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## Distribution of Termites in the Ryukyu Archipelago

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# DISTRIBUTION OF TERMITES IN THE RYUKYU ARCHIPELAGO

Sadao IKEHARA

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## 1. INTRODUCTION

Termites are primitive insects related to cockroaches. They are organized into colonies which have given rise to different kinds of individuals or castes fitted structurally to perform definite functions in the life of each colony. The termites are widely distributed over the world, although predominantly in the tropics. About 1,900 species have been described (Snyder, 1935; Nakashima, 1959). The occurrence of termites is well known to man because of the enormous damage caused by their attacks on wooden structures and even living trees and shrubs. Hence, any work on termites is of considerable value and contributes to present human welfare.

So far as the Ryukyu Archipelago is concerned, there has never been a comprehensive study on the Ryukyuan termites. This paper is the result of a study on the Ryukyuan termites with special reference to their geographical distribution.

### Historical data

Although considerable amount of investigation on termites has been done in Formosa and the Japanese Archipelago from the beginning of this century, We have little information on termites in the Ryukyu Archipelago. Early traditions show that termites have existed in the Ryukyu Archipelago for many years. No comprehensive study on the termites has appeared in this archipelago previous to this paper.

In 1909, Watase, Kuwano, and Namie performed a scientific expedition in the archipelago on their travels to Formosa and collected a number of termites. In the same year Saeki in Okinawa collected termites at Naha, Okinawa and sent them to the Tokyo Imperial University. Later, Hozawa (1915) reported four species of termites based upon the specimens obtained from Okinawa by Watase et al and Saeki. The species identified by Hozawa at that time were as follows:

*Hodotermopsis japonicus* Holmgren

*Kaloterme koshunensis* Shiraki

*Leucotermes speratus* (Kolbe)

*Coptotermes formosanus* Shiraki

In 1910, Iwasaki, former Chief of Meteorological Station of Ishigaki, collected a species of termite and sent it to Nawa in Gifu Prefecture. Nawa (1910) identified it as the species *Coptotermes formosanus* Shiraki. This was the first report of termite from the Yaeyama-gunto.

In 1911, Nawa, U. (1911a) reported *Kaloterme kotoensis* Oshima from the specimens obtained on Ishigaki-jima by Iwasaki. So far as the Ryukyu Archipelago is concerned, this was the first report about this species.

During the year 1912, Iwasaki collected many specimens of termites from



Ishigaki-jima and sent them to Nawa, U., Hozawa and Oshima. These specimens were later identified by Nawa (1912a, b, c) and Hozawa (1915).

In 1913, Nawa, U. visited Amami-oshima for a survey of termite and collected the Japanese large termite, *Hodotermopsis japonicus*, in the forest near Nase City. In the same year Iwasaki obtained a species of termite from Ishigaki-jima and sent it to Gifu, where it was identified as *Kaloterme satsumensis* (Matsumura) (Konchu Sekai, 1913, 17:153, p1. 7). This species has not been found on Ishigaki-jima since its first discovery.

In 1914, a termite survey was made by Nawa, Y. on Amami-oshima and Okinawa-jima. He obtained *Hodotermopsis japonicus*, *Coptotermes formosanus* and *Leucotermes speratus* from Amami-oshima, and *Coptotermes formosanus*, *Odontotermes formosanus*, *Kaloterme koshunensis*, and *Kaloterme kotoensis* from Okinawa-jima. This was the first time that the previously known species, *Odontotermes formosanus* and *Kaloterme kotoensis* were reported from Okinawa-jima. Accordingly, ten species of termites existing in the Ryukyu Archipelago had been reported by 1914. They are as follows:

*Hodotermopsis japonicus* Holmgren  
*Kaloterme satsumensis* (Matsumura)  
*Kaloterme koshunensis* Shiraki  
*Kaloterme fuscus* (Oshima)  
*Kaloterme kotoensis* Oshima  
*Leucotermes speratus* (Kolbe)  
*Coptotermes formosanus* Shiraki  
*Odontotermes formosanus* Shiraki  
*Eutermes takasagoensis* Shiraki  
*Capritermes nitobei* Shiraki

So far as the Ryukyu Archipelago is concerned, since 1915, much attention has been paid to economic and practical methods of preventing termite attacks upon wood and its products, but no biological studies of the termites have been made in the Ryukyu Archipelago.

In 1954, Ueno et al (1954) collected a number of *Hodotermopsis japonicus* on Nakano-shima lying between Amami-oshima and Yaku-shima, Satsunan-shoto. This is the first report of occurrence of this species in the islands.

In 1956, Esaki (1956) described the alates of *Hodotermopsis japonicus* from the specimens found on Yaku-shima by Shirozu and Kurosawa. This is the first description of the alate of this species.

From 1951 to the present time, the author made many termites investigations throughout the Ryukyu Archipelago with special reference to zoogeography. A part of this work has already been reported in the abstract of the Ninth Pacific Science Congress (1957b) and the Bulletin of Arts and Science Division, No. I-Iv (1957b 1958, 1959a, 1959b).

It is regrettable that those studies of termites by the author were not begun many years ago. Such studies on this subject were started in 1951 when the author became a member of the staff of the University of the Ryukyus. Since then, he has tried to make many extensive investigations on the termites in the Ryukyu Archipelago. Such a survey, however, does not cover all the islands in this area. It would be desirable to make a survey covering the islands of the archipelago in future.

### **The Scope of this Study**

In this paper it is planned to illustrate in detail the geographical distribution of ten species of termites in the Ryukyu Archipelago. A special attempt has been made to consider the present northern limits of distribution and to find some way to determine the logical northern limits of distribution of the Ryukyuan termites.

This paper consists of three major parts: (1) It concerns the geographical and climatic status of the Ryukyu Archipelago as the habitat of termites, and illustrates the geographical distribution and local occurrence of the Ryukyuan termites. (2) The relationship between the termite fauna of the Ryukyu Archipelago and those of the neighboring regions. An attempt is made to find the method of dispersal by which the Ryukyuan termites may migrate from or to the neighboring regions and among the islands in the archipelago. (3) Factors operating to control the distribution of termites and the preferred temperature of termites as an index by which the logical northern limit of distribution may be presumed are discussed. Some parts of this paper are not yet completed. Details and further investigations are needed, the results of which will appear later.

### **Acknowledgments**

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There are many other persons who provided facilities and assistance which made it possible to carry out expeditions on the islands in the Ryukyu Archipelago. The author wishes to express his cordial thanks to them for their help in various ways.

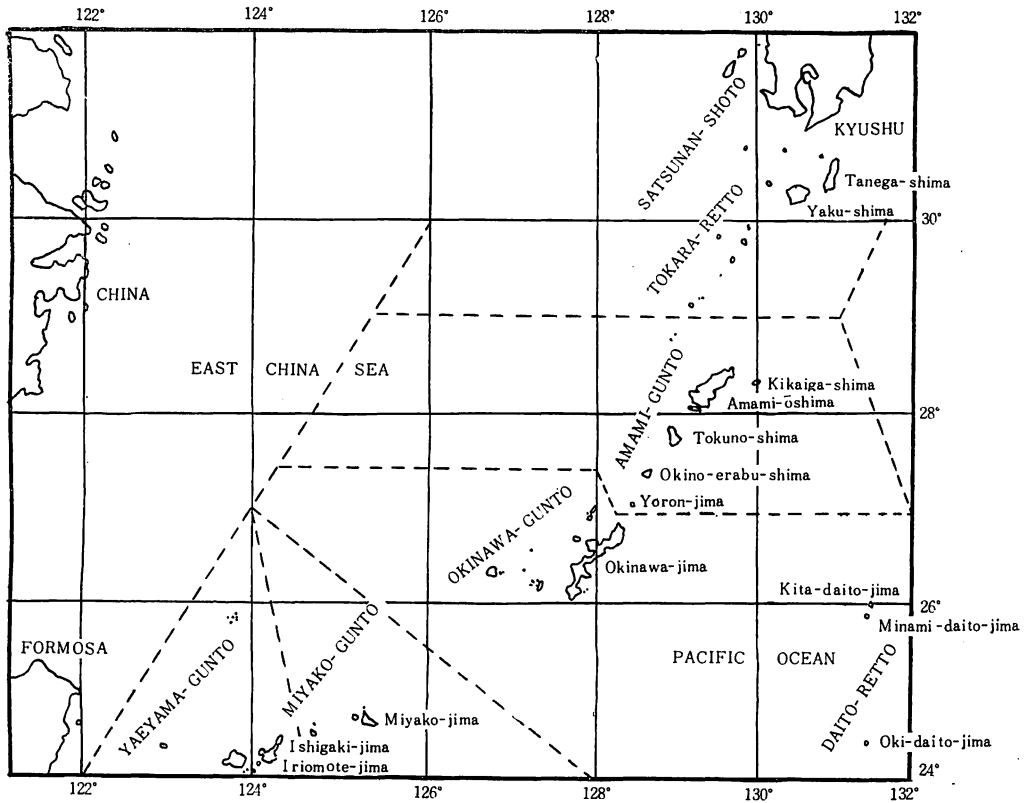
## II. THE RYUKYU ARCHIPELAGO

### Geographical Sketch

The Ryukyu Archipelago (Text-fig. 1) consists of about 140 islands, reefs and shoals extending on a northeast-southwest line from about  $131^{\circ}$  to about  $122^{\circ}56'$  east longitude and between about  $24^{\circ}22'$  and  $30^{\circ}51'$  north latitude. According to Kato (1877), Hanzawa (1932, 1935a,b) etc., the islands of the Ryukyu Archipelago are peaks of submerged mountains, forming three distinct longitudinal mountain series, curving convexly from Kyushu southward to Formosa. The outer curve, composed of Tertiary and younger rock, includes Tanega-, Kikai-shima, the southern part of Okinawa-, Miyako- and Iriomote-jima. The central curve is composed of palaeozoic and igneous rocks, and supports the larger islands of the archipelago, viz., Yaku-, Amami-oshima, Tokuno-, Okinoerabu-shima, Yoron-, Okinawa-, Iheya-, Keruma-, Ishigaki- and Kobama-jima. The inner curve is composed of volcanic origin, including Take-, Io-, Kuro-, Kuchinoerabu-shima, all the islets of the Senkaku-retto. Beside these three curves there is another series of small islands namely, the Daito-shoto, lying to the southeast of Okinawa-jima. Coral reef formations occur on or around most islands of the archipelago, and are particularly conspicuous around the southern islands of the Ryukyu Islands.

These lines of islands may be divided into eight groups from the view-point of their geographical situations. They are the Satsunan-shoto (shoto means a group of islands), Tokara-retto (retto means a chain of islands), Amami-, Okinawa-, Miyako-, Yaeyama-gunto (gunto means a group of islands), Senkaku-retto and Daito-shoto.

The Satsunan-shoto consists of two large islands, namely, Tanega- and Yaku-shima, and several satellite islets. It is the northernmost part of the Ryukyu



Text-fig. 1. Map showing the Ryukyu Archipelago.

Archipelago, extending from the southern end of Kyushu to Amami-Oshima. The islands which extend from Yaku-shima to Amami-oshima are called the Tokara-retto and are of volcanic origin. The Amami-gunto is situated between Yaku-shima and Okinawa-jima, and are composed of three large islands, viz., Amami-oshima, Tokuno-shima and Okierabu-shima, and several satellite islets. Amami-oshima is the largest island in the Amami-gunto and supports many scientifically important plants and animals. From the biogeographic view-point this island holds an important position. Okinawa-jima and its satellite islets are usually called the Okinawa-gunto. It also includes many small reefs and rocks which support only a small number of indigenous plants. Okinawa-jima is the largest island not only in this group of islands but also in the whole Ryukyu Archipelago, and supports relatively rich fauna and flora.

A group of islands lying on the south of the Okinawa-gunto is called the Miyako-gunto. The islands of the Miyako-gunto are all flat and level, having maximum elevation of only 110 meters. Coral formations are particularly conspicuous on all the islands of the Miyako-gunto. Miyako-jima is the largest of these islands. A group of islands lying at the southern end of the Ryukyu

Archipelago is called the Yaeyama-gunto. This group is composed of two large islands, namely, Iriomote- and Ishigaki-jima, and many islets, reefs, shoals or rocks.

Beside the so-called "the Ryukyu Curve", there are three small islands at a distance of about 820 Kilometers to the southeast of Okinawa-jima. These are called the Daito-retto or Borodino and Rasa Islands. Another group of islands lies to the north of the Yaeyama-gunto. It is called the Senkaku-retto occupying the southernmost end of the inner curve of the Ryukyu Archipelago. The Senkaku-retto, however, are omitted from the discussion in this paper, as this survey does not cover it.

### Climatic Status

**Air temperature.** According to Okada (1931) and data compiled by major observatories in the Ryukyu Archipelago, the Ryukyu Archipelago has a subtropical marine climate with relatively high and constant temperatures throughout the year. This is due largely to the influence the Japanese Current or Kuroshio, which begins in the equatorial ocean currents north of the Philippines and flows northeastward through the waters surrounding the Ryukyu Archipelago. During the summer, the Japanese Current intensifies the heat and humidity of the sultry monsoon winds from the north. The result is both an increase in year round temperature and humidity and a modification of the climate.

A glance at Table 1 shows that the Ryukyu Archipelago has a subtropical climate. The summer heat is not very high and the winter coldness is not severe. The diurnal and annual ranges of air temperatures are both small. This is true, however, only during the winter months, when air temperatures are progressively lower in the overall range of the Archipelago.

Table 1. Mean air temperature (°C.) on seven islands of the Ryukyn Archipelago compiled by seven observatories on these islands.

Stations	Months												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Ishigaki 1897 ~ 1956	18.0	18.0	19.7	22.3	24.9	27.2	28.3	28.0	27.0	24.6	22.1	19.4	23.3
Miyako 1938 ~ 1948	17.5	17.5	19.1	21.1	24.3	26.6	27.5	27.3	26.9	24.7	22.1	19.3	22.8
Daito 1947 ~ 1955	17.6	17.8	19.1	20.9	23.6	26.1	27.8	27.7	27.5	25.2	22.6	19.6	23.0
Naha 1891 ~ 1940	16.1	16.0	17.7	20.7	23.1	26.1	27.9	27.7	26.6	23.9	20.8	17.7	22.0
Nase 1897 ~ 1957	14.3	14.3	16.2	19.3	21.9	25.2	27.7	27.5	26.1	22.8	19.4	16.2	20.9
Nakano-shima 1941 ~ 1951	12.1	12.7	15.5	18.7	22.3	24.8	27.3	28.1	25.9	22.1	18.0	14.5	20.2
Yaku-shima 1938 ~ 1957	11.3	11.4	13.8	17.1	20.4	23.6	26.8	26.8	25.2	21.4	17.7	13.5	19.1

4.2°C. from south to north. On some islands of the Satsunan-shoto, snows and frosts are seen occasionally. During the summer months, the degree of the heat is much the same for all islands in the archipelago. January, February are the coldest months, and July and August are the warmest months, averaging about 27-28°C. throughout the archipelago.

**Earth temperature.** The earth temperature varies with the depth. Generally speaking, both of diurnal and annual temperature variations of earth temperature are smaller than those of the air temperature. In the Ryukyu Archipelago the highest and lowest monthly mean temperature of earth (0.5 M. in depth) appear almost at the same months as those of the coldest and warmest months, respectively. But on some islands, for examples, Okinawa- and Minamidaito-jima, it appears a month later than that of the coldest and warmest months. Earth temperature data compiled by five observatories in the archipelago are given in Table 2.

Table 2. Earth temperature data compiled by five observatories in the Ryukyu Archipelago (0.5 M. in depth).

Stations	Months												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Ishigaki 1932 ~ 1956	19.9	19.5	20.8	22.9	26.1	28.5	30.1	29.8	29.3	27.0	24.4	21.5	25.0
Naha 1947 ~ 1939	18.2	17.7	18.5	20.7	24.1	26.5	29.1	29.3	28.7	26.3	23.0	17.2	23.0
Daito 1947 ~ 1955	19.8	19.7	21.2	22.7	25.5	27.3	29.5	29.5	29.6	28.0	24.7	21.4	34.9
Nase 1897 ~ 1940	15.4	15.2	16.3	19.3	23.0	25.7	28.8	29.0	28.0	24.8	21.2	17.6	22.0
Yaku-Shima 1938 ~ 1957	12.7	12.1	14.3	17.4	21.0	23.7	27.5	28.5	27.6	23.6	19.6	15.5	20.3

**Atmospheric humidity.** The mean annual moisture content of the air around the Ryukyu Archipelago is excessive, averaging 79 percent or more over the

Tabele 3. The mean annual monthly relative humidity compiled by the six observatories in the Ryukyu Archipelago.

Stations	Manths												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Ishigaki 1897 ~ 1956	77	78	80	82	84	85	82	83	81	77	77	77	80
Miyako 1938 ~ 1948	73.5	77.3	78.1	80.6	80	87.1	85.2	84.8	81.6	75.3	75.9	74.3	79.9
Daito 1947 ~ 1955	71	73	75	82	86	88	82	83	80	77	76	71	79
Naha 1891 ~ 1940	74.6	75.3	76.8	80.4	83.4	85.6	26.7	83.1	81.9	77.7	75.2	73.2	79.1
Nase 1897 ~ 1957	73	73.2	73.4	76.6	79.5	81.6	80.4	81.7	80.8	76.3	73.7	72.1	76.8
Yaku-shima 1938 ~ 1957	70.6	69.9	71.2	72	76.4	80.9	80.3	80.2	79.	74.8	72.0	71.0	74.9

whole area. Humidity is particularly high during the period from April to September. According to the Observatory at Naha, diurnal humidity variation is never very great. In the summer it fluctuates about 20 percent and in the winter the mean fluctuation is about 14 percent. In every month the diurnal maximum occurs between 5 a.m. and 6 a.m., and the minima between 1 p.m. and 3 p.m. Information on the mean annual and monthly relative humidity compiled by the seven observatories are given in the following table (Table 3).

**Precipitation.** Rain fall is heavy throughout the Ryukyu Archipelago. There is, however, considerable variation in the amount of rainfall from island to island and from season to season. At Ammbo in Yaku-shima, for example, the mean annual precipitation reaches about 4314.2 millimeters. The reason for the heavy rainfall on Yaku-shima is probably due to the fact that the island is situated directly in the path of the warm Japanese Current. The winds blowing over this area contain considerable amount of moisture. Another reason for heavy rainfall here is the presence of many mountains, about 30 of which have peaks exceeding 1,000 meters above sea level. At Minami-daito-jima, which lies outside of the path of the Japanese Current, the mean annual rainfall is only 1711.4 millimeters.

Generally speaking, in the Ryukyu Archipelago, the summer season receives more precipitation than the winter season. Exception for Yaku- and Tanegashima, no frost and snow have been seen in the archipelago. Table 4 gives information on precipitation compiled by seven main observatories in the Ryukyu Archipelago.

Table 4. Precipitation data compiled by the seven main observatories in the Ryukyu Archipelago (in mm.).

Stations	Months												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Ishigaki 1932 ~ 1956	144.1	122.2	139.4	126.7	144.3	163.8	199.3	183.2	166.3	151.2	117.9	163.3	2189.4
Miyako 1938 ~ 1948	119.0	123.0	204.0	188.0	209.0	300.0	252.0	245.0	125.0	117.0	160.0	178.0	2220.0
Daito 1947 ~ 1955	93.7	83.3	94.9	160.2	280.6	220.0	153.8	157.5	93.5	156.9	165.9	101.2	1711.4
Naha 1891 ~ 1940	130.8	130.0	161.1	157.0	253.5	269.0	188.5	265.5	182.9	164.6	134.4	105.2	2142.5
Nase 1897 ~ 1957	187.5	195.9	218.3	233.7	348.3	424.4	245.4	309.7	295.0	269.1	223.4	172.1	3213.1
Nakano-shima 1907 ~ 1918	165.2	192.4	229.2	264.9	304.3	463.4	248.2	182.6	304.8	227.6	144.7	176.2	3132.1
Yaku-shima 1951 ~ 1957	225.9	173.5	278.0	269.9	515.8	753.7	233.4	440.1	600.0	377.1	292.6	154.2	4314.2

**Winds and typhoons.** The prevailing winds in the Ryukyu Archipelago are characterized by monsoons. From September to April northeasterly and northerly

monsoons prevail throughout the archipelago. During these months strong wind and rough sea make navigation very difficult. Northeasterly winds prevail until June, when a period of extremely variable winds occur and mean wind direction gradually shifts towards the east and south. From June the southerly winds of the summer monsoon become established and continue to prevail untill late August.

The Ryukyu Archipelago lies within the typhoon belt of the East China Sea. From 12 to 45 typhoons affect certain regions of the archipelago. The months of greatest typhoon frequency are June through September. If such a typhoon passes over a region, it usually causes severe property destruction and damage to crops and other plants.

### Vegetation

In the Ryukyu Archipelago vegetation fairly abundant under the influence of high temperature and moderately heavy rainfall. Banyan trees, palms, bananas and other tropical species grow in the archipelago. The original nature of vegetation in the archipelago is characterized by a broad-leafed evergreen subtropical forest. A coniferous forest consisting of the Ryukyuan pine tree is seen on most islands of the archipelago. However, the forest of cedar trees are hardly found here with the exception of Yaku-shima.

Among the cultured plants, sugar-cane, sweet potato and pineapple are the most common and are found throughout the archipelago. Generally speaking, in the islands which are flat the soil is adequate for the culture of sugar-cane and sweet potato in the archipelago. Consequently, the natural dense foliage is not seen on these islands.

### III. BRIEF NOTES ON TERMITES OF THE RYUKYU ARCHIPELAGO

Representatives of four of the five living families of termites are found in the Ryukyu Archipelago. The primitive family *Mastotermitidae* is not present here. No fossil of termites has been found in the archipelago as well as in other Oriental regions. An analysis of termites known to occur in the Ryukyu Archipelago is given in the following table (Table 5).

The termite fauna of the Ryukyu Archipelago consists of 4 families, 7 genera and ten species. All of the seven genera are adventive. Of the 10 species the only endemic one is *Hodotermopsis japonicus* Holmgren, making 90 percent of the fauna adventive. The ten species of termites known to occur in the Ryukyu Archipelago are listed below:

1. *Hodotermopsis japonicus* Holmgren
2. *Kalotermea koshunensis* Shiraki



Table 5. Tabular list of termites known to occur in the Archipelago.

Family	Genus		Species	
	Endemic	Adventive	Endemic	Adventive
Hodotermitidae	0	1	1	0
Kalotermitidae	0	1	0	4
Rhinotermitidae	0	2	0	2
Termitidae	0	3	0	3
Total	0	7	1	9

3. *Kalotermes satsumensis* (Matsumura)
4. *Kalotermes fuscus* (Oshima)
5. *Kalotermes kotoensis* Oshima
6. *Leucotermes speratus* (Kolbe)
7. *Coptotermes formosanus* Shiraki
8. *Odontotermes formosanus* Shiraki
9. *Eutermes takasagoensis* Shiraki
10. *Capritermes nitobei* Shiraki

Before proceeding to the main subject, a brief biological background of each species of termite known to occur in the Ryukyu Archipelago is given here.

#### Family Hodotermitidae

##### *Hodotermopsis japonicus* Holmgren

*Hodotermopsis Japonicus* Holmgren, 1912a. Annt. Zool. Jap., 8(1): 11

*Hodotermopsis Japonica*, Esaki, 1956. Bull. Nat. Sci. Mus., 3(2):86-88, pl. 19, fig 1.

The Japanese large termite, *Hodotermopsis japonicus*, was first described by Holmgren in 1912 as the second species of the genus *Hodotermopsis* (Holmgren 1912a). Subsequently, soldiers and nymphs were described precisely by Hozawa (1915) and Emerson (1933). The description of winged form has never been made previous to Esaki's paper (1956). Esaki made a detailed description of the winged form based upon the specimens of dealate and one winged male obtained from Yaku-shima.

This species is the only endemic species of termite known to occur in the Ryukyu Archipelago. A related species was found at Tonking, South China (Holmgren, 1911). The main distribution region of *H. japonicus* seems to be the northern part of the Ryukyu Archipelago (Ikehara, 1956, 1959a, 1959b). Since this species has never been found in the southern half of the archipelago, Formosa

and East China, it is of interest that its related species, vis., *Hodotermopsis sjöstedti* was found in Tonking.

*Hodotermopsis japonicus* is a typical forest termite and is found in huge dead stumps and dead portions of living trees. This species does not produce excrement in loose pellet form but it is used for repairs of its galleris. If the gallery of this species is broken, soldiers appear at the broken portion and make a sound of alarm. It is highly probable that the mating flight of this species occurs in July through August because in July, 1956, two winged reproductives were obtained by the method of rearing in a laboratory.

#### Family *Kalotermitidae*

There has been some confusion in the use of *Kalotermes* or *Calotermes*, and hence varied the spelling of the family name. According to Shiraki (1954), the original spelling was with a "K" by Hagen in 1853. Therefore, the spelling should be *Kalotermitidae* for the family and *Kalotermes* for genus name in accordance with the International Rules of Zoological Nomenclature.

##### *Kalotermes koshunensis* Shiraki

*Kalotermes koshunensis*, Shiraki, 1909.

Trans. Ento. Soc. Jap., 2(10):241.

*Calotermes (Neotermes) koshunensis*, Holmgren,

1912, Annot. Zool. Jap., (1):229-242.

Shiraki (1909) described this species for the first time from the specimens obtained from the Koshun district, Formosa. This termite is usually found in dead trees, stumps, dead portions of living trees but not in woodwork of buildings, furniture, bridges, fence poles, and other man-made structures.

According to Light (1929b), the species *Neotermes sinensis* Light, known to occur in China, would be a synonym of *Kalotermes koshunensis* because the only outstanding difference between both species is found in the gula. Light conclusively states, "It seems very probable, indeed, that more extensive collections will show them to be synonymous." Unfortunately, no opportunity available to examine the specimens of *Neotermes sinensis*, and hence no expression of opinion is herewith made.

This species is usually found in dead portions of living trees, stumps and fallen trees, forming an irregular nest in them. It is often seen that this species attacks living parts of trees. Within the galleries or runways it is difficult to make confusion with other species of *Kalotermes*. Some pellets are used for repair of its nest. In the Ryukyu Archipelago the colonizing flight occurs in late July and August, and is repeated during the season in a colony. Few alates emerge during any one flight.

##### *Kalotermes satsumensis* (Matsumura)

*Termes satsumensis*, Matsumura, 1907, System. Ent. 1:53.

*Calotermes satsumensis*, Yano, 1910, Inses. Wor. 14:602.

*Glyptotermes longicephalus*, Oshima, 1912, 3rd off. Rep Term. 64.

*Calotermes (Glyptotermes) satsumensis*, Hozawa, 1915, J. Coll. Sci., Imp. Univ. Tokyo, 35(7):33-47.

This species was first reported by Matsumura (1904) as *Termes sp.*, based only on an alate found in Kagoshima Prefecture, Japan. Since then, this species has been found in Miyasaki Prefecture and Formosa. It is said that Iwasaki collected this species on Ishigaki-jima (Konchu Sekai, 1913, 17:153, p1.7).

This species is usually found in stumps, and fallen trees, forming an irregular nest. Shimizu et al (1958a) reported that a colony of this species, approximately 3-4 years old, consisted of about 200 individuals. Little is known about its ecology.

#### *Kalotermes fuscus* (Oshima)

*Glyptotermes fuscus*, Oshima, 1912, 3rd off. Rep. Term., 67.

*Calotermes (Glyptotermes) fuscus*, Hozawa, 1915, J. Coll., Imp. Univ. Tokyo, 35(7):42-51.

Oshima (1912) first described this termite under the name of *Glyptotermes fuscus* from the specimens obtained in Formosa. This species is the smallest termite among the species of the genus *Kalotermes* known to occur in the Ryukyu Archipelago. The winged form of this species has a blackish brown color, while other species of the genus are characterized by a light brown color. Its blackish color serves to identify this species from other species of *Kalotermes* in the Ryukyus.

It is typically a forest termite and is found in stumps, dead portions of living trees and fallen trees, forming narrow tunnels in them instead of a regular nest. The colony is usually found in the protected, inner, harder wood such as in the pasania tree. The colony of this species is rather small in comparison with the subterranean species. From about 100 to 250 individuals have been collected from a 3-4 year-old colony. This species, like other wood-dwelling termites, produces distinctive pellets. The pellets can be found in the gallery and runways in considerable quantities.

In the Ryukyu Archipelago no serious damage is caused by this species to dwelling houses, furniture, bridges and other man-made structures.

#### *Kalotermes kotoensis* Oshima

*Calotermes kotoensis*, Oshima, 1912, 3rd Off. Rep. Term., 67.

*Calotermes (Cryptotermes) ogasawaraensis*, Oshima, 1913, Philip. Journ. Sci., D, 8(4):274.

This species was first reported by Holmgren (1911), but the next year,

Oshima (1912) described this species under the name of *Calotermes kotoensis*. Oshima (1913, 1914a) described a new species from the Bonin Islands under the name of *Calotermes (Cryptotermes) ogasawaraensis*. Hozawa (1915), however, concluded that *Calotermes (Cryptotermes) ogasawaraensis* is a synonym of *Calotermes kotoensis*.

The head of soldier of this species is black in front and reddish brown in the back. The head is subquadrate and very thick, not truncate in front sloping down towards the back. These outstanding characters will serve to distinguish this species from other species of *Kalotermes* of the Ryukyu Archipelago.

It is principally a home-infesting termite. It may be found in all parts of woodwork or buildings. *Kalotermes kotoensis* especially attacks the wood of the attic and frames, doors and window jams, door sills, rafters and sheathings, and even in daily used furniture. The nest is very simple in its composition and consists of a widened gallery which serves as a storage place for pellets. The pellets of *K. kotoensis* are often thrown out from the infested areas, and the ejected pellets sometimes form conspicuous heaps around the bottom of the timber in wooden structures. Between compartments of the nest there are narrow passages which allow one individual to pass through (Pl. 1A). If the colony is disturbed, a soldier seals up this narrow passage with its head. This adds the difficulty to control this species.

#### Family Rhinotermitidae

##### *Leucotermes speratus* (Kolbe)

*Termes speratus*, Kolbe, 1885, Zur. Naturges. Term. Jap. Berl. Ent. Zeisch., 147.

*Leucotermes speratus*, Shiraki, 1909, Trans. Ent. Soci. Jap., 2(10):230

*Termes (Leucotermes) flaviceps*, Oshima, 1909, off. Rep. Term., 30.

*Leucotermes (Reticulitermes) flaviceps*, Oshima, 1914, 4th off. Rep. Term., 1.

This termite was first reported by Kolbe (1885) under the name of *Termes speratus*. Studies of the species of *Leucotermes* known to occur in the Asiatic regions of the palaearctic age were carried out by many termite investigators. Such studies, however, do not clarify the distribution of one Japanese species, *L. speratus*, a Chinese and Formosan species, *Reticulitermes flaviceps* Oshima, and *Reticulitermes chinensis* Snyder of Northern and Western China.

In the present studies, the species of *Leucotermes speratus* obtained from the Ryukyu Archipelago, Kyushu, and Honshu were carefully examined. Little difference were observed various specimens obtained from different localities. It would be appear that these three species of *Leucotermes* and *Reticulitermes* may possibly be variety of a single Asiatic species, *Leucotermes speratus* (Kolbe).

As it is well known, this species requires much moisture, and the colony is found in decayed wood in contact with the soil or adjacent to damp masonry

projecting from damp soil which simulates a wick providing capillary action. Therefore, in the Ryukyu Archipelago the size of its nest does not exceed more than 2.5 meters above the surface of the ground. In the Japanese Archipelago, however, it is not seldom that the size of its nest extends as high as 3-4 meters. The inside of its nest becomes dirty and stained with its fecal pellets. The excrement of this species are not formed into pellets but massed and are left within the nest.

In the Ryukyu Archipelago the colonizing flights of outdoor colonies of *Leucotermes speratus* occur in the early spring, during January or February. Diurnal swarming usually occurs, and immense number of alates are seen to rise from its colony between about 11 a.m. to 2 p.m. The alates of day-flying species, *L. speratus* are characteristically darkly pigmented.

#### ***Coptotermes formosanus* Shiraki**

*Coptotermes formosanus*, Shiraki, 1909, Trans. Ento. Soci. Term., 2(10):239

*Coptotermes formosae*, Holmgren, 1912, Annot. Zool. Jap., 8(1):121.

Shiraki described this termite under the name of *Coptotermes formosanus* from the specimens obtained in Formosa. In the Ryukyu Archipelago this termite is the only species whose soldiers are characterized by a habit of secreting milky fluid in drops from a foramen on the forehead when they are disturbed.

It builds a carton nest in which the king and queen are found. The carton nest is not always built in the ground, but may also be found in the woodwork of buildings, where there is sufficient moisture supply. If they meet with some obstacles such as concret, stones, bricks, etc., they pierce and perforate them or make earthen runways on the obstacles. Thus, it is successful in reaching its objectives.

The swarming flight occurs in the evenings from April to July, and the winged forms are readily attracted to light. The swarming flight ordinarily occurs at the beginning of the rainy season in the early evening. The swarming alates emerge during this time over large areas if the same meteorological conditions prevail.

This species is by far the most destructive species among all the species known to occur in the Ryukyu Archipelago. Consequently, much attention has been given to this species, particularly by Japanese and American investigators.

#### **Family Termitidae**

##### ***Odontotermes formosanus* Shiraki**

*Termes formosanus*, Shiraki, 1909, Trans. Ent. Soci. Jap., 2(10):234.

*Odontotermes* (*Cyclotermes*) *formosanus*, Holmgren, 1912, Term., III, K.

Svenska Ventenska Handl, 48(4):38.

This termite was first reported by Shiraki (1909) as *Termes vulgaris* Haviland, but later, he proposed a new name *Termes formosanus*. The alates of this species are very large (body length, 12.5-13.5 mm.), and has blackish brown color.

The colony of this termite is composed of a large number of individuals which construct subterranean nests consisting of "nurseries" or special chambers for the young and the permanent royal cell in the protected part of the nest. Mushrooms are grown in the fungus garden as a special food (plate 1, B). The mushrooms emerge on the ground during late July or early August in Okinawa-jima. It is not uncommon to find 7-8 mushrooms arising from one nursery (plate I, C).

In the Ryukyu Archipelago the colonizing flight of this species occurs during late May and early June on rainy, windy evening. The alates are not attracted to light.

#### *Eutermes takasagoensis* Shiraki

*Eutermes takasagoensis*, Nawa, U., Insec. War., 1:415

*Eutermes (Eutermes) piciceps*, Holmgren, 1912, Term., III, K. Svenska, Ventensk. Handl., 45(4):38.

