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An infrared thermographic visualization of the bumblebee (*Bombus diversus* and *B. ignitius*) colony

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Abstract. Effective colony thermal control is an important factor for social insects like bumblebees. With the temperature maintained at the adequate level in the colony nest, the development of their young and other colony activities can be carried out properly. If adequate temperature maintenance is lost, it will result in the deformation of the emerging adults or the abandonment of the larvae. Although fluctuation in ambient air temperature can be threatening for the colony thermal control, worker bees are known to take action for better control, by fanning their wings to enhance nest ventilation when it gets warm, or by covering the brood area to generate heat when the temperature goes down. There exist some studies examining the activities of worker bees in relation to the thermal change, however, fundamental data on the temperature and humidity in bombus nest are still limited. In this study, the changes of temperature and humidity were recorded in the *Bombus diversus* nest which was reconstructed in a way similar to the feral one. Changes in temperature and humidity were also recorded using an artificially reared *B. ignitus* colony. Thermal distribution of these bombus colonies were analyzed using thermography images.

Key words: bumblebee, colony reconstruction, thermographical visualization

Introduction

Bumblebees are a group of bees that are distributed mainly in cool and moist climate of the northern hemisphere temperate and subarctic zones. Their life cycle starts in spring when a hibernating queen bee wakes up and starts making her nest. After the emergence of the first few worker bees, the colony speeds up its development from summer to autumn. Reproductive castes are born in autumn. New queens mated with male bees overwinter and the rest of the colony members terminate their lives to close the one year cycle of bumblebees.

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Unlike honeybees that distribute in tropical to subtropical zones and overwinter as a colony in closed space, bumblebees with their distribution area in temperate to subarctic zones have to manage and survive through the severe temperature changes in early spring by a queen bee alone. Therefore, very efficient energy exchange is required for bumblebees to regulate body temperature. Some bumblebees are known to be able to fly to some extent when the ambient temperature is -3.6 ℃ (Bruggemann, 1958, cited in Heinrich, 1979). So the thermo-regulating ability of bumblebees is regarded to be excellent.

Recently, bumblebees play one of the essential roles as the pollinating insects in crop production, and the stable rearing and supply of the pollinating colonies are getting more significance. Basic data of bumblebee rearing refers mostly to Yoon (2002) and Ono & Mitsuhata (1994), and further data are not likely to be published from the commercial producers of bumblebees (Velthius & Doorn, 2006). Watanabe et al. (2013) reports on the life cycles of *Bombus deuteronymus deuteronymus* and *Bombus deuteronymus maruhanabachi*, on the basis of the data from the indoor reared colonies, but they do not refer to the thermoregulations by the bees.

In this paper, we observed how bumblebees control the temperature of the colony as a whole, by setting up a colony nesting indoor in the condition similar to that in nature. Next, we visualized and analyzed the thermal distribution of the colony using thermography. Then, reports were made on heat retaining behavior, flight, and thermoregulation in nest that are induced by the change of environmental factors such as temperature and humidity, which will be useful basic data for the rearing of pollinating insects.

Material and Methods

1. Bombus diversus diversus Smith, 1869

(1) Collection of B. diversus colony

A feral colony of *B. diversus* was collected from Kawaguchiko, Yamanashi Prefecture on August 26th, 2007. The entrance of the colony nest was very narrow, less than 3 centimeters in diameter (Fig. 1A). The nest, made of mud and straw, was dug out from 1 meter deep under the ground. Some parts of the nest were removed and worker bees were all picked out to be kept separately in a case (Fig. 1B).

(2) Reconstruction of the colony in a cage

An aquarium (60 × 60 × 45 cm) was used as the glass cage for rearing the bees. Aiming to recreate a natural environment for *B. diversus*, several flowering plants were set on the layers of soil and charcoal at the bottom of the aquarium, flowers as the bee forage and charcoal as the anti-fungi material, (Fig. 2A). Sugar solution (60%) and fresh pollen pellets were given every other day, to supplement the food available from the flowers in the cage. Plants were watered once a week.

