, as was the case when the mini fan decreased to less than 30 Hz.

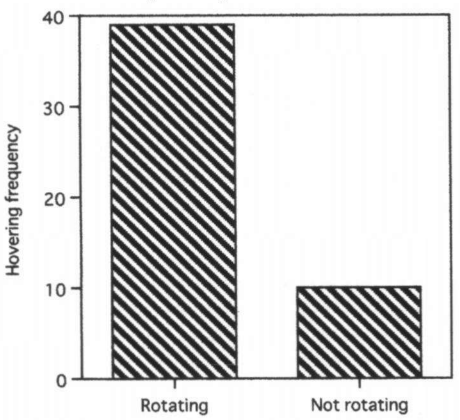

Fig. 3. Hovering frequency of *Anotogaster sieboldii* males during the rotation and no rotation phases of a mini desk fan. Duration of hovering in the latter phase was very ambiguous; less than one second. Duration of each phase of observation: 60 min (Difference: P<0.001)

There was no significant difference in HVR (P>0.9) between the colours of the propeller blades. Pale green propeller blades, HF: n=14/ VF: n=39, pink blades, HF: n=13/ VF: n=35, at each duration of observation (20 min).

It was unusually cool for early August, and the air temperature at the site was 22-23 °C. Even at such low temperatures for summer, males responded to rotation of the fans by hovering. Also, interesting additional observations were made during the experiments: one male hovered to a large female cranefly (wingspan: 8 cm) ovipositing at the site, and another hovered to a *Sympetrum* dragonfly (wingspan: 7.5 cm) flying up vertically.

Table I

Hovering rate (hovering frequency/visiting frequency) of *Anotogaster sieboldii* males in relation to the disc pattern. – [Numbers in parentheses show diameter of discs, rotation velocity and hovering duration: SD; – *: ambiguous value less than one second. – Disc pattern: YBC: yellow and black concentric circle; – YBS: yellow and black stripes; – OBCr: black cross on an orange background; – YPB: yellow polka dot on a black background; – OPB: orange polka dot on a black background; – WPB: white polka dot on a black background; – HXL: black counter clockwise helix on a white background; – HXR: black clockwise helix on a white background; – BlPB: blue polka dot on a black background; – BlPW: blue polka dot on a white background; – BPW: black polka dot on a white background; – GW chek: green and white check pattern; – WR chek: white and red check pattern; – WB: 30° arc patches of white and black; – YB: the same pattern as that of WB, yellow and black; – OB: orange and black; – RB: red and black; – GB: green and black; – BlB: blue and black. – Patterns of the discs other than YPB (9, 6), WB, YB, OB, RB, and GB, BlB that were painted by a computer were hand-painted using colour felt-tip pens]

Disc pattern	Hovering rate Mean (%)	Rotation velocity Mean (Hz)	Hovering duration Mean (s)	Duration of observation (min)
WPB (12)	93.8	299.0 (21.8)	12.1 (11.9)	30
YPB (14)	90.9	278.8	6.8 (4.0)	10
GWchek (12)	85.7	282.9 (49.4)	6.8 (2.7)	30
OPB (13)	74.7	307.0 (125.1)	9.7 (10.9)	105
GB (13)	69.2	103.2 (30.9)	11.8 (11.3)	50
RB (13)	69.2	81.6 (15.2)	12.8 (11.5)	20
OB (13)	60	109.6 (34.9)	8.3 (7.7)	20
BlB (13)	53.3	88.7 (27.0)	8.8 (9.4)	40
HXR (14)	50	179.7	5.2 (3.0)	10
YPB (9)	44.4	500	8.3 (8.1)	10
Green (14)	42.5	102.6 (34.9)	13.2 (11.8)	20
YBC (14)	38.5	143.9 (22.6)	5.8 (3.1)	20
White (14)	30	71.3 (6.1)	2.8 (2.3)	20
YBS (14)	29.4	108.3 (43.9)	5.3 (1.8)	20
YPB (6)	27.3	358.8 (106.5)	4.0 (1.4)	30
Black (14)	25.8	69.8 (1.3)	6.9 (9.5)	20
WRchek (6)	25	354.4 (92.3)	4.5 (3.9)	30
HXl (14)	25	178.7	17.5 (7.5)	10
Red (14)	23.5*	194.1 (1.6)	- *	20
WB (13)	20	188.9 (106.5)	12.5 (10.5)	20
YB (13)	16.7	136.0 (80.0)	2.0	20
BlPB (12)	10	124.7	3.0 (1.0)	10
OBCr (13)	6.3	211.4 (23.6)	8.0	20
BPW (12)	0	96.8	-	10
BlPW (12)	0	96.8	-	10
Blue (14)	0	65.4 (2.6)	-	20
Orange (14)	0	69.9 (0.9)	-	20
Yellow (14)	0	68.3 (4.0)	-	20