This species was originally described by Nawa, U. under the name of *Eutermes takasagoensis* Shiraki (1911). In the Ryukyu Archipelago this is the only species which belongs to the so-called nasute termites, and hence, this species can be easily distinguished from other species by its soldier bearing a snout.

It has a remarkable habit of building a round, blackishbrown, carton nest on trees, rocks, stone-walls, ground, etc. (plate 1, D). Average size of nest measures about 35 cm. in diameter, and larger nests, up to about 80 cm. may be found. From the nest several prominent covered run-ways are made on the surface of rocks, trunks, etc., which branch out in many directions to a distance of 5 meters or more and this affords a protected tubing for the working castes. In the Yaeyama-gunto it was observed that the covered runways on a standing tree reached to as high as 8.5 meters from the surface of the ground. The covered runways seem to be constructed of plant materials and special substances obtained from its saliva.

Nymphs with well-developed wing-pads and also some mature imagos, were found in many nests in the Yaeyama-gunto during early May. Hence, it is highly probable that the pairing flight of this species would occur in July.

#### *Capritermes nitobei* (Shiraki)

*Eutermes nitobei*, Shiraki, 1909, Term. Ent. Zool. Jap., 2(10):238.

*Termes (Eutermes) longicorais*, Oshima, 1910, Dobutsu Z., 22:516.

*Capritermes (Capritermes) watasei*, Holmgren, 1912, Term. III, K. Svenska Ventenskapsad Handl., 48(4):116.

*Capritermes suleatus*, Holmgren, 1912, b, Annot. Zool. Jap., 8(1):30.

*Capritermes (Capritermes) nitobei*, Hozawa, 1915, J. Coll. Imp. Univ., Tokyo, 8(4):145-155.

Shiraki (1909) originally described this species and named it *Eutermes nitobei*. This is a very rare species in the Ryukyu Archipelago, being confined to the Yaeyama-gunto. The soldiers are distinguished by their a symmetrically crumpled, band-shaped mandibles. As yet little is known about the habit of this species in the archipelago.

#### IV. GEOGRAPHICAL DISTRIBUTION OF TERMITES IN THE RYUKYU ARCHIPELAGO

The distribution pattern of termites are not all similar throughout the Ryukyu Archipelago. Some species are restricted to several islands. Some species occur throughout the range of their host-plants. Some groups are found in both high and low lands: other groups occur only in low lands. In this chapter an attempt is made to present the status of geographical distribution of termites in the Ryukyu Archipelago on the basis of observations in connection with these studies.

##### Distribution of Each Species

*Hodotermopsis japonicus* Holmgren. This species was first described by Holmgren from soldiers and workers which were collected by Watase, et al in a decayed tree on a hill near Nase, Amami-oshima. When Holmgren's paper "Die Termiten Japans" was published, this species had been reported only from Amami-oshima. Then, from the zoogeographical point of view, \*Watase considered *Hodotermopsis japonicus* as a representative of the southern species, and that the island of Amami-gunto marked off the extreme north-eastern boundary of the Oriental Region.

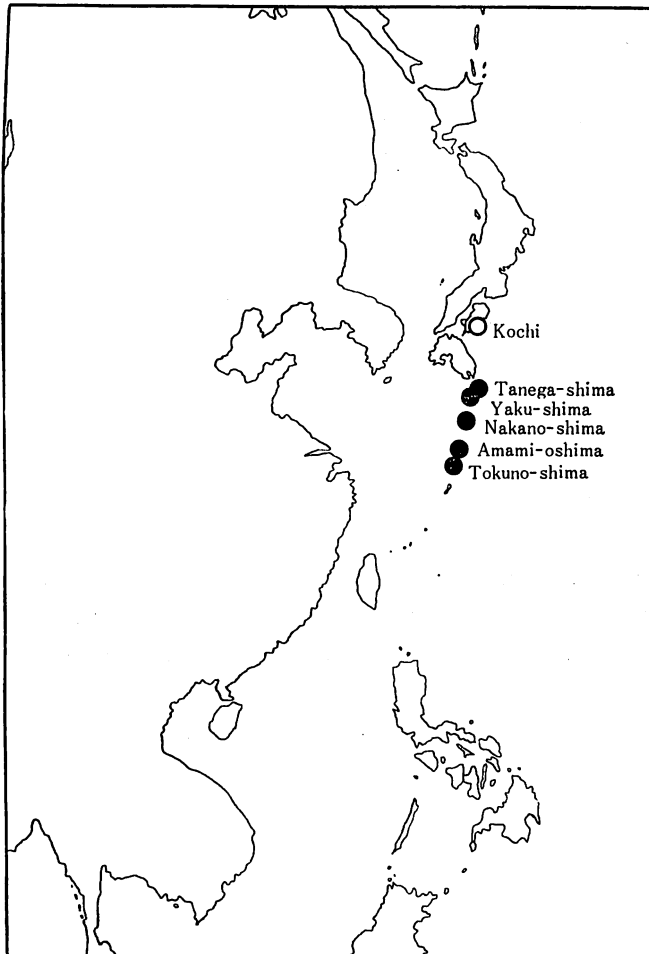
Since that time, however, it has also been found on Tokunoshima (Nawa, U. 1914; Esaki, 1934; Ikehara, 1958), Nakanoshima (Ueno, 1954; Ikehara, 1959 b), Yaku-shima (Esaki, 1956; Ikehara, 1958, 1959a) and Tanega-shima (Ikehara, 1959a). So far as the Ryukyu Archipelago is concerned, this species is confined to several islands in the northern part of the archipelago.

On Tokuno-shima this species does not commonly occur throughout the island, but is found on the mountain sides of Mt. Inokawa and in the forest of Mikyo. On the largest island of the Amami-gunto, namely, Amami-oshima, this

\* Foot-notes of Holmgren's paper, 1912, Annot. Zool. Jap. 8. part 1, 109.

termite is commonly found in the forest areas. In the Takara-retto lying between Amami-oshima and Yaku-shima, this termite seems to occur on only Nakano-shima, which is the largest island in the Tokara-retto. It is not a rare species on Nakano-shima, being often found in decayed wood, dead trunks and stumps. In the Satsunan-shoto it is confined to Yaku-shima and Tanega-shima. In August, 1958, the author collected a number of soldiers, workers and nymphs in the Furuta National Forest in Tanega-shima. This collection seems to be the first report of its occurrence on this island. The range its distribution appears to occur as high as 950 meters above sea level in Yaku-shima.

According to Matsumura (1932), *Hodotermopsis japonicus* inhabits Kyushu and Shikoku. Onoda, et al (1937) also recorded Kyushu and Shikoku as the distribution range of this species. Recently, Nakashima, Professor of Miyazaki



Text-figure 2. A map showing the distribution of *Hodotermopsis japonicus*.

Solid circles showing the localities of specimens obtained by the author and a blank circle, no specimen obtained by him.



University, reported that he examined the specimens of this species obtained from Kochi Prefecture. Judging by the above facts, it is highly probable that this species exists in southern Kyushu and Shikoku. Therefore, so far as it is known, the northern limit of distribution of this species may be recorded on Kochi Prefecture.

The known areas of distribution of *Hodotermopsis japonicus* (Text-fig. 2) are as follows:

Japanese Archipelago.....Southern Kyushu: Kochi Prefecture.  
 Satsunan-shoto.....\*Tanega-shima: Yaku-shima  
 Tokara-retto ..... Nakano-shima  
 Amami-oshima..... Amami-oshima (p1. II, A): Tokuno-shima  
 \* Locality given an under-line is originally added by the author.

*Kaloterme*s *koshunensis* Shiraki. So far as the Ryukyu Archipelago is concerned, this species was first recorded by Nawa, U. (1911), based on the specimens obtained on Ishigaki-jima by Iwasaki. In 1914, Nawa, Y. visited Okinawa-jima on a termite survey and collected this species at Shuri in the southern part of Okinawa-jima. Saeki collected this termites on April 9th, 1909, in Naha and sent the specimens to the Tokyo Imperial University, and later Hozawa (1915) identified it as *Kaloterme*s *koshunensis* Shiraki. Most islands in the archipelago have not been completely examined for the occurrence of this species previous to the author's paper (1957), except Ishigaki- and Okinawa-jima.

In the Yaeyama-gunto this species is one of the most common termite and is found on Ishigaki-, Iriomote-jima and others. This species is also commonly found in the Miyako-gunto, where it was found on all islands on which the termite survey was carried out by the author. Studies in the Miyako-gunto, however, did not covers Tarama- and Minna-jima. It is very probable that this species also occur on these two islands.

*Kaloterme*s *koshunensis* is a serious pest in the Miyako- gunto where trees are scanty, because ot attacks the windbreak trees sourrounding residences and farm fields. In the Okinawa-gunto it is a rare species, being restricted to the southern half of the island. This species has not been found in the Amami-gunto, Satsunan-shoto, Tokara-retto and Daito-shoto. Therefore, at least to the present, the northern limit of distribution of this species may be estimated as Okinawa-jima.

Judging from Light's article (1929), it is highly probable that *K. koshunensis* occurs in Chima. He mentioned in his article, "On the basis of these characters it seems neccessary to place our Chinese species in the genus *Neoterme*s, a contingency which I foresaw in my paper. Like other termites of the Fukien region, this species shows very close relationship to its congener in Formosa, *Neoterme*s *koshunensis* Shiraki. It seems very probable, indeed, that more

extensive collections will show them to be a synonym." If, as Light mentioned, *Neotermes sinensis* Light is synonymous to *Kalotermes koshunensis*, this species should occur in China.

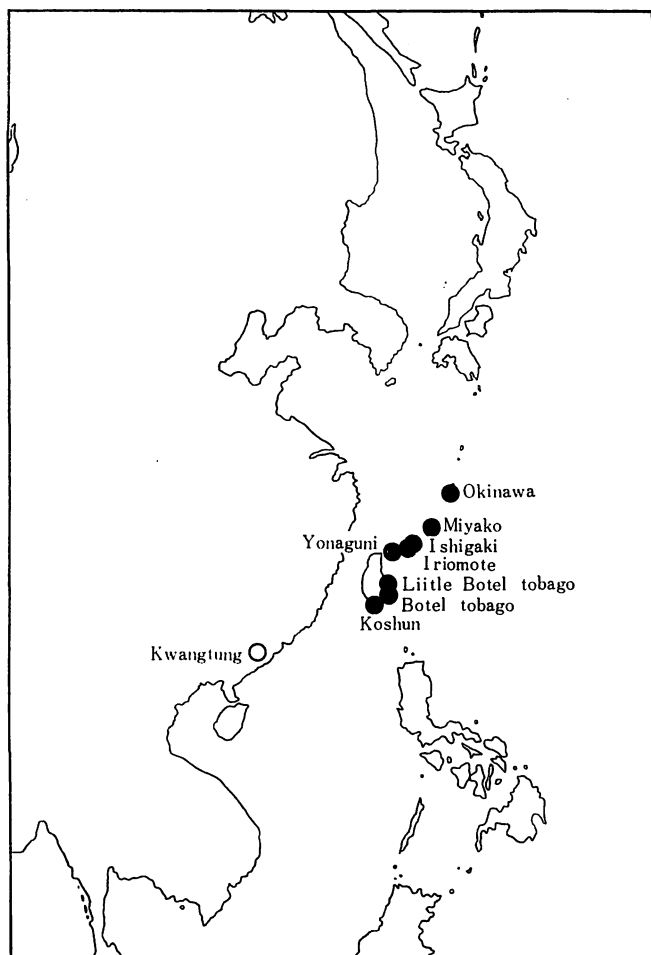
The known areas of distribution of this species (Text-fig. 3) are as follows;

Yaeyama-gunto.....Yonaguni-, Hateruma-, Kuro-, Iriomote-,  
Ishigaki- Kohama-jima.

Miyako-gunto .....Miyako-, Irabu-, Shimoji-, Kurima-, Ikema-,  
Ogami-gima.

Okinawa-gunto.....Okinawa-jima.

Others .....Formosa, Botel-tobago, Little Botel-tobago,  
China (if *Neotermes sinensis* is to be  
considered as a synonym of *Kalotermes  
koshunensis*).

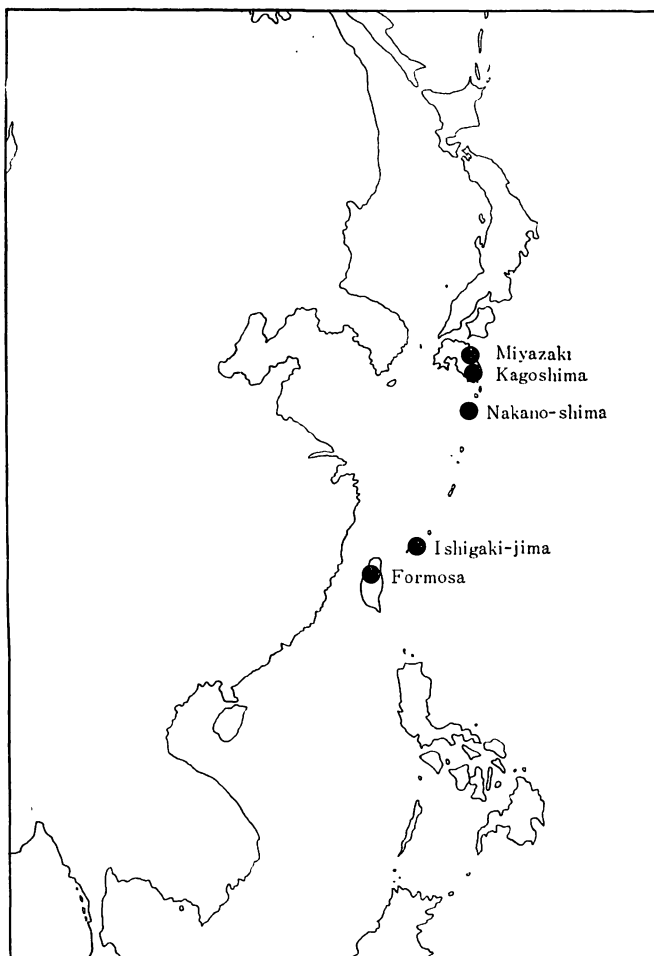


Text-figure 3. A map showing the geographical distribution of *Kalotermes koshunensis* by solid circle. Blank circle shows the occurrence of the probable synonym of *K. koshunensis*.

*Kaloterme s satsumensis* (Matsumura). This termite is very rare species in the Ryukyu Archipelago, being restricted to Nakano-shima (Ikehara, 1959b). It is said that Iwasaki collected this species from Ishigaki-jima in 1913. But most termite investigators still doubt the occurrence of this species on that island. During the years from 1955 to 1959, the author visited this island several time on termite surveys, but no specimens of this termite were found there.

In September 1957, two colonies of termites were discovered on Nakano-shima of the Tokara-retto. The author carefully examined and identified them as *Kaloterme s satsumensis* (Matsumura). There was no previous record as to the occurrence of *K. satsumensis* in the Tokara-retto. Therefore, this is the first report of occurrence of *K. satsumensis* in the Tokara-retto.

Recently, Shimizu, et al (1958a) reported the occurrence of this species in



Textl-fig. 4. A nap showing the distribution of *Kaloterme s satsumensis* by solid circles. The map is based on the author's survey and the interpretation of published records.

Miyazaki and Kochi Prefecture. They mentioned in their article, "The full description of this species was given by Holmgren (1912, 1913) from the specimens collected by himself at Tosa (Kochi Prefecture) and Formosa". But Hozawa (1915) mentioned in his article, "The full description of this species was given by Holmgren (1912, 1913) from the specimens collected by myself at Tosa, Formosa." Judging from the above statements, Holmgren did not collect this species in Tosa (Kochi Prefecture), but Hozawa collected it at Tosa in Formosa. Hence, if Shimizu, et al considered the occurrence of this species as Tosa (Kochi Prefecture) on the basis of the Hozawa's paper (1915), there appears to be a misunderstanding in connection with Hozawa's statement. Therefore, it is doubtful that this termite occurs in Kochi Prefecture. The author could not find this species in Kochi Prefecture during his stay there for a week in 1959. There follows a list of known distribution of *Kaloterme satsumensis* (Text-fig. 4):

Yaeyama -gunto.....Ishigaki-jima?

Tokara-retto.....Nakano-shima

Others .....Formosa, Kagoshima Prefecture, Migazaki  
Prefecture, Kochi Prefecture?

*Kaloterme fuscus* (Oshima). This species was first collected by Hozawa (1911) at Kuraru, Formosa, but Oshima (1912) first described it. In the Ryukyu Archipelago Iwasaki first collected it on Ishigaki-jima in 1912, and sent the specimens to Hozawa and Nawa, U. This is the first available information on *Kaloterme fuscus* in the archipelago. Later, Nawa, Y. visited Okinawa-jima on a termite survey and found this species in the forest near Nago.

Since 1915, the author has made an extensive survey of termites throughout the Ryukyu Archipelago, and therefore the distribution of this species became more clear. Previous to this survey, the northernmost distribution of this species was Okinawa-jima (Nawa, Y. 1914b). But evidence accumulated shows that this species existed on Tokuno-shima, Okierabu-jima, Amami-oshima, Nakano-shima, Yaku-shima and Kagoshima Prefecture (Ikehara, 1957a, 1958, 1959a, 1959b).

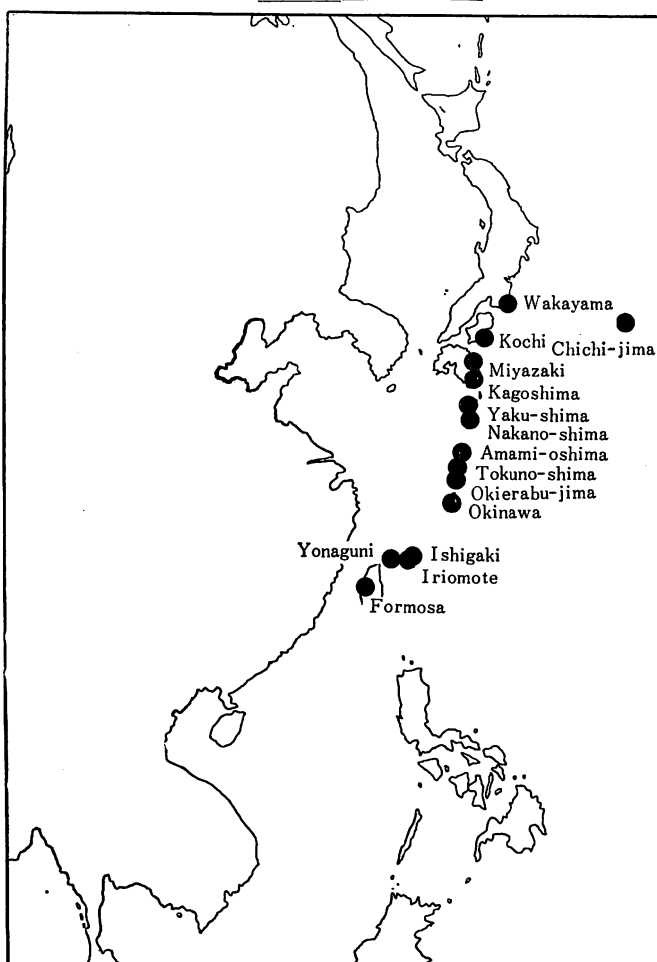
Laboratory tests had been made for the purpose of foreseeing the more northern limits of this termite. In October, 1959, a field survey along the Pacific Coast of the Japanese Archipelago was made based on the results of these tests, and the specimens of this species were collected in Miyazaki (plate II, B) Kochi and Wakayama Prefecture (plate II, C). In May, 1962, the author also collected this species on Amakusa Island, Kumamoto Prefecture. Therefore, at present, the northernmost limit of this species may be recorded in Kii Peninsular, Wakayama Prefecture.

Since China is a land of widely varied continental climate, numerous termite fauna would be expected, particularly in warmer areas. However, very little is known of the termite fauna of China, in spite of Light's investigations (1929b).

In China *Kalotermes fuscus* is not known to occur so far. However, it seems quite certain, indeed, that more extensive collections will give the evidence of the occurrence of this species in China.

Known distribution of *Kalotermes fuscus* (Text-fig. 5) are summarized as follows;

Yaeyama-gunto.....Yonaguni-jima, Iriomote-jima, Ishigaki-jima.  
 Okinawa-gunto.....Okinawa-jima, Zamami-jima Tokashiki-jima.  
 Amami-gunto .....Amami-oshima, Tokuno-shima, Okierabu-jima.  
 Tokara-retto.....Nakano-shima.  
 Satsunan-shoto .....Yaku-shima.  
 Others .....Formosa, Boin Islands, Kagoshim, Miyazaki,  
Kochi, Wakayama



Text-fig. 5. Map showing distribution of *Kalotermes fuscus* in Far East. Solid dots represent occurrence of the species. Map is made mainly based on the author's survey.

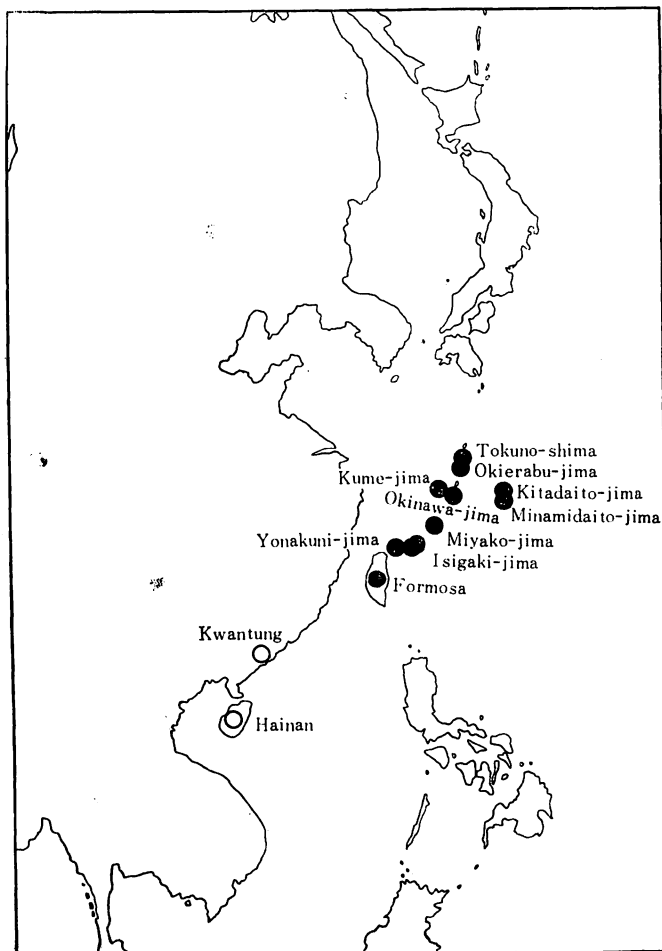
*Kaloterme kotoensis* **Oshima**. Oshima (1912) fully described this species under the name of *Caloterme kotoensis* based upon the specimens obtained by himself from Formosa. He (Oshima, 1913, 1914a) also described a new species of *Caloterme*, *Caloterme (Cryptoterme) ogasawaraensis* from the Bonin Islands. Hozawa (1915) states in request to Oshima's new species that "I have examined carefully many specimens from the same localities comparing with those from other localities and came to the conclusion that *Caloterme (Cryptoterme) kotoensis* Oshima is but a synonym of *Caloterme (Cryptoterme) ogasawaraensis* Oshima." Therefore, it may be safely concluded that *K. kotoensis* occurs in the Bonin Islands.

*Kaloterme kotoensis* is one of the most widely distributed termite in the southern half of the Ryukyu Archipelago. In this area it is found even on the islands where the two commonest species, *Coptoterme formosanus* and *Leucoterme speratus*, have not been found up to this time. This is an economically important drywood termite next to *Coptoterme formosanus*. In the Amami-gunto it is a rare species, existing on Yoron-jima, Okierabu-jima and Tokuno-shima. So far as it is known, the northern limit of distribution of this species may be recorded on Tokuno-shima.

Light (1929) has considered that the Chinese drywood termite, *Cryptoterme campbelli* Light might be a synonym of *Kaloterme kotoensis* Oshima based upon the specimens obtained from Hainan Island and Kwangtung. Judging from the climatic conditions, it is highly probable that this species may occur in South China.

The known distribution of this species (Text-fig. 6) are listed below:

- Yaeyama-gunto.....Yonaguni-, Hateruma-, Iriomote-, Ishigaki-  
Taketomi-, Kobama-jima-, Kuro-shima.
- Miyako-gunto .....Miyako-, Irabu-, Ikema-, Shimoji-, Kurima-,  
Ogami-jima.
- Okinawa-gunto .....Okinawa-, Kume-, Ie-, Tokashimi-, Zamami-,  
Miyagi-jima.
- Amami-gunto .....Yoron-, Okierabu-jima, Tokuno-shima.
- Daito-shoto .....Minamidaito-jima, Kitadaito-jima
- Others.....Botel-tobago, Bonin Islands, Formosa, Hainan,  
Kwangtung or mainland of China (if *Cryptoterme campbelli* Light is a synonym of *Kaloterme kotoensis*).



Text-fig. 6. Map showing distribution of *Kaloterms kotoensis* in Far East by solid circles. Blank showing the occurrence of synonymous of this termite.

*Leucotermes speratus* (Kolbe). The known range of distribution of *Leucotermes speratus* (Text-figure 7) is from Formosa through the Ryukyu Archipelago as far north as Hokkaido including Korea. Comparing with other species, the range of distribution of this species extended to the most northern area.

This is the most common species in the Ryukyu Archipelago ranking with *Coptotermes formosanus* not only in number of colonies, but also in its width of range of distribution. It occurs not only at sea level, but also in mountain regions, and even in such places as the tops of Mt. Omoto (Ishigaki-jima), Komi (Iriomote-jima), Yonaha (Okinawa-jima) and Uwan (Amami-oshima). Furthermore, this species occurs at an elevation of 1,150 meters in Yaku-shima (Ikehara, 1959a). The northern range of distribution of this species may be

limited to somewhere in Hokkaido. The known distribution of this species is shown Text-figure 7.

Following is a list of the known distribution of *Leucotermes speratus*:

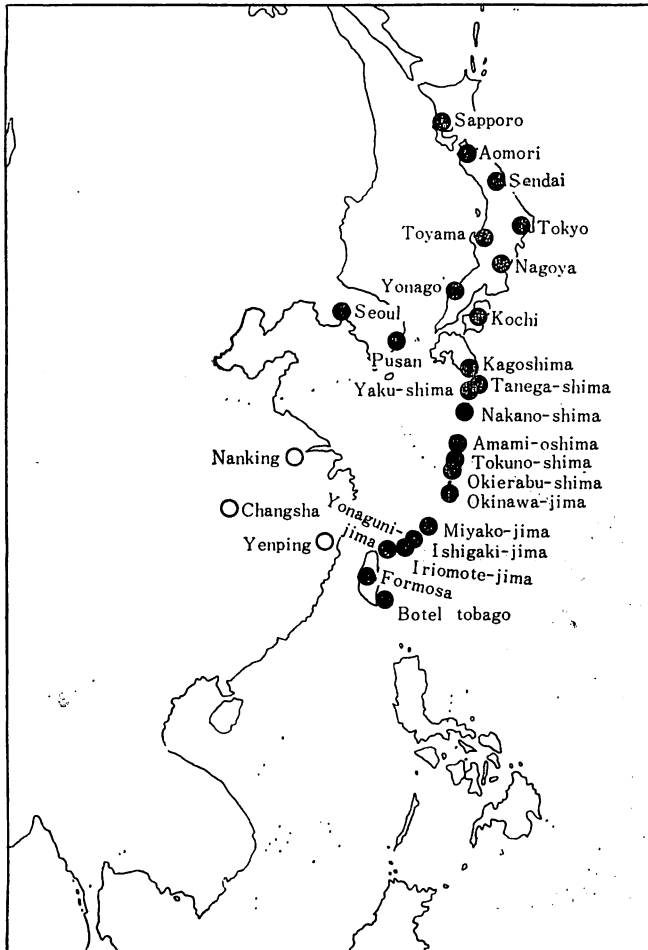
Yaeyama-gunto.....Ishigaki-jima, Yonaguni-, Hateruma-, Iriomote-,  
Taketomi-, Kobama-jima, Kuro-shima.

Mizako-gunto.....Miyako-, Irabu-, Shimoji-, Ikema-, Kurima-,  
Ogami-iima.

Okinawa-gunto.....Okinawa-, Kume-, Zamami-, Keruma-, Ie-,  
Miyagi-, Kamiyama-jima.

Amami-gunto.....Amami-oshima, Tokuno-, Okinoerabu-, Kikai-,  
Yoron-jima.

Satsunan-shoto.....Yaku-, Tanega-, Kuchinoerabu-, Take-, Io-,  
Kuro-shima.



Text-fig. 7. Map showing distribution *Leucotermes speratus* in Far East by solid circles. O.....occurrences of synonymous of *Leucotermes speratus*.



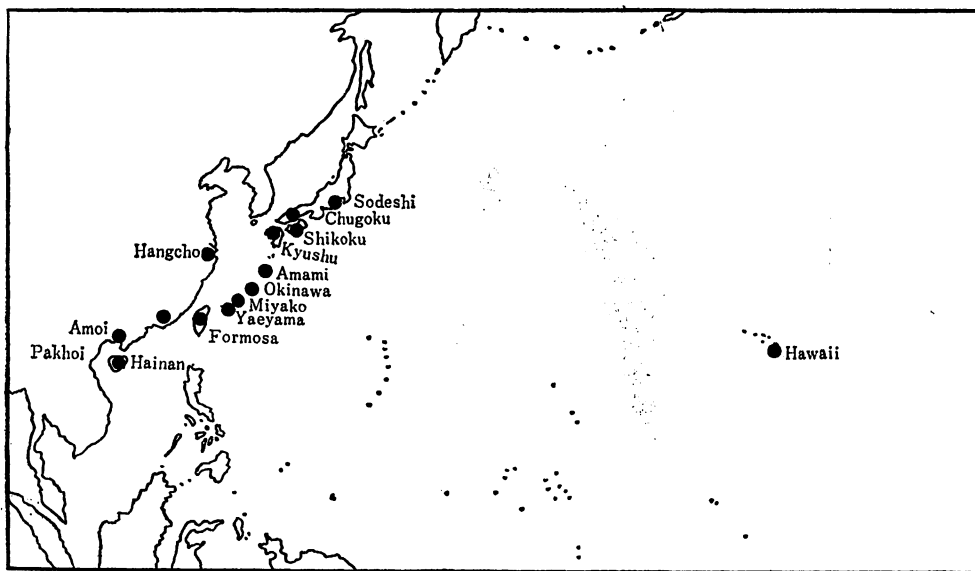
Others ..... Formosa, Botel Tobago, Little Botel Tobago, Korea, Kyushu, Honshu, Hokkaido, China (from Szechuan to north Fukien, if both *Reticulitermes chinensis* and *Reticulitermes fukiensis* are synonym of *Leucotermes speratus*).

***Coptotermes formosanus* Shiraki.** This termite was studied by Shiraki (1909) from the specimens obtained in Formosa. A map (text-fig. 8) indicates that the range of distribution of this species covers South China, the East China sea coast of China, Formosa, the Ryukyu Archipelago, southern half of the Japanese Archipelago and the Hawaii Islands.

In the Ryukyu Archipelago this species has been found on most islands where the author made termite surveys. But no colony of this species was found in the Daito-shoto even after some considerable effort.

According to Light (1929b) the distribution of this species in China ranges from Pakhoi and Hainan Island, to as far as Yenping in North Fukien, and there it has been reported from Shanghai. So far as it is known, Hainan Island is the southern limit of geographical distribution of this species.

In Abe's excellent work (1937) regarding the geographical distribution of this species, he concludes that "In this country *Coptotermes formosanus* Shiraki inhabits the warmer parts, where the mean temperature of the coldest month, i.e. of January, is found to be higher than 4° C. and at the same time,



Text-fig. 8. Map showing distribution of *Coptotermes formosanus*. Solid circles showing the occurrences of this species. Map is made on the basis of author's surveys and the interpretation of published records.

the monthly average of the minimum day temperature of January is higher than 0° C. His conclusion has been substantiated by many termite investigators.

The known ranges of distribution of this species are listed below:

Ryukyu Archipelago.....The same as the distribution of *Leucotermes speratus*, with exception of Daito-shoto.

Others.....Formosa including Botel-tobago, Hainan, Chinese Coastal region from Kwangtung to Shanghai, southern half of the Japanese Archipelago, Hachijo-jima and the Hawaii Islands.

***Odontotermes formosanus* Shiraki.** This termite was first studied by Shiraki (1909) from the specimens obtained in Formosa. Since that time, this termite has been found in many regions in Asia. A glance at the map (Text-figure 9) shows that at least present, the northern limit of distribution of this species may be principally on the Chinese Continent, i.e. Shanghai, and is limited to Okinawa-jima in the Ryukyu Archipelago. Comparing the latitudes of these two northern limits, the former is about 6 degrees higher than the latter. The latitude of Shanghai, namely, about 32° N. is very close to that of Akune or Miyazaki, Kyushu. So far as the latitude is concerned, this comparison indicates that *Odonotermes formosanus* may exist successfully in the southern Kyushu and in other northern islands in the Ryukyu Archipelago. But the author did not find this species in the Amami-gunto, Tokara-retto, Satsunan-shoto and southern Kyushu in spite of considerable effort. Why this species fails to expand its range of distribution northwards beyond those areas is not known. This is an interesting problem to investigate and will be considered in this paper later on. Holmgren (1912) reported the existence of this species in Siam (Bangkok) and Hongkong, South China, etc., and Hozawa (1915) did Burma and China, etc.

The first written information on this species from the Ryukyu Archipelago was that of Nawa, U. (1911). He identified *Coptotermes formosanus* from specimens obtained from Ishigaki-jima by Iwasaki. During his expedition of termite to Okinawa-jima, he collected this species from the island. So far as Okinawa-jima is concerned, this is the first report of this species. A much more detailed study of the geographical distribution in the archipelago has been presented by the author. Parts of these studies relating to the geographical distribution have already appeared (1957a, 1957b).