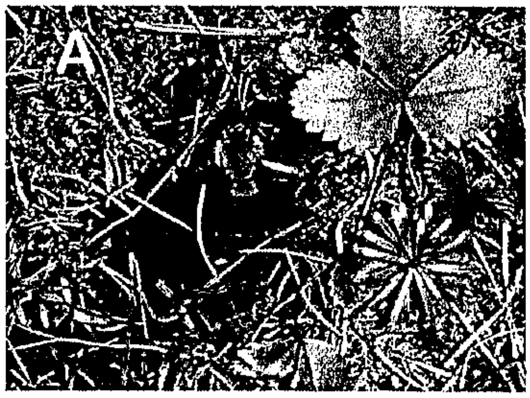

Fig. 1A. Entrance of a *B. diversus* feral colony nest

Fig. 1B. Inside the *B. diversus* nest

Sphagnum *Hypnum plumaeforme* was around and covering the nest when the feral *B. diversus* colony was found in Kawaguchiko. So we supplied the same sphagnum into the cage repeatedly as the nest material. After placing the wild bumblebee nest, the worker bees were also introduced into the cage. The worker bees started to reconstruct their nest with the moss provided, by drying small piece of the moss (Fig. 2B), and bringing them back home to cover the old nest (Fig. 2C).

The colony continued its development inside the nest (Fig. 2D). In the glass cage, we placed the feeders as much apart from the colony, aiming to induce the feeding behavior like in the field. Worker bees were observed to fly back to the nest carrying pollen in her pollen basket (Fig. 2E).

(3)Thermoregulation of the colony

Temperature and humidity of the nest in the glass cage were recorded every ten minutes for 20

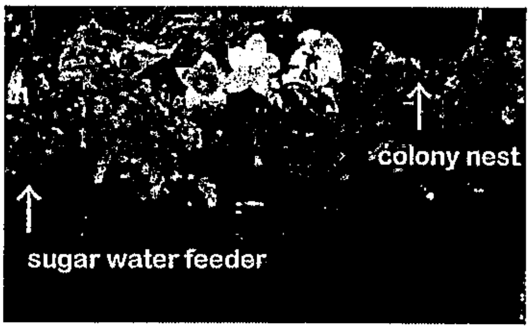

Fig. 2A. Nature-like environment in the glass cage


Fig. 2B Worker bee rolling dried sphagnum.

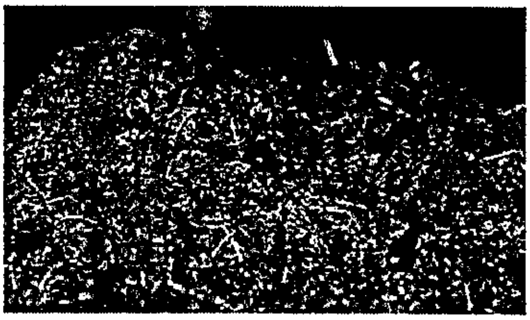
Fig. 2C Nest re-covered with sphagnum

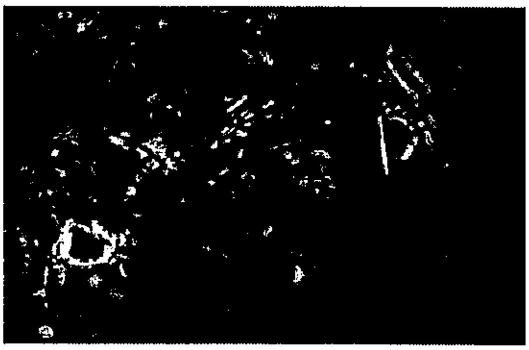
Fig. 2D Growing *B. diversus* colony in the nest


Fig. 2E *B. diversus* worker fly back home with a pollen pellet

days from September 21st to October 10th, 2007. The cage was placed in a room of 25℃, with a light over the cage food which was on from 09:00 to 18:00. A sensor (Ondotori RTR-72) was implanted in the nest of a colony with more than 50 worker bees. Specific visual data of nest temperature distribution was also obtained using thermography.