RESPONSE TO THE ROTATING IMAGE IN THE MIRROR (Exp. 4)

HVR of RP in the mirror (HF: n=10/VF: n=24) was 41.7%, which was similar to that of direct RP without the mirror (HVR: 57.6%, P>0.1). One male was sighted dashing to the rotating image of a mini fan in the mirror and hitting the mirror directly several times. However, when rotation of the image of the fan was stopped, males passed the site without response. When only the mirror was set facing the flight course without the fan, males did not respond.

RESPONSE TO THE ROTATING FAN SET IN THE SOUND INSULATED BOX (Exp. 5)

HVR of RP in the sound insulated box (91.7%) was not significantly different from that of RP outside of the box (83.3%, P>0.5). The distance between the fan and the starting point of hovering was 0.5 m shorter with the fan inside the box compared to that of the fan outside the box (2.5 m). Since the box was dark inside, it may have been hard for males to perceive the rotation of the fan.

RESPONSE TO ROTATIONS OF DISCS OF VARIOUS PATTERNS (Exp. 6)

Table I shows responses to the rotation of discs of various patterns. Males did not respond to rotations of discs painted yellow, orange or blue, but showed high HVR (42.5%) for a green disc. No response was shown to discs of blue polka dot or black polka dot on a white background.

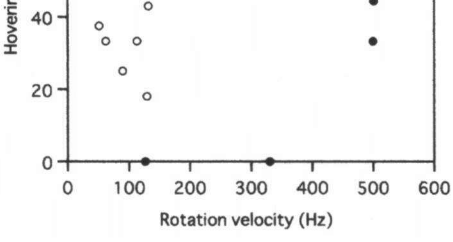

Fig. 4. Relation of the hovering rate (hovering frequency/ visiting frequency) of *Anotogaster sieboldii* males to the rotation velocity of a fan ○ or a disc ●. The fan was a mini desk fan (diameter: 14 cm), the disc: an orange polka dot on a black background (diameter: 13 cm).

Males showed 30% HVR to a white disc. Discs with a black helix on a white background resulted in high HVR (anti clockwise: 25% and clockwise: 50%, respectively). For a check pattern of green and white, HVR increased to 85.7%.

HVR to a disc of concentric circles of a yellow and black pattern reached nearly 40%. For the three discs with the same pattern, (diameter ranged 6-14 cm), the smaller one (6 cm diameter) showed HVR of 20%. The larger the diameter, the higher was the HVR shown (Tab. I).

Compared to an orange disc, a black cross added to the disc increased HVR by 6%. Furthermore, males responded highly to a disc of orange polka dots on a black background (referred to OPB), showing 74.7% HVR.

The response to a red disc was ambiguous, and the hovering duration was mostly less than one second. Although the response to a disc (6 cm in diameter) with a check pattern of red and white was not so high (25% HVR), individuals showed clearer hovering than to that of the plain red one. They showed no response to a blue disc but, for the discs of compound pattern of blue and black, HVR was higher (see discs in Tab. I; 10% for BlPB and 53.3% for BlB). In discs with a circle patched alternatively black and another colour in 30° arcs, HVR of red and black, and green and black were both 69.2%, orange and black; 53.3%, and blue and black; 60%, but HVR in black and white, and black and yellow were both less than 20%.