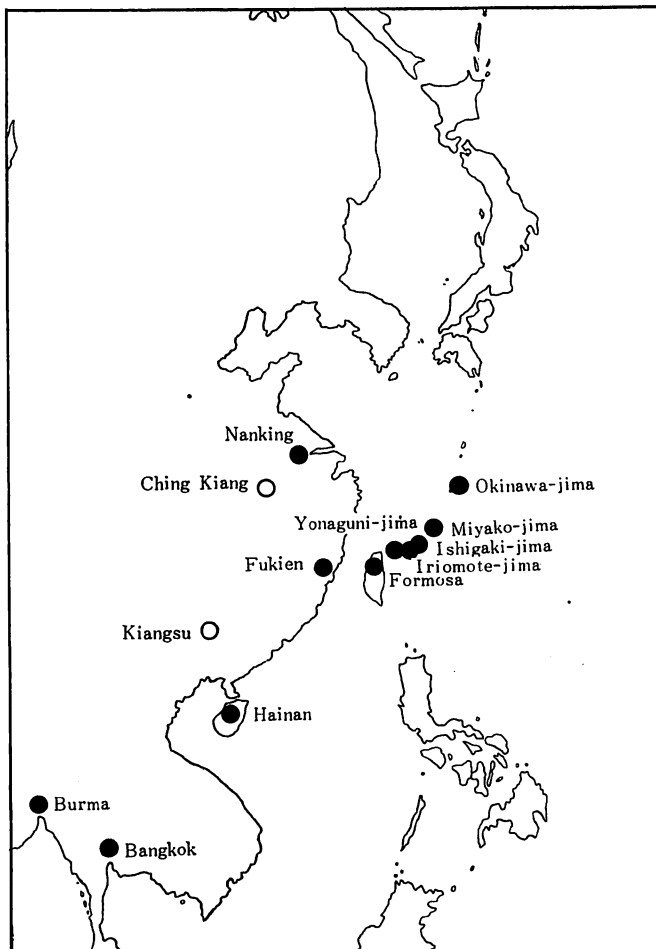
A List of the known distribution of this species as follows:

Yaeyama-gunto.....Yonaguni-, Iriomote-, Hatoma-, Taketomi-, Kobama-,  
Ishigaki-jima.

Miyako-gunto.....Miyako-jima.

Okinawa-gunto .....Okinawa-jima.

Others ..... Burma, Thailand, South China, Formosa.



Text-figurt 9. Map showing distribution of *Odontotermes formosanus* in Far East. O.....showing the distribution of synonyms of *Odontotermes formosanus*.

*Eutermes takasagoensis* Shiraki. Nawa, U. (1911) first described this species from specimens obtained in Formosa. Botel-tobago and Little Botel-tobago were added to the list of localities by Hozawa et al (Hozawa, 1915). Holmgren (1912) recorded this species from Christmas Island, and Hozawa's report (1915) followed that of Holmgren. This species not been found in China, the Philippines and East Indian Archipelago.

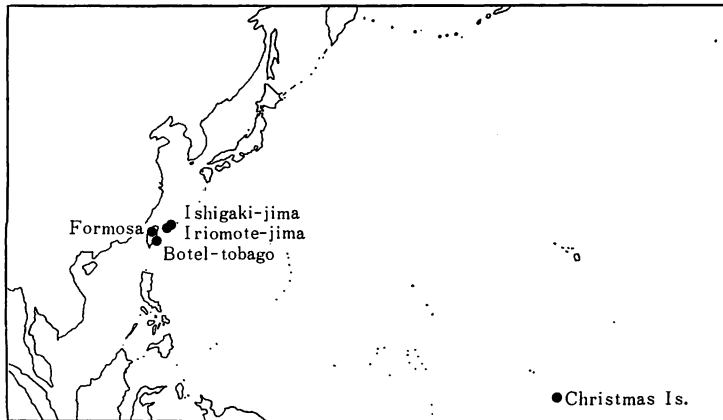
In the Ryukyu Archipelago *Eutermes takasagoensis* is restricted in range within the Yaeyama-gunto, and has never been found in the Miyako-gunto and northwards. Therefore, at present, the northern limit of distribution of this

species may be Ishigaki-jima.

A list of distribution areas of *Eutermes takasagoensis* based mainly upon the author's studies and supplimented by those of Holmgren, Yano, Hozawa, Nawa, U. and others, as listed below:

Yaeyama-gunto.....Ishigaki-, Yonaguni-, Hateruma-, Iriomote-,  
Taketomi-, Kobama Kuro-shima

Others .....Botel-tobago, Little Botel-tobago, Formosa, Christmas  
 Island.



Text-fig. 10. Map showing distribution of *Eutermes takasagoensis*.  
 Map being made on the basis of the interpretation of published records.

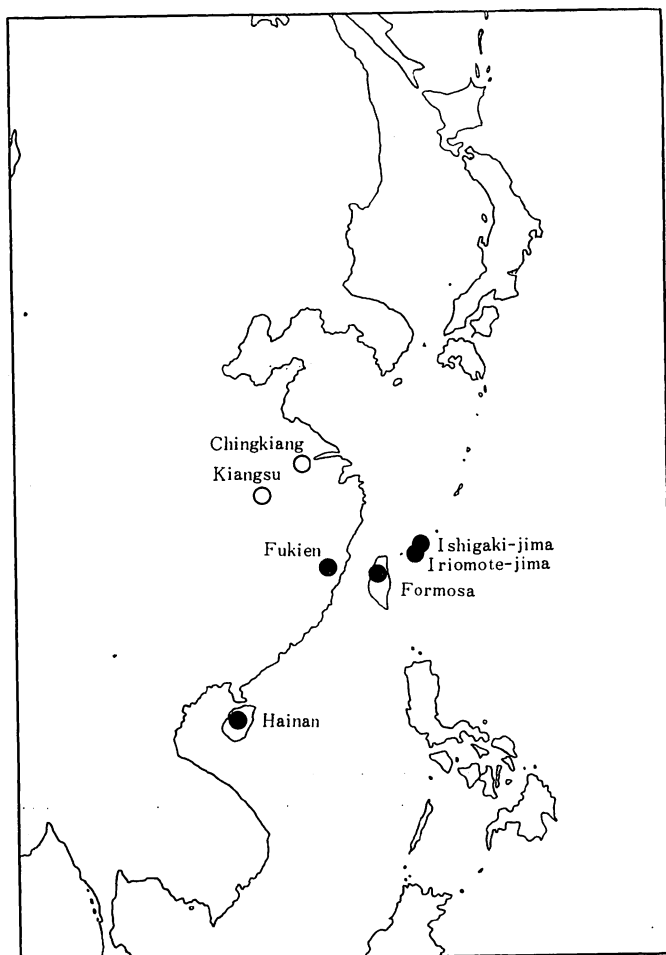
***Capritermes nitobei* Shiraki.** The first discription of this species can be found in Shiraki's paper (1909). He gave it the name, *Eutermes nitobei*, at that time. So far as the Ryukyu Archipelago is concerned, this species was first collected by Iwasaki from Ishigaki-jima in 1912 (Hozawa, 1915). In March, 1955, it was collected by the author on Ishigaki- and Iriomote-jima. So far as it is known, the northern limit of distribution of this species in the Ryukyu Archipelago is Ishigaki-jima.

Maki (1918) reported that he found this species in many districts in Formosa and that this termite often attacked the up-land rice plants in reclaimed hilly lands. Light (1929) reported that this species occurred on Hainan Island and in South China.

The known regions of distribution of this species are as follows:

Yaeyama-gunto.....Ishigaki-jima, Iriomote-jima.

Others .....Formosa, Hainan Island, South China from  
 Kwantung to northern Fukien.



Text-fig. 11. Map showing the distribution of *Capritermes nitobei* in Far East.

#### General Characters of Geographical Distribution.

The total number of species of termites recorded in the Ryukyu Archipelago is 10, belonging to four different families. The present status of distribution of each species is already mentioned in the foregoing paragraph. The author will attempt to explain the general characters of geographical distribution of termites in the Ryukyu Archipelago in the following paragraphs.

From the view-point of geographical distribution, this assemblage of 10 species can be classified into three major types, namely, the whole-area-type or those occurring in the entire area, the south area-type or those that occur in the south area, and the remote-area-type or those that occur only in particular area.

Before preceeding, it may be of some value to explain the various terms as they are used in this paper to prevent misunderstanding. In using the

expression "the whole-area-type" reference is made to those cases in which species of termites are present over practically the entire Ryukyu Archipelago, extending into the Japanese Archipelago on the northeast and into Formosa on the south.

Termites which have their limits of distribution within the Ryukyu Archipelago are called the southern-area-type. The remote-area-type refers to the occurrence of some species being restricted to a particular region or being far remote from the major regions of distribution of the same or their related species.

**The whole-area-type.** This type includes three species, namely, *Kaloterme fuscus*, *Leucotermes speratus* and *Coptotermes formosanus* representing two different genera and two different families. As it is shown in the maps (Text-fig. 5,7,8), these three species are distributed not only throughout the Ryukyu Archipelago but also in the Japanese Archipelago on the northeast and in Formosa in the south. Excepting *Kaloterme fuscus*, there is no room for doubt that the ranges of distribution of both *Leucotermes speratus* and *Coptotermes formosanus* overlap in the area of the archipelago. Therefore, as far as the Ryukyu Archipelago is concerned, it is difficult to find outstanding differences between the geographical distribution other than their local occurrences. In fact, these three species are widely distributed and are found on every island in the archipelago, overlapping their ranges of distribution.

On the other hand, the range of distribution of *Kaloterme fuscus* presents a peculiar feature of distribution (Text-fig. 5). The range of distribution of this species covers Formosa, the Ryukyu Archipelago, Bonin Islands and the southern half of the Japanese Archipelago. The regions of distribution of *K. fuscus* in the Ryukyu Archipelago are rather dispersed. This species does not always occur on larger islands. On occasions, it is found on small islands, i.e. Zamami-jima, Tokashiki-jima, etc., but absent in some larger island, i.e. Miyako-, Kikai-jima, Tanega-shima, etc. The factor which causes such peculiar distribution will be discussed in a later chapter.

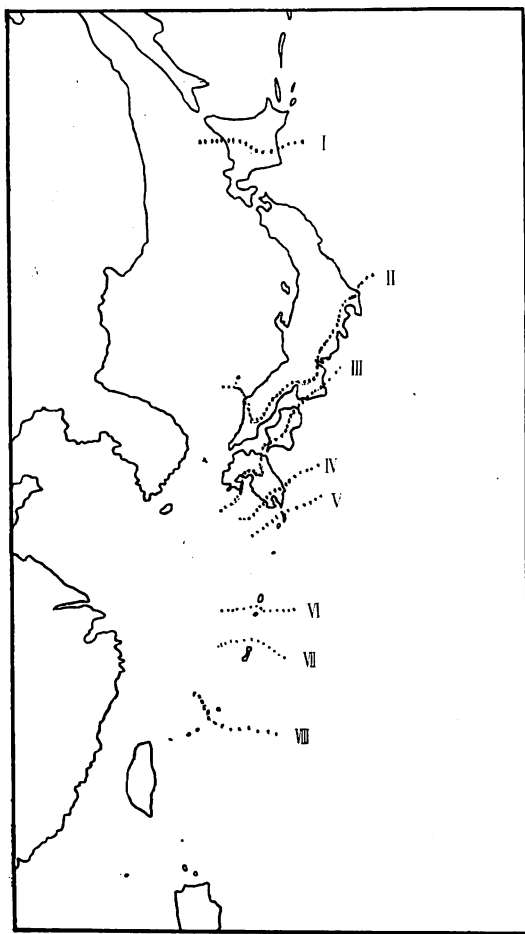
**The south-area-type.** The south-area-type includes five termite species, namely, *Kaloterme koshunensis*, *Kaloterme kotoensis*, *Odontotermes formosanus*, *Eutermes takasagoensis* and *Capritermes nitobei*. Of the 10 species known to occur in the Ryukyu Archipelago, five species have their northern limits of distribution within the archipelago. Two of these five species, viz. *E. takasagoensis* and *Cap. nitobei*, are restricted in their distribution northwards at Ishigaki-jima, and another two, namely, *O. formosanus* and *K. koshunensis*, at Okinawa-jima. The range of distribution of *K. kotoensis* seems

to terminate further north at Tokuno-shima.

It is very important to know the northernmost limit of distribution of termites, because we can forecast the possibilities of their expansion to the north and this is helpful in the explaining the operating factors which control their spread northwardly. The known northernmost limits of distributions of 10 species of termites are summarized Text-figure 12.

The following list designates the northernmost limits of distributions of south-area-type:

*Kaloterme*s *koshunensis*.....Okinawa-jima



Text-fig. 12. Map showing the known northernmost limits of distributions of 10 species of termites.

- I.....*Leucotermes speratus*; II.....*Coptotermes formosanus*;  
 III.....*Kaloterme*s *fuscus*; IV .....*Hodotermopsis japonicus*;  
 V .....*Kaloterme*s *satsumensis*; VI.....*Kaloterme*s *kotoensis*;  
 VII.....*Kaloterme*s *koshunensis* & *Odontotermes formosanus*.  
 VII.....*Capriterme*s *nitobei* & *Eutermes takasagoensis*.

<i>Kaloterme s kotoensis</i> .....	Tokuno-shima
<i>Odontoterme s formosanus</i> .....	Okinawa-jima
<i>Eutermes takasagoensis</i> .....	Ishigaki-jima
<i>Capriterme s nitobei</i> .....	Ishigaki-jima

**The remote-area-type.** The species, *Hodotermopsis japonicus* and *Kaloterme s satsumensis*, belong to this type. Of the two species, *H. japonicus* is regarded as a species indigenous to northern part of Ryukyus and southern part of Japan. As mentioned previously, the known range of distribution is the northern half of the Ryukyu Archipelago and covering Tokuno-shima, Amami-oshima, Nakano-, Yaku- and Tanega-shima. In communicating with Prof. Nakashima of Miyazaki University, he states that recently he examined the specimens of this species obtained from Kochi Prefecture, Japan. Since its related species, namely, *Hodotermopsis sjöstedti*, is found in Tonking, South China, this species is regarded as belonging to the remote-area-type.

Watase added a foot-note to Holmgren's paper (1912) "Die Termiten Japans" in which he suggested that the boundary line between the Oriental Biota and the Palaearctic Biota be marked off between Amami-oshima and Yaku-shima, because *Hodotermopsis japonicus* was restricted to Amami-oshima and the species most nearly allied to it was found in Tonking. But the evidence of the status of distribution of this species to date is not sufficient to establish a so-called "Watase's Line" as to the termite distribution.

There is evidence to indicate the remote distribution group. *Kaloterme s satsumensis* is often found in Formosa and rarely found in Kagoshima and Miyazaki Prefecture, but never been found in the most middle part of the Ryukyu Archipelago. In the Ryukyu Archipelago this species is found on Ishigaki-jima being at the south part of the archipelago and on Nakano-shima being at the north part of the archipelago. Therefore, the region of distribution of this species on Nakano-shima and Southern Kyushu are absolutely remote from its major region of distribution, Formosa.

#### **Distribution According to Altitude.**

There is considerable literature citing examples of distribution of plants and animals according to altitude. But little attention has been given to distribution of termites according to altitude. A comprehensive study on this subject has been rarely attempted in Asia. Previous to this paper, the author briefly reported the distribution of termites according to altitude on Yaku-shima (Ikehara, 1959a). But at that time there was no opportunity to discuss this subject because of the lack of sufficient data. Inspections have been made since then on the highest mountain of each group of islands in the Ryukyu



Archipelago.

The Miyako-gunto and Daito-sho, however, are excluded from this discussion, because they are low, flat islands having maximum elevation of 110 (Miyako) and 68 meters (Daito), respectively. Consequently, it may be difficult to find any outstanding character of distribution according to altitude in these groups of islands. There are other areas which must be excluded. These are the high mountain areas, such as Mt. Ontake of Nakano-shima of the Tokara-retto. Mt. Ontake is an active volcanic plateau, so that it supports poor vegetation near the peak of the mountain.

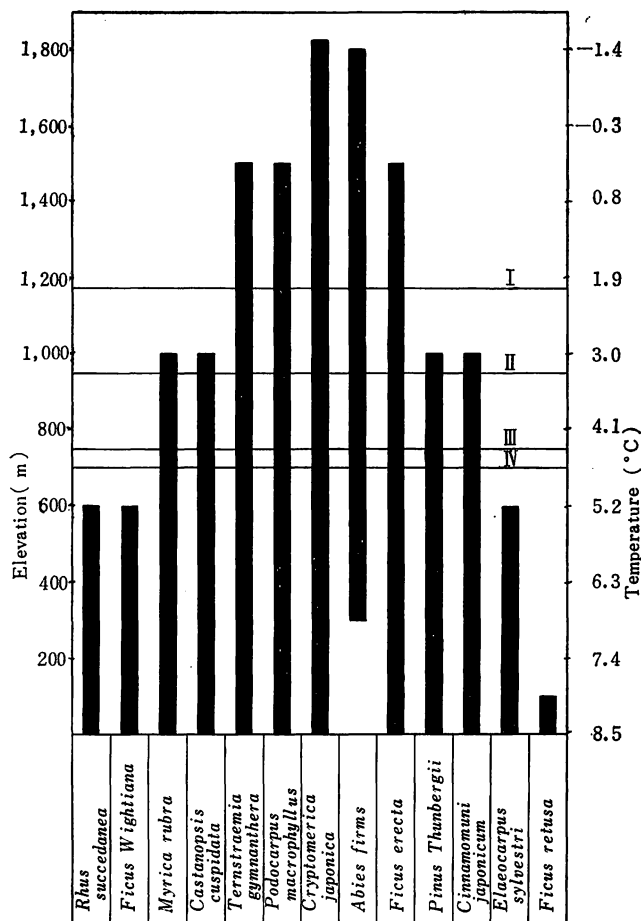
The status associated with the distribution of termites according to altitude is conspicuous at Mt. Miyanoura (1935 m. above the sea level) on Yaku-shima. The known maximum elevation where termites occur on Yaku-shima is 1,120 meters for *Leucotermes speratus*; 950 m. for *Hodotermopsis japonicus*; 750 m. for *Coptotermes formosanus* and 700 m. for *Kalotermes fuscus*. *L. speratus* occurs generally from the sea shore to as high as about 1,000 meters. *C. formosanus* is by far most abundant at the coastal region than at the higher elevations. *H. japonicus* was not found at the coastal, low land, but it is sometimes found in the higher locations. *K. fuscus* is particularly abundant at the fringes of mountains. A comparison of the distribution of four termites on Yaku-shima according to altitude with their northern limits of distribution indicates that, like plants and animals, the species which is found at the higher altitude extends its range of distribution the more northward. Consequently, one can roughly speculate the order of the northernmost limit of distribution of termites, from north to south, from the order of the occurrence of termites according to altitude.

The Text-figure 13 shows that the distribution of termites according to altitude is closely related to changes in both vegetation and temperature as decrease with altitude. Data on vegetation were obtained from the works of Tashiro (1923) and Horikawa (1958). Referring to the climatic data compiled by the Kagoshima District Meteorological Observatory during the period extending from 1938 to 1957, the mean daily minimum temperature of the coldest month is 8.5° C. at Ittso, Yakushima. It is said that in mountainous areas, the temperature decrease about 0.55° C. as the elevation increases 100 meters (Okada, 1927). The range of temperature in Text-figure 13 is given on the basis of above facts.

The figure shows that the maximum occurrence of species of trees differs with species. The fir, pasania, pine-tree which are food trees for *Hodotermopsis japonicus*, and are also found at higher elevations. *H. japonicus* is also found at this elevation. *L. speratus* particularly prefers the pine and fir trees for its food. These trees extend up to high elevations, exceeding the maximum

occurrence of this termite. The pine, fir, pasania and pinuserecta trees are also favorable food trees for *Coptotermes formosanus* and are distributed on high elevation, exceeding the maximum elevation of distribution of *C. formosanus*. The pasania tree is particularly attacked by *Kalotermes fuscus*, the distribution of which spread to high elevations, exceeding the maximum occurrence of this termite. Generally speaking, the four species of termites existing on Yakushima has surplus food available at the altitude beyond the maximum occurrence of the four species of termites. These data indicate that some other factors are operating to limit the expansion of distribution of termites to the higher altitudes.

The Text-figure 13 indicates that temperature controls the distribution of termites according to altitude. It is clear from the figure that the number of termite species decrease with increase in altitude. The sequence of species



Text-fig. 13. Relationship between altitudinal distribution of termites and change of vegetation and temperature on Yakushima.

I ..... *L. speratus*, II ..... *H. japonicus*, III ..... *C. formosanus* IV ..... *K. fuscus*.

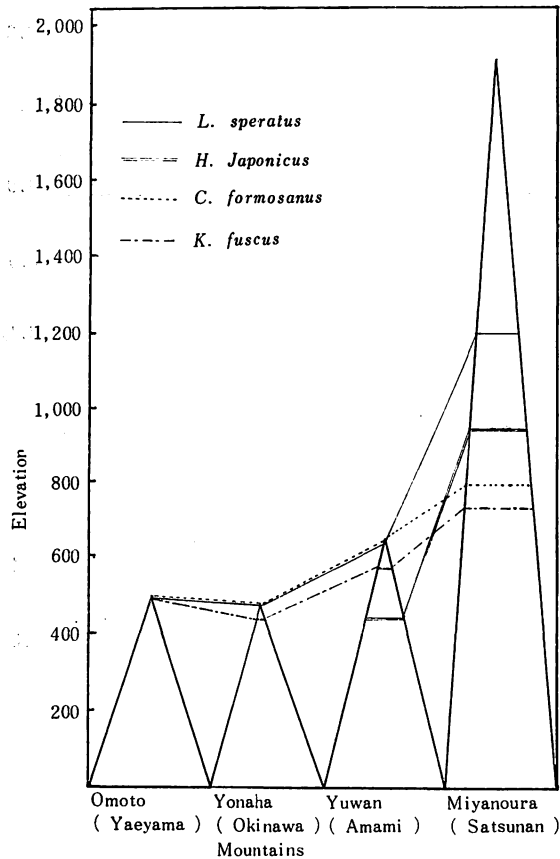
according to the preferred minimum temperature, from low to high, as follows (see p.143~144):

*Leucotermes speratus*→*Hodotermopsis japonicus*

→*Kalotermes fuscus*→*Coptotermes formosanus*

This sequence of four termites as to the preferred minimum temperature for them is closely related to species distribution according to altitude on Yaku-shima. The preferred minimum temperature of *K. fuscus* is lower than that of *C. formosanus*, but the former is slightly less than the latter in the occurrence at the high elevation. It may be due to the difference in their nesting habits, which will be discussed later in this paper.

The distribution of termites according to altitude in the whole Ryukyu Archipelago is summarized in Text-figure 14. Two species of the whole-area-type, viz., *C. formosanus* and *L. speratus*, are found at the highest elevation (900-1,200 m.) of the main islands of the archipelago. *K. fuscus* is found on the highest elevation (about 500 m.) of the Yaeyama-gunto but not in Okinawa-jima



Text-ig. 14. Distribution according to altitude on representative islands in the Ryukyu Archipelago.

and Amami-oshima owing to the existence of a larger number of bamboo rather than pasania trees. Therefore, the presence of quantities of food trees (pasania trees) seems to have influence upon altitudinal distribution of *K. fuscus*. The figure shows that the distribution of the whole-area-type at the highest elevation on Yaku-shima is greater than on the other islands. This indicates that the elevation factor has no effect upon the distribution of termites according to altitude in case of the whole-area-type.

It is very difficult to associate any characteristic of altitudinal distribution on the remaining six species. Their distribution seems to be influenced by environmental factors other than elevation.

## V. LOCAL OCCURRENCE OF TERMITES

The local occurrence of termite colonies are restricted by the effect of certain factors which are commonly referred to as climatic. Atmospheric and soil moisture have been considered as one of the most important factors. Since termites have only a delicate outer covering, they are usually exposed to loss of water from the body. They protect themselves against loss of water from the body by means of their habits of living in closed burrows.

Moisture may not be always the most important factor limiting the local occurrence of all species of termites in the Ryukyu Archipelago. In so far as the termites which occur in the Ryukyu Archipelago are concerned, it is only in the case of *Leucotermes speratus* that the local occurrence seems to be influenced by moisture. The remaining species are not always locally controlled by the occurrence of the amount of moisture. The Ryukyu Archipelago has a semi-tropical and oceanic climate, and it has moderate rainfall. Thus, it has a considerable amount of atmospheric and soil moisture throughout the year. This may be caused to the existence of sufficient moisture that controls the local occurrence of termite colonies in the archipelago that are not always dependent upon the difference of the amount of moisture present.

It is well known the the damp-wood termite, *Leucotermes speratus*, is particularly dependent upon abundant moisture, so that its occurrence is restricted to localities in which continuously high humidity is prevalent. But the destructive termite, *Coptotermes formosanus*, is in sandy soil which is a much more favorable condition than the heavier, less porous, clay like soils. *Kalotermes kotoensis* is the dry-wood termite, so this species is commonly found in woodworks of building which do not keep much moisture.

In this chapter the terms "rare" and "common" defines as follows; when colonies of a certain species of termites "A" are relatively fewer in number compared with some other species, usually it may be concluded that the species

"A" is rare. If the colonies of a certain species of termites "B" are numerous relative to some other species, it may be concluded the species "B" is common. If it is concluded that the species "A" is rare, the colonies of a species (A) are few relative to some other species. This method may be suitable for identifying the local occurrence of termites on an island.

The following method of field inspection which the author adopted, may be too uncertain to obtain accurate data on the local occurrence of termites in different islands. All data accumulated on the local occurrence of termites were obtained from field survey made under the following rules:

a. Data can be obtained by waking across the island along a straight belt (2 m. in width) which will usually pass through places being representative of the natural condition of the island.

b. A location at which a colony is found can be represented by a corresponding numeral of the following index (Table 6).

Table 6. Index for obtaining data as to the local occurrence of termite in the Ryukyu Archipelago.

Mark	Explanation of locality
A-1	Level sea-side region exclusive farm land
A-2	Housing area
A-3	Farm land
A-4	Swamp, paddy field and riverside
A-5	Hillside forest
A-6	Summit of mountain or hill
A-7	Mountainous inland
A-8	Dingle
A-9	Steeply sloping rocky hillside rising from the coast
A-10	Rocky seaside region

c. The location of a colony can be checked by a corresponding numeral of the following index (Table 7).

Table 7. Index for studying the habitats of termites in the Ryukyu Archipelago.

Mark	Explanation of habitat
B-1	Windbreak along the coast
B-2	Roadside trees and windbreak surrounding a residence
B-3	Shelter-belt-wood in farm land
B-4	Grove in premises of shrines, temples, etc
B-5	Building including furniture
B-6	Man-made structures in open land
B-7	Thicket massed with weed and dwarf trees
B-8	Copse

Table 8. Percentage of 3259 colonies of termites classified by their localities. Data based upon the author's study in the Ryukyus from 1951 to 1959. Figures with blackkets showing the true numbers of colonies, not those of the percent.

[illegible]

[illegible]

B-9	Forest
B-10	Land supporting stumps

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Field investigations of local occurrence and habitats of termite have been conducted by the author in the Ryukyu Archipelago from 1953 to 1957. In the accompanying table (Table 8 & 9) all data obtained from these investigations have been assembled and classified for the purpose of arriving at the frequency of local occurrence and the habitats of termites. Table 8 and 9 show that the local occurrence and habitats of termites differ from species to species. Some species occur abundantly in one particular locality of an island. The local occurrence of some species appear independent of ecological conditions. Other species, however, are known to occur under a rather restricted ecological requirement.

*Hodotermopsis japonicus*—The range of distribution of this species is confined to the northern half of the Ryukyu Archipelago and Shikoku. The local occurrence of its colony on each island is confined to mountainous regions (Table 8). It also appears from Table 9 that this species is restricted to a forest. Thus, the region of *H. japonicus* can be distinguishable from those of other species. In the forest, this species is conclusively stated that *H. japonicus* is distributed in the northern half of the Ryukyu Archipelago and Shikoku, and its occurrence is restricted to the forest in the mountainous region where it feeds on the pine, fir and pasania trees.

*Kalotermea satsumensis*—This species is confined to Nakano-shima, Kagoshima and Miyazaki Prefectures, and Formosa. This rare species has been frequently found in forest, and rarely found in infesting houses. But it is very difficult to say conclusively about the local occurrence and habitat of this species in the Ryukyu Archipelago because of too little available information on them.

*Kalotermea koshunensis*—This species is widely distributed in the southern half of the Ryukyu Archipelago. Table 8 shows that the colony of this species has been frequently found in housing areas and on hillsides. Table 9 indicates that the occurrence of its colony decreases as the latitude increases northward. Difference in abundance of the colony on the different group of islands seems to be largely influenced by temperature, especially by the winter minimum temperature. Therefore it is certain that this species is widely distributed in the southern half of the archipelago, and the abundance of its colony decreases as the latitude increases northwards. The common habitat of this species is the areas of windbreak, the housing areas and farm land (Table 9).

*Kalotermea fuscus*—The range of geographical distribution of *K. fuscus* extends as far north as Wakayama Prefecture. Table 8 indicates that in



the southern Ryukyu this species is found even at the summit of mountain, but in the northern part of the archipelago, the range of its occurrence shifts from inland to seaside as the latitude increases northwards. According to unpublished studies, this shifting tendency is evident in the southern portion of the Japanese Archipelago. It may be due to the influence of temperature, because in winter the seaside region is generally warmer than the inland. Table 9 indicates that the main habitat of this species is forest and copse in the mountainous inland in the Ryukyu Archipelago, but also in the hillside facing the sea in the southern Japanese Archipelago,

*Kaloterms kotoensis*—The house infesting termite, *K. kotoensis*, is one of the common species in the southern half of the Ryukyu Archipelago. Data in Table 8 shows that 76 percent of its colonies have been found in the housing areas on Okinawa-jima, 40 percent on Miyako-jima and 42 percent on Ishigaki-jima. Since in the archipelago the housing areas are usually situated near the seaside, these percentages mean that *K. kotoensis* occurs more frequently in the seaside region than other places. Table 9 indicates that in the Okinawa-gunto, about 50 percent of its colonies have been found in buildings. Though it is not so conspicuous as in the Okinawa-gunto, there is also high percentage of occurrence in buildings in Miyako- and Ishigaki-jima. Thus it may be said that this species usually occurs in the housing areas and builds its colony in woodwork of houses including wooden furniture.

*Leucotermes speratus*—The damp-wood termite, *Leucotermes speratus*, it is the most widely distributed species, and the range of its distribution covers South China, Formosa, the Ryukyu Archipelago, Korea and the Japanese Archipelago. It is true that this species particularly depends upon considerable moisture. A knowledge of this dependence on moisture throws a light upon the local occurrence of the species. In fact, this termite was commonly found in mountainous inland where there is sufficient moisture supply (Table 8).

*Coptotermes formosanus*—This termite is the most widely distributed species next to *Leucotermes speratus*. It is a well established fact that this species is found in sandy soils much more than in heavier, less porous clay type soils. Consequently, in general, the main area of its occurrence is found in the coastal region and less in the mountainous inland. Although the data presented are suggestive, Table 8 and 9 indicate the character of local occurrence of this termite. This species is erroneously considered that it requires much moisture and occurs in swampy ground. Contrary to popular belief, it does not always require much moisture. It is true, however, that *C. formosanus* has the ability of living without connection with the ground where there is a more constant water supply. In the swampy ground the nest of this species would be submerged

in the subterranean water during a rainy season.

*Odontotermes formosanus*—So far as the author has observed, the colonies of this termite are found in the sloping land covered with shrubbery. Such localities are favorable for nest building of this species. It is believed in the Ryukyu archipelago, this species builds its nest in the soil. Therefore this species would be expected to build its nest to prevent being submerged during heavy rainfall. Since only 35 colonies have been found throughout the area of the archipelago during the course of this study, it is difficult to make any conclusion in regard to the local occurrence of this species. The characteristics of local occurrence and habitat remain to be studied. But Table 8 and 9 seem to suggest that this species is usually found in the sloping land covered with shrubbery.

*Eutermes takasagoensis*—In the Ryukyu Archipelago this species is restricted to the Yaeyama-gunto, where it is one of the common termites. As is shown in Table 8, this termite has been found in various locations on the islands, being particularly abundant in the sloping land. This species does not seem to like much moisture, because it occurs mainly on the sandy soil or coastal region and the hills which are well drained. This termite lives in the sunny bushy region or forest and attacks stumps, dead branches and dead portions of living trunks. Mostly, its carton nest is found on trunks which bears many runways. The runways can be observed on the surface of trunk from the carton nest to the ground. Judging from Table 8 and 9, it may be said that *E. takasagoensis* is commonly found in sloping ground on which grows shrubbery.

*Capritermes nitobei*—Though the range of distribution covers South China, Formosa and the Yaeyama-gunto, this termite is very rare in the Yaeyama-gunto. Only four colonies have been found on Ishigaki-jima and Iriomote-jima during the course of this study. Of the four colonies three were found in the sloping land where bush growth occurs, and one in a housing area. Maki (1919) reported that *Capritermes nitobei* had been obtained from various environments in Formosa. It seemed to be distributed in higher altitudes from about 1,000 to 1,500 meters above the sea level. He also reports that it commonly attacks roots of certain kinds of pampas grass, but sometimes attacks roots of wild banana-plants. Judging from Maki's and the author's observations, the local occurrence of this species seems to be principally frequent in the hillside region.

To determine the gross feature of local occurrence of termites in the Ryukyu Archipelago, an extensive survey was conducted by the author from 1953 to 1957 in which a rough statistical method was used. The result of these studies are summarized as follows:

- (1). Generally speaking, the hill side facing the sea is particularly abundant in the number of species and colonies of termites in the Ryukyu Archipelago.

On the other hand, the dingle, mountainous inland and rocky coast support fewer numbers of species and colonies.

(2). In view of their habitats, the copse on skirts of mountains seem to serve as favorable habitats for termites in the archipelago. It is known from the result of this study that the inland forests do not seem to be suitable for *Hodotermopsis japonicus* and *Leucotermes speratus*.

(3). The feature of prevailing occurrence and habitat of each species of termite is as follows;

*Hodotermopsis japonicus*.....Forest in mountainous inland.

*Kalotermes satsumensi* .....Copse on skirt of mountain.

*Kalotermes koshunensis*.....Windbreak surrounding housing area or farm field.

*Kalotermes fuscus*.....Copse on hillside

*Kalotermes kotoensis* .....Woodwork of building.

*Coptotermes formosnus*.....Timber on skirt of mountain.

*Odontotermes formosanus* .....Shrubland on hillside

*Eutermes takasagoensis* .....Shrubland on hillside.

*Capritermes nitobei*.....Shrubland on hillside.

(4). The locality of occurrence of any species of termites tends to shift from inland to coastal region as the latitude increasing northwards.

## VI. THE TERMITE FAUNA OF THE NEIGHBOURING REGIONS

It might be well to give some attention to the termite fauna of the neighbouring regions in order to have some knowledge of the present status of the distribution of termites in the Ryukyu Archipelago. As yet there has been little information concerning termite fauna of the Oriental Continent, South East Asia, and the Philippines.

