

# 環 動 昆

## 報 文

- 浜谷 徹・河野 敏明・青野 力三・西本 孝一：磁化木材の性能に関する研究（第2報）磁化木材とその防蟻効果（英文） .....171
- 北原 正彦：一地域チョウ類群集の春～初夏期間の各種の年次出現パターン（英文） .....178
- 南手 良裕・浅井 洋・神崎 務・勝田 純郎：ピレスロイド系殺虫成分を含有する液体式電気蚊取用水性リキッドのアカイエカ成虫に対する殺虫効力 .....192
- 吉田 宗弘：チョウ類群集による大阪市近郊住宅地の環境評価 .....198
- 野口佐登司・森 直樹・比嘉ヨシ子・桑原保正：ヤンバルトサカヤスデ（オビヤスデ目，ヤケヤスデ科）の分泌物主成分，マンデロニトリルの同定（英文） .....208

## 研究奨励賞受賞論文

- 宇賀 昭二：公園砂場におけるトキソカラ属線虫卵汚染状況の調査研究 .....215

会 報 .....

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## Research on Magnetic Wood (II) Termite Resistance of Magnetic Wood

Toru HAMAYA<sup>1)</sup>, Toshiaki KONO<sup>1)</sup>, Rikizo AONO<sup>2)</sup>,  
and Koichi NISHIMOTO<sup>3)</sup>

- 1) *Bio Science Laboratories, Meiji Seika Kaisha, Chiyoda, Sakado-shi, Saitama 350-02, Japan*
- 2) *Tokyo Institute of Technology, Department of Bioengineering, Nagatsuta, Midori-ku, Yokohama, Kanagawa 226, Japan*
- 3) *Japan Wood Preserving Association, Toranomom, Minato-ku, Tokyo 105, Japan*

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磁化木材の性能に関する研究 (第2報) 磁化木材とその防蟻効果 浜谷 徹<sup>1)</sup>, 河野敏明<sup>1)</sup>, 青野力三<sup>2)</sup>, 西本孝一<sup>3)</sup> (1)明治製菓株式会社生物科学研究所, 2)東京工業大学生命理工学部生物工学科, 3)㈪日本木材保存協会)

酵素反応を利用して, 磁性体 (マグネタイト:  $\text{Fe}_3\text{O}_4$ ) を木材 (アカマツ) 内で発生させた. この磁化木材をイエシロアリの食害試験に供した. その結果, 未処理木材の食害率が31.3%であったのに対し, もっとも高い飽和磁化 ( $14.53 \times 10^{-2}$  emu) を有する酵素区で15.1%. 低い飽和磁化 ( $2.47 \times 10^{-2}$  emu) を有する酵素不使用区が12.7%で共に防蟻性を有する傾向を示した. しかし, ほとんど磁化を示さない ( $0.33 \times 10^{-2}$  emu) 硫酸第一鉄区では25.1%であり, 防蟻性を示さなかった. 木材に対し耐候操作を行った結果, 酵素区及び酵素不使用区の磁化木材は防蟻能が高くなり, 食害率は共に6.1%であった. しかし, 両実験区のばらつきをみると, 酵素区では食害率が0%, 死虫率が100%となる場合がある一方, ほとんど効果を示さない場合もあった. この原因として, 木材間で酵素反応が不均一に進行した可能性も考えられ, この点の改良により, さらに高い防蟻性能を有する磁化木材を調整できることが期待された. 死虫率と食害率には負の相関関係があり, 磁化木材を摂取することによりシロアリが死亡したことが推定された. 実際, 死んだシロアリの約80%は黒変し, 腸管から鉄が検出され, 磁化木材を接取して死んだことが示された. しかし約20%は白いままであり, 磁化木材を忌避し餓死した可能性も残された.

Magnetic material ( $\text{Fe}_3\text{O}_4$ ) was generated inside wood (*Pinus densiflora*) blocks by an enzyme-dependent or a chemical reaction. Studies examining termite (*Coptotermes formosans* SHIRAKI) attack on this magnetic wood were done. Untreated wood showed 31.3% weight loss, while the enzyme-treated magnetic wood that had the strongest saturation magnetization (Ms,  $14.53 \times$