The relationship of HVR to the rotation velocity was not clear, because the precision of the tacho-meter was lowered due to diffused reflection outdoors (Fig. 4). In OPB, HVR ranged from 0-100% at frequencies of 120-500Hz; high frequencies over 300Hz were ambiguous because of lowering of the precision of the tacho-meter used outdoors, and 75-100% at between 150-300Hz. The mini fan showed high HVR at frequencies of around 100 Hz. However, it was not constant, and some cases showed low HVR.

Duration of hovering by males to discs of various patterns ranged from 2 to 70 seconds. For white discs it was short, at 2.8±2.3 seconds. However, no significant difference was shown among discs and fans ($P>0.05$), and the mean hovering duration to discs was 9.4±10.0 seconds ($n=227$), and to mini fans it was 10.9±10.3 seconds ($n=117$).

RESPONSE TO PHOTOGRAPHS OF AN OVIPOSITING FEMALE (Exp. 7)

None responded to the photographs of an ovipositing female, and also never showed interest in swinging of the photograph.

RESPONSE TO A SUSPENDED MALE AND FEMALE (Exp. 8)

Table II

Response of *Anotogaster sieboldii* males by hovering to a suspended male and female. Experiments were made on a suspended male on August 29, and on a suspended female on August 30, 2001. Duration of observation was 10 minutes. – [Numbers in parentheses indicate hovering to both the fan and the male alternately]

Fan	Hovering frequency	Suspended ♂	Hovering frequency	Passing
Rotating	8	Not fluttering	0	3
Not rotating	0	Not fluttering	0	5
Not rotating	0	Fluttering	4	0
Rotating	10 (4)	Fluttering	14 (4)	0
Fan		Suspended ♀		
Rotating	5	Not fluttering	0	2
Not rotating	0	Fluttering	5	0

Table II shows HF of conspecific males to a suspended male and female. When the suspended specimens did not flutter, the conspecific males passed without response or, if the mini fan was set alongside the specimens, they responded to the fan. However, when the suspended male or female was fluttering vigorously or was warming up (wing beat frequency 30-35 Hz) the visiting males responded. Some approached the suspended male, while others grasped at the female and took a tandem form. Also some males hovered close to males hovering near the female.

DISCUSSION

The playback sounds of the fan of an air conditioner, a mini fan and lip vibration did not influence VF of *A. sieboldii* males. We believe both RP and NRP did not affect the VF of males because the males are not territorial and the patrolling flight along streams can be regarded as searching flight for females (*Cordulegaster boltoni*, KAISER, 1982; *A. sieboldii*, ARAI, 1985). The fact that at RP *A. sieboldii* males responded by hovering agreed with ARAI's observation (1986).

Judging from the fact that *A. sieboldii* males responded to rotation of the mini fan that could be seen through the window of the sound insulated box, in which the fan had been set, it was assumed that males did not respond to the sound. However, in the case of a blue disc to which they had never responded, males responded from a right angle to the rotation of the tapered blades (this was sometimes observed with other discs). As the sound is characteristically loud at a right angle to a pivot, there may be some response to sound in this case (Dr N.W. Donnelly, pers. com., August 19, 2001). We do not know whether the following behaviour might be related to the response to sound, however, a curious behaviour of the males was observed every day. After the start of the experiment for the day males passed the experiment site producing the sound of wing beating, which they had not done prior to the experiments.

The response to rotation of the mini fan was not due to thermoregulation since males responded to the rotating image of the mini fan in the mirror or to rotating discs which did not generate wind. Also, the response was observed at low temperatures of around 22°C, so we assumed it was not for orientation to the wind to decrease body temperature. Figure 5 shows the relationship of Tb of males to Ta. They maintain high Tb, therefore, they may decrease their Tb in hot weather by orienting themselves toward the wind. But in such low ambient temperatures they may unlikely do it intentionally.

The larger the diameter of the disc, the higher the HVR. Also, the marginal rotation velocity at which males responded was estimated at faster than 11 Hz of an electric fan, because males did not respond at a rotation velocity of less than 11 Hz. The upper margin could not be estimated, however, since males seemed to recognize the rotation up to 300 Hz, flicker fusion frequency of the dragonfly, which has never been investigated, may be related to the value.