### China

Little consideration has been given to the termites of China. According to Light (1929), only five species have been reported from China during a period of 10 years from 1914 to 1923, viz. *Coptotermes formosanus* Shiraki, *Termes formosanus* Shiraki, *Coptotermes hongkongensis* Oshima, *Termes sinensis* Holmgren and *Reticulitermes chinensis* Snyder. In 1924, Light reported ten species belonging to the Chinese fauna. In Light's later paper (1929), 15 species were listed.

Among the fifteen species of Chinese termites mentioned in Light's articles, three have been known to occur in the Ryukyu Archipelago. Light also mentioned that *Reticulitermes chinensis* Light and *R. fukiensis* Light were

varieties of a single Asiatic species, *Leucotermes speratus*, which is the most common termite in the Ryukyu Archipelago.

The termites known to occur in China and their occurrence in the Ryukyu Archipelago, Formosa and the Japanese Archipelago are shown in Table 10.

Table 10. Chinese termites and their distribution in China and the Ryukyu Archipelago. Data on Chinese termites principally based upon Light's articles (1929).

Chinese species	Probable synonym	Distribution	
		China	Ryukyus
<i>Neotermes sinensis</i> L.	<i>Kalotermes koshunensis</i> S.	Kwantung	*
<i>Cryptotermes campbelli</i> L.	<i>Kalotermes kotoensis</i> O.	Hainan Is., Kwantung main land?	*
<i>Cryptotermes piceatus</i> Sny.		Hongkong	
<i>Reticulitermes chinensis</i> Sny.	Var. of <i>Leucotermes speratus</i> (K)	Szechuan, Chansha, Yenpin?	*
<i>Coptotermes formosanus</i> S.		From Pakhoi and Hainan Is. to as far north as Yenpin, and report has it, as far north as Shanghai	* ○
<i>Macrotermes barneyi</i> L.		Kuliang near Foochow, Amoy, Hainan Is.	
<i>Termes fontanelus</i> Kem.	<i>Odontotermes fontanelus</i> Kem. <i>Termes formosanus</i> S.	Chinkiang, Kiangsu	*
<i>Termes formosanus</i> S.	<i>Odontotermes formosanus</i> S.	Hainan Is. to Nanking	○
<i>Termes hainanensis</i> L.	Sub. of <i>Termes formosanus</i> S.	Hainan Is.	*
<i>Nasutitermes parvonastus</i> S.	<i>Eutermes parvonastus</i>	Yenping, North Fukien	
<i>Procapritermes sowerbyi</i> L.	<i>Procapritermes mushae</i> O.	Yenping and Kuliang, North Fukien	
<i>Capritermes nitobei</i> S.	<i>Capritermes jantsekiangensis</i> K.	Hainan Is. to Yenping, North Fukien and to Kiangsu	○
<i>Capritermes fuscotibialis</i> L.		Hongkong	

Total	15 species	○.....7
		*.....3

○.....Occurring  
\*.....Occurring. if synonym is justiful; including variety and subspecies.

Regarding the above table, there is no doubt that more than 30 percent of the species of termites known to occur in the Ryukyu Archipelago have been found in China. The species which are common to China and the Ryukyu Archipelago, are *Coptotermes formosanus*, *Odontotermes formosanus* and *Capritermes nitobei*. If all synonyms of Chinese termites suggested by Light are justifiable and if the variety and subspecies are regarded as the corresponding species, nearly 90 percent of the Ryukyuan termites should be found in China. Though the Chinese large termite, *Hodotermopsis sjöstedti* Holmgren, has not yet been taken in the archipelago, its related species, *Hodotermopsis japonicus*, occurs in the northern part of the archipelago.

The above facts indicate that the termite fauna of China had much influence upon that of the Ryukyu Archipelago, and that many years ago the archipelago once formed a continuous ridge of Asia continent according to geology. Needless to say, more study on Chinese termites will clarify the relation between the termite fauna of China and that of the Ryukyu Archipelago.

Formosa

The literature dealing with Formosan termites is very extensive. The works of outstanding importance are those of Oshima (1909-1923), Yano (1909-1915), Holmgren (1912), Hozawa (1915, 1932), Maki (1916, 1919), and others. Although Located within the subtropiacl or tropical zone, the termite fauna of Formosa itself is not large. It includes 15 species as listed below (Table 11), while Mexiko has 44 species (Light 1946b) even though it is estimated in the same latitude as Formosa. The termite fauna of Formosa probably owes its sparseness to the geographical isolation from its neighbouring regions by waters. The known species of termites in Formosa and their distribution are shown in Table 11 with there occurrence in China and the Ryukyu Archipelago.

Table 11. The termites known to occur in Formosa and their distribution in China and the Ryukyu Archipelago.

Formosan species	Distribution		
	Formosa	China	Ryukyus
<i>Kalotermes koshunensis</i> S.	Formosa, Botel-tobago Is.	*	○
<i>Kalotermes satsumensis</i> (M)	Tosna, Formosa		

<i>Kaloterme</i> <i>fuscus</i> (O.)	Kuraru, Formosa		○
<i>Kaloterme</i> <i>kotoensis</i> O.	Formosa, Botel-tobago Is.	*	○
<i>Leucoterme</i> <i>speratus</i> (K)	Botel-tobago Is. Little botel-tobago Is.	*	○
<i>Arrhinoterme</i> <i>japonica</i> Hilm.	Botel-tobago Is. Little Botel-tobago Is.	*	○
<i>Coptoterme formosanus</i> S.	Formosa, Botel-tobago Is. Little Botel-tobago Is.	○	○
<i>Odontoterme</i> <i>formosanus</i> S.	Formosa, Botel-tobago Is. Little Botel-tobago Is.	○	○
<i>Eutermes</i> <i>takasagoensis</i> S.	Formosa, Botel-tabago Is. Little Botel-tobago Is.	○	○
<i>Eutermes</i> <i>parvonasutus</i> S.	Formosa	*	
<i>Procapriterme</i> <i>mushae</i> O.	Formosa	*	
<i>Capriterme</i> <i>nitobei</i> S.	Formosa	○	○
<i>Kaloterme</i> <i>inamurai</i> O.	Formosa		
<i>Kaloterme</i> <i>dentatus</i> O.	Formosa		
<i>Eutermes</i> <i>kinoshitai</i> Hoz.	Formosa		
Total species 15		○..... 3 *..... 5	○..... 9

Table 11 shows that of the 15 species of Formosan termites, nine have been found in the Ryukyu Archipelago. On the other hand, three species and five probable synonyma of Formosan termites have been in China. The only species, *Hodotermopsi japonicus*, has not been found in Formosa up to this time, but has been found in the northern part of the Ryukyu Archipelago. The termites which have been known to occur in Formosa but not known in the archipelago are five species, viz., *Kaloterme inamurai*, *K. dentatus*, *Arrhinoterme japonica*, *Eutermes kinoshitai* and *E. paranasutus*. Oshima described two new species, namely, *Kaloterme inamurai* (1912, 1913) and *Kaloterme dentatus* (1914a, 1914b), from Formosa. So far as the author knows, other than Oshima and Hozawa, no one has collected these species from Formosa. Thus, the

occurrence of these three species in Formosa should need further study.

The comparison of termite fauna among these regions there is no doubt that the termite fauna of Formosa is closely related to that of China and the Ryukyu Archipelago. This fact indicates that most of the Ryukyuan termites may have migrated from the tropical zone through China and Formosa to the Ryukyu Archipelago.

### The Japanese Archipelago

The Japanese Archipelago supports only few species of termites. It has only five species (Hozawa, 1915; Holmgren, 1912; etc.) as shown in Table 12. While California is in the same latitude as Japan, it has 19 species (Snyder, 1946b). The fauna of Japan probably owes its sparseness to facts that its geographical distribution is isolated from the Asia Continent and the temperature plays the role of controlling.

Table 12. The termites known to occur in the Japanese Archipelago and their distribution in the archipelago accompanying distribution in the neighboring regions.

Japanese species	Distribution			
	Japanese Archipelago	Ryukyu Archipelago	Formosa	China
<i>Hodotermopsis japonicus</i> (H.)	Kochi Prefecture	○		
<i>Kalotermes satsumensis</i> (M.)	Kagoshima Miyazaki	○	○	
<i>Kalotermes fuscus</i> (O.)	Kagoshima Miyazaki Amakusa Kochi Wakayama	○	○	
<i>Leucotermes speratus</i> (K.)	From Kyushu to Hokkaido	○	○	*
<i>Coptotermes formosanus</i> S.	From Shizuoka to Kyushu	○	○	○
Total 5 species		○..... 5	○..... 4	○..... 1 * ..... 1

All the termites known to occur in the Japanese Archipelago have also been found in the Ryukyu Archipelago. With one exception, *Hodotermopsis japonicus*, all the Japanese species have also been found in Formosa. This fact indicates that the termite fauna of the Ryukyu Archipelago and Formosa have exerted an influence upon the termite fauna of the Japanese Archipelago.

Since *Coptotermes formosanus* and the probable varieties of *Leucotermes speratus* occur in China, the existence of *C. formosanus* and *L. speratus* in the Japanese Archipelago seemingly owes its presence to the Ryukyu Archipelago and Formosa because of climatic conditions, oceanic currents, means of dispersal of termite, etc.

Above speculation is highly probable not only judging from the similarity of the termite fauna but also from climatic condition, means of dispersal, etc. This theory will be discussed in more detail in the following chapter.

### Summary

It may be reasonable to consider that the termites which are associated with the termite fauna of the Ryukyu Archipelago may have migrated from South China through Formosa into the archipelago, not from the Philippines. It is also probable that the termite fauna of the Ryukyu Archipelago has had much more influence upon that of the Japanese Archipelago than that of China.

Judging from the faunal affinity of termites, the termite fauna of the Ryukyu Archipelago has been influenced by those of Formosa and China. On the other hand, the termite fauna of the Philippines distinctly differed from the other localities. It may be worthy to mention here Light's opinion regarding the termite fauna of the Far East. He made a systematic study of termites of the Philippines and China (1921a, 1921b, 1929a, 1929b, 1930, 1936, 1946). He (1929) states,

".....an increasing knowledge of the termite fauna of the China Coast but emphasized its affinities with the Formosan fauna on the one hand and its striking differences from the Philippines fauna on the other. Species of eight genera on the coast parallel the same, or very related species in Formosa. Of these eight genera, two, *Reticulitermes* and *Paracepritermes*, are not known from the Philippines; four, *Cryptotermes*, *Neotermes*, *Coptotermes* and *Nasutitermes*, are represented, but by very distinct species."

He continued,

"Unpublished studies of Philippines termites show the same to be the case for *Capritermes*. Unpublished studies of Philippines termites show that there are two distinct species, the most widespread of which is very similar to *Termes formosanus* Shiraki. These last are the only species showing any similarity in the two regions and they have ranges which probably meet in Borneo."

Concerning the Light's studies, none of the 44 species of the Philippines termites occur in Formosa, China and the Ryukyu Archipelago.

## VII. MEANS OF DISPERSAL



It may not be unreasonable to suppose that termites, like other animals, show a tendency to spread in every direction, constantly tending to enlarge the area which they inhabit. Although there is no evidence regarding the original habitat of termites, it has been generally agreed by termite investigators that, roughly speaking, the termite might has its origin in the tropics and extended its range of distribution into the subtropical and temperate zones. This is evidenced by the fact that more species of termites are thriving in the tropical zone than in the subtropical and temperate zones.

As mentioned previously in this paper, the termite fauna of the Ryukyu Archipelago bears resemblance to those of Formosa and South China. However, if so, it raises the question as to what principal ways did the termites of Formosa and South China take to have reach the archipelago. If such distribution has accounted for the origin of fauna in the archipelago, is there any sound basis of the possibility of these dispersal to other islands by way of the seas? The answer to such question appears quite obvious. A survey of early literature reveals that the many ways and means of dispersal are normal the same as the means by which plants and animals spread about the world.

Actually, there is some information concerning overseas dispersal of termites. In this chapter an attempt has been made to explain means of dispersal of termites in the Ryukyu Archipelago. There are four principal ways by which the termites might have reached the archipelago and may migrate in the future to other island still free from termite populations. The principal ways may be flight, marine drift, wind and transportation.

### Flight

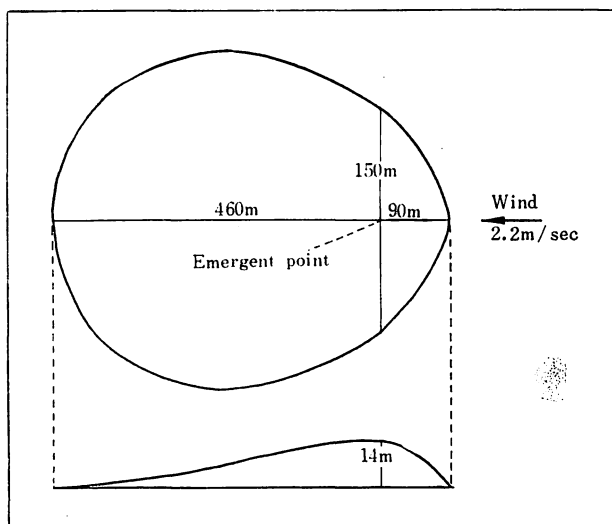
Generally speaking, flying insects are limited in dispersal by physical factors. However, there is great variation in the power of flight in different groups of flying insects. Among flying insects, termites have much weaker powers of flight, but the termites differ widely from species to species in the speed and duration of flight of their alates and in the distances traversed while swarming. According to Light (1946a), in general, the wood-dwelling termites are stronger flier than the earth-dwelling species and capable of more extended flights. He also states, "Termites of higher species often have much weaker powers of flight, and except when wind-carried, seem to cover relatively short distances in the swarming flight."

Harvey (1946) gives an excellent account of his observations regarding the swarming flight of the alates of American dry-wood termite, *Kalotermes minor*, which is known to be characteristically a day flier. He reported that this species was able to fly from half a mile to a mile or more. In nature it seems to be impossible to determine accurately the full length of flight for each species

because the length of flight is influenced by winds, configuration of the ground, elevation of emerging point, and other factors.

Herewith are several, actual examples regarding the flight of termites observed in the Ryukyu Archipelago. Speed of flight for individuals of alates of *Coptotermes formosanus* was observed at the campus of the University of the Ryukyus, Okinawa. On May 12, 1959, from 6:30 to 7:20 pm. with a steady but moderate southwest wind (mean 2.2 m/sec.), careful observations showed that the alates of *C. formosanus* attained a height of about 14 meters from the emerging point. The alates flew slowly in definite directions, although most of them preferred to follow the wind direction. The flight of the alates was aimless and more or less at random in the open land where similar observations were made. Text-figure 15 shows an estimated range covered by descending alates and a cross sectional view of demention of flight. The maximum distance of flight was about 460 meters from the point of emergence. Data on the speed of flight for 20 alates were obtained from following them leeward as far as 50 meters. According to the careful examination, the mean speed of flight becomes 0.7 meters per second. This speed corresponds to  $1/3$  of that of the wind (2.2 m/sec.). Thus, judging from the results of observations in connection with the duration of flight and speed of wind, there seems every reason to believe that *C. formosanus* covers a relatively short distance in the swarming flight, probably within 1,000 meters.

According to unpublished data taken relative to the swarming flight of *Leucotermes speratus* in a street of Naha City and a farm field near Koza City, the maximum distance of flight is at most 90 meters when the wind



Text-fig. 15. Sketch showing an estimated range covered by descending alates of *Coptotermes formosanus* and a cross sectional view of dimension of flight.

velocity was 3.5 meters per second. This distance is by far shorter than that of *C. formosanus*. Although further details will need mentioning, this species has many reasons of being unable to fly more than 300 meters during its swarming period.

In the Ryukyu Archipelago the swarming of the dry-wood termite, *Kalotermes kotoensis* is commonly observed in the evening on calm days from July to August. The alates of this species have a weak power of flight, and seem to cover relatively short distances while swarming, probably no more than about 300 meters at most.

The author has made two observations relative to the swarming of *Odontotermes formosanus* on the campus of the University of the Ryukyus, Okinawa: one was on May 17, 1959, from 7:30 to 8:00 pm., with southeast wind, 7.6 meters per second, and another on June 8, 1959, from 7:00 to 8:00 pm., with a strong southeast wind, 8.7 meters per second. A heavy shower fell before and during swarming flight. Alates seemed to be carried by winds for a distance of several hundred meters. It was impossible to chase individual flying alate for more than 50 meters because of the repidity of flight, the twilight and the intricate flight pattern of the insect. Winged reproductives of this species seemingly can reach a distance of nearly 1,000 meters with the winds.

Unfortunately, the author has no detail data as to the swarming flight of the remaining species of termites existing in the Ryukyu Archipelago. It is inferred, however, that the distance traveled by the remaining species while swarming might be less than 1,000 meters because of their short periods of emergence while swarming.

The foregoing discussion leads to the following conclusion in regard to flight as means of dispersal of termites in the Ryukyu Archipelago. Termites are weak fliers therefore not capable of traveling great distances. Thus, the flight potential of alate cannot be considered as the primary agent of dispersal, except when carried by the wind. Therefore wind influences the geographical distribution of termite in the Ryukyu Archipelago, but considered only as the primary agent for the local dispersal or the agent of dispersal among neighbouring islands.

### Wind

The work of Glick (1939) shows that wingless insects, spiders and mites are carried by air currents to great heights. Likewise, there is no doubt that swarming alates of termites are also carried by winds for 1,000 meters or more, although this may not be of great importance in the establishment of new colonies in unoccupied remote islands.

According to data compiled at several major observatories in the Ryukyu

Archipelago and the Kagoshima District Observatory, the monsoon winds blow with a mean velocity of less than 4 meters per second through the season of colonizing flight of the Ryukyuan termites, from April to September. The climatic condition during the season of swarming flight of *Odontotermes formosanus* is most windy, comparing with flight of any other Ryukyuan termites. So far as it is known, yearly flights of termites in the Ryukyu Archipelago usually tend to fly in warm, quiet evenings or at noon. According to data at hand, the mean maximum velocity of wind during the period of emergence is 8.7 meters per second for *Odontotermes formosanus*. Therefore, the normal monsoon winds can not be considered as an important means of dispersal which could influence the geographical distribution of termites in the archipelago. However, it is largely abnormal rather than normal that weather conditions have accounted for the dispersal of termites among the islands of the archipelago.

Zimmerman (1948) reports that it is the abnormal, cyclonic winds which account for the dispersal of a large part of the insects of the mid-Pacific. Convection currents may carry insects high into the air to the anti-trade wind zone which blows strongly from the west, and upon attaining those high strata, insects may possibly be transported for considerable distance. He suggested a possibility of dispersal of insects by abnormal winds to considerable distances. In the Ryukyu Archipelago, it is believed that typhoons could be considered as an important agent of dispersal of termites.

Man who has not actually observed typhoon may find it difficult to understand the influence of typhoons on organisms. Typhoons with speed in excess of 50 meters per second have frequently destroyed wooden buildings, and have carried plant material, sand, or sometimes tile and sheet-zinc of roof to great distance. Boughs are broken, and leaves and twigs hurled high in the air. It is not seldom that big trees measuring more than 0.4 meters in diameter are broken or blow down. The typhoon usually strike the archipelago once or more a year. Information regarding the typhoons on Okinawa compiled by Naha Observatory are given in Table 13.

It may be reasonable to expect that typhoons have played a part in the dispersal of termites from island to island in the archipelago. Although the season of typhoon from April to September coincides with that of swarming for most species of termites, alates may not be carried away by typhoons great distances, because the alates of termites are extremely sensitive to weather conditions and they do not emerge at such abnormal weather conditions. The typhoon strikes the archipelago during the season of establishing new colony, and hence the Typhoon may carry the new colonies forming in dead trunks, fallen twigs, wood pieces, etc. to great distance. Therefore, it is highly probable that the typhoons play a role on expansion the range of distribution of termites from

island to island in the archipelago.

Table 13. Frequency of the Typhoon (the verocity of wind, 20m/sec.) which strike the Ryukyu Archipelago during a period from 1946 to 1957. Data compiled at Naha Observatory.

Year	Apr.	May	Jun.	Jul.	Aug	Sept.	Oct.	Nov.	Dec.	Total
1946	—	—	1	1	—	1	—	—	—	3
1947	—	—	—	—	1	—	—	1	1	3
1948	—	—	—	1	1	1	1	1	—	5
1949	—	—	1	3	1	1	1	—	—	7
1950	—	—	1	1	—	—	—	1	—	3
1951	—	1	1	—	1	—	1	—	—	4
1952	—	—	1	—	1	—	—	2	—	4
1953	—	—	1	1	1	—	1	—	—	4
1954	—	—	—	—	1	2	—	—	—	3
1955	—	—	—	1	—	1	1	—	—	3
1956	1	—	—	—	2	3	—	—	—	6
1957	—	—	1	—	1	1	—	—	—	3
Total	1	1	7	8	10	10	5	5	1	48

### Marine Drift

The Japanese Current (Kuroshio) which sweeps past the Ryukyu Archipelago arises in the equatorial ocean currents north of the Philippines and flows northeast through the waters surrounding the archipelago. This would strongly indicate that the fauna of the archipelago might have been much more affected by currents from the south than the north or west.

Marine drift might have played a part in the dispersal of termites from island to island. However, there appears to be little information available concerning termite being dispersal by marine drift. Nawa (1926) suggested that, if wood infested with termites were submerged in water, it did not kill them since they thrive in high moisture environment and even can protect themselves from too much water which may threaten their colony. Emerson (1949) indicated that the geographical distribution of the genus *Reticulitermes* in the Oriental islands was prevalent in seaside districts, because *Reticulitrmes* was able to migrate by driftwood from island to island.

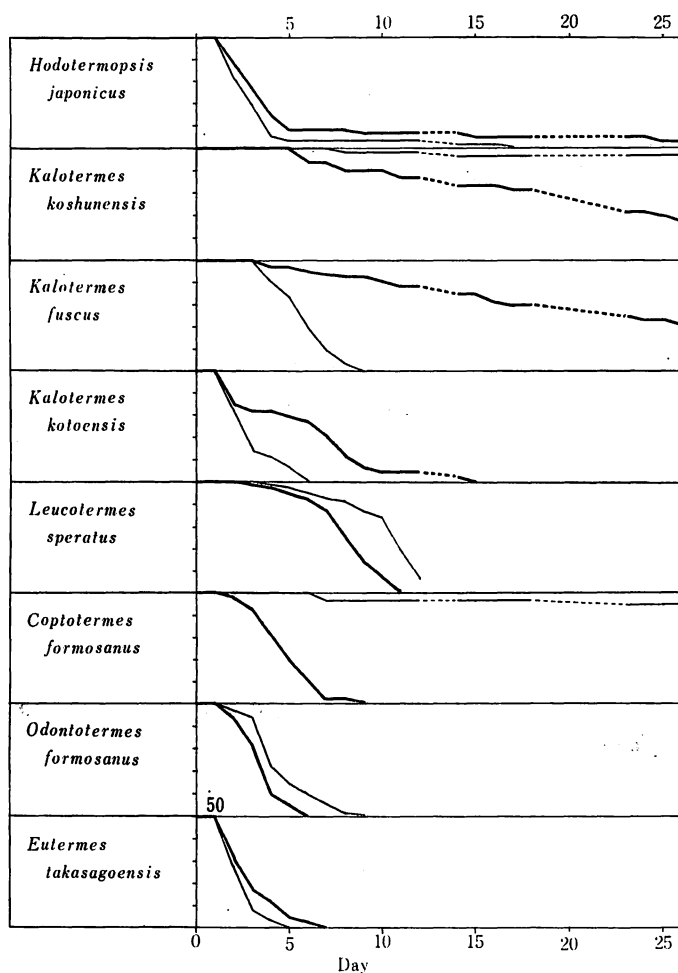
So far as the writer knows, no particular test concerning the possibility of dispersal of termites by marine current has appeared. To obtain some information on this subject some test were carried on during the summer of 1959. One test was made in a laboratory and others in the open air.

#### Test VII- I. Preliminary Test on Tolerance against Sea-water.

Materials and method- The termites which were used in the preliminary

laboratory test were *Hodotermopsis japonicus*, *Kaloterme*s *koshunensis*, *Kaloterme*s *fuscus*, *Kaloterme*s *kotoensis*, *Coptoterme*s *formosanus*, *Odontoterme*s *formosanus*, *Leucoterme*s *speratus* and *Euterme*s *takasagoensis*. Two rare species, *Kaloterme*s *satsumensis* and *Capriterme*s *nitobei*, were not used in these tests, because they are very rare species and are difficult to obtain in sufficient numbers for testing purposes. All the species of termites used in these test had been cultured in their nests in the laboratory.

Fifty individuals, both soldiers and workers, were used in these tests. The insects were kept in petri dishes with filter paper for food. Two dishes were prepared for each species for the test. The filter paper of one dish for a control



Text-fig. 16 Salinity-effect on termites. Thick lines.....survivors in dishes with filter papers moistened with a few drops of sea-water; thin lines..... survivors in dishes with filter papers moistened with a few drops of freshwater.

was moistened with a few drops of freshwater and another with a few drops of sea-water. Careful attention was paid to control moisture condition by means of covering the dish with a pieces of moistened cloth. The test was undertaken at room temperature at about 27°-30.5° C.

Observations on the death of test insects were made at 4:p.m. every day during the test, with a few exception of the difficulty of going to the laboratory during typhoons. The natural survival periods of the insects might be affected by frequent need of making observations, but this factor did not affect the results.

Result- This preliminary test was only approximate, but it indicated the possibility of dispersal of termites by marine drift. Text-figure 16 presents the results of the preliminary test. It appears that the wood-dwelling termites *H. japonicus*, *K. koshunensis*, *K. kotoensis* are more strongly tolerant against the sea water than the soil-nesting and the carton-nest termites, *C. formosanus*, *L. speratus*, *O. formosanus* and *E. takasagoensis*. Regarding their food habits (Chapter V III, p.115), the fungi-growing and the debris or grass termites, *O. formosanus* and *E. takasagoensis*, have a weaker tolerance to sea-water than the species belonging to other food-habiting termites. There was no difference in mortality among the eight species within an exposure of one day. In other words, no individuals were killed within a day after the test started.

A distinct increase mortality was observed from the second and third day on *H. japonicus*, *O. formosanus* and *E. takasagoensis*, and was observed between the fourth and eighth days on *C. formosanus* and *L. speratus*. No specific increase was observed throughout the test in *K. koshunensis* and *K. fuscus*.

The curves (Text-fig. 16) for the survival rates of the termites show that they can be divided into two major groups on the basis of their resistance to salinity, i.e., the negative and passive groups. If the survivors decrease, as compared with control, their survival periods and numbers of survivors depend upon existing salinity in their environment, they may be defined as the negative group, and if increase, they may be termed the passive group. It is quite apparent from Text-figure 16 that the negative group includes *C. formosanus*, *K. koshunensis*, *L. speratus* and *O. formosanus*, and the passive group includes *H. japonicus*, *K. fuscus* and *K. kotoensis*.

Discussion- In general, salinity is expected to affect the life of termite, and the effect of salinity varies with species. From the result of this test it appears that the eight species of termites treated in the test can be divided into two major groups, based upon the effect of salinity.

The explanation of the difference in salinity-effect must be explore by further tests. Such a study, however, may not indicate why some species are passively influenced by salinity and others are negatively effected. It is supposed that, in the case of the passive group, the salinity probably acts on controlling or killing

fungi or bacteria which may be harmful to termites. On the other hand, in case of the negative group, it may play a role of direct destruction of fungi on which this group depends for its food. The body-water of termites affected by osmosis does not seem to influence the duration of survival of termites, because there is no particular difference in body weight between individuals in the sea-water and in the fresh water.

The result of this test strongly suggests that the termites belonging to the passive group might be dispersed from island to island by marine drift wood inhabited areas. As the passive group mostly consists of the wood-dwelling termites, the possibility of dispersal by marine drift becomes more possible. Though the negative group has shortened survival period by salinity, 50 percent of the mortality occurred at least after three days or more continuous exposure to the sea-water. This fact indicates that the negative group could also be dispersed in a living state for considerable distances by marine driftwood.

No report of similar test on termites has been found in the literature. Therefore it is unable to compare the result of this test with some other data. It should be ascertained by repetition. However, the purpose of this preliminary test is only to conjecture the possibility of overseas dispersal of termites by marine drift. The results of this test contributes to concern the overseas dispersal of termites, although the test has left many unsolid problems for further experimental varification. The results, whether conclusive or not, are presented to stimulate further investigation.

Although two rare species, *Kaloterms satsumensis* and *Capriterms nitobei*, were eliminated from the test, it is inferred that they may be classified with one of the groups. Judging from the result of the test, *K. satsumensis* may belong to the passive group like most species of the genus *Kaloterms*, and *Cap. nitobei* may belong to the negative group like other fungi or debris termites.

Summary- The preliminary test of salinity-effect on termites was carried out in order to learn of the possibility of overseas dispersal of termites. The test with eight species of termites was made in Petri dishes with filter-papers moistened by sea-water and by fresh water. The result of these tests were comparative. The principle findings resulting from these tests are as follows:

- 1). Salinity-effect on termite survival seems to be divided into two major group, i.e., the passive group and negative group. The former mainly consists of the wood-dwelling termites and the latter the earth-dwelling termites.

- 2). It is very probable that the passive group which are composed of the wood-dwelling termites has an ability to spread overseas with marine driftwood in which they inhabit. Although a species of wood-dwelling termite, *K. koshunensis*, belongs to the negative group, this species may be dispersed by marine drift wood from island to island, judging from 50 percent of mortality



for this species which occurred at 3 weeks or more after starting the test.

3). In general, the duration of survival of the negative group is shorter than that of the passive group continuous exposure to sea-water. However, 50 percent of individuals were still alive for a day after the test was initiated. Thus, the overseas dispersal of this group is also very probable, particularly for short distances.

#### Test VII—II. Outdoor Test on Survival in the Sea-water.

As far as the writer has learned, field observations with regard to overseas dispersal of termites are very scarce. Therefore, a few attentions on this subject have been made. The result of the foregoing laboratory test indicated that marine drift was credited with survival of termites under exposure to the sea-water for considerable days. In August, 1959, a field test was conducted in order to ascertain the possibility of overseas dispersal of termites in the vicinity of Tomari Harbor, Okinawa.

Field tests were carried on with two species, *Leucotermes speratus* and *Coptotermes formosanus*. Two timbers were used (one: 7x9x30 cm. infested by *L. speratus*, another; 5x7x56 cm. infested by *C. formosanus*). These timbers were found in Kamiyama-jima lying at a distance of about 11,500 meters to the west of Tomari Harbor. These two timbers infested by the two species were set afloat on the sea with a string at 2:00 pm. and left until 9:00 am. on the next day. About 1/4 of the timbers appeared on the surface of the sea, but on occasions they were entirely submerged in the water by waves. When the test was over the timbers were removed for the examining of survivor.

Observations were made by splitting these previously infested timbers. On observation, many living individuals of the two species of termites were found in the galleries formed within the timbers. Consequently, it seems quite safe to say in general that the species of our common termites, *L. speratus* and *C. formosanus*, survive in the marine driftwood for more than a day, and that marine drift may be one of the important means of overseas dispersal for them. The outdoor test was not attempted with the remaining species, but one can speculate that the remaining species would have been able to survive for a day or more in the marine driftwood on the basis of the result of Test VII— I and VII— II in this chapter.

#### Test VII—III. Survival Test to Movement of Waves.

The third test was made for the purpose of determining whether termites could survive under the condition of extreme movement of waters. A log, Japan cedar, infested with *C. formosanus* were used for this test. The log was about 12cm. in diameter and about 80 cm. in length. The end of the log was tied firmly with a rope and was tied to a motor boat to allow it free from the waves.

The log was pulled on the sea for 90 minutes from Kamiyama-jima to Tomari Harbor (about 11,500 m.).

An examination of this log was done just after the boat reached the pier of the harbor. The covered runways on the surface of the log were entirely washed off by the sea water. The log was torn off with a hatchet for the inspection. Many living individuals were observed in the galleries and runways which were built in the inner side of the log.

It appears from these results that the individuals of the species of *C. formosanus* can survive the violent movement of the log in water for more than one and half of hours. The movement of water under typhoon condition would not be so violent as this test. Therefore, the observation of this test indicates that individuals would no doubt survive for a considerable period under extreme movement of waves.

**Discussion for Marine Drift as Means of Dispersal.** The literature is considerable with example of plants and animals being transported across wide stretches of the sea. These examples, however, are usually only the records of the larger animals like monkeys, crocodiles, reptiles, etc. There appears to be little information concerning the overseas dispersal of insects, particularly of termites.

The Ryukyu Archipelago is usually devastated by typhoons at least once a year, and typhoons usually accompany excessive rainfall, so that under such conditions small natural streams become great rivers. During excessive rains the flood carry to the sea vast quantities of driftwood. Occasionally large rafts or masses of debris make up "floating islands". It is highly probable that such masses of driftwood could mingled with some wood in which the colonies of termites are inhabited. It is conceivable therefore that some of the colonies, on occasions, could travel from island to island with such drift-materials.

How long will the termites be alive in such drift-materials in the sea, and how long will they be able to persist in rough movement of waves is questionable. The results of foregoing tests may answer this question. The results of Test V II-I indicate that about 50 percent of individuals of any species of termites used for the test can survive for at least two days in alkaline surroundings. The results of Test V II-II indicate that even the weaker termites resist against salinity as *L. speratus* and *C. formosanus*, could survive for 14 hours in the floating timbers. In case of individuals of the species *C. formosanus* in timbers under to excessive water movement of waves they could survive for more than 90 minutes, if they were not washed away (Test VII-III). These facts indicate that when the termites were carried out to the sea with wood, they are able to endure the rough movements of the sea-water under conditions of typhoon.

The results of this series of test lead us to assume that natural rafts of

considerable size such occasional typhoons may be one of the important ways of dispersal of termites and at time the colonies may survive for a long period under the conditions of typhoon. It appears quite probable from the field observations that some of the colonies could establish themselves on the seaside regions when the floating timbers are washed upon the foregin shores.

**Conclusion.** Laboratory and field tests on the possibility of overseas dispersal of termites by marine drift suggest the following conclusions:

1). Result of the laboratory test in the Petri dishes shows that the termites have the power of resistance to alkalinity, and that the survival duration of termites varies with species.

2). From the standpoint of alkaline-effect, termites may be divided into two major groups, namely, the negative and positive group. The former probably includes the so-called earth-dwelling termites and the latter the wood-dwelling termites.