2. Bombus ignitus Smith, 1869

(1) Materials for B. ignitus rearing

To keep *B. ignitus* in our laboratory, the colony-rearing technique of Katayama and Ochiai (1981) was basically applied (Fig. 3A,B). The colony used here was originally collected in Nagano Prefecture and had altered its generations successively. The nesting box (25 × 27 × 15 cm) was made of plastics.

(3) Thermoregulation of the colony

Temperature and humidity of the *B. ignitus* nest were recorded with a sensor (Ondotori, RTR-72) implanted in there, in the same way as was done with *B. diversus*. To investigate the effect of the outer air temperature onto that of inner brood area, a colony with more than 50 worker bees was placed in an incubator. Data were recorded every ten minutes for about two days, in the incubator of the ambient temperature set at 30, 25, 20, 15, and 10℃ respectively.

Specific data of nest temperature distribution was obtained using thermography. If given some vibration, the nest thermo-distribution would have changed easily. So the box was brought out from the incubator very carefully and was taken the thermal

Fig. 3A *B. ignitius* primary colony

Fig. 3B *B. ignitius* developped colony

images without delay. Thermographs of *B. ignitus* colony were captured when temperature and humidity measurement in the incubator of the ambient temperature sets respectively at 30, 20, and 15℃ were over.

Results and Discussion

We succeeded in letting a feral *B. diverse* colony from Kawaguchiko, Yamanashi Pref. reconstruct their nest in a glass cage box. Using sphagnum as the nest material, the bees covered their nest with moss layers, which worked effectively to maintain the nest environment and to support colony development (Fig. 2). Temperature and humidity of the nest in the cage box were recorded every ten minutes for 20 days from September 21st to October 10th, 2007. Average temperature of the brood area was 32.5 ℃ (maximum and minimum temperatures were 33.4℃ and 31.6 ℃, respectively). Average humidity of the

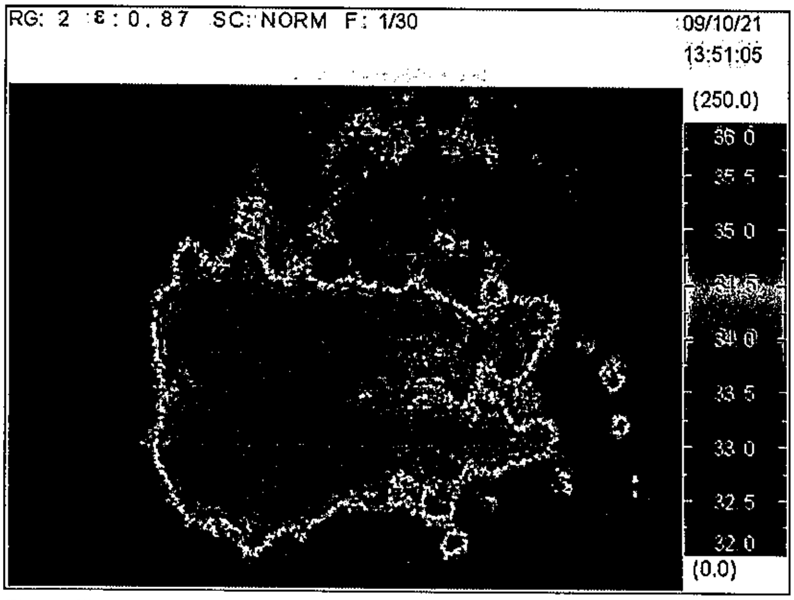

Fig. 4 Thermograph of a *B. ignitius* colony under the incubation temperature setting at 30℃

brood area was 64%, with max 69% and min 57%. Fig. 4 shows the nest temperature distribution obtained from thermography. Temperature of nest center indicated here is as high as 32℃. Temperature of nest surroundings was stable around 28–29℃. When the temperature went up, the bees removed some moss cover of the nest to make an opening hole. They also started fanning to enhance ventilation. In this way the bees were regulating the temperature and humidity conditions of their nest.

To further investigate the thermoregulation of the colony, an artificially reared *B. ignitus* colony was placed in the incubator. Ambient temperature in the incubator (AT), ambient humidity (AH), brood area temperature (BT), and brood area humidity (BH) were recorded under the incubation temperature sets of 30℃, 25℃, 20℃, 15℃, and 10℃ respectively.