$10^{-2}$  emu) had 15.1% weight loss, and that magnetic wood with no enzyme treatment which had weak Ms ( $2.47 \times 10^{-2}$  emu) was 12.7%. In contrast, the wood treated with only iron (II) sulfate, which had a very low Ms ( $0.33 \times 10^{-2}$  emu) showed no termite resistance and lost 25.1% of the weight of the blocks. The termite resistance of the magnetic wood was increased by leaching. Both magnetic wood treated with and without enzyme had 6.1% weight loss, but the deviation was significantly different between these two treatments. In the case of enzyme treatment, both perfect (100% mortality and 0% weight loss) and almost no effect against termite attack were observed. This implied that the enzyme reaction would not have uniform effects among the woods and it is expected that overcoming this problem might improve the resistance of the enzyme-treated magnetic wood. The correlation between mortality of termites and weight loss of wood blocks suggested that the termites died after ingesting the magnetic wood. Actually, about 80% of the dead termites obtained after the bioassay in the enzyme treatment were black in color and the element of iron was detected in the intestine. This indicated that the termites died after ingesting the wood. But the 20% of the dead termites that did not change color implied the possibility that they avoided the magnetic wood and died of starvation.

**Key words :** Termite, Magnetic wood, Saturation magnetization, Urease

### Introduction

Termites cause much biological deterioration of many kinds of structures made of wood. Therefore chemically synthesized termiticides are usually applied to wooden materials to protect them from the attack of termites. Recently, natural antifeedants extracted from plants such as *Phellodendron amurense* (KAWAGUCHI *et al.*, 1989) or *Citrus natsudaidai* HAYATA (SERIT *et al.*, 1991) have been studied, considering the environmental hazards associated with chemically synthesized termiticides. However, these extracts seem to be difficult for commercial use at the present because their effectiveness and durability are not sufficient. The relationships between magnetic fields and living organisms have also been studied. Certain kinds of termites have the ability to

sense a magnetic field (BECKER *et al.*, 1977). If termites sense and avoid a magnetic field, this behavior may be used as a new preservation system for wooden materials.

Recently, a method of generating magnetic materials (magnetite,  $Fe_3O_4$ ) in solution and inside some polymer materials by an enzyme-dependent reaction has been developed (HAMAYA *et al.*, 1989a, 1989b, 1993). Magnetic wood is possible to make by this method (HAMAYA *et al.*, 1996). In this paper we report the effects of the magnetic wood on termite (*Coptotermes formosans* SHIRAKI) attack.

### Materials and methods

#### Sample preparation

Blocks of Japanese red pine (*Pinus densiflora* (SIEB *et* ZUCC.)) ( $1 \times 1 \times 2$  cm) were dried in a vacuum at 50 °C until the weight became

constant. Ten pieces of the dried wood were placed in a bottle (1 ℓ) and 500 ml of urease (Sigma Type IX) solution (800 IU/ml), measured at 40 °C, was used to impregnate the wood by a vacuum method. After checking to ensure that every piece had sunk in the solution, the woods were removed from the solution, excess liquid on the surface was wiped off, and the blocks were freeze dried.

(1) Enzyme treatment.

A reaction mixture containing 10 mM iron (II) sulfate, 5 mM urea, and 200 mM potassium nitrate was used to impregnate the dried wood by the same method as used for the enzyme solution. This experiment was named the "enzyme treatment".

(2) No enzyme treatment.

Dried wood without enzyme was treated in the same manner for use as the control. This experiment was named the "no enzyme treatment".

(3) Iron sulfate treatment.

Wood blocks were infused with only 10 mM iron (II) sulfate solution for the purpose of comparison. This experiment was named the "iron sulfate treatment".

Each sample was transferred with its reaction mixture or iron (II) sulfate solution into a heat-proof bottle. The atmosphere in each bottle was replaced with nitrogen gas and the bottles were kept at 50 °C. After 3 days of incubation, they were autoclaved (121 °C, 60 min). The wood was then removed, rinsed with water, and oven-dried at 50 °C until the weight became constant.

#### ***Analysis of magnetic performance***

The magnetic hysteresis of the woods was analyzed using a magnetometer BHV-50 (Riken Electric Co.). Saturation magnetization (Ms), which means the magnetization at saturated strength of the magnetic field, was calculated from the hysteresis curve and was used for the

comparison of magnetic strength between each treatment.

#### ***Leaching treatment***

The procedure used for the leaching treatment was that of the Japan Wood Preserving Association Standard No. 11. Wood blocks were soaked in water for 30 seconds and stored in a desiccator containing water at the bottom at 26 °C for 4 hours. Then the blocks were stored in a drying oven at 40 °C for 20 hours. Both treatments were repeated 10 times.