3). When termites are placed on the filter-paper moistend with sea-water, 50 percent of mortality occurs at least within a 48 hour period.

4). Judging from the results of a series of tests, it is conceivable that the termites could survive for many days in drift wood floating in water.

5). Finally, it can be safely concluded that the marine drift may be one of the most successful methods of termite dispersal.

#### **Dispersal Aided by Men.**

Overseas dispersal of termites aided by man is probably of importance, and in certain instances, may be responsible for certain distribution of termites. This may usually by brought about by the transportation of infested soils, timbers and wooden structures in the ordinary route of commerce.

**Observation.** In the course of this study, the overseas dispersal of Ryukyuan termites has been one of the author's main focus of attention. Data were obtained in cooperation with Mr. Retsuo Nakayoshi, Biology Teacher of Kume-jima Senior High School.

In the summer, 1959, the first swarming fligh of *C. formosanus* on Kume-jima occurred on May 4, but in southern Okinawa it occurred on May 9. Two ships, viz., the Haikawa-maru and Yuko-maru, arrived at Tomari Harbor on the 5th of May, the day after the occurrence of the swarming flight on Kume-jima. The former ship set sail from the Hanasaki Harbor of Kume-jima and the latter from Nakadomari Harbor of the same island. Inspections were made as soon as these two ships were lied alongside the pier.

Many alates and dealates of *Coptotermes formosanus* were found in the ships, and a large numbers of wings were scattered here and there on the decks.

It was not a difficult task to find dealates or alates on the incoming cargo.

Thus, judging from the observations made in May 1959, it was quite obvious that these alates and dealates of *C. formosanus* were introduced from Kumejima to Tomari because the first swarming flight of this species in Okinawa was on the 9th of May. Therefore, there is no doubt that transportation plays an important role of dispersal of termites from island to island in the Ryukyu Archipelago.

A survey of the literature reveals a multitude of records concerning the occasional transport of termites by traffic from one locality to another or from island to island. Kofoed (1946), speaking of the occasional transport of the oriental termite, *Coptotermes formosanus*, said, "In a smaller way, the transport of household furniture, second-hand infested timbers, living plants, etc., affords a mechanism where by colonies of termites become established in newly developing centers of known population and in regions wholly new for the species. An example of the latter is seen in the arrival in Hawaii of the Oriental termites, *Coptotermes formosanus*, from Asiatic ports, and it occupied by at least three other native species." Ehrhorn (1946) said that *Cryptotermes piceatus* Snyder has been known to occur in the Hawaiian Islands, Fanning (1932 Light) and the Marqueses (Light 1932), but this species was found in south China by Light (1925). According to Snyder (1946), *Cryptotermes piceatus* was shipped from Honolulu from Hongkong. Esaki (1937) reported that the American large termite, *Zootermopsis angusticollis* (Hagen) was introduced from Oregon, U.S.A. to Kobe, Japan by the transportation of infested timber through the ordinary route of commerce.

From these previous studies and from the author's observation, there is no doubt that termites are carried by traffic from island to island or from locality to another locality and become established in previously uninfested regions.

**Examples of distribution.** There are two good examples of the distribution of termites by occasional transport. One example is the distribution of termite in the Daito-shoto. The Daito-shoto (Text fig. 1) or Borodino Islands consist of three islands called Kita-daito-jima, Minami-daito-jima and Okino-daito-jima. Minami-daito-jima is the largest of the three islands, and is located between 25°48' and 26°02' N. of the parallel and between 131°12' and 131°15' E. of the Meridians. Kita-daito-jima is located about 8 kilometers to the northeast of Minami-daito-jima. Okidaito-jima or Rasa Island is a small island lying at a distance of 90 nautical miles to the south of Minami-daito-jima.

In September 1959, a termite exploration was conducted on Minami- and Kita-daito-jima. The result of this exploration showed that the termite fauna of these islands is composed only of the species of *Kalotermes kotoensis*. It is

interesting to note that two widely distributed species, *C. formosanus* and *L. speratus*, were never found on these island in spite of the author's efforts. These islands have a subtropical marine climate.

There seems to be no factor which limits the establishment of colonies of these two commonest species. Rainfall is heavy on these islands and the vegetation flourishes luxurially in all seasons.

The only reasonable explanation for the absence of the two species on these islands is probably due to the fact that these oceanic islands are located more distant from any other islands of the Ryukyu Archipelago. There is very little traffic between Okinawa-jima and the islands of Daito-shoto. Only once or twice a month, and no traffic between these islands and any other island in the archipelago. In addition, the history of exploration on these islands is limited to more or less 100 years. Therefore, it is highly probable that *C. formosanus* and *L. speratus* would not have become established on these island because of such infrequent traffic during such a short historical time.

On the other hand, *Kaloterme kotoensis* occurs on these islands and this termite is the only species existing there. This species is a house termite and is usually found in wooden buildings, shelves, and even in furniture such as desks and chairs. Thus, it is highly probable that this species is introduced from one island to another in secondhand timbers, furniture, etc. Judging from this habit of the species, this household termite might be transported to the Daito-shoto with secondhand timbers, old furniture, etc., which might have been taken into these islands by men. The normal route of traffic connects these islands with Okinawa-jima where this species thrives well. There seems to be no factor which keeps these islands from being established with colonies when traffic enters there.

Another example is the sporadic distribution concerns occasional transports of *Kaloterme satsumensis*. *K. satsumensis* has been found in Formosa, southern Kyushu and Nakano-shima, but has not been found in the central part of the Ryukyu Archipelago. The region of distribution of this species jumped from Formosa to Nakano-shima and southern Kyushu and shows an irregular distribution (Text-fig. 5). Why this species is not found in the central part of the archipelago is very difficult to answer. Data of historical biogeography would be unquestionably of great importance to answer this question. Unfortunately, data on historical biogeography regarding the Ryukyu Archipelago are lacking. Geographical evidences are wanting, and no uniformity of opinion has been reached in even the most fundamental problems. Moreover, no fossil termites have been found in the Oriental regions. Thus it is difficult to explain such irregular termite distribution even by making systematic studies among species at present time.

However, there are many records with regard to the sporadic distribution of

termites which are caused by various occasional transport in the world, such as the success of the oriental species, *Coptotermes formosanus*, in the Hawaiian Islands. Probably such overseas dispersals might have occurred even in the past. Thus, *K. satsumensis* may have been introduced in the past from Formosa through the normal route of commerce to southern Kyushu where the species become established.

Here is another example of distribution of termite by traffic. The Japanese large termite, *Hodotermopsis japonicus*, is distributed in the northern half of the Ryukyu Archipelago and southern portion of the Japanese Archipelago. A related species, *Hodotermopsis sjostedti*, was recorded from Tonking in South China. The species of the genus *Hodotermopsis* has not yet been taken from any other locality in Asia except Tonking, the northern part of the Ryukyu Archipelago and the southern portion of the Japanese Archipelago (Text-fig. 2). Various speculation may be made of the present status of distribution of *H. japonicus*, but among them it is quite natural that this species could originally be introduced from south China by occasional transport to the southern part of the Japanese and the northern part of the Ryukyu Archipelago.

**Conclusion.** From the discussion above, overseas dispersal of termites by man is probably one of the most important means in the Ryukyu Archipelago. The most probable method by which the accidental introduction of termites might be accomplished, would appear to be by their rare transportation in infested soil and wood by shipment. It is believed that, if the study of dispersal by traffic is carried out more intensively, it would enable one to estimate accurately man's influences on the modification of distribution of termites.

### Summary.

1). From the similarity of the termite fauna in the Ryukyu Archipelago, Formosa and South China, the termites known to occur in the Ryukyu Archipelago might have been introduced from these two southern regions.

2). There seems to be four principal means by which the ten species of termites now occurring in the Ryukyu Archipelago might have reached the archipelago and spread among the islands. These are flight, abnormal winds, marine drift and traffic.

A. Flight:- Termites are weak fliers, except when wind-carried, and seem to cover relatively short distances in the swarming flight. The role of the wind while swarming seems to be little, because the termites are extremely susceptible to weather conditions and never emerge on extremely windy days. Flight may not be of great importance in overseas dispersal.

B. Abnormal winds:- The Ryukyu Archipelago lies within the typhoon belt of the East China Sea. From 12 to 45 typhoons affect Okinawa region each year.

Such typhoons usually carry vast quantities of wood pieces, twigs, etc., from island to island. It is highly probable that such materials would hold the infested twigs, pieces of wood, etc., and that the termites may have had an opportunity of establishing their colonies on the various islands

C. Marine drift:- Laboratory and field tests should lead us to the assumption that the marine drift wood could be one means of dispersal for termites. The excessive rainfall during the typhoon carries to sea vast quantities of driftwood. Such driftwood may carry colonies of termites from island to island.

D. Traffic:- No doubt, the traffic has played an important role in the geographical distribution of termites. Most of the sporadic irregular distribution of termites may be explained, without the help of land bridges, by considering the occasional transport.

3). Distributional map of termites of the Ryukyu Archipelago at present will be modified in the future by these means and by other unknown methods of dispersal.

### **VIII. THE RELATIONSHIP BETWEEN VEGETATION AND THE GEOGRAPHICAL DISTRIBUTION OF TERMITES.**

Attention is now turned to the relationship between vegetation and the geographical distribution of termites. An attempt is made here to deal with this subject mainly on the basis of field observations and literature, with special reference to the food habits of the termites.

Insects depend upon plant for their food, protection from radiant energy, changes in temperature, enemies, as well as for favorable situations to survive and to rear offspring as much as other animals, and there is an enormous scientific literature dealing with this subject. However, so far as is known, there seems to be no comprehensive study on this subject with special reference to termites.

Termites are important scavengers of dead wood in the forest areas, and they owe their food to wood. The food of termites is primarily cellulose from the wood. It is well known that, except in the family Termitidae, termites can utilize cellulose with the aid of several kinds of minute animals belonging to flagellated Protozoa, numerous types of bacteria and various kinds of spirochetes which are associated with these cellulose requiring termites (Buscalion et al; 1929, Child; 1934, etc.).

Though there are some exceptions, termites primarily avail themselves of cellulose after the death of plants. For this reason they occur predominantly in stumps, fallen logs, stubs, standing dead trees, dead branches, dead portions of

living trees, woodworks of buildings, and in exposed and hidden roots. The earth-dwelling termites destroy wood, not attacking it directly from the outside but rather by invading it from the ground. The wood-dwelling termites, however, enter the wood directly from the air, through racks and nail-holes, but the colony is confined to wood and works entirely within wood.

### Food Habit Type of Termites.

The many different species of termites may be easily divided into a small number of defined groups if it considers from the stand-point of their food habits. The Termite Investigations Committee of America (Kofoid et al, 1934) divided termites into several groups according to the place where they were to be found, i. e., their habitats, and a few of their significant habits. It may be useful to know the ecology of termites on the basis of both the Committee's criteria and food habits proposed by the author.

The food habit grouping for termites in the Ryukyu Archipelago studied by the author are listed in the following outline.

- A. Euryphagous type termites
  - 1. Acerose tree termites
    - a. *Leucotermes speratus*
    - b. *Coptotermes formosanus*
  - 2. Debris or grass termites
    - a. *Eutermes takasagoensis*
    - b. *Capritermes nitobei*
  - 3. Fungi-growing termite
    - a. *Odontotermes formosanus*
- B. Stenophagous type termites
  - 1. Huge tree termite
    - a. *Hodotermopsis japonicus*
  - 2. Hard-wood termites
    - a. *Kalotermes fuscus*
    - b. *Kalotermes kotoensis*
- C. Soft-wood termites
  - a. *Kalotermes satsumensis*
  - b. *Kalotermes koshunensis*

Needless to say, not all species of termites fit snugly into such a small number of food habit groups mentioned above. Undoubtedly, if similar studies are made in other countries where occurs more species of termites, some other groups will be added to the above groups. The author does not believe that the classification presented here is the best method of grouping from the standpoint of the food habits. The method of grouping and the names of groups will



probably be revised by further studies.

### Brief Notes on Each Type

Euryphagous Type Termites-. Although the food habits of most of species of termites living under natural conditions are fairly stereotyped, some of them display considerable adaptability at times and will attack a variety of substances and materials, including some that contain no cellulose. The euryphagous type of termite is defined as those which have considerable adaptability in their food habits.

#### 1. Acerose tree termites

As the name implies, termites which especially prefer the acerose trees for their diet are defined as the acerose termites. While the termites belonging to this group usually attack the acerose trees, they also attack other kinds of plants when there is a shortage of acerose trees.

##### a. *Leucotermes speratus*

It is well known that this species of termite occurs predominantly in stumps and in exposed or hidden roots of acerose trees, and that it requires much moisture, but it frequently attacks other timbers such as posts, piles, railroad ties, and rotten parts of buildings placed in contact with the earth or damp masonry.

According to field observations, there does not seem to be any kind of timbers throughout the Ryukyu Archipelago, whether it be native or foreign, which will be free from infestation by this species, if it is wet and decayed. Frequency of occurrence in the wood is much higher on the mountainous inland than on the coastal area or on level land. Some peculiar plants and some other substances attacked by this species are enumerated below, and following data were presented by the author unless otherwise indicated:

*Cinnamomum Camphora* Sieb.; *Cyca revoluta* Thumb.; *Zandanus var. liukiuensis* Warb.; *Toddalia asiatica* Lam.; Pine apples; Tea-trees; sugar-cane; Sweet-potato; Books and papers (Kasuya, 1911).

##### b. *Coptotermes formosanus*

In the Ryukyu Archipelago this species is found so frequently in conifer wood, especially in pine-trees, that local people believe that every species of termites live in the pine-trees. It has been revealed by the results of observations that this species lives predominantly in the conifer wood, but contrary to the popular belief, the conifer wood is not its exclusive food.

Although its preference for food is predominantly conifer wood, it is found living on many other kinds of plants. Some of the interesting plants, substances and materials which are attacked by this termite are enumerated below;

Bamboo; Corn-plants; Cotton clothing; Wool clothing; Rubber; Leather; Dry

ponite; Bone (Nakashima, 1959); Concrete; Cover of cab-line.

## 2. Debris or grass termites

Termites which habitually attack debris or grass are defined as the debris or grass termites. Although the principal food is debris and grass, sometimes these termites attack fairly sound wood. They feed on twigs, fallen leaves, portions of decayed wood, etc., which are usually piled up on or under the ground in bushy area.

### a. *Eutermes takasagoensis*

This termite lives in forests or bushy districts attacking mostly fallen trees, dead logs, well decayed stumps, fallen twigs, fallen leaves, etc. There is no record of its attacking poles, house timber, bridges, fences, and other man-made structures.

So far as it is known, the conifer wood is not attacked, but the decaying latiholiate wood is the basic food. It is said that many species of *Eutermes* in Australia are grass feeders, and *E. exitiosus* has been found attacking living plants and such peculiar materials as bones.

### b. *Capritermes nitobei*

Of the three species belonging to the debris or grass termites, this species especially attacks the grass. Maki (1919) reported that during the dry weather this species attacked rice-plants and some kind of pompas grass in the mountain regions of Formosa. Bhiraki (1954a) classified this species as a noxious insect for the rice-plants. However, so far as the Ryukyu Archipelago is concerned, this species is restricted to the Yaeyama-gunto, and never been found attacking rice-plants.

Because of its rare occurrence and restricted distribution, the food habit of this species is as yet little known in the Ryukyu Archipelago.

## 3. Fungi-growing termites

A group of termites which grow fungi in their nests are called the fungi-growing termites. The fungi-growing termites are especially dependent upon the fungi which are growing in their fungus garden, although all termites owe their diet, more or less, to fungi.

### a. *Odontotermes formosanus*

There is only one species, *Odontotermes formosanus*, of the fungi-growing termite in the Ryukyu Archipelago. During dry weather it is difficult to observe its feeding activities on debris on the ground. As soon as rain falls, the workers of this species cover the debris with soil one after another (Plate II, D&E), and carry the soft portions of them into the galleries to considerable depth below the ground. They store food nodules of eaten wood bound together with secretion (Plate III, A&B). Many studies on symbiosis between termites and fungi have been done. The three roles of fungi growing in the nests of termites are said furnishing food (Hungate, 1936; Hendee, 1946; etc.), Keeping high temperature

(Luscher, 1951; etc) and obtaining high humidity in the nest (Kofoid, 1946).

**Stenophagous type Termites.** Generally speaking, the food habits of most species of termites, living under natural conditions, are comparatively stereotyped, although many display considerable adaptability at times. For instance, the stenophagous termites feed on several inclusive species of wood only.

The stenophagous termites are divided into three groups, the huge tree termites, hard-wood termites, and soft-wood termites.

#### 1. Huge tree termite

In the Ryukyu Archipelago this group is represented by *Hodotermopsis japonicus*. *H. japonicus* is found in stumps, dead portions of trunks, standing dead trees, etc. in forests. It is highly probable that this species is usually found in huge wood which is at least more than 40cm. in diameter at ground level. But on quite a few occasions this termite has been found in wood smaller than 40cm. in diameter, if the small wood is close to huge wood inhabited by this species.

However, it is worth noting that this species is not always found in all kinds of huge trees even if they are large enough to inhabit, but are conventionally found in quite a few kinds of trees. Observations so far indicate that this species of termite seems to prefer particular species of trees for its food. Information according to the food trees for this termite are listed below:

Kind of tree	Number of finding	Locality
<i>Abies firma</i> S. et. Z.	1	Yaku-shima
<i>Pinus Thunbergi</i> Parl.	2	Yaku-, Tanega-shima
<i>Pinus luchuensis</i> Mayer	6	Amami-oshima
Pasania tree	17	Toku-, Nakano-, Yaku-shima, Amami-oshima.

As it is obvious from the above list, this termite is feeding on firs, pine-trees and pasania trees.

#### 2. Hard-wood termites.

It is said that most termites attack soft wood or soft portion of wood more than hard or heartwood. Contrary to popular belief, the soft-wood is not the natural food of all termites; some species feed on the physically dense and hard wood, protecting themselves from attacks by other termites. A group of hard-wood eaters is defined as the hard-wood termites. In the Ryukyu Archipelago two species belong to the hard-wood termites. They are *Kaloterme fuscus* and *Kaloterme Kotoensis*.

##### a. *Kaloterme fuscus*

This species of termites commonly occurs in the hard-wood or hard portions of wood which are resistant to weathering or attacks by other species of termites. It attacks both the dry- and damp- wood in a forest and shrub, but

never attacks the woodwork of house, furnitures or poles. All hard-wood are not always attacked by this hard-wood termite, but quite a few kinds of hard-wood are exclusively attacked by this termites. Wood known to be inhabited by this hard-wood eater are listed below:

Kind of tree	Number of finding	Locality
<i>Bischofia javanica</i> Bl.	2	Ishigaki-, jima
Pasania tree	53	Iriomote-, Yonakuni-, Ishigaki- Okinawa-, Keruma-, Kume- Okierabu-jima, Amami-oshima Tokuno-, Nakano-, yaku-shima Kagoshima Pref., Kochi Pref. Miyazaki Pref., Wakayama Pref.
<i>Rhus succedanea</i>	1	Okinawa-jima

As it is obvious from the above list, this termite has been found only in three kinds of trees, being particularly abundant in the pasania trees.

b. *Kaloterme kotoensis*

A species of dry-wood termite, *Kaloterme kotoensis*, belongs to the hard-wood termites. It occurs more frequently in the woodwork of houses or furniture than in stumps, dead portions of trees, dead branches under natural conditions. Therefore, it may be called a house termite. The frequency of its occurrence is by far most abundant in the coastal regions, housing areas and farms than in the forest or bushy areas.

So far as it is known, this species feeds on such as trees listed below:

Kind of tree	Number of finding	Locality
<i>Picus Wightiana</i> Wall	23	Yonaguni-, Hateruma-, Iriomote-jima Kuro-shima, Ishigaki-, Miyako-, Kurima-, Irabu-, Okinawa-, Okierabu-Kume-, Yoron-, Taketomi-, Ikema-, Ogami-, Shimoji-jima.
<i>Ficus retusa</i> L.	18	Same as above, except Okierabu- & Yoron-jima.
<i>Cryptomerica</i>	15	In woodworks of houses at the Yaeyama- gunto, Miyako-gunto, Okinawa-gunto, Yoron-jima, Okierabu-jima
Chinese black pine	54	All islands investigated, from Tokuno- shima to Yonakuni-jima.
<i>Teromstroemia gymnanthers</i>	37	In woodworks of houses on all islands investigated, from Okinawa-jima to Yonakuni-jima.
<i>Calophyllum Inophyllum</i> L.	29	Ditto.
<i>Pouteria obvata baehni</i>	17	Ditto.

*Bischofia javanica* Bl. 6 Ishigaki-, Iriomote-jima.

### 3. Soft-wood termites

Of the so-called wood-dwelling termites, the termites which are found more often in the soft-wood or weathered wood than in the hard-wood or heartwood, are defined as the soft-wood termites. Two species of the wood-dwelling termites, *Kaloterms koshunensis* and *Kaloterms Kotoensis*, belong to this group.

#### a. *Kaloterms koshunensis*

There are no records of this species causing significant damages to the woodwork of a building or man-made structures. On most islands of the Ryukyu Archipelago there are a great number of trees surrounding houses and farms. These windbreaks are favorite habitat of this species. Data with regard to wood on which this termite feeds are as follows:

Kind of tree	Number of finding	Locality
<i>Picus tashiroi</i> Maxim.	24	All islands investigated, from Okinawa- to Yonaguni-jima.
<i>Picus retusa</i> L.	19	Ditto
<i>Citrus stipulosa</i>	12	Ditto
<i>Citrus Wightiana</i> Wall	8	Ditto
<i>Citrus depress</i> Hayata	3	Yonaguni-jima
<i>Acer oblongum</i> var. <i>Itoanum</i> Hayata	14	All islands investigated, from Okinawa- to Yonaguni- jima
<i>Elaeocarpus sylvestri</i>	18	Ditto
<i>Rhus succedanea</i> L.	16	Ditto
<i>Ardisia Sieboldii</i> Miq.	9	Ditto
<i>Ficus erecta</i> Thumb.	19	Ditto
<i>Cinunumonum daphnoides</i> S. et Z.	8	Ditto

It is highly probable that more kinds of food trees will be added to the above list by future study.

#### b. *Kaloterms satsumensis*

It was a common understanding that this species was found in stumps in the field. Nakashima et al. (1958), however, reported that they found colonies of this termite in electric poles and woodwork of houses in Miyazaki Prefecture. The author found two colonies of this termites on Nakano-shima. One was found in the stump of *Rhus succedones* L. and another in a rotten stump of an unknown tree—too decayed to identify.

So far as it is known, this species feeds on only two kinds of trees, viz., *Cryptomeria japonica* and *Rhus succedonea*.

**Distribution According to Food** It is a familiar principle that animal distribution tends to be limited by the presence and amount of food. Termites,

like other animals, tend to be limited in their distribution by the available plants upon which they feed under natural conditions. For this reason the relationship between the food of termites and their geographical distribution will be considered here.

### 1. The coniferous tree termites

Two species, *Leucotermes speratus* and *Coptotermes formosanus*, belong to the coniferous tree termites. Coniferous trees are widely distributed from subtropical zone to frigid zone. Therefore, termites belonging to this group have an abundant source of food. Latifoliate are also food resources of this group. Owing to a moderate climate, the Ryukyu Archipelago and the Japanese Archipelago are covered with forests except for the farming regions. Moreover, in the populated areas there are many wooden buildings, and as civilization advances, human culture also avails itself of cellulose in ever increasing amount and uses. It may be agreed that such abundance in food resources resulted in flourishing of the coniferous tree termites in both Archipelagos.

### 2. Debris or grass termites

Two species of termites belong to this group in the Ryukyu Archipelago. They are *Eutermes takasagoensis* and *Capritermes nitobei*, both belonging to the family *Termitidae*. Many individuals of these species have been examined and found to contain no Protozoa in their intestines. Concerning their food and the absences of Protozoa in their intestines, these termites supposedly feed on fungal fibers in organic debris or materials which have been decomposed through chemical processes in combination with some fungi or bacteria.

Since there are abundance of organic debris in nature, the resources of food for them are infinite. Because of the abundance of food in the Ryukyu Archipelago, this may not be the factor which operates to control the geographical distributions besides the faunas of fungi or bacteria. There are surplus of food resources in their unoccupied areas, so that their distributions do not seem to be limited by the absence or insufficiency of food. Though it is said (Maki, 1919) that *Capritermes nitobei* occasionally attacks living plants, this has never been found in the Ryukyu Archipelago. Thus, the distribution of this species may not be affected by the presence and amount of such living plants.

### 3. The fungi-growing termites

It is said that there are many species of fungi-growing termites in Africa (Sjöstedt, 1925), Ceylon (Escherich, 1911), and in the Philippines (Light, 1946), but only one species, *Odontotermes formosanus*, has been found to be the fungi-growing termite in the Ryukyu Archipelago.

This species builds fungus gardens as a special food where fungi grow throughout the year. In the beginning of summer mushrooms are grown in fungus

gardens, and they appear on the earth penetrating through the soil (plate III, C&D). As it is known, the family *Termitidae*, to which *Odontotermes formosanus* belongs, have no Protozoa in their hind-intestines. This fact indicated that this species owes its diet to the fungi because of the absence of Protozoa which seems to be necessary for the utilization of wood by termites (Cleveland, 1924; Hendee, 1933; ect.).

As this termite feeds on debris, well decayed wood, fallen leaves, etc., it, no doubt, has plenty of food resources in nature. It may be said that the wide distribution of this termite from the tropical zone to the temperate zone is due to sufficient food resources. However, in the Ryukyu Archipelago the northern limit of distribution of this termite is marked on Okinawa-jima. It may not be the food factor but some other factors which operate to control the distribution of this termite in the unoccupied areas.

#### 4. The huge tree termite

Of the Ryukyuan termites only one species, i.e., *Hodotermopsis japonicus*, belongs to this group. The known trees inhabited by this species are widely distributed throughout Formosa, the Ryukyu Archipelago and the Japanese Archipelago. This species occurs in the huge tree stumps or trunks more than 40cm. in diameter. In the Ryukyu Archipelago quite a few islands have forests of such large trees. Consequently, the distribution of this termite in the Ryukyu Archipelago is confined to several islands, i.e., Tokuno-shima, Amami-oshima, Nakano-shima, Yaku-shima and Tanega-shima where there are many huge trees in the forests.

Concerning the above distribution, it may not be the food factor alone but some other factor, such as temperature, operating to control the distribution of this species in the regions where the forests consist of huge trees.

#### 5. The soft-wood termites

This group includes two species of the family *Kalotermitidae*. These two species are *Kalotermes Koshunensis* and *Kalotermes satsumensis*.

*K. koshunensis* is widely distributed over the southern half of the Ryukyu Archipelago. So far as it is known, this species utilizes 15 species of trees as its food, and most of these trees are poor in their physical qualities and hardness. These trees may be said to be widely distributed over the Ryukyu Archipelago and more than half of them extend their range of distribution into the Japanese Archipelago. It appears to be a fundamental attribute of living organisms to tend to use all available food supply. The abundance of suitable food trees suggests that the northern half of the Ryukyu Archipelago is presumably open to invasion and infestation by this soft-wood termite of *Kalotermes koshunensis*.

Another species belonging to the soft-wood termites is *Kalotermes*

*satsumensis*. The range of distribution of this species irregularly covers Formosa and southern Kyushu. In the Ryukyu Archipelago it has been found on Ishigaki-jima and Nakano-shima. So far as it is known, this species prefers the cryptophagacia tree as its food. However, this tree does not grow in the Ryukyu Archipelago under natural conditions, with the exception of the high altitude of Yaku-shima.

Therefore, it is very probable that the absence of this species on most islands in the Ryukyu Archipelago has resulted from the absence of its food tree, the cryptophagacia tree, in most islands of the archipelago.

#### 6. The hard-wood termites

Here two species of termites belong to the group of hard-wood termites, viz., *Kaloterme fuscus* and *Kaloterme kotoensis*.

*Kaloterme fuscus* an extremely conventional food habit. A good example of relationship between food tree and the geographical distribution of species is seen in the case of *Kaloterme fuscus*. This species always feeds on pasania tree (Shiinoki in Japanese) with quite a few exceptions. As it is shown in the list of food tree for this termites (see P.119), the pasania tree is not found in all islands of the Ryukyu Archipelago, but is mostly restricted to islands being situated in the central curve of the Ryukyu Archipelago. In addition, this tree is not found on islands or parts of islands which are covered with limestones or younger deposits. *Kaloterme fuscus* has never been found on such islands or parts of islands, and is restricted only to islands or portions of islands where the pasania tree is growing under natural conditions.

For example, Okinawa-jima is geographically divided into two parts, i.e., the northern part and southern part. The northern part is composed of paleozoic and igneous rocks but the southern part is composed of tertiary and younger rocks and are covered with raised coral-reefs. The distribution of the pasania tree is confined to the northern part and is never found in the southern part. The extensive survey on Okinawa-jima revealed that the distribution of *K. fuscus* occurred in the northern part where the pasania trees are growing well in nature.

There are a few exceptional islands on which *K. fuscus* has not been found yet in spite of the author's efforts. The pasania tree is growing naturally on these islands. They are Kume-jima, Takara-jima, Kuchino-shima, Kuchinoerabu-shima, kuro-shima and Tanega-shima. A more intensive survey should be conducted on these islands.

According to Horikawa (1958), the range of distribution of the pasania tree covers the northern half of the Japanese Archipelago. The northernmost occurrence of *K. fuscus* is Wakayama Prefecture. This species has an abundant food resource in the northern half of the Japanese Archipelago. Therefore, the



food resources may not be the limiting factor of the geographical distribution for the termite.

Another termite belonging to the hard-wood termites is *Kalotermes kotoensis*. This species is one of the most common and widely distributed termite throughout the southern half of the Ryukyu Archipelago. It is well known that of the archipelago's timbers, *Podocarpus macrophyllum* (Inumaki in Japanese), *Ternstroemia gymnanthera* (Mokkoku in Japanese), *Bischofia javanica* (Akagi in Japanese), etc., are highly resistant to the attack of *Coptotermes formosanus* because of their structures being physically dense and hard. But these hard-woods are quite susceptible attacks by *K. kotoensis*. The extensive use of unseasoned, untreated hard-wood in the Ryukyus is bringing into play a more rapid distribution of termites and is increasing the infestation with termite to these untreated wood.

People believe that this increase is due to new invasion of this species after the world War II. Contrary to popular belief, *K. kotoensis* is not newly introduced from foreign countries, but is a native species. Strictly speaking, as it was pointed out in the author's previous paper (1959a), this increase is not due to new invasions, but only to the utilization of new resources of wood provided by man.

The 14 known species of trees which are attacked by this termite are widely distributed over the Ryukyu Archipelago in nature or in timbers used in buildings. From the standpoint of food supplies, it is highly probable that *K. kotoensis* will establish its colony in regions readily accessible beyond the present northern limit of distribution of this species.

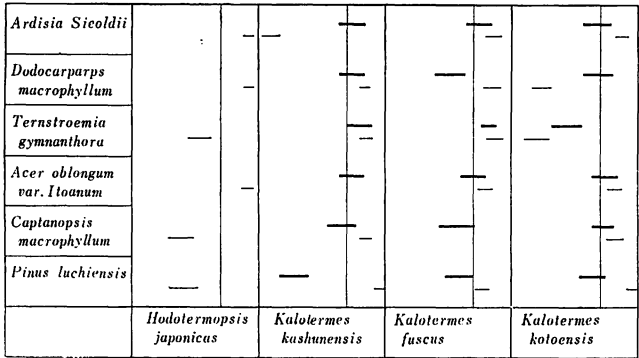
**Preliminary Wood Preference Test.**— According to field observations, each species of the stenophagus termites occurs only in particular species of wood. Why are they found in specific kinds of wood? To give satisfactory answers to the above question there seems to be many factors being analyzed.

The test herein described was made for the purpose of determining the general tendency of wood preferences shown by several species of the stenophagus termites. At the present time there are no records with reference to wood preference on any species of stenophagus termites occurring in the Ryukyu Archipelago.

The histories of the wood samples employed in this test are unknown, and test wood pieces (0.5cm. X 1cm. X 3cm.) were cut from wood which were already attacked by termites; hence, it seemed that these wood pieces were regarded to be favorable condition for their food. A hole (2mm. in diameter) was drilled in the surfaces of test pieces to a depth 3mm. The test was made in Petri dishes laid with moistened filter papers and the pieces of wood were radially arranged in the dishes alternately with preferred and unpreferred wood.

The six species of wood used were *Acer oblongum* var. *Itoanu m*, *Ardisia Sieboldii*, *Podocarpus macrophyllus*, *Pinus luchuensis*, *Captanopsis oustidata* and *Ternstroemia gymnanthera*. The termites used were dealates, soldiers, reproductive nymphs of *Kalotermes fuscus*, *Kalotermes koshunensis*, and *Kalotermes kotoensis*. Two series of tests were set, one involved for dealates and the other for other castes.

The test was allowed to continue for about a month, during which time observations were made twenty-five times on twenty-five different days, and the number of individuals of termites adhering to each piece of wood were recorded. Five sets of dishes were prepared for each species in each series and the number of termites in each piece of wood in each series was added up and represented by the percentage.



Text-fig. 17. Results of wood preference test to four different species of wood-dwelling termites. Thick lines.....dealates, thin lines.....other castes

Results of the tests are summarized in the Text-figure 17. The number of tests made is far too small to obtain sufficiently valid data for determinationnt, of wood preference on each species of termites. Although the data are not sufficie results of test indicate the following two points:

- 1). The wood preference shown by soldier and reproductive nymphs of four different species seems to differ considerably from species to species, and the wood showing the highest preference in the test coincides comparatively with the wood which has been frequently attacked by each species in nature.
- 2). On the other hand, in the case of dealates the wood preference obtained from the test does not coincide with the wood chosen by each species in nature. In other words, the wood preference shown by dealates of each species of the stenophagus termites does not seem to be conspicuous.