In each test, data was collected every ten minutes for 3 days. The results are shown in Table 1.

Both BT and BH were affected by AT and AH, but at the same time, had tendencies to keep constancy against the changes. The most preferable BT is said to be about 30℃. When AT goes down, BT correlates to it and finds its constancy below 30℃. BT was managed not to drop down below 25℃, but when AT was as cold as 10℃, colony thermal maintenance became difficult. BT dropped down to 18.05℃ on the average, and the activities of the worker bees were found depressed. Maximum difference of BT and AT was 7.66℃ in the incubator temperature set of 15℃. Likewise, BH was found to have tendency to keep constancy against outer changes. In various temperature sets, BH was kept between 45.28% and 53.95%. AH showed wider range than BH, and the maximum difference of BH and AH was as much as 36.34% again in the incubator temperature set of 15℃. Humidity of the *B. ignitus* nest was found to be actively controlled by the bees living in there.

B. ignitus colony was brought out of the incubator very carefully not to interrupt their activity, and was promptly taken the thermal images. Fig. 4 shows the thermograph of the colony that was taken when the monitoring of 30℃ set was over. Nest center was warmest around 37℃, and the outside of the nest was relatively high around 30℃. Fig. 5 shows

Table 1. Temperature and humidity of *B. ignitius* nest under various temperature sets.

			Incubation temperature				
			30° C	25° C	20° C	15° C	10° C
Temperature (° C)	Ambient(AT)	Average	27.7	24.6	19.9	17.6	12.7
		Max	28.3	25.2	20.6	18.5	13.7
		Min	26.3	23.3	19.0	16.7	11.6
	Brood area (BT)	Average	30.0	28.4	26.3	25.3	18.1
		Max	30.5	29.1	26.9	25.9	25.7
		Min	26.2	27.8	25.8	24.1	15.5
Humidity(%)	Ambient(AH)	Average	53.0	65.1	82.5	83.1	80.3
		Max	58.0	72.0	90.0	90.0	87.0
		Min	40.0	51.0	75.0	77.0	71.0
	Brood area (BH)	Average	45.3	50.6	51.1	46.8	54.0
		Max	51.0	56.0	55.0	53.0	64.0
		Min	33.0	40.0	46.0	43.0	38.0
Average difference		BT-AT	2.3	3.9	6.4	7.7	5.4
		BH-AH	-7.7	-14.5	-31.3	-36.3	-26.4

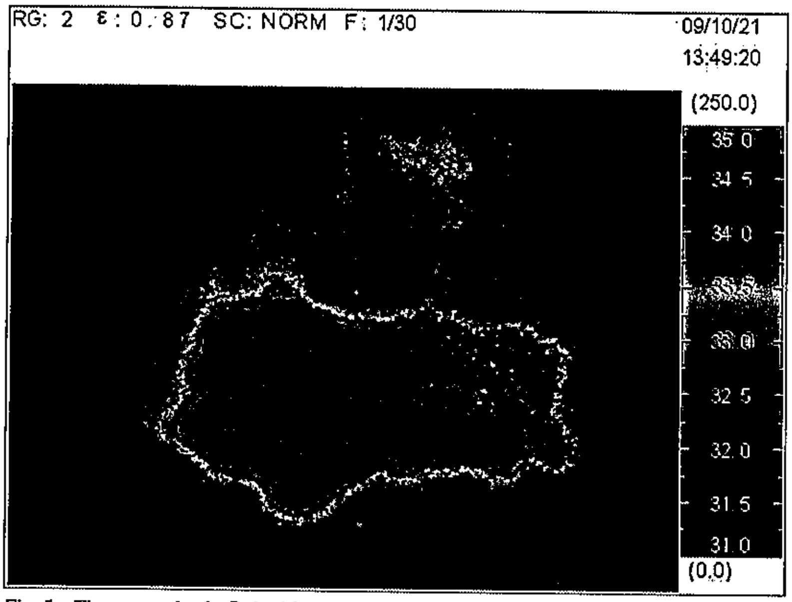

Fig. 5 Thermograph of a *B. ignitius* colony under the incubation temperature setting at 20℃