#### ***Bioassay***

The procedure used the feeding test for termites was also that of the Japan Wood Preserving Association Standard No. 11. Wood blocks were dried at 60 °C for 48 hours and cooled in a desiccator for 30 minutes at room temperature, then the weight was measured. Five wood blocks (the orders of weight gain during preparation in each treatment are 1st, 3rd, 5th, 7th and 9th) were chosen and each block was settled in a feeding cage with 150 workers and 15 soldiers of *C. formosonus*. The feeding was continued for 21 days at 28 °C in a dark place. Then the blocks were dried under the same conditions as described above and the weight was measured. The weight loss of the blocks and the mortality of the termites were noted.

#### ***SEM observation and X-ray analysis***

The termites used for the bioassay were stored at -20 °C until the observation. The termites were dissected in water and the intestine was removed. Then vacuum evaporation with carbon was done on the contents of the intestine and they were observed using a scanning electron microscope S-570 (Hitachi Co. Ltd.) at 30 kv. Additionally an X-ray analysis using an EDAX-9900 (Philips Co. Ltd.) was done to analyze the elements in the contents.

## Results and discussion

### Formation of magnetic wood

The wood of the enzyme treatment and the no enzyme treatment were brown to black in color after incubation but the wood of the iron sulfate treatment remained yellow. The increase ratio of the weight was 5.4% in the enzyme treatment, 3.9% in the no-enzyme treatment, and 1.3% in the iron sulfate treatment (Table 1). On the other hand the Ms was  $14.53 \times 10^{-2}$  (emu) in the enzyme treatment,  $2.47 \times 10^{-2}$  (emu) in the no-enzyme treatment, and  $0.33 \times 10^{-2}$  (emu) in the iron sulfate treatment (Table 1). The order of strength of Ms was found to correspond to the weight gain of the wood. The amount of formed magnetic materials in the total materials which caused the weight gain was higher with the enzyme treatment than with the no-enzyme treatment, suggesting that the rapid hydrolysis of urea by autoclave treatment seems to lead to the production of magnetite, but its amount was small.

### Effects of magnetic wood on termites

Each formation of wood was bioassayed for

termite resistance. The results are summarized in Table 2. Untreated wood blocks showed 31.3% weight loss, while enzyme-treated wood blocks had 15.1% weight loss and no-enzyme treated wood blocks lost 12.7% of their weight. On the contrary, in the iron sulfate treated wood 25.1% weight loss was seen, with no termite resistance. The enzyme-treated and the no-enzyme treated woods tended to be protected from the termite attack.

According to the results of the leaching treatment, the termite resistance of the wood was substantially increased in the enzyme-treatment and in the no-enzyme treatment (Table 3). The mortality of enzyme-treatment was increased to 69.5% and that of no-enzyme treatment was done to 60.5%. Both the enzyme and no-enzyme treated wood showed 6.1% weight loss but little change was observed in the case of the iron sulfate treatment. One possible reason for the increased mortality and reduced weight loss by leaching treatment after the enzyme treatment and no-enzyme treatment should be the crystallization of magnetite during the leaching treatment. The crystallization is generally

Table 1 Formation of magnetic wood

Formation	Initial weight (g)	Final weight (g)	Weight gain (%)	Ms** ( $\times 10^{-2}$ emu)
Enzyme	1.0657	1.1236	5.4	14.53
No enzyme	1.0830	1.1249	3.9	2.47
Iron sulfate	1.0749	1.0890	1.3	0.33

\* Mean of 5 replicates (?)

\*\* Saturation magnetization

Table 2 Effects on *C. formosanus* worker termites by wood block treatment

Formation	Mortality*		Weight loss of wood block*	
	Min. - Max.	Mean	Min. - Max.	Mean
Enzyme	16.7 - 23.3	19.7	13.9 - 16.5	15.1
No enzyme	22.0 - 31.3	26.3	10.7 - 14.5	12.7
Iron sulfate	4.7 - 10.7	7.9	21.5 - 26.3	25.1
No treatment	2.0 - 3.3	2.5	29.9 - 33.5	31.3

\* Values from 5 replicates

Table 3 Effects on *C. formosanus* worker termites by wood block treatment after leaching test

Formation	Mortality* (%)		Weight loss of wood block* (%)	
	Min. - Max.	Mean	Min. - Max.	Mean
Enzyme	26.7 - 100	69.5	0 - 14.5	6.1
No enzyme	44.0 - 76.0	60.5	4.1 - 8.4	6.1
Iron sulfate	16.0 - 38.7	22.4	17.3 - 25.8	21.1

\*Values from 5 replicates

increased at high temperatures and previous studies (HAMAYA *et al.*, 1989b, 1993) also supporting. But this is the subject for a future study.

The relationship between the mortality of termites and the weight loss of wood blocks after leaching treatment is shown in Fig. 1. Comparing