This differetiation of wood preference between dealates and other castes of the same species of stenophagus termites indicates that the dealates seek crack

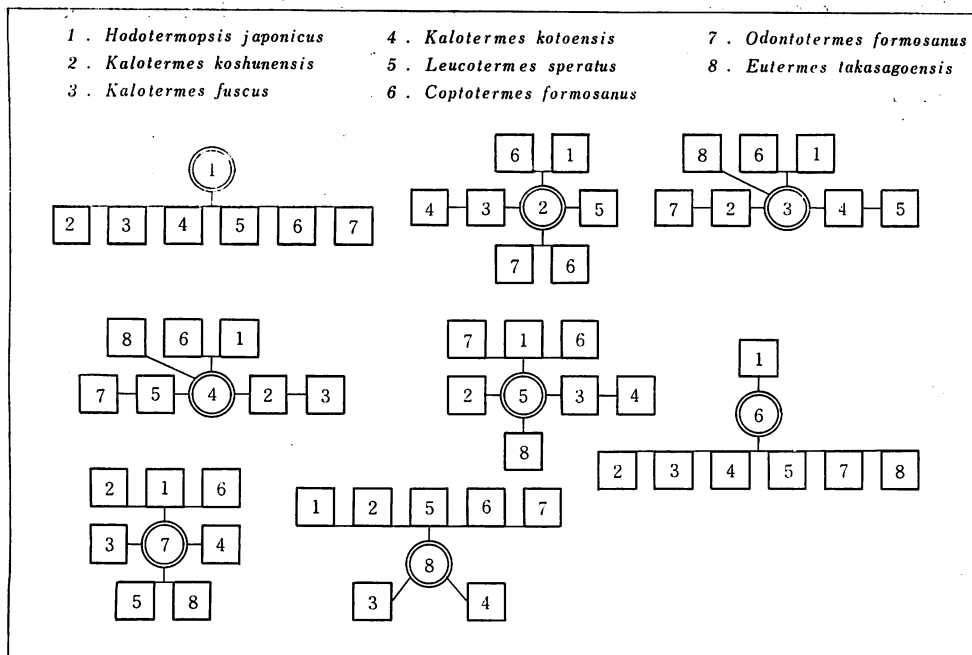
or crevice for the establishment of their new colonies. This does not mean that it is suitable as food because it does not seem that the dealates can afford enough time to seek a crack in a suitable wood for food in a brief period of colonizing flight. If they hit a suitable wood for food by chance, they would succeed in establishing a new colony; if not, they or their offspring would die sooner or later, so that, each species of stenophagus termites would occur in particular kinds of trees. It is baseless, however, to discuss this subject further on the basis of such simple tests. It is better to leave this subject for future study.

**The Relationship between Species of Termites to Food.**— Although termites have sufficient food resources, they cannot directly make use of all food resources. Some food resources are too hard to eat and others are poor in moisture content. Therefore the termites are compelled to be limited in the amount of food resources. In addition, several species aim at the same kind of food.

In this regard the relationship between species of termites to food is one of the important subjects to consider in the geographical distribution or local occurrence of termites, especially when considering a certain species invades new regions which are occupied by other species. The test herein described was conducted for the purpose of determining the principal part of struggles between species of termites.

The test was made in Petri dishes (12 cm. in diameter and 2.5 cm. in height) with moistened filter papers. A test block of each species consisted of 50 individuals containing workers, soldiers, younger nymphs. The number of soldiers was determined on the basis of proportions of soldiers to other castes in natural colonies based on the data at hand. The eight different species used in this test were *Hodotermopsis japonicus*, *Kalotermes Koshunensis*, *Kalotermes fuscus*, *Kalotermes kotoensis*, *Leucotermes speratus*, *Coptotermes formosanus*, *Odontotermes formosanus* and *Eutermes takasagoensis*. Two different blocks were put into a dish and observed for one hour. Results of the test are summarized in table 20. Table 20 and Text-fig. 19. give us some idea of struggle between species for their food.

It is not certain that such a struggle between species would actually occur in nature. In nature they seem to avoid each other or different species occupy the same stump rather than struggle among species. Kato (1960) said that a co-action between species at the same trophic level would be competition between them. It may be true, and if we analyze the co-action between species according to their food, we shall find the sort of competition between them as an important agent to operating to control the distribution or local occurrence of



Text-fig. 18. Summary of inter-species struggle of termites. Winer being put above; failer, under; slightly dominant, slanting above; and no struggle, sideways.

Table 20. Summary of the results of inter-species struggle.

1—*H. japonicus*, 2—*K. Koshunensis*, 3—*K. fuscus*, 4—*K. kotoensis*,  
 5—*L. speratus*, 6—*C. formosanus*, 7—*O. formosanus*, 8—*E. takasa-goensis*

	1	2	3	4	5	6	7	8
1		O	O	O	O	O	O	O
2	X		*	*	*	X	O	O
3	X	*		*	*	X	*	<u>X</u>
4	X	*	*		*	X	*	<u>X</u>
5	X	*	*	*		X	X	*
6	X	O	O	O	O		O	O
7	X	X	*	*	O	X		O
8	X	X	<u>O</u>	<u>O</u>	X	X	X	

O.....Predominance in desperate struggle

X.....Defeat in desperate struggle

\*.....Renunciation of struggle

O.....Slightly dominant in occasional struggle

X.....Slightly inferior in occasional struggle

termites. However, present study on this subject was just started, so that it is difficult to introduce anything conclusive about it.

*H. japonicus* has five different species of food competitors in its range of distribution; they are *K. satsumensis*, *K. fuscus*, *K. kotoensis*, *L. speratus* and *C. formosanus*. Among them, *K. fuscus*, *L. speratus* and *C. formosanus* are food competitors with *H. japonicus*. Table 20 indicates that this species struggles severely against all competitors and it can keep a dominant position with any competitor.

*K. koshunensis* has seven food competitors in the present range of distribution and one expected species of competitor in the unoccupied area. *H. japonicus* is the expected competitor and it shows predominance in competition with *K. koshunensis*. But *K. koshunensis* exists mainly in the housing area or coastal region and the kinds of food trees do not interfere with those for *H. japonicus*. Therefore, there seems to be no trouble between *H. japonicus* and *K. koshunensis* if the latter invades the regions which *H. japonicus* occupies. *K. koshunensis* did not compete with *K. fuscus*, *K. koshunensis* and *L. speratus* (Table 20). One reason may be that *K. koshunensis* is a soft-wood termites and *K. kotoensis* and *K. fuscus* are hard-wood termites. They feed on different food. *L. speratus* prefers decayed, moistened wood but *K. koshunensis* prefers dry and rather sound wood than dump-wood, so that they do not compete for the same food.

*K. fuscus* feeds on the hard-wood or heartwood, particularly of the pasania tree. Table 20 indicates that this species does not fight with other wood-dwelling termites, *K. koshunensis*, *K. kotoensis* and *L. speratus*. We can understand from its food habit the reason why it attacks only hard portion or heartwood remaining from attacks by other species. But this species was defeated by *H. japonicus* and *C. formosanus*. These two species are also found in the hard portion of the pasania trees, so that such competition demonstrated in this test would occur in nature.

*K. kotoensis* belongs to the hard-wood termites and is usually found in the woodwork of buildings. Therefore, it may not have had a chance to meet other wood-dwelling termites, a fact which induced no challenge to struggle with other wood-dwelling termites. It has one competitor, namely, *C. formosanus*. Both of them prefer the same food and therefore being expected to compete each other within house timbers. On the test this species fought with *E. takasagoensis* but not severely.

*L. speratus* is a damp-wood termite and occurs usually in places where constant moisture is present. This species did not fight the so-called wood-dwelling termites (Table 20). It can not be due to similar food habits because this species prefers to attacks damp, decayed wood and the others do not. This

termite fought with *C. formosanus* and *O. formosanus* and many individuals were killed by these two species. All these three species belonging to the euryphagous type has the similarity of their food habits, and hence they seem to compete each other for food.

Results of the test showed that *C. formosanus*, one of euryphagous group, fought with every species used in the test. This fact indicates that struggle with other species would be caused by competition for food.

*O. formosanus* fought with all species, except *K. fuscus* and *K. kotoensis*. The former species is a species of fungi-growing termites and it usually attacks debris or well decayed wood. On the other hand, the latter two species are hard-wood termites. The nonsimilarity of food habit has probably induced a nonchallenge in fighting with them.

*E. takasagoensis* is a species of euryphagous type and they feed mainly on debris. Though this species fought with all other species used for the test, it is difficult to explain from the viewpoints of food habit and habitat. But it may be explained that this species competed with six species, excluding two hard-wood species, for the same food. It is difficult to understand why this species fought with two hard-wood termites in spite of the non-similarity of food.

The results of this test are all comparative and should be ascertained by future study. The results indicate the following points:

(1). A struggle between species of termites is more severe between species which have similar food habit than those having different food habits.

(2). A struggle between species of termites is more severe between the species occurring in similar habitat than those occurring in different habitats.

**Discussion.**—Wood is the most resistant and durable product of vegetation, and is usually free from general insect attacks. It is physically resistant to their feeble eating mechanism, and chemically unsuitable for food. However, termites, among insects, accomplish a unique way of utilizing wood for food. Termites thus occupy specific levels in food chains and food pyramids. The extreme specializations of termites for taking special types of food are scarcely possible without the fungi and protozoa.

Comprehensive studies on fungi as food for termites have been made by Cleveland (1926, etc.), Hendee (1934a, b, 1935, etc.), Hungate (1941), etc. The results of these investigators indicate that the fungi offer a source of proteins, and probably supply vitamins which are essential to the growth and development of termites. Judging from the results of investigations, no colony of any species of termites, is without the presence of fungi in the walls of the burrows. Since species of the family *Termitidae* have no protozoa in their intestines, i.e., the fungi-growing termite (*O. formosanus*) and the debris or grass

termites (*E. takasagoensis* and *Cap. nitobei*), fungi may play an essential role in the tropical forests with enough heat and water offers sufficient source of food to these group of termites. In view of the above facts, it may be said that the existence of food to these group of termites is not a essential factor of termite distribution. In other words, the lack of fungi, makes these termites defer their invasions to the temperate zone. Table 20 indicates that all species of termites in the Ryukyu Archipelago have a surplus of food in their unoccupied areas.

All species of termites, except for these of the family Termitidae, keep protozoa and some other microorganisms in their intestines. The problem of the physiological relationship between the microorganisms and their hosts has been studied by Cleveland (1924-1934). The Physiological studies of the function of the intestinal Protozoa in Japanese termites have been done by Yamasaki (1930, 1931, 1937). It is well known by their works that Protozoa and bacteria in the digestive tract of termites may probably share in the chemical process by which cellulose is broken down into sugar.

Groups of the huge tree termite, the aceros tree termites, the soft-wood termites, and the hard-wood termites depend upon intestinal Protozoa for the utilization of wood for their food. The food habits of some species of these groups are fairly stereotyped; in other words, the food preference of them differs from species to species. The readiness with which certain termites attack a particular wood depends upon factors such as moisture content of the wood, its physical quality and hardness, and on the presence of extractives. If so, why have these species of termites never been found in similar wood under natural condition? What substance is the extract and is it actually toxic to particular species of termites? Is the extract a repellent or is it toxic to either the termites themselves or to the Protozoa? Many studies have appeared in this field from the stand-point of economic significance (Oshima, 1914a; Kofoid, 1934c; Dadswell et al, 1931; Erman, 1946; etc.). However, they do not present satisfactory answers for these questions. Studies in this area still remain as future projects.

It is very probable from the results of wood preference test and field observations that dealates of termites search about for a suitable crevice but not for a suitable wood for food. The reason for the absence of a particular species from certain kinds of wood may be physical resistance and chemical unsuitability for digestion rather than being repellent or possessing actual toxicity. In fact, the dealates of termites did not display conspicuous wood preference and they started new colonies in any wood pieces at random. Dealates which meet a suitable crevice or hole in a suitable wood probably will exist; if not, they will die because of the difficulty in their prevalent modes of digestion.

**Summary.**—The main conclusions may be summarized as follows:

(1). Although the food habits of most species of termites are fairly stereotyped, termites can be divided into two major types, the euryphagous and stenophagous type, according to their food habits. It can not be said that the former group is more northerly distributed than the latter group, and that the converse is true except *Coptotermes formosanus* and *Leucotermes speratus*.

(2). From the stand-point of food habit, termites also can be divided into two groups, the Protozoa-containing termites and fungi-growing termites. The former is distributed more northerly than the latter with no exception.

(3). A species of stenophagous type, *Kalotermes fuscus*, has never been found on islands or in regions where the pasania tree does not grow naturally.

(4). Wood preferences of the stenophagous termites do not seem to be strong at the beginning of the establishment of a new colony, but other castes of each species in the old colony show considerable preference for wood.

(5). There is a sufficient surplus of food resources in the unoccupied range of distribution of each species. This indicates the possibility of extension in the range of distribution of each species unless there are other controlling factors.

(6). Competition for food between species of termites is very important factor to consider in the local occurrence of termites, but so far as the Ryukyu Archipelago is concerned, it is not so significant when the geographical distribution is concerned.

## IX. THE INFLUENCE OF TEMPERATURE ON THE GEOGRAPHICAL DISTRIBUTION OF TERMITES.

Many termite investigators have made attempts to mark out ranges of distribution of termites on the basis of temperature. For example, Emerson (1934) prepared a map attempting to indicate the general area of the globe inhabited by termites. He indicated that there is an average of 10° C. between the mean annual isotherm, both north and south, and emphasized the controlling influence of climate. From a comparison of the temperatures of winter and summer of the northern limits of distribution of *Coptotermes formosanus* in Asia with corresponding records on the Pacific Coast of America, Kofoid (1934) suggested the possibilities of invasion and infestation in American tropics by this oriental species. In Japan, Abe (1937) indicated that the northern limits of the oriental termite, *Coptotermes formosanus*, might coincide with the 4° C. mean minimum daily temperature in January.

Most of these previous studies on this subject were attempted to find the relationship between the geographical distribution of termites and mean



temperatures. However, if a mean temperature is to be used as an agent controlling the distribution of termites, it should be backed up with the results of laboratory tests. An attempt on this subject has been done in this chapter on the basis of laboratory tests and mean temperatures.

Several laboratory tests were carried out to determine the innate capacity of each species of termite against the temperature factor. The innate capacity is very important in the geographical distribution of termites. Knowing the influence of temperature on the geographical distribution, three series of laboratory tests were conducted; 1). Tests on the differentiation of death rates among eight species of termites to the extremely low and high temperatures. 2). Comparison of preferred temperatures among eight different species. 3). Measurements of temperatures in the nests of several species of termites in nature or in a laboratory to determine favorable temperatures within which termites perpetuate their populations.

### Test on Temperature

**Test IX -I. Deathrate to low temperature extreme.**— The innate capacity of each species of termites to survive extremely low temperature probably varies with species. Therefore, it may be assumed that a rank of species according to their deathrate could be related to the rank of species occupying the northernmost limits of distribution. The following test was undertaken, based upon this assumption.

Materials and method.

Informations on eight species of termites used in this test are given in a tabular form in Table 21.

Table 21. Informations on eight species used in the test deathrate to the low temperature extreme.

Species	Date of collection	Locality
<i>Hodotermopsis japonicus</i>	Sept. 8, '59	Fun cha pass near Nase, Aami-oshima
<i>Kaloterms koshunensis</i>	Jul. 17, '59	Kinjo-cho, Naha, Okinawa Yona
<i>Kaloterms fuscus</i>	May 29, '59	Urasoe, Okinawa
<i>Kaloterms kotoensis</i>	May 29, '59	Urasoe, Okinawa
<i>Leucoterms speratus</i>	Jul. 17, '59	Kinlo-cho, Naha, Okinawa
<i>Coptoterms formosanus</i>	May 19, '59	Campus of Univ., Naha
<i>Odontoterms formosanus</i>	As occasion demands	Kinjo-cho, Naha, Okinawa
<i>Eutermes takasagoensis</i>	Aug. 15, '59	Nagura, Ishigaki

All the species of termites with the exception of *Odontoterms formosanus* were brought into a laboratory with trunks, stumps, timbers, logs, etc., which were infested by them, and were cultured as carefully as possible to keep them

under satisfactory conditions. The drywood termites, namely, *K. koshunensis*, *K. fuscus* and *K. kotoensis* were the most easily handled species. The damp-wood termites, namely, *H. japonicus*, *K. fuscus*, and *K. kotoensis* were best in a very damp atmosphere, or with a few drops of water. The earth-dwelling termite, *C. formosanus*, was also the most easily handled species. If it is kept in a warm place with a slightly humid atmosphere, it did very well. Another earth-dwelling termite, *O. formosanus*, was the hardest species to handle. Therefore, it was collected from the field as occasion demanded in order to obtain good results. *E. takasagoensis* is an easily handled termite. If it is kept in a damp atmosphere it does very well. The rare species, *K. satsumensis* and *Cap. nitobei*, were excluded from the test because their occurrences are restricted to only one or two islands, and moreover, their colonies was rarely found on those islands.

Workers were utilized for the following reason; (1) the workers by far the largest number in the colony and they are obtained in quantity. (2) It is the workers that do all the works of the colony, such as taking care of and feeding of other castes, gathering foods, building the tunnels, mounds, nests and fungus gardens. They do the most important functions to maintain the colony. The genus *Kalotermes* is without workers, and the functions of the workers are accomplished by the immature stages or nymphs of soldiers and reproductive nymphs (Light, 1924; Shiraki, 1954; etc.). For this reason the reproductive nymphs were used in this test. Care was taken to use only healthy, active, uninjured workers or reproductive nymphs.

Use of the freezing mixture (ice 3 ; salt 1 by weight) has always been a popular method to obtain low temperatures. This method was adopted to obtain low temperatures because of its simplicity and the results are believed to be as accurate and indicative as those obtained by more complicated procedures. In the apparatus used in the test, it kept the isothermal condition for 25 minutes to rise 1°C. Consequently, the length of time in which termites were exposed was 20 minutes. The number of individuals of each species was 50 for each test group and three groups were prepared for each species and for each grade of temperature. Hence the results were obtained from the average of numbers of individuals in three replications of test for each species at the same grade of temperature.

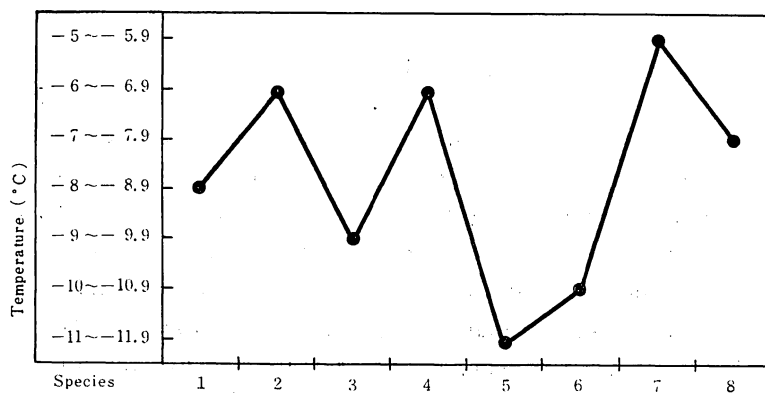
Prior to starting the test, the termites were kept in Petri dishes covered with moistened filter papers. When the temperature came to a desirable point, the termites were put into a beaker set in the apparatus. In this case care was taken to scatter the termites equally on the bottom of the beaker. If the termites were not placed equally, they were scattered by a small hair brush. The beaker with the termites were removed from the apparatus 20 minutes after putting them into the beaker. In order to examine the individuals in the beaker

were put out on a sheet of paper. When they were touched with the small hair brush, the termites which did not show any motion at the antennae, legs and bodies were judged to be dead.

The test was undertaken in room temperature at about 25-28.5°C. Records of relative humidity during this test showed a variation from 86 to 92 percent. The test was carried out in September, 1959.

#### Results.

The results of the test showing deathrates at extremely low temperatures of eight different species of termites are shown in Text figure 19. Text figure 19 presents a comparison of 50 percent of deathrate for eight species of termites. It is obvious from Text figure 19 that the L. D. 50 (i.e., the exposure required to kill half the termites in the sample) differs from species to species in the temperature at which 50 percent of the individuals were killed by exposure to the low temperature extreme for 20 minutes. The L. D. 50 of the eight different species of termites appeared between  $-5^{\circ}$  and  $-12^{\circ}$  C., and *L. speratus* seems to have the strongest tolerance to the low temperature extremes of  $-11^{\circ}$  to  $-11.9^{\circ}$  C. of the L. D. 50. *O. formosanus* seemingly has the weakest tolerance to the low temperature extremes and showed the L. D. 50 between  $-5^{\circ}$  and  $-5.9^{\circ}$  C. by exposure for 20 minutes. Two wood-dwelling termites, i.e., *K. koshunensis* and *K. kotoensis* have weaker tolerance and the low temperatures of the L. D. 50 for them were between  $-6^{\circ}$  and  $-6.9^{\circ}$  C.



Text-fig. 19. The L. D. 50 for eight species of termites against low temperature extremes. 1.....*Hodotermopsis japonicus*, 2.....*Kaloterme koshunensis*, 3.....*K. fuscus*, 4.....*K. kotoensis*, 5.....*Leucotermes speratus*, 6.....*Coptotermes formosanus*, 7.....*Odontotermes formosanus*, 8.....*Eutermes takasagoensis*.

From the results of this test the rank of species of termites according to the low temperature of the L. D. 50 from low to high, is as follows:  
*Leucotermes speratus*—*Coptotermes formosanus*—*Kaloterme fuscus*—

*Hodotermopsis japonicus*→*Eutermes takasagoensis*→*Kaloterms kotoensis*=  
*Kaloterms koshunensis*→*Odontotermes formosanus* .....Rank I

#### Discussion

The lethal influence of low temperature has been the subject of much study, especially by entomologists. Little attention has been paid to termites regarding this subject. It is generally accepted by many investigators that the geographical distribution of genera and species of termites is determined by minimum and maximum limits of temperature. This may be true. How does low temperature operate to limit the distribution of termites? Is it by killing them directly within a short time or over a long period? It is very difficult to give answers to these questions and it requires further study to obtain satisfactory answers. If the winter minimum temperature operates to limit the distribution of termites by killing them directly, the northernmost limits of distribution is perhaps closely related to their tolerances against the exposure to low temperature extremes.

So far as it is known, the rank of eight species of our oriental termites according to latitudinal distribution, from north to south, are as follows:

*Leucotermes speratus*→*Coptotermes formosanus*→*Kaloterms fuscus*→*Odontotermes formosanus*→*Hodotermopsis japonicus*→*Kaloterms kotoensis*→  
*Kaloterms koshunensis*→*Eutermes takasagoensis*

.....Rank II

Comparing rank I and II, they do not entirely coincide with each other, although they are partly alike. It may be said that the rank of species according to their northern limits of distribution would not always be determined by the strength of their tolerances to the low temperature extremes.

It is thoughtless, therefore, to apply the results of this test to termites living in nature. The matter is not simple but is complicated by the following considerations: (a) Different stages in the life-cycle as well as different castes may have different tolerances to the extremely low temperatures. (b) The sudden change of temperature used in this test never occurs in nature. (c) From the viewpoint of acclimatization, the condition of termites prior to the test must be taken in consideration. Detailed discussion of these matters should be left until further studies are conducted. According to the data at hand, the lethal influence of low temperature does not seem to differ widely among castes of termites.

The winter minimum temperatures at the northern limits of geographical distribution of the eight species of termites are higher than the temperature grades in which termites were killed by the exposure for 20 minutes. In addition, the temperatures in the nests never stand at such temperature below zero degrees centigrade as the author obtained in the test. In this regard, ex-

tremely low temperature of several degrees below freezing point may not be considered as the important agent controlling the northward expansion of ranges of distribution of termites, but the strength of tolerance of termites closely relates to the northern limits of distribution of termites.

#### Conclusion.

The above discussion leads to the following conclusion:

1). The L. D. 50 of termites against the low temperature extremes differs from species to species. The rank of species according to the tolerance to the extremely low temperature, from strong to weak, are as follows:

*Leucotermes speratus* → *Coptotermes formosanus* → *Kalotermes fuscus* → *Hodotermopsis japonicus* → *Eutermes tahasagoensis* → *Kalotermes kotoensis* = *Kalotermes koshunensis* → *Odontotermes formosanus*.

2). The L. D. 50 of the eight species living in the Ryukyu Archipelago occur between  $-5^{\circ}$  and  $-12^{\circ}$  C. when they are exposed in low temperature extremes for 20 minutes.

3). The extremely low temperature, several degrees below freezing point, probably does not operate to control the northward expansion of ranges of distribution of termites by killing them directly, but the strength of tolerance of termites seems closely related to northern limits of distribution of termites.

4). From the results of tests of deathrates due to low temperature extreme, the tolerance of *Kalotermes satsumensis* and *Capritermes nitobei* may be predicated, although they were not used for the test. The former will rank between *C. formosanus* and *H. japonicus*, the latter will be placed last.

**Test IX-II. Deathrate to High Temperature Extreme.**—A comparison between the tolerance against low temperature extreme and the northern limits of distribution of termites has already been discussed. As the next step, the author attempted to consider the relationship between the tolerance of termite to high temperature extreme and the southern limits of distribution of termites.

There are many studies on thermal death point of many kinds of animals, especially of insects. So far as the termites are concerned, there has been much work done on the lethal influence of high temperature than of low temperature. Work on the termite in this field have been done mostly by American investigators. O'kane et al. (1922) reported on controlling *Reticulitermes flavipes* by raising the temperature of steam piping to  $135^{\circ}$  F. for 48 hours. Snyder (1915, 1916a, 1916b, 1919, 1926, 1931, 1935) has done much work on the use of heat for termite control. Recently, In Japan, Shimizu et al. (1958) reported that the workers of *C. formosanus* were killed by exposure to  $45^{\circ}$  C. for at least 32 minutes.

The following test was undertaken on the assumptions that termites which

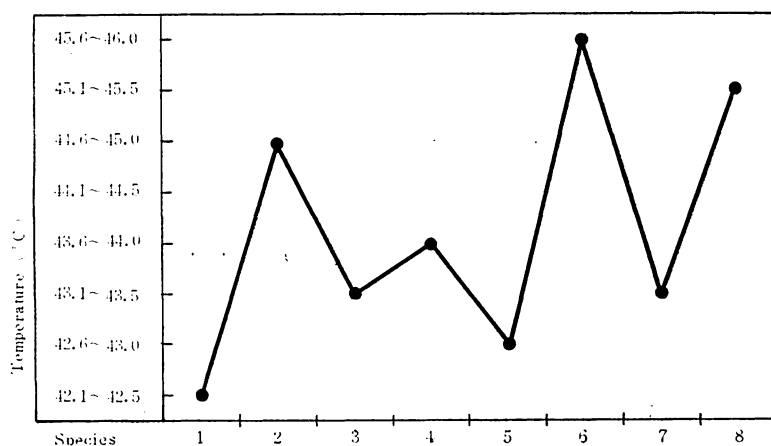
had extended their ranges of distribution northerly might have weaker tolerance to extremely high temperature and the converse might be true, and that *Hodotermopsis japonicus* might be limited by high temperature extremes to infest southward, because the southern limit of distribution of this species would be marked within the Ryukyu Archipelago.

#### Materials and Method.

Information on materials are the same as those of Test VII-I. Eight wide-mouth glass bottles (5 cm. in diameter and 11 cm. in depth) were fastened with a string in a shallow tin-can. This tin-can with eight bottles were put into a thermostat and kept in suitable depth by using several sinkers, but water did not go into the bottles. When the temperature in the bottles was set at a desirable degree, a test group of each species of termite was put into the different bottle respectively. 30 minutes after putting the termites, the bottles were taken out with the tin-can from the thermostat. The termites were then taken out on a sheet of paper for examination. The dead were distinguished from the living by the same method as in Test VII-1.

#### Results and Discussion.

The results of the test for tolerance of termites to high temperature extremes are given graphically in Text-figure 20. The figure indicates that the L. D. 50 of the termites by exposure to high temperature for 30 minutes differs from species to species. *C. formosanus* seems to have a strong tolerance against high temperature extremes, and *H. japonicus* seems to have the weakest capacity. *L. speratus* also has a weak tolerance to high temperature, showing



Text-fig. 20. The L. D. 50 for eight species of termites against high temperature extremes. 1.....*Hodotermopsis japonicus*, 2.....*Kalotermes koshunensis*, 3.....*K. fuscus*, 4.....*K. koshunensis*, 5.....*Leucotermes speratus*, 6.....*Coptotermes formosanus*, 7.....*Odontotermes formosanus*, 8.....*Eutermes takasagoensis*.

the L. D. 50 at high temperature between 45.1° and 45.5° C. *O. formosanus* and *K. fuscus* seemingly have equal tolerance to high temperature extreme and the L. D. 50 for them occurs at 43.1°-43.5° c. The rank of species according to the tolerance to high temperature extreme for eight species, from weak to strong, is as follows;

*Hodotermopsis japonicus*→*Leucotermes speratus*→*Kaloterms fuscus*=  
*Odontotermes formosanus*→*Kaloterms kotoensis*→*Eutermes takasagoensis*→  
*Coptotermes formosanus*. .....Rank III.

Contrary to expectations, the rank does not entirely coincide with rank II, but is partly similar to each other. If each species is carefully examine, it suggests a valuable fact which serve to elucidate the geographical distribution of termites. For example, *H. japonicus* seems to have the weakest tolerance to high temperature extreme among the eight species. This species has the weakest tolerance and has the southernmost limit of distribution among the Ryukyuan termites. This fact indicates that the lack of innate capacity to withstand high temperature extremes is probably responsible to limit the expansion of distribution of this species southwards. *L. speratus* also showed a weaker innate capacity to tolerate high temperature extreme and is the most northerly distributed. It is highly probable that the thriving of this species in the northern regions may be influenced by its low capacity to tolerate high temperature extreme and that the southernmost limit of distribution seems to be marked northwardly somewhere next to *H. japonicus*. *C. formosanus* probably has the strongest capacity and is the southernmost distributed species next to *O. formosanus*. This fact indicates that at the southernmost limits of the range of distribution its invasion to warmer regions may be limited by its innate capacity.

But there are several species whose northern or southern distribution does not seem to be closely related to their innate capacities to high teperature extreme. For example. *O. formosanus* is one of the southwardly distributed termite among the Ryukyuan termites, but the innate capacity to stand high temperature is not strong but rather weaker. The range of distribution of *O. formosanus* is farther south than that of *K. koshunensis*, but Text-figure 20 indicates that the latter is weaker than the former in the capacity to tolerate high temperature extreme.

Most termite investigators report that the lethal point of *C. formosanus* is 45° C. (Tamura, 1956; Morimoto, 1958; Shimizu et al, 1958). According to the author's study, the L. D. 50 of this species by exposure to high temperature occurred between 45.6° and 46°C. Data at hand show that some workers of the test sample still showed feeble movement at their antennae, legs and maxillary palps, though they were placed in 46.5° C. for 30 minutes. The lethal temperature of this species is a little higher than the previous investigators. It is a very

interesting problem to pursue in the future if the difference of the lethal temperature between the author's and previous investigators' is due to acclimatization or some other reasons.

Judging the results of the test, the extremely high temperature adopted in the test does not seem to control the geographical distribution of termites in the Ryukyu Archipelago by killing them, because any meteorological temperature never rise as high as 40° C. There is a tendency for the termites to keep their nest cooler than the air on extremely warm days. Doubtless, they may escape from the high temperature extreme to the favorable range of temperature in their residences. It is generally said that the southern limits of distribution of termites are determined by the summer maximum temperature. But it is very difficult to find out what degree of high temperature operate to control the geographical distribution by killing them directly in nature. Although the assumption prior to the test had to be given up, the rank of some species of termites according to the innate capacity of tolerance to high temperature extreme is going in line with the rank according to the geographical distribution, from north to south.

Snyder (1926) reported that the dry-wood termite, *Cryptotermes brevis*, in Southern Florida was killed in furniture in an attic with glass skylight where the sun's rays caused temperatures of 17° to 24° F. higher than the maximum outdoor temperature. This report indicates that the local occurrence of some species of termites was controlled by extremely high temperatures. Snyder's study was the case of the high temperature extreme operating to control the local occurrence of termites, but not the case of geographical distributions. In addition, the soil nesting termites can select their favorable temperature by passing through their passages, but the dry-wood termites are enclosed themselves in the wood and can not escape from high temperature extreme. Therefore, it seems difficult to explain the southernmost distribution of termites by high temperature extremes which kill the termites directly.

#### Conclusion.

The laboratory study on the deathrate by temperature extremes for eight species of termites leads us to the following conclusion:

1). The extremely high temperature which caused the L. D. 50 of each species of termites varies with species when it is exposed for 30 minutes. The range of high temperature causing the L. D 50 for the eight species seems to be between 42° and 46°C.

2). The rank of species according to the L.D.50 by exposed high temperature extremes from weak to strong, is as follows:

*Hodotermopsis japonicus* → *Leucotermes speratus* → *Kalotermes fuscus* = *Odontotermes formosanus* → *Kalotermes kotoensis* → *Eutermes takasagoensis* →



*Coptotermes formosanus.*

3). The geographical distribution of *H. japonicus* seems to be controlled southerly by the high temperature factor because of the relationship between the rank of innate capacity and that of the geographical distribution.

4). In the Ryukyu Archipelago the innate capacity of termites to tolerate temperature extremes does not seem to influence geographical distribution of termites but seems to affect local occurrence.

**Test IX-III. Preferred Temperature.**— The relationship between the temperature extremes and the geographical distribution of termites has been discussed. As the next step, the author attempts to consider the relationship between the preferred temperature of termites and their geographical distribution.

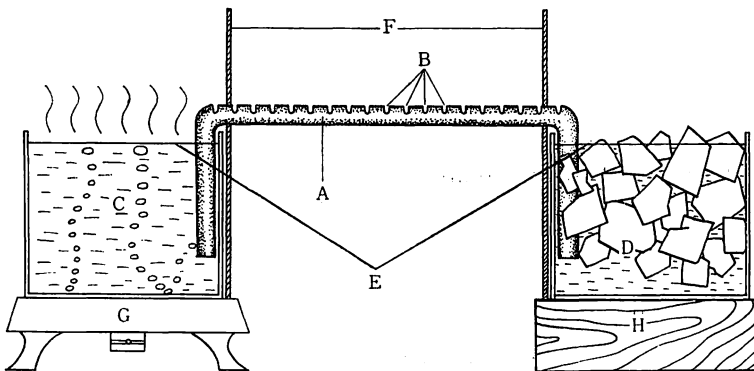
If an animal is exposed to a low or high temperature which is beyond the favorable range, it may be killed directly, or it may continue to live for an indefinite period but fails to grow or produce any young. Termites, like other animals, have optimum ranges of temperatures. However, the concept of optimum in ecology is hard to understand unless the life process is specified. Many examples indicate that no one point on the thermal scale can be designed as the optimum for the entire growth of an organism, but that optimum value differs according to the life stage of each species.

In this regard the author has adopted in this paper the concept of preferred temperature for the purpose of analyzing the distribution of termites in stead of the optimum temperature. The term "preferred temperature" follows the definition of Andrewartha et al (1954). That is, "When animals are allowed to move freely along a temperature gradient, they usually congregate between quite narrow limits of temperature. This narrow band of temperature has been called the preferred temperature or temperature preferendum". Since all life stages of termites have been found in any colony of termites throughout the year, a range of temperature within which the termites, as a whole, show their normal activities and behaviors should be considerably high. Therefore, the author has attempted to explain the geographical distribution of termites from the standpoint of optimum temperature. However, the concept of optimum in ecology is hard to understand unless the life stage is specified. It is the author's hypothesis that the preferred temperature of poikilothermal animals may be nearly the same as their optimum temperature. Consequently, the author believes that it is a short-cut method to explain the geographical distribution of termites from the standpoint of the preferred temperature instead of the optimum temperature.

**Materials and Method.**

Information on termites used in this test is the same as that of Test VII-I. However, the number of individuals for each group was not confined to a specific number because it was difficult to equalize the number of individuals of each test group due to the apparatus adopted for the test. Equalization of the number of individuals is not always suitable to attain the purpose of this test. In a defined area a favorable number of individuals for a certain species may not always be favorable for other. In terms of the habits of the termites, the higher density population shows their natural activities more than in the lower population.

A device for testing is shown in Text-figure 21. An iron-bar (70cm. in length and 2.5cm. in diameter) was turn down in the edges to 15cm. On the upside of the bar many small holes were made in order to take the temperature at the corresponding portions of the bar. One end of the bar was put into ice-water and the other was soaked in boiling water. It took about 30 minutes to make the temperature settle in each hole.



Text-fig. 21. Sketch showing a device testing preferred temperature of termite. A.....Iron bar, B.....Holes, C.....Boiling water, D.....ice-water' E.....Water level marks, F.....Heat protector, G.....Heater, H.....wooden stand.

When the temperature settled, termites were placed as many as possible equally on the bar. As they were allowed to moved freely along a temperature gradient of the iron-bar, they shifted and congregated in a favorable range of temperature. However, at the extremely hot range, most of the termites fell down from the iron-bar and few succeeded in shifting from the hot range to the favorable range. On the other hand, at the extremely cold range, some of them stuck there after the short locomotion and the rest fell from the bar or moved into the warmer range.

The count of termites in the temperature gradient of the iron-bar was done by taking photographs (plate III) from several directions at at one time, 30 minutes after the test started. It is very difficult to determin the accurate range of

preferred temperature for animals. Termites, however, quickly responded to the temperature change and they arrange themselves between quite narrow limits of temperature. The congregation of termites in the temperature gradient is very conspicuous and characterized by the types of swarms presented by each species of termites.

The following index was adopted to determine the limits of preferred temperature:

1). The status of activities in the range of preferred temperature is judged by deliberate movement of antennae, moderate movement on the whole body and motionless or gentle locomotion in a short distance.

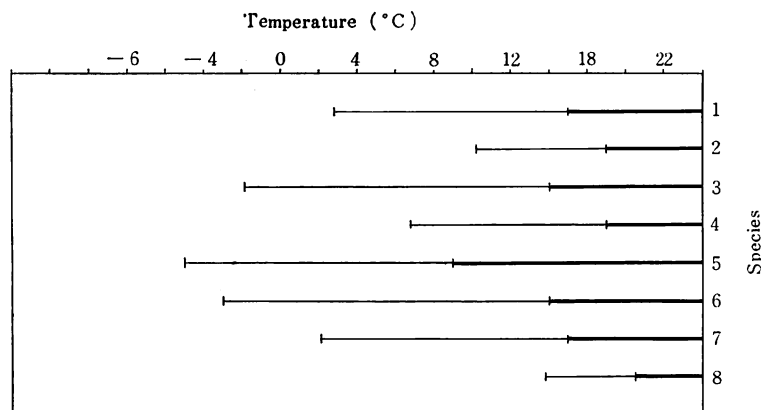
2). The status of activities in the range of high temperature is irritating movement of antennae, vigorous and irregular movement of the whole body.

3). The status of activities in the range of lower temperature is slow or rare movement of antennae, adherence at the same place or slow walking and feeble movement of the whole body.

4). The doubtful regions between the preferred temperature and the lower or higher temperature are determined by dividing the doubtful range into two. In this way the boundaries of preferred temperature were determined.

#### Result.

Result of Test IX-III are summarized in Text-figure 22. The figure indicates that termites prefer quite narrow limits of temperature. The data in Text-figure 22 show that the distribution of termites in the temperature gradient characterized the kind of termites. Some species arranged themselves at the higher part of



Text-fig. 22. The lowest preferred temperatures of eight species of termites (the end of thick lines.)

- 1.....*Hodotermopsis japonicus*, 2.....*Kalotermea koshunensis*,  
 3.....*K. fuscus*, 4.....*K. kotoensis*, 5.....*Leucotermes speratus*,  
 6.....*Coptotermes formosanus*, 7.....*Odontotermes formosanus*,  
 8.....*Eutermes takasagoensis*

range of preferred temperature and others congregated at the lower part of range. Some species congregated within a narrow range and other were distributed in a fairly wide range.

*H. japonicus*.— This species congregated within the limits of 18° and 29° C., and particularly abundant at about 24° C. About 70 percent of the individuals stayed and showed their normal activities in this narrow 11° C. range of temperature.

*K. Koshunensis*.— The preferred temperature range for this species seems to be fairly wide, ranging from 20° to 34° C. and over 75 percent of the individuals settled in this 14° C. band of temperature.

*K. fuscus*.— As it was shown in Text-figure 22, the preferred temperature range for this species is considered to be between the limits of 17° and 34° C. and over 75 percent of the individuals came to rest within this 17° C. band of temperature, congregating most abundantly at about 27° C.

*K. kotoensis*.— The preferred temperature of this species appears to be between 20° to 30° C. and about 80 percent stayed at this 17° C. band of temperature, being particularly abundant between 25.5° and 28° C.

*L. speratus*.— The preferred temperature range of this termite was widely spread, ranging from 12° to 30° C. About 80 percent came to rest in this 18° C. band of temperature, especially congregating between 25.5° and 28° C.

*C. formosanus*.— This species particularly exhibits a remarkable tendency to prefer a favorable temperature. Over 80 percent of the individuals arranged themselves between the limits of 17° and 32° C., particularly between 22° and 32° C.

*O. formosanus*.— According to Text-figure 22, this species also a remarkable tendency to prefer favorable temperatures. Most individuals arranged themselves between the limits of 18° to 33° C. Over 80 percent stayed and showed their normal activities in the above range of temperature being most abundant at about 27° C.

*E. takasagoensis*.— This species like *C. formosanus* has an extreme inclination to the temperature. Over 70 percent swarmed between the limits of 21.5° and 36° C., being particularly abundant between 33° and 36° C.

The preferred temperatures of eight different species of termites obtained from the result of Test IX-III are summarized in Table 21.

Table 21. Showing the preferred lowest temperatures of the eight different species of termites occurring in the Ryukyu Archipelago.

	<i>H. japonicus</i>	<i>K. koshun- ensis</i>	<i>K. fuscus</i>	<i>K. kotoensis</i>	<i>L. speratus</i>	<i>C. formosa- nus</i>	<i>O. formo- sanus</i>	<i>E. taka- sago- ensis</i>
Lowest pref. temp.	18	20	17	20	12	17	18	21.5

Highest pref. temp.	29	34	34	36	30	32	33	36
Range of pref. temp.	11	14	17	16	18	15	15	14.5

The lowest and highest limits of preferred temperature of termites vary with species. The rank of species according to the lowest limit of preferred temperature, from low to high, is as follows:

*Leucotermes speratus* → *Coptotermes formosanus* = *Kalotermes fuscus* →  
*Hodotermopsis japonicus* = *Odontotermes formosanus* → *Kalotermes*  
*koshunensis* = *Kalotermes kotoensis* → *Eutermes takasagoensis*

.....Rank IV

#### Discussion.

The tendency to move in a definite direction along a temperature gradient until termites come to rest in some particular part of it may sometimes be recognized as an adaptation which helps the termite to avoid the temperature extremes. The termites show response to temperature gradient. This tendency undoubtedly depends upon the innate habit of termites. In nature the termites develop their burrows so as to shift their location to avoid exposure to the extremely high or low temperature. Differences in concentration of individuals some times have been seen between the north and south sides of stumps may be correlated with the differential exposure to the sun's heat. In winter the earth-dwelling termites also shift their location to the inner burrows deeper in the location to shift their location there. The wood-dwelling termites also shift their earth and the inner burrows to avoid the temperature extreme. Thus, the preferred temperature of each species of termites obtained from the test is valuable to understand the geographical distribution and local occurrence of termites.

According to the result of Test IX-III, the preferred temperature of termite varies not only with species but also in width of range, lowest and highest limits, density of population, etc. Generally speaking, species of termites which are distributed in the southern areas, and there having wide range of preferred temperature are more widely distributed geographically. As it is obtained in Text-figure 22, *H. japonicus*, *K. fuscus*, *L. speratus*, *C. formosanus* choose the lower preferred temperature than *K. koshunensis*, *K. kotoensis* and *E. takasagoensis*, and the former extend their range of distribution further north than the latter. *K. fuscus*, *K. kotoensis* and *L. speratus* have the wider range of preferred temperature as compared to *H. japonicus*, *K. koshunensis* and *E. takasagoensis*, and the former are distributed in wider areas than the latter. Although *C. formosanus* and *O. formosanus* have narrow ranges of preferred temperature, they are widely distributed. These two species belong to the earth-dwelling termites, hence, their narrow ranges of preferred temperature may be supplemented by their earth-dwelling habits.

Comparing Rank IV with II, they do not entirely coincide with each other, but they are very similar in the order. In Rank IV, *C. formosanus* and *K. fuscus* are placed at the same order in spite of the former preceeding the latter in the Rank II. The reason is that the former is able to expand its range of distribution by their earth-dwelling habit more north-wardly than the latter. In Rank IV, *K. koshunensis* and *K. kotoensis* are also placed in the same order, though the latter preceeds the former in Rank II. The two species are wood-dwelling termites, but *K. koshunensis* is a forest termite and *K. kotoensis* is a household termite. Undoubtedly it is warmer in the house than in the outdoors during the winter minimum temperatures, and *K. kotoensis* has great opportunity of dispersal by man than *K. koshunensis*. Consequently, it is reasonable that *K. kotoensis* is more northerly distributed than *K. koshunensis* in spite of having the same lowest limit of preferred temperature. One more point of disordance between the Rank IV and II is in the case of *H. japonicus* and *O. formosanus*. The former is damp-wood termite and the latter is the fungi-growing termite. It is very probable that *O. formosanus* could spread more northwardly than *H. japonicus* owing to its soil-nesting and fungi-growing habit.

If the preceeding discussion is valid, the rank of species according to temperature from the lowest to the highest, coincides completely with the northernmost limit of distribution, from north to south, and hence the preferred temperature becomes valuable in considering the geographical distribution of termites. But, before discussing the distribution of termites, we must know the temperature in the termite's nest which allows them to carry on their normal activities. This aspect will be discussed later in this chapter.

#### Conclusion.

From the results of the tests conducted on the preferred temperature within the temperature gradient, the following conclusions can be made:

1). When termites are allowed to move freely along a temperature gradient, they quickly arrange themselves within a narrow range of temperature. This narrow limit within which the termites congregate varies not only with species but also with the width of the range, population density and the minimum-maximum limits.

2). There is a tendency for termites having a wide range of preferred temperature to be widely distributed.

3). The lowest limit of preferred temperature seems to be worthy of consideration in the geographical distribution. The rank of eight species according to their preferred temperatures, from the lowest to the highest, is as follows:

*Leucotermes speratus* — *Coptotermes formosanus* = *Kalotermes fuscus* —  
*Hodotermopsis japonicus* = *Odontotermes formosanus* — *Kalotermes*

*koshunensis* = *Kalotermes kotoensis* → *Eutermes takasagoensis*.

4). The rank of preferred temperature does not entirely coincide with the rank of geographical distribution of termites, and the discordance between the ranks appears to be due to the difference in their behaviors responding the temperature factor.

### Temperature in the Nests of Termites.

From the results obtained in the series of tests, some hypotheses relative to the influence of temperature on the termites were postulated in order to know the environmental temperature within which termites conduct activities of self-preservation and reproduction. It is not the atmospheric temperature but the temperature in the nest that influences the termites. For the next step, therefore, the temperature in the nest of termites must be considered.

The temperature in the nest is not constant throughout the year but changeable with variations in species, season, locality, day or night, weather, depth from surface of soil or wood, population of colony, etc. It is, therefore, not an easy task to find a particular degree of temperature to meet every environmental condition.

An attempt has been made by the author to determine the relationship between the temperature in the nest and the geographical distribution of termites. For this study a common laboratory thermometer, thermograph were used. All the thermometers were adjusted to the standard temperature in the Ryukyu Meteorological Station in Naha, Okinawa.

#### 1. Temperature in the nest of *Hodotermopsis japonicus*.

The Japanese large termite, *Hodotermopsis japonicus*, is usually found in portions of dead trunks, decayed trees, stumps in forest. The nest temperature of this species was taken on Yaku-, Nakano-shima and Amami-oshima. Data on the nest temperature of this species are summarized in Table 22.

Table 22. Data relative to the temperature in the nest of *Hodotermopsis japonicus*.

Date	Time	Weather	Temperature		** Depth	Locality
			Air	Nest		
Mar. 4, '57	10:00	Cloudy	7.5	18.6	3	Koshugidani, Yaku-shima
Mar. 8, '57	13:00	Rainy	10.9	18.8	4	Ittso, Yaku-shima
Sept. 23, '57	14:00	Fine	27.7 (28.5 20.3)*	27.8	5	Shirisaki, Nakano-shima
Sept. 24, '57	11:00	Fine	27.4 (28.6 24.0)*	28.2	3	Takao, Nakao-shima
Sept. 25, '57	12:00	Fine	26.6 (26.2 23.5)*	27.4	4	Nanatsuyama, Nakano-shima

\*.....Maximum and minimum air temperatures on Nakano-shima offered by the

Nakano-shima Observatory.

\*.....Depth from the surface of wood in which these temperature were taken.

Table 23. Comparison of temperature in the nest of *H. japonicus* with those of atmosphere and surroundings of the nest at Funcha near Nase City; Amami-oshima.

Date		Weather	Temperature					
			* Atmosphere Max.	Min.	Surrounding Max.	Min.	**Nest Max.	Min.
Sept.	3. '59	Fine	33.5	24.6	31.2	25.1	28.1	27.2
"	4. '59	"	33.4	24.1	31.3	24.7	27.9	27.4
"	5. '59	"	34.4	24.1	32.0	24.4	28.3	27.7
"	6. '59	"	33.9	25.6	31.3	25.7	28.2	27.5

\*.....Offered by the Nase Meteorological Station.

\*\*.....Three cm. inside stump-root, and 20 cm. under the ground level.

In cool weather the temperature in the nest of *H. japonicus* was a little higher than that of the surrounding air (Table 22). On the other hand, during summer the nest temperature always stood between the maximum and minimum temperature of both the atmosphere and the surrounding air. It is worthy to note that the highest temperature in the nest was about 28° C. during the test period of September. It may be due to the following reasons: as it is well known with bees and other social insects, the termites can keep their nest warmer than the surroundings in the extremely cold weather by means of metabolism. In Extremely hot weather the temperature in the nest could be lowered by evaporation of moisture in the nest or surrounding the nest.

It is obvious from the results of nest temperature readings that the temperature in the nest of *Hodotermopsis japonicus* is not constant but changeable depending on weather, time of day and follows seasonal change of the air temperature. Data on the nest temperature of this species are still inadequate to make valid conclusions. Unfortunately, there are no obvious records relative to the nest temperature of this species. Therefore, the author hesitates to make any conclusions about it. Judging from Table 22 and 23, it is highly probable that on an extremely hot day in summer, the temperature in the nest of *H. japonicus* stands between the daily minimum and maximum air temperatures and on an extremely cold day in winter, it always keeps higher temperature than the daily air temperature.

## 2. Temperature in the nest of *Kaloterms koshunensis*.

In January, 1959, the survey on temperature in the nest of *Kaloterms koshunensis* was made at the edge of woods in Kinjo-cho, near the campus of the University of the Ryukyus. The colony in which the author took the



temperature was found in a stump (about 12cm. in diameter) in the center of woods and was located 1.2 meters above the ground level. The woods also covers considerable area of the hillside facing south and is dotted with buildings here and there.

In taking the temperature, the nests were drilled about 3cm. and inserted with a maximum-minimum thermometer. The crevices between the thermometer and wood were stuffed with cottons so as to obtain a reliable temperature. After taking the temperature, the author made sure that the club of thermometer had been inserted into the chamber in taking the temperature. The results of recordings are summarized in Text-figure 23 and Table 24.

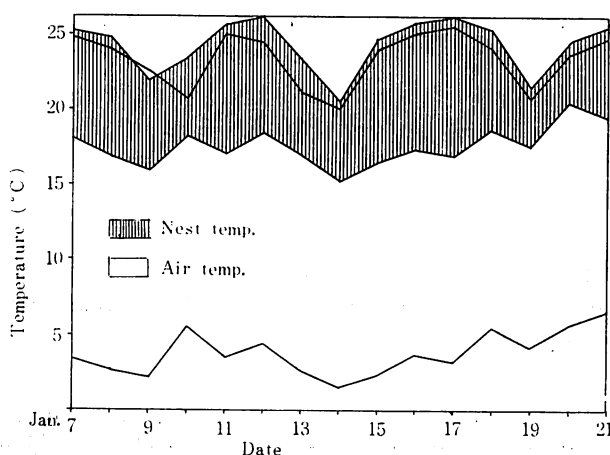
Table 24. Comparison of temperature in the nest of *Kaloterms koshunensis* with that of surrounding air in winter and summer.

Period	Locality	Temperature						
		Nest			Atmosphere			
		Mean	Max.	Mean min.	Diff.	Mean min.	Mean max.	Diff.
Jan. 2—14, '59	Kinjo-cho, Shuri	22.3		19.8	2.5	17.6	12.4	5.2
Sept. 2—24, '59	Sakashita, Naha	30.0		28.6	1.4	30.1	27.2	2.9

In winter the temperature of the nest of the species was continuously higher than that of the atmosphere and the mean daily maximum temperature of the nest was 4.7° C. higher than that of the atmosphere (table 24). The differences between the mean maximum and minimum temperature of the nest and the atmosphere are 2.5° C. and 5.2° C. respectively. From the study of the nest temperature, it is very probable that the temperature of the atmosphere and the mean daily minimum temperature of the nest is 6.4° C. higher than that of the atmosphere. In summer, however, there is no conspicuous difference between the temperature of the nest and the atmosphere. The difference is seen only between the daily minimum temperatures, the mean daily minimum of the nest being 1.4° C. higher than that of the atmosphere. It is very probable that in summer the temperature change of the nest of this species fluctuates with the temperature change in the atmosphere, but the daily minimum temperature of the nest being slightly higher than the atmosphere.

From Table 24 and Text-figure 23 it is obvious that the temperature of the nest of this species is not constant but varies with the day and seasons on environmental temperature. From the study of the temperature conditions of the nest of *Kaloterms koshunensis* it may be safe to make the following statements:

- 1) In winter the mean daily minimum temperature of the nest of *Kaloterms*



Text-fig. 23. Comparison of nest temperature of *Kalotermea koshunensis* with the surrounding air temperature.

*koshunensis* seems to be constantly a few degrees higher than that of the atmosphere. The difference between both temperatures was 6.4° C. in January on Okinawa.

2). During the summer no conspicuous difference may be found between the temperature of the nest and the atmosphere, but the nest seems to be slightly higher in the mean daily minimum temperature than the atmosphere.

3). The temperature in the nest of *K. koshunensis* is not constant but varies with variation in season, time of the day, and temperature of the atmosphere.

### 3. Temperature in the nest of *Kalotermea kotoensis*

This species is the hard-wood termite usually found in hard-wood, forming irregular nests in them. It is not an easy task to take the temperature in the nest of this species because this species builds its nest in the hard-wood and the nest is too small to insert the bulb of the thermometer. Even if the thermometer can be inserted, it would still be difficult to ascertain either or not it is taking the temperature in the nest. Due to this difficulty, considerable time and labor were spent in taking reliable temperatures in the nest of this species.

A study of the temperature in the nest of *Kalotermea kotoensis* was made in April, 1960. A timber (12cm. X 12cm. X 36cm.) infested by this species was brought into the laboratory. First, two small holes were made towards the nest, directed at the gallery percussion sound, to enable insertion of the bulbs of thermometer. The bulbs of maximum-minimum self-resistering thermometer (manufactured by Tayler Instrument Companies, New York) were inserted into the holes and the crevices between the bulbs and wood were stuffed with cotton, and then the timber bearing the thermometer was placed in a refrigerator. A self-registering thermograph (manufactured by Nakasa & Co. Ltd., Tokyo) was put

into the refrigerator to take the temperature of the surrounding air. The door of the refrigerator was opened and closed at irregular intervals during the day, and kept closed at night for three hours in order to change the temperature in the refrigerator.

Temperature data in the nest of *Kaloterme kotoensis* obtained from the laboratory measurement were summarized and given in Table 25

Table 25. Comparison of the mean daily minimum and maximum temperatures between the nest of *Kaloterme kotoensis* and the surrounding air obtained from laboratory tests.

Date	Temperature					
	Nest		Diff.	Surrounding air		Diff.
	Mean max.	Mean min.		Mean max.	Mean min.	
Apr. 10—25, '60	24.4	20.6	3.8	23.7	12.4	11.3

It is obvious from Table 25 that the temperature of the nest is higher than the surrounding air. The mean daily maximum temperature of the nest is about 1°C. higher than that of the surrounding air. On the other hand, the mean daily minimum temperature of the nest is 8.2° C. higher than that of the surrounding air. The temperature difference between the maximum and minimum is smaller in the nest (3.8° C.) than in the surrounding air (11.3° C.).

Data were not obtained from the colony in its natural habitat and the temperature changes were artificial. Therefore, the results of this test probably do not represent the status of the temperature in the nest of this species in nature. Before drawing any conclusions, there are many matters to be taken into consideration, but the results, no doubt, present some characteristics of the temperature in the nest of *Kaloterme kotoensis*.

It may be safe to say from the results of the test that:

1). The mean daily maximum and minimum temperatures in the nest of *Kaloterme kotoensis* are probably higher than those of the surrounding air in the cool weather.

2). The temperature in the nest of this species may not be constant but changeable with variation in time of day, weather, season, etc.

3). In cold weather the mean daily minimum temperature in the nest of this species seems to be about 8.2° C. higher than that of the surrounding air.

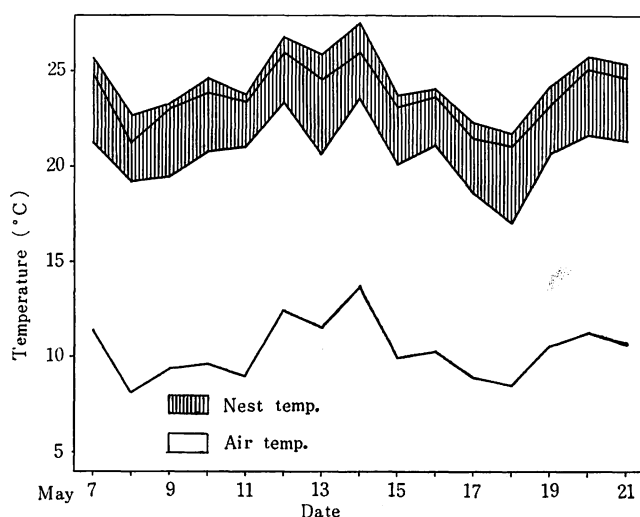
4. Temperature in the nest of *Kaloterme fuscus*.

*Kaloterme fuscus* is the hardwood termite and usually found in stumps, dead trees, dead portions of living trees. It does not live in decayed wood or softwood but in the heart portion of the hardwood. Thus, it is very difficult to take the temperature in the nest of this species. A survey of the temperature of

the nest of this species was made in May, 1959.

The pasania trunk (about 24cm. in diameter and 32cm. in length) infested by this termite was obtained from Mt. Onna, Okinawa. Two small holes were made to insert the bulb of the thermometer. Then, the stump with the thermometer was placed into a refrigerator with thermograph. The door of refrigerator was opened and closed at irregular intervals.

Data are summarized and shown in Table 26 and Text-figure 24.



Text-fig. 24. Comparison of nest temperature of *Kaloterme fuscus* with the surrounding air temperature.

Table 26. Mean daily maximum and minimum temperatures of the nest of *Kaloterme fuscus* and the surrounding air obtained from the laboratory test.

Date	Temperature					
	Nest			Surrounding air		
	Mean Max.	Mean min.	Diff.	Mean max.	Mean min.	Diff.
May 7—21, '59	24.1	20.6	3.5	23.6	7.7	15.8

At the close of the test the timber was slit to verified that the individuals of this colony were alive and that the portion of the bulb of the thermometer were surrounded by the galleries or runways. Thus, the results of this test are fairly reliable.

Needless to say, there remained many matters to be followed up before drawing valid conclusions. But the data obtained from the test seem to present the status of temperature in the nest of this termite in nature. In cold area the temperature in the nest showed several degrees higher than the temperature in the surrounding air. The difference between the maximum and minimum is

more conspicuous in the surrounding air than in the nest. This means that the nest is more stable to temperature changes than the surrounding air. It is noteworthy that the mean daily minimum temperature in the nest of this species is 13.4° C. higher as compared to that of the surrounding air.

From the results of the laboratory test of the temperature in the nest of this termite, it may be safe to say that:

1). The temperature in the nest of *Kaloterмес fuscus* does not seem to be constant but varies with variations in the temperature of the surrounding air.

2). In cold weather the variation in temperature is probably not so conspicuous in the nest as compared to the surrounding air.

3). The mean daily minimum temperature in the nest of *K. fuscus* in the coldest month is probably 13° C. higher than the mean daily minimum temperature of the atmosphere.

#### 5. Temperature in the nest of *Leucotermes speratus*.

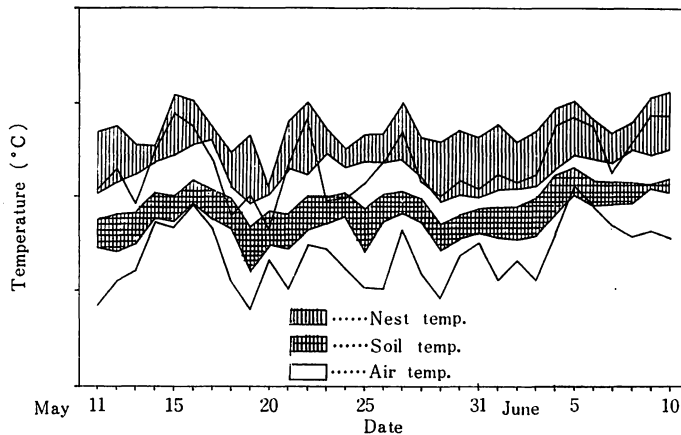
Unfortunately, data on the temperature in the nest of *Leucotermes speratus* are meager and furthermore there is no dependable previous report concerning the temperature in the nest of this commonest termite.

When the author was in Sendai, Miyagi Prefecture, he took a set of temperature readings in the nest of this species at Fukuromachi, Sendai City. One was at 6:30 a. m., January 23, 1960 and the other was at 7:00 a. m., January 25, 1960. A colony was found in the dead portion of a plum-tree trunk and the temperature was taken in the nest at about 12cm. in depth. It was -5.2° C. in the surrounding air in January at 6:30 a. m. and 6.7° C. in the nest. At 7:00 a. m. the surrounding air temperature stood -7.1° C. but the temperature in the nest was 6.7° C. at that time.

Judging from this study, the temperature in the nest of this species at Sendai is about 12-14° C. higher than atmospheric temperature on cold days. However, this requires further confirmation.

#### 6. Temperature in the nest of *Coptotermes formosanus*.

From the end of May to June, 1959, the author surveyed the temperature in a branch-nest of this species which was located in an unused brick oven. The brick oven was constructed of bricks and concrete, rising to a height of over 80cm., and was situated in the open land. Therefore, the temperature in the branch-nest seems to be influenced by the temperature changes in the surroundings. The temperature in the neighbouring soil was also measured at 30cm. in depth near the nest. Data are summarized and shown in Table 27 and Text-figure 25.



Text-fig. 25. Comparison of nest temperature of *Coptotermes formosanus* with those of soil and air.

Table 27. Comparison of the mean daily minimum and maximum temperatures in the nest of *Coptotermes formosanus*, surrounding air, and adjacent soil at Shuri, Okinawa

Period	Temperature								
	Atmospheric Temp.			Nest temp.			Soil temp.		
	Mean max.	Mean min.	Diff.	Mean max.	Mean min.	Diff.	Mean max.	Mean min.	Diff.
May 11 to June 10, 1959	27.1	21.9	5.2	28.7	26.2	2.5	24.9	23.3	3.6

The temperature fluctuated between 1.5° and 6.6° C. in the air, 0.2° and 1.8° C. in the soil, and 0.2° and 3.0° C. in the nest. The mean daily maximum temperature in the nest was higher than that in the soil but was lower than that of the atmosphere. The mean daily minimum temperature in the nest, however, was higher than those in the atmosphere and in the soil. Text-figure 25 shows that on warmer days the temperature in the nest exceeds the maximum air temperature, and that on cool days the temperature in the nest is lower than the maximum temperature in soil or equal to the minimum. It is probably due to absence of individual termites from the branch-nest: on cool days no termites were found in tunnels which connected the branch-nest with the earth. The author postulates that individuals of a colony would move to a true nest somewhere in the earth.

Tamura (1953) reported that the temperature in the nest of this species stood 28° C. when the surrounding air and soil temperatures were 11°–12° C. and 14° C. respectively. This means that *C. formosanus* would be able to keep the temperature 17°–18° C. higher than that of the surrounding air. This fact is very important when considering the northern limits of distribution of this species.

In this paper the author has made attempt to find the relationship between the temperature in the nest of termites and the northernmost distribution of termites. Besides Tamura's report, there are no other available reports that can be used as basis of comparison.

More data on nest temperatures during the coldest month should be gathered in order to make some sound conclusions.

In this respect the author has some data at hand, but they were obtained in Okinawa where the winter is mild and may not serve adequately to discuss the difference between the nest temperature and the minimum temperature during the coldest month at the northern range of distribution of this species.

From available data, the following factors may be brought out:

1). On warmer days the mean daily maximum temperature of the branch-nest of *Coptotermes formosanus* located above the ground is slightly higher than that of the surrounding air or the neighbouring soil at 30cm. in depth. In the case of the mean daily minimum temperature, the branch-nest is several degree higher than those of soil and surrounding air.

2). Concerning the difference between the mean daily maximum and minimum, the difference in the air is the largest, the branch-nest second, followed by the soil.

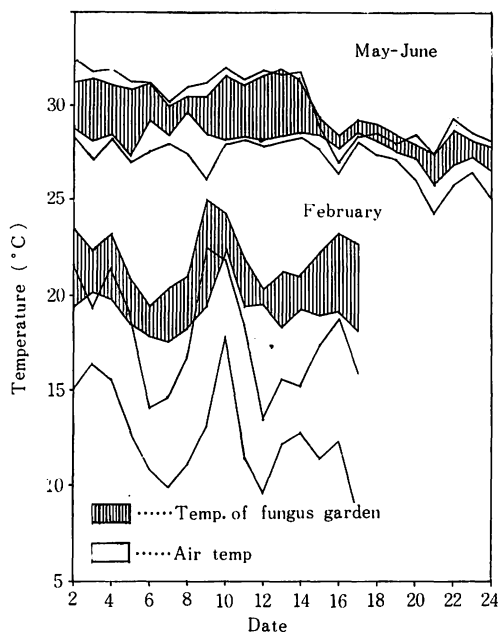
3). On cold days in the northern region of distribution, the nest temperature of this termite is probably 11°–12° C. higher than that of the atmosphere.

#### 7. Temperature in the nest of *Odontotermes formosanus*.

It is difficult to find the nest of *Odontotermes formosanus* in soil even when its fungus garden is found. It is even more difficult to find out the royal-cell. Fortunately, the author found its nest in a wood facing east on the campus of the University of the Ryukyus. To take the temperature, care was taken to dig the soils and reach the fungus garden to insert the bulb of a subterranean thermograph into the fungus garden which was situated about 40cm. below the ground surface. Care was given to avoid soil entering into the

Table 28. Comparison of the mean daily maximum and minimum temperatures among the atmosphere, the fungus garden of *Odontotermes formosanus* and the earth in Okinawa.

Period	Temperature								
	Atmosphere			Fungus garden			Surrounding earth		
	Mean Max.	Mean min.	Diff.	Mean max.	Mean min.	Diff.	Mean max.	Mean min.	Diff.
May 2 to June 24, 1959	26.0	21.9	5.0	29.1	26.3	2.8	22.7	21.5	1.2
Feb. 2 to 17, 1958	17.7	12.9	4.8	23.9	19.1	4.8			



Text-fig. 26. Comparison of temperature of fungus garden of *Odontotermes formosanus* with the air temperature,

fungus garden when the soil was put back. Temperature recording of this fungus garden was carried out in February, 1959 and June, 1959. Results of the study are summarized in Table 28 and Text-figure 26.

Many studies have appeared with regard to the temperature in the fungus garden of the fungi growing termites (Emner, 1920; Holaway, 1948; Geyer, 1951; etc.). For example, Iusscher (1951) conducted the study of temperature in the nest of a fungus growing termite, *Marotermes bellicosus*. He reported that *Marotermes bellicosus* maintained a high temperature of 30° C. in its nest by cultivation of fungi.

According to the author's data, in winter the temperature in the fungus garden of *Odontotermes formosanus* fluctuated between 0.5° and 1.1° C. for 13 days, with 2.7° and 6.5° C. fluctuations in the atmosphere during the same period. The mean daily minimum temperature of the nest is 6.2° C. higher than that of the atmosphere (Table 28), and is a few degrees higher than the mean daily maximum temperature of the atmosphere. Text-figure 22 indicates that the daily minimum temperature of the fungus garden is higher than even that of the atmosphere.

During the summer the mean daily minimum temperature of the fungus garden is higher than the mean daily maximum temperature and the earth. The differences are 5.0° C. in the atmosphere, 2.8° C. in the fungus garden, and 1.2° C. in the earth, respectively. This means that in the summer, the temperature



in the fungus garden is more stable than that the atmosphere but more changeable than that of the earth.

From the results of this study on the temperature of the fungus garden of *Odontotermes formosanus* the following factors can be mentioned:

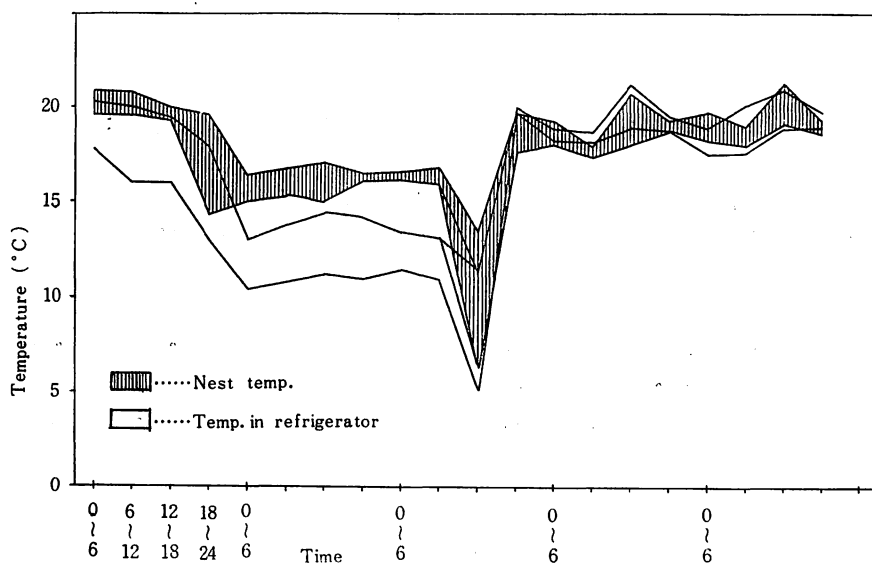
- 1). The temperature of the fungus garden of *Odontotermes formosanus* is not constant but varies with the season, day and environmental temperature.
- 2). In winter the mean daily minimum temperature of the fungus garden of this species is several degrees higher than that of the atmosphere and the earth.

#### 8. Temperature in the nest of *Eutermes takasagoensis*.

A carton nest of *Eutermes takasagoensis* (27cm. in diameter and 23cm. in height) which has been collected on Ishigaki-jima was brought into a laboratory and used in this study. Needless to say, this nest contained a number of workers, soldiers and other castes. The bulb of a subterranean thermograph was inserted into the center of the nest. The test was first made under uncontrolled room temperatures from August to September, 1959.

After this test was over, the nest was removed into a refrigerator. The temperature in the refrigerator was changed by intermittent opening and closing the refrigerator door.

The results of tests are summarized in Table 29 and Text-figure 27.



Text-fig. 27. Comparison of nest temperature of *Eutermes takasagoensis* with the surrounding air temperature.

Table 29. Mean daily minimum and maximum temperatures in the nest of *Eutermes takasagoensis* in room temperature and refrigerator temperatures.

	Temperature					
	Nest			Indoor		
	Mean Max.	Mean min.	Diff.	Mean max.	Mean min.	Diff.
Uncontrolled indoor	31.9	28.6	3.3	31.8	27.8	3.9
Refrigerator	18.0	16.7	2.3	16.0	12.4	3.4

Table 29 shows that during the summer, the mean daily maximum temperature of the nest is almost the same as that of room temperature, but in the minimum temperature the former is slightly higher than the latter. This means that the temperature fluctuation is smaller in the nest than the mean maximum air temperature. In the refrigerator the temperature fluctuation is conspicuously smaller in the nest than in the surrounding air.

Text-figure 27 indicates that the temperature in the nest generally follows that of surrounding air, being usually a few degrees higher than the minimum of the air but sometimes lower than the maximum air temperature. The Text-figure 27 shows that the nest temperature is always higher than the air temperature until about the midway of the figure. However, in the later half of the figure the opposite phenomenon is seen. This phenomenon was presumably due to the death of termites. In fact, when this test was over, all individuals were found to be died, although individuals which were separated from the same colony before the test started, still showed their normal activities under room temperature. This fact indicates that this species can not live when it is placed in such low temperature as 5° C. for a few hours.

In nature the nest of this termite is usually found on rocks, dead portions of living trunks, stone-wall, etc. Thus, the temperature in the nest seems to be influenced considerably by changes in air temperature. Results of this test are summarized as follows:

1). In a very warm place the temperature of *Eutermes takasagoensis* probably follows the change of the temperature of the surrounding air, maintaining almost the same degree.

2). In a cool place the mean minimum temperature of the nest is higher than the minimum of the surrounding air.

3). If this termite is placed in an environment of 5° C. for several hours, its survival is doubtful.

#### 9. Summary.

Generally speaking, the temperature in the nests of eight different Ryukyuan

species of termites is not constant but varies with the time of day, environmental temperature and season. In general the summer the difference between the minimum temperature of the nest and the surrounding air is not marked. In the winter or in cool places the mean daily minimum of the nest is higher than the daily minimum of the air or soil. The temperature in the nests of the Ryukyuan termites are summarized in Table 30.

Table 30. Comparison of the mean daily maximum and minimum temperatures in the nests of the Ryukyuan termites and the surrounding air.

Species	Temperature						
	Summer or warm places			Winter or cool places			Diff. Min. of nest and air in winter
	M. max	M. min.	Diff.	M. max.	M. min.	Diff.	
<i>H. japonicus</i>	*N. 28.3	27.7	0.6		18.8		7.9
	**A. 34.4	24.1	10.3		10.9		
<i>K. Koshunensis</i>	N. 30.0	28.6	1.4	22.3	18.8	3.5	6.4
	A. 30.1	27.2	2.9	17.6	12.4	5.2	
<i>K. fuscus</i>	N.			24.1	20.6	3.5	12.8
	A.			23.6	7.8	15.8	
<i>K. kotoensis</i>	N.			24.4	20.6	3.8	8.2
	A.			23.7	12.4	11.3	
<i>L. speratus</i>	N.				7.6		12.8
	A.				-5.2		
<i>C. formosanus</i>	N. 28.7	26.2	2.5		29.0		7—8
	A. 27.1				11—12		
<i>O. formosanus</i>	N. 29.1	26.3	2.8	23.9	19.1	4.8	6.2
	A. 26.9	21.9	5.0	17.7	12.9	4.8	
<i>E. takasagoensis</i>	N. 31.9	28.6	3.3	18.0	16.7	2.3	4.3
	A. 31.8	27.8	3.9	16.0	12.4	3.4	

\*.....Temperature in the nest, \*\*.....Temperature in the air,

Needless to say, it is very probable that the temperature of the nest of a species of termites might vary with locality, time of day, size of the colony, season, weather, etc. Therefore, it is hard work to find the temperature in the nest of a certain species to be representative of all nests of this species in nature. Studies relative to nest temperatures of termites has only presented preliminary data of temperature variation in the nests of termites in the Ryukyu Archipelago. In this paper the author will attempt a detailed discussion on the basis of above data, although these data obviously indicate need for further investigation.

### General Discussion

Animal activity is possible within relatively narrow temperature limits.

Most species are active between  $0^{\circ}$  and  $40^{\circ}$  C; but some animals live within a few degrees below freezing temperature of pure water, and a few regularly live above  $50^{\circ}$  C. No one animal is sufficiently elastic in its organization to withstand a wide range of environmental conditions.

On the other hand, the earth as the habitat of animals and plants has the largest gradient in temperature intensity between the poles and the equator. This temperature gradient is one of the most important factors which affects the distribution of animals and plants throughout the world.

Termites are widely distributed throughout the world, including the arctic and antarctic. In the Far East a damp-wood termite, *Leucotermes speratus* live in the temperate regions and sometimes as far north as Hokkaido. However, there are greater numbers of species and higher population densities per species in the warmer, southern sections of the Japanese and Ryukyu Archipelago. As it was illustrated before, in the Ryukyu, there are certain islands where only few occur. Why are certain areas not inhabited by certain termites? The author considers that temperature is the most important single factor limiting the geographical distribution of termites in the Ryukyu Archipelago from low to high latitude. The author has attempted to explain the relationship between temperature and the geographical distribution of each species of termites known to occur in the Ryukyu Archipelago.

It is generally said that the temperature factor operates to limit the distribution of plants and animals at two extremes of the winter minimum and summer maximum. The winter minimum kills organisms not adapted to such temperature; the summer maximum is less apt to kill, but affects the reproductive cycle. Owing to the sheltered life of the termites, the population of the temperature factor in the occurrence of colonies and the geographical distribution of species is very difficult to explain under natural conditions. However, many entomologists have attempted to explain the northernmost limits of geographical distribution of insects from the viewpoint of the lethal low temperature. For example, Kinoshita et al (1930) advocated that the northernmost limit of distribution of paddy borer would be limited to regions where the lowest air temperature has been recorded as  $-3.5^{\circ}$  C. because the degree of supercooling was  $-3.5^{\circ}$  C. Koizumi (1939) suggested that the thermal death-point of low temperature would be the factor limiting the northern distribution of insects.

It may be true some free-living insects that the winter minimum temperature can be adapted for the lethal low temperature controlling the distribution of insects by killing them directly. The sheltered life of termites tend to moderate or reduce the operation of the temperature factor. Therefore, the temperature which affects the life of termites is that of the nest and not of the atmosphere. As Kato (1938, 1948, 1953, etc.) pointed out, the temperature which

affects the life of peculiar insects such as ant lions, strawberry blossom weevils, rice leaf minors, etc., is that of the nest or residence but not of the atmosphere. A study the geographical distribution of termites was made from two aspects of the temperature; the lethal and preferred temperatures.

Termites respond quickly to temperature changes. Their behaviors which result in modification of their seasonal, local and diurnal distribution, are largely influenced by the temperature factor. The temperature factor which affects the termites is the temperature in the nest. If the range of temperature within which termites maintain their lives throughout the year is to be determined, the nest temperature throughout the year must be determined. For this reason nest temperatures of eight different species of termites in the Ryukyu Archipelago were taken.

Since the low and high temperature extremes in the nest seems to limit the distribution of termites, the author tried to ascertain the maximum and minimum temperatures in the nests, using the mean daily maximum and minimum temperatures in the nests as substitutes for them. The purpose of this paper is to discuss the distribution of termites with special reference to the Ryukyu Archipelago, situated in the northern hemisphere. Consequently, the mean minimum temperature of the nests especially in winter was considered.

It is certain that there is a temperature gradient in the nests of termite, and individuals move freely along the temperature gradient. The preferred temperature is regarded as an important index to know the innate capacity of the termite. Thus, the preferred temperature of each species was obtained from laboratory tests. Attention was given to determine the lowest and highest limits of preferred temperature for each species of termite. The author found that the mean daily minimum and maximum temperatures in the nests under very cold conditions almost coincided with the lowest and highest preferred temperatures; the range of temperature in the nest of a certain species of termites was fairly close to the range of preferred temperature of this species.

The author also showed the difference between the mean daily minimum temperature of the atmosphere compiled by the meteorological station and the mean daily minimum temperature in the nest of certain species of termite. These differences in temperatures differ from island to island and from locality to locality. If the lowest preferred temperature for each species is regarded as the lowest temperature for each species able to get along, the northernmost limit of species of termite may be known from the lowest preferred temperature for each species. Since a favorable range of temperature seems to be based upon the innate capacity of each species of termite, it is not unreasonable to discuss the geographical distribution of termites from the standpoint of preferred temperature.

If the foregoing discussion is agreeable, the lowest preferred temperature of a species of termites ( $P_t$ ) is equal to the mean daily minimum nest temperature of the coldest month at the northernmost limits of distribution of this species ( $N_t$ ). Therefore, the following formula may be introduced:

$$P_t = N_t$$

$P_t$  .....The lowest preferred temperature of a certain species.

$N_t$  .....The mean lowest nest temperature of a certain species at the northernmost limits of distribution of this species.

The lowest preferred temperature for each species of termite seems to depend upon the innate capacity of each species of termite. consequently, the following formula may be introduced to predict the northernmost limits of distribution of termites:

$$P_t \leq A_t + D_t$$

In the formula,

$P_t$  .....The lowest preferred temperature of a certain species of termite.

$A_t$  .....The mean daily minimum temperature of the coldest month at the place where a certain species of termite would be found.

$D_t$  .....The difference between the mean daily minimum temperature in the coldest month at a certain place ( $A_t$ ) and the mean minimum nest temperature of the species in the coldest month at that place ( $N_t$ ). Therefore,  $D_t = N_t - A_t$ .

$P_t$  value is presented in this paper on the basis of results of tests, and  $A_t$  value is easily obtained from publications compiled by the meteorological stations, and  $N_t$  value would be able to find by means of taking the nest temperature of termite in the coldest month. Hence,  $D_t$  value ( $=N_t - A_t$ ) can be calculated.

If  $P_t$  value is equal to  $A_t + D_t$ , the northernmost distribution of this species would be limited to a certain region of which the  $A_t$  value was used for the calculation. If  $P_t$  value is smaller than  $A_t + D_t$ , this species probably has a potentiality of more northward distribution than the place where the species is found. If  $p_t$  value is larger than  $A_t + D_t$  the distribution of this species in this place is probably isolated from its southern major region of distribution or this region where this species is found may be particularly warmer than the adjacent area. Hereinafter, the author will attempt to discuss each species of termites on the basis of the above formula.

#### *Hodotermopsis japonicus*

So far as it is known, this species is restricted to the northern region of the Ryukyu Archipelago and as far north as Kochi Prefecture, Japan. No record of its occurrence in Formosa has appeared until this time, although of the ten species of Ryukyuan termites, nine overlap in distribution into Formosa.

Therefore, for the present, the northern distribution of this species may be marked on Tanega-shima and the southern limit on Tokuno-shima.

Results of Test indicate that this species prefers a low temperature range and the lowest preferred temperature ( $P_t$ ) is  $18^\circ$  C. Table shows that the nest temperature ( $N_t$ ) of this species is  $18^\circ$  C. when it is  $7.5^\circ$  C. in the atmosphere ( $A_t$ ). The mean daily minimum temperature in the coldest month on Tanega-shima ( $A_t$ ) is  $8.7^\circ$  C. (Table).

In the formula  $P_t \leq A_t + D_t$ ,

$P_t$  .....  $18$  (for *Hodotermopsis japonicus*)

$A_t$  .....  $8.7$  (on Tanega-shima)

$D_t = N_t - A_t = 18.6 - 8.7 = 9.9$

Hence,  $A_t + D_t = 8.7 + 9.9 = 18.6$

Therefore,  $P_t < A_t + D_t$

The formula means that this species can probably extend further northward than Tanega-shima where the mean daily minimum temperature is  $8.7^\circ$  C. The values of  $N_t$  and  $D_t$ , however, are not the mean minimum because these values in Tanega-shima were not obtained on the coldest day in winter. Judging from these calculations, the occurrence of this species in Kochi Prefecture is very probable, although this species has not been found by the author in this region.

#### *Kaloterme koshunensis*

So far as it is known, the northernmost limit of distribution of *K. koshunensis* stops at Okinawa-jima. The lowest preferred temperature of this species is  $20^\circ$  C. (Table 21). Table 24 shows that the mean daily minimum nest temperature of this species during the coldest month on Okinawa-jima is  $19.8^\circ$  C. at Naha. According to data compiled by Naha Meteorological Station, the mean daily minimum air temperature in January is  $13.1^\circ$  C. at Naha.

In the formula  $P_t \leq N_t + D_t$ ,

$P_t$  .....  $20$

$N_t$  .....  $19.8$

$A_t$  .....  $13.1$

However,  $D_t = N_t - A_t = 19.8 - 13.1 = 6.7$  Thus,  $D_t = 6.7$

Therefore,  $A_t + D_t = 19.8$

Hence,  $P_t \neq A_t + D_t$

These calculation mean that the lowest preferred temperature of this species coincides with the mean daily minimum nest temperature of this species in the coldest month on Okinawa-jima. This coincidence indicates that this species will hardly succeed in extending beyond the known northern limit of distribution. In fact, this species has hardly found in the northern part of Okinawa-jima and has never been found on Yoron-jima, Okinoerabu-jima, and other areas north of

Okinawa-jima.

The calculations indicate that it is improbable for this species to succeed in extending the range of its distribution further north than its present limits in the Ryukyu Archipelago.

### *Kaloterme fuscus*

The northernmost occurrence of this species was reported on Okinawa (Nawa, 1914) prior to this work. Through extensive surveys, the author ascertained that the distribution range of this termite covered as far north as Kagoshima Prefecture. The author assumed that the northern limit of distribution of this species should extend to some region in the Japanese Archipelago. For the purpose of predicting the northernmost limit, an assumption was made based upon the results obtained from the following formula:

$$P_t \leq A_t + D_t$$

In the formula,

$$P_t \dots\dots\dots 17 \text{ (Table 21)}$$

$$D_t = N_t - A_t = 14.9 \text{ (Table 25)}$$

However,  $D_t = N_t - A_t$

Since  $P_t$  is equal to  $N_t$ , in theory, at the northernmost limit of distribution,

Consequently,  $14.9 = 17 - A_t$

$$\therefore A_t = 17 - 14.9$$

$$A_t = 2.1 \text{ (C}^\circ\text{)}$$

The  $2.1^\circ \text{ C.}$  of value means *Kaloterme fuscus* can inhabit in the northern regions where the mean daily minimum temperature in the coldest month is  $2.1^\circ \text{ C.}$  The  $2.1^\circ \text{ C.}$  temperature almost coincides with the mean daily minimum temperature for February at Kii Peninsular, Wakayama Prefecture.

To ascertain this assumption, the author carried out a survey along the Pacific Coast of the Japanese Archipelago as far as Kii Peninsular, Wakayama Prefecture, and found this termite at Osumi Peninsular (Kagoshima), Nichinan (Miyazaki), Shimizu (Kochi), and Shiono-misaki (Wakayama). This survey did not cover regions further north.

Judging from these factors it may be said that *Kaloterme fuscus* could be distributed as far north where the mean daily minimum temperature in the coldest month is  $2.1^\circ \text{ C.}$

### *Kaloterme kotoensis*

So far as it is known, *Kaloterme kotoensis* is known to occur as far north as Tokuno-shima. According to data compiled by the Nase Meteorological Station, the mean daily minimum temperature during the coldest month ( $A_t$ ) is  $11.7^\circ \text{ C.}$  on Tokuno-shima known as the northern limit of distribution of this termite.



The result of test indicates that the lowest preferred temperature ( $P_t$ ) of this species is about  $20^{\circ}$  C.

Therefore, in the formula  $p_t \leq A_t + D_t$ ,

$P_t = 20$  ..... Table 21

$D_t = 10.2$  ..... Table 25

$A_t = 11.7$  ..... on Tokuno-shima

Hence,  $A_t + D_t = 11.7 + 10.2 = 21.9$

Thus,  $P_t < A_t + D_t$

These calculation indicate that *Kaloterms kotoensis* can probably extend its range of distribution to the north. In other words, judging from the lowest preferred temperature of this species, this species would succeed in establishing itself in the northern part of the Japanese Archipelago. Since this termite is a house termite and easily transported by man through infested furniture, it may easily be distributed in southern Kyushu in the very near future,

#### *Leucotermes speratus*

It is mentioned that this termite is distributed as far north as Sapporo, Hokkaido. The mean daily minimum temperature in the coldest month at Sapporo is  $-10.9^{\circ}$  C. The minimum nest temperature of this species for certain period of February at Sendai was  $7.6^{\circ}$  C. when the atmospheric temperature was  $-5.2^{\circ}$  C. The result of Test-III shows that the lowest preferred temperature of this termite is  $12^{\circ}$  C.

In the formula  $P_t \leq A_t + D_t$ ,

$P_t = 12$  ..... Table 21

$D_t = 14$  ..... at Sendai, Tohoku (Table)

$A_t = -10.9$  ..... at Sapporo, Hokkaido

If the  $D_t$  value at Senda is adopted,

$A_t + D_t = -10.9 + 14 = 3.1$

Hence,  $P_t > A_t + D_t$

The last calculation indicates that the occurrence of *Leucotermes speratus* in Sapporo is negative in spite of actual occurrence. The reason for this discord between the actual northern limit and the theoretical limit is probably due to the use of  $D_t$  value at Sendai in stead of Sapporo. According to the calculation, *L. speratus* can not be found in cold places where the mean daily minimum temperature is as low as  $-10.9^{\circ}$  C., but it has been found in warmer habitats such as woodworks of buildings, sunny places, woodworks around fireplaces, etc. at Sapporo, Hokkaido.

#### *Coptotermes formosanus*

This termite is one of the most common and widely distributed species, and

the northernmost limit of distribution stops at Shizuoka Prefecture. In this paper the author attempts to explain the northernmost limit of the species from the standpoint of the lowest preferred temperature.

The result of Test-III shows that the lowest preferred temperature for this species is  $17^{\circ}\text{C}$ . According to Tamura (1953), the nest temperature of this species was  $29^{\circ}\text{C}$ , when it was  $11\sim 12^{\circ}\text{C}$  in the surrounding atmosphere.

In the formula  $P_t \begin{smallmatrix} \leq \\ \geq \end{smallmatrix} A_t + D_t$ ,

$P_t = 17$ .....Table 21

$A_t = -0.3$ .....at Shizuoka Prefecture

$D_t = N_t - A_t = 29 - 11$  or  $12 = 17$  or  $18$  .....mentioned above

Hence,  $A_t + D_t = -0.3 + 17$  or  $18 = 16.7$  or  $17.7$

Therefore,  $P_t \approx A_t + D_t$

The final calculation indicates that the known northernmost limit of distribution of this species would be stable at present. Based upon the above discussion, this species probably thrives in regions where the mean daily minimum air temperature in the coldest month is  $0^{\circ}\text{C}$ . This point was brought out by Abe (1932) and confirmed here by the author on the basis of preferred temperature of this species.

#### *Odontotermes formosanus*

The fungi-growing termite, *Odontotermes formosanus*, is a widely distributed species in the southern part of the Ryukyu Archipelago. The northern limits of distribution of this termite is considered as Shanghai in China and Okinawa-jima in the Ryukyu Archipelago.

According to the results of Test-III, the lowest preferred temperature of this species is  $18^{\circ}\text{C}$ . The mean daily minimum temperature in the fungus garden was  $19.1^{\circ}\text{C}$  on Okinawa for a certain period in January, with the mean daily minimum temperature of the atmosphere being  $12.9^{\circ}\text{C}$ .

Consequently, the northern limit of distribution of this species seems to be speculated as follows:

In the formula  $P_t \begin{smallmatrix} \leq \\ \geq \end{smallmatrix} A_t + D_t$ ,

$P_t = 18$ .....Table 21

$A_t = 12.9$  .....mentioned above

$N_t = 19.1$  .....mentioned above However,

$N_t - A_t = D_t$

Therefore,  $19.1 - 12.9 = 8.2 = D_t$

$A_t + D_t = 12.9 + 8.2 = 21.1$

Hence,  $P_t < A_t + D_t$

The last calculation indicates that Okinawa-jima is probably not its actual northern limit of distribution. In fact, there is a report on the occurrence of

this species as far north as Nanking (Light, 1929). Based upon these calculations, the northernmost limit of distribution would not be stable on Okinawa-jima, but is very probable that *Odontotermes formosanus* can extend to more northern regions not yet occupied by this termite.

*Eutermes takasagoensis*

So far as it is known, the northernmost limit of distribution of this species extends to Ishigaki-jima. The result of Test-III indicates that the lowest preferred temperature of this species is 21.5° C. Table 29 shows that the mean minimum nest temperature was 16.7° C. when the mean minimum temperature of the surrounding air for a certain period of days was 12.4° C. According to data compiled by the Ishigaki Meteorological Station, the mean daily minimum temperature at Ishigaki-jima during the coldest month is 15.1° C.

Therefore, in the Formula  $P_t \leq A_t + D_t$ ,

$P_t = 21.5$ .....Table 21

$A_t = 12.4$ .....mentioned above

$N_t = 16.7$ .....mentioned above

However,  $D_t = N_t - A_t$

Thus,  $D_t = 16.7 - 12.4 = 4.3$

$A_t + D_t = 15.1 + 4.3 = 19.4$

Hence,  $P_t > A_t + D_t$

The final calculation indicates that the northern limit of distribution of *E. takasagoensis* would extend to regions further south than Ishigaki-jima or that the occurrence of this species on Ishigaki-jima would be due to isolation from the major region of distribution. However, data obtained from the test are questionable, because individuals of this species used in the test were weakened by transportation from Ishigaki-jima to Okinawa or by test exposures to low temperatures which they might never encounter under natural condition. Therefore, it further discussion should be based upon more reliable data in the future.

Temperature and moisture are inseparable as environmental factors of termites. Moisture, however, is not as important factor as far as the geographical distribution of termites is concerned in the Ryukyu Archipelago because abundant and constant source of moisture is found in soils and in the atmosphere. Temperature is by far the most important single factor in the geographical distribution of the termites in the Archipelago.

In this paper, first, the relationship between the extremely low and high temperatures and the geographical distribution of termites was discussed. However, the modification of the environmental temperature by soil, wood or special behaviors make complicated matters. A long-term study on the basis of

life-stage of termites would add tremendously to the knowledges of the relationship between temperature and distribution.

As individuals of all life-stages are found in the colonies of termites and their activities extend throughout the year, nests of termites should keep fairly high temperatures. In this regard, an attempt was made to find the relationship between the geographical distribution and the preferred temperatures of termites. It was found that there was a parallel relationship between both and this relationship is important to determine the range of distribution of termites. The northern limits of distribution of the Ryukyuan termites were discussed from the viewpoint of preferred temperature and summarized in Text-figure 25.

The ten species of termites in the Ryukyu Archipelago can be divided into two groups from the standpoint of the northern limit of distribution 1) termites whose northern limits of distribution are stable, and 2) termites whose northern limits of distribution are mobile. They are classified as follows:

- 1) Species having stable northern limits;

*Hodotermopsis japonicus* (if its occurrence in Kochi Prefecture is fact)

*Kaloterme fuscus*

*Leucotermes speratus*

*Coptotermes formosanus*

*Kaloterme koshunensis*

*Eutermes takasagoensis*

- 2) Species having unstable northern limits:

*Kaloterme kotoensis*

*Odontotermes formosanus*

### Conclusion

Laboratory and field studies on the relationship between temperature and geographical distribution of termites have led to the following general conclusions:

1. The mortality of termite by exposure to low temperature extremes varies with species, and the rank of species according to the L.D. 50 from the strong to the weak, did not entirely coincide with the rank according to the northern limits of distribution from the north to the south.

2. The mortality of termites by exposure to high temperature extremes also varies with species, and the rank of species according to the L. D. 50, from the weakest to the strongest, did not coincide with the rank of the northern limit of distribution of termites, from the north to the south.

3. It seems that the lack of association among these variables is due to the modification of temperature by soil, wood and behaviors of termites which

control temperature changes in their nests.

4. Each species of termite seems to prefer a different range of favorable temperature. When individuals are placed in a temperature graient, they congregate within narrow ranges of temperature. This congregation is characteristic of species. The range of preferred temperature is important in considering the distribution of termites.

5. The nest temperature of termites is not constant but varies with the variations on temperature of the air, time of day, weather, seasons, etc., being several degrees higher than that of the surrounding air in winter. During the summer, however, the nest temperatures seem to be lower than that of the atmospheric temperature.

6. The following formula is advanced to predict the geographical distribution of termites:

$$P_t \leq A_t + D_t$$

$P_t$  .....The lowest preferred temperature of a certain species of termite.

$A_t$  .....The mean daily minimum air temperature in the coldest month in a certain region.

$D_t$  .....Temperature difference between nest temperature ( $N_t$ ) of certain species in the coldest month at a certain region and  $A_t$ .

$$D_t = N_t - A_t$$

If  $P_t < A_t + D_t$ ,

this species would be distributed in the northernmost regions than in the region at which  $A_t$  value used in culculation was taken.

If  $P_t = A_t + D_t$ ,

the northernmost distribution of this species would be stable at the region where  $A_t$  value was obtained.

If  $P_t > A_t + D_t$ ,

the occurrence of this species in a region would be temporal and isolated from its southern major range of ditribution, or the region would be partly warmer than the surrounding regions.

## X. CONCLUSION

Laboratory and field studies on the geographical distribution of termites in the Ryukyu Archipelago have led to the following general conclusions:

1. Of the ten species of termites known in the Ryukyu Archipelago, nine have been found in Formosa, and three species have been found in South China. Four or five species of the Ryukyuan termites have been found in the Japanese Archipelago, but no species has been found in the philippines. Judging from the affinity of their termite faunas, It may be said that if these species are all of tropical origin, the termites known in the Ryukyu Archipelago must have

migrated from the tropical regions through South China and Formosa, but not by way of the Philippines, and expanded into the Japanese Archipelago.

2. Principal means of dispersal from the tropical regions to the Ryukyu Archipelago and between islands in the archipelago, seem to be by marine drifts, flights, winds and men's transports. Among them, Men's transports may be the most important factor responsible for the irregular distribution of termites.

3. The distribution of five species of the Ryukyuan termites is limited within the range of the Ryukyu Archipelago, viz., *Kaloterme*s *koshunensis*, *Kaloterme*s *kotoensis*, *Odontoterme*s *formosanus* (the northernmost limit is Shanghai in China), *Eutermes* *takasagoensis*, and *Capriterme*s *nitobei*. Of the ten species of the Ryukyuan termites, only one, *Hodotermopsis* *japonicus*, seems to be limited to the southern limits of distribution within the Ryukyu Archipelago.

5. The abundance of colonies of given species of termites shifts from the mountainous regions to the flat land and from inland to coastal regions as the latitude increases. The distribution of termites according to altitude is conspicuous on Yaku-shima but not on other islands. The rank of species according to altitudinal distribution, from the highest to the lowest, coincides fairly with the rank of species according to latitudinal distribution, from the north to south.

6. The lowest preferred temperature ( $P_t$ ) of each species of termite shows relative coincidence with the mean daily minimum nest temperature ( $N_t$ ) of species during the coldest month at its northern limits of distribution. The  $N_t$  is always several degrees higher than the mean daily minimum air temperature ( $A_t$ ) during the coldest month. Therefore, the status of the northern limit of distribution of a species may be judged from the relationship among  $P_t$ ,  $N_t$  and  $(N_t - A_t) = D_t$ .

$$\text{If } P_t < A_t + D_t,$$

the northernmost limit of distribution of a species would probably enable it to shift further more north than the locality where the nest temperature of the species was taken.

$$\text{If } P_t = A_t + D_t,$$

the northern limit of distribution of the species is probably stable in the locality where the nest temperature was measured.

$$\text{If } P_t > A_t + D_t,$$

the distribution of the species in the region is probably temporary or the occurrence of the species in the region is probably due to isolation from its southern major ranges of distribution and the range is probably warmer than the neighbouring regions.

7. The distribution of termites is closely related to their food plants. Therefore, the former can be determined by the latter. The grouping of termites

from the standpoint of their food habits seems to be convenient not only to determine the status of distribution of termites, but also to find methods for prevention and control of termites.

8. From the results of this study, particularly from the preferred temperature of termite and the food habits, the following species will be able to invade more northerly regions in which they are not known to occur at present:

*Hodotermopsis japonicus* (if Tanegashima is the northern limit of distribution)

*Kaloterme fuscus*

*Kaloterme kotoensis*

*Odontoterme formosanus*.

## XI LITERATURE

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### EXPLANATION OF PLATES

#### Plate I.

- A. Photograph showing passageway of the common dry wood termite (*Kaloterms kotoensis*) in a piece of house timber. Note that a soldier passing through a narrow passageway (p.63).
- B. C. Fungi grown as food by *Odontotermes formosanus* in the Ryukyu Archipelago (p.65).
- D. Carton tree nest of *Eutermes takasagoensis* in the forest, near Ishigaki City, Yaeyama (p.65).

#### Plate II.

- A. Habitat of the large termite, *Hodotermopsis aponicus*, near Nase City, Amami-oshima (p.61).
- B. Decayed portion of tree in which *Kaloterms fuscus* was found, Shiono-misaki, Wakayama Prefecture (p.71).
- C. Forest where *Kaloterms fuscus* was found, near Nichinan City, Miyazaki Prefecture (p.71).
- D. E. Covered ways composed of particles of earth, constructed by the fungus-growing termite (*Odontotermes formosanus*), in the forest near Ishigaki City, Yaeyama. (p.117).

#### Plate III.

- A. B. Nurseries or special chambers of *Odontotermes formosanus*. Note that food nodules of eaten wood bound in the chambers (p.121).
- C. D. Mushrooms grown by a nursery in the beginning of July (p.121).
- E. Distribution of individuals of *Coptotermes formosanus* in the temperature gradient of the iron-bar (p.141).



Plate I

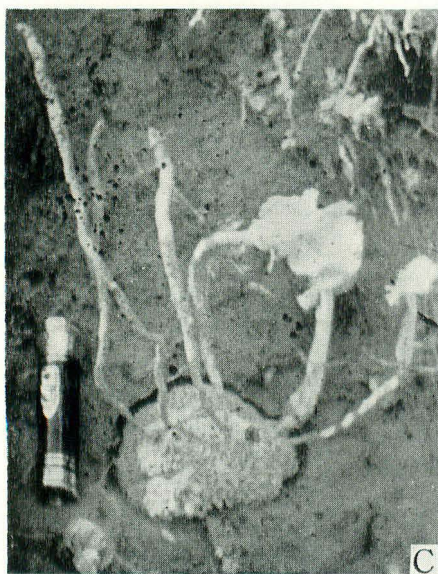
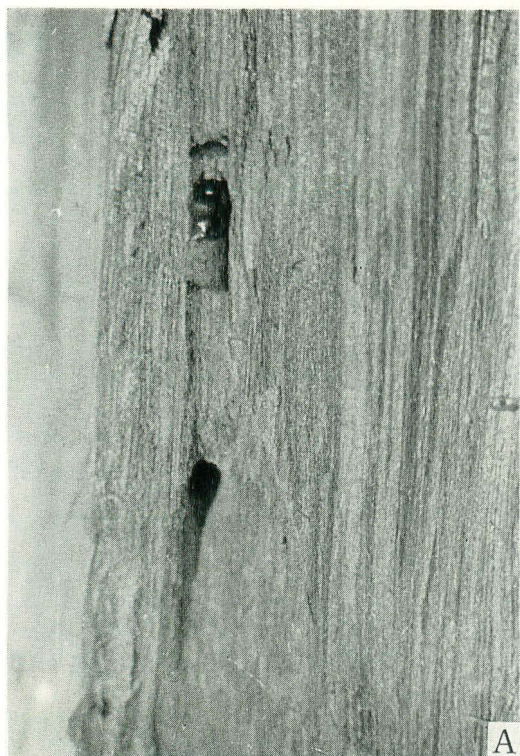




Plate II





Plate III