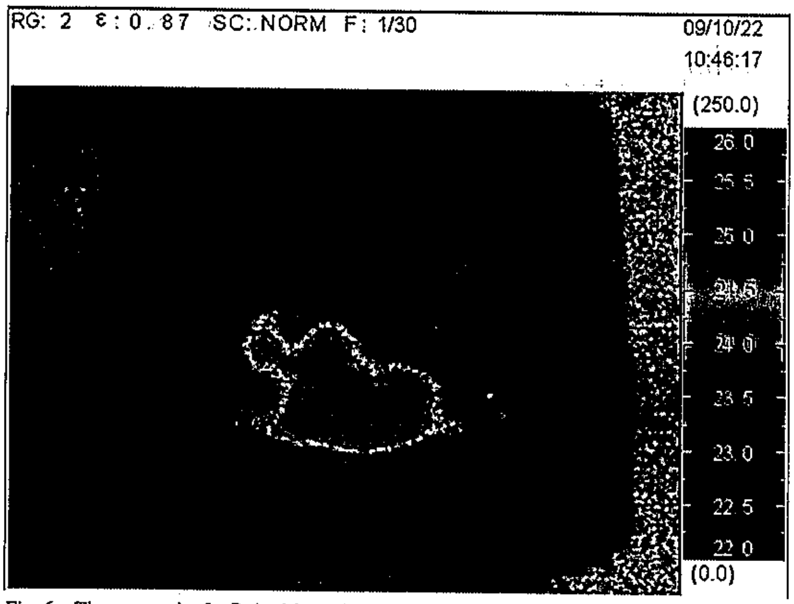

Fig. 6 Thermograph of a *B. ignitius* colony under the incubation temperature setting at 15℃

the thermograph of the colony taken after the monitoring of 20℃ set. Nest center was still very warm around 36 ℃, but the warmed area was smaller when compared to that in Fig. 4. Fig. 6 shows the colony thermograph after 15℃ set. The heated space was smaller than in the case of 20℃ set and bees were maintaining over 27℃ only the central area of their nest.

While *B. diverse* colony controlled the temperature in the nest center about 33 ℃ and the whole nest about 29–30℃, *B. ignitus* colony showed wider difference in the two measuring points. Unlike *B. diverse* with sphagnum moss, *B. ignitus* was given no material to cover their nest. So the worker bees covered the central comb area by themselves (Fig. 2B) and generated heat from their bodies. This behavior caused wider temperature difference in and around their nest, and it was captured clearly in the thermograph images. In the central part of the nest, bumblebee larvae and pupa are raised. Worker bees seem to give priority to keep them warm, and leave the nest outer rims out of their control. It was found that by limiting the heating space, they were maintaining the brood area temperature in a stable condition. On the other hand, *B. ignitus* was found to prefer lower humidity than *B. diverse* for their nest, specifically the average of BH for *B. ignitus* 45–55%, and *B. diverse* 55–70%. Preferences of thermal and humidity conditions of the bumblebee nest are thought to differ from one species to other. It will reflect their choice of habitat and nesting site. Yoon (2002) made some investigations on the temperature and humidity control of B. ignitus. According to the paper, the preferable indoor rearing conditions are 27℃ and 65%. In our study, BT ranged from 25℃ to 30℃, but 27℃ can be said as a comfortable thermal condition for colony rearing room. As to the humidity, *B. ignitus* like relatively dry condition such as 45–55% as was just mentioned above. Hoshiba et al. (2006) analyzed the preliminary stage of colony formation of *B. ignitus* using the thermography images. In that report, the average temperature of pupal surface was 29.7℃, and adult bee body temperature ranged from 28.3℃ to 39.7℃. In our study, the temperature shown on the images went up over 37 ℃, and it could have reflected the body temperature of adult bees covering the brood combs to some extent. On the temperature and humidity control, the central part of the nest was given priority to keep warm and stable by leaving the outer rims out of control and minimizing the heated area when the temperature outside goes down.

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