These experiments did not reveal precisely how *A. sieboldii* males recognized colours and patterns. However, they seemed to show weak association to monochromatic white, yellow, orange, red and blue, and strong association to black and green. In *Sympetrum rubicundulum*, receptors in the eye respond from ultra-violet (340 nm) to orange red (620 nm) (MEINERTZHAGEN et al., 1983). *A. sieboldii* may recognize black and green, since its body includes black and its eyes are emerald green. However, there are also yellow markings on the body, and the respond to discs of this colour is weak. As mentioned above, both sexes of *A. sieboldii* have the same morphology, hence the male cannot recognize the female without approaching close to her. The fact that males showed a high HVR to black and green patterns resembling their body colours may suggest it.

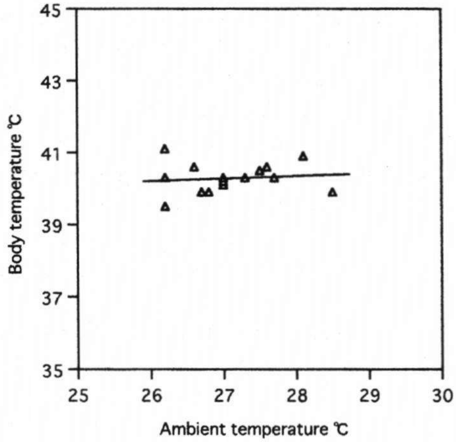

Fig. 5. The body temperature of *Anotogaster sieboldii* males in relation to the ambient temperature in the shade. Data were collected on August 19, 1990 at the same site as the experiments were made. n=15, Y=0.064X+38.565 r=0.107

However, judging from the high HVR to an even black helix pattern on a white background, it was suspected that the males might have recognized the magnitude of movement of the edge of a rotating pattern, rather than the colour. As they showed a propensity for high HVR for colour patterns with a black background, movement and silhouette of patterns with a black composite may be recognized more clearly than those of other colours.

Since only males responded to rotating objects, it was suggested that they might have regarded the rotating discs as females. This was also indicated in Experiment 7 since the males showed no response to photographs of an ovipositing female or to swinging a photograph of one.

There have been some reports indicating that morphological patterns, colours and behaviours of dragonflies are signals for sexual recognition. FRANTSEVICH & MOKRUSHOV (1984) described that, in *Sympetrum* patterns of wings allow recognition of the male. The experiment of ANDREW (1966) indicated that the abdominal colour of *Erythemis simplicicollis* is one factor in sexual recognition, and UBUKATA (1983) reported that, in *Cordulia aenea amurensis*, the swinging movement of the thick abdomen is a signal for female recognition. In *A. sieboldii*, wing beating may be a signal for female recognition. This was suggested by the fact that the conspecific males responded to the suspended male and female only when the latter were fluttering. Therefore, their behaviours to a cranefly and to a *Sympetrum* suggested that the males suspected them of conspecific females.

Males were often observed hovering in line at intervals of 30 to 50 cm in front of the fan, or when a male was hovering to the fan, another male began hovering in response to the former. In one case, a diamond formation consisting of four males was observed for an instant. These cases were usually followed by pursuit flights. Such behaviour is typically adopted by males. KAISER(1982) reported that, in *C. boltoni,* aggressive behaviour to conspecific males was seen, but they showed no territoriality. However, in *A. sieboldii,* the above-mentioned behaviour may not be aggressive behaviour, but behaviour to ascertain whether opponents are females or not.

This was a preliminary study on *A. sieboldii,* and we could not determine pattern recognition or the relation of it to the rotation velocity. Further investigation is required. Furthermore, we could not confirm the response to sound by *A. sieboldii.* This also requires further investigation. It may be extremely difficult to show ethologically, therefore, electrophysiological experiments may be necessary.

ACKNOWLEDGMENTS

We are grateful to Mr K. INOUE and Dr H. UBUKATA for literature, to Dr K. ARIKAWA, Dr P.S. CORBET, Dr T. DONNELLY, Mr H. ISHII, Mr H. KARUBE, Dr D. PAULSON, Mr M. SAOTOME, and Dr T. UÉDA for useful advice.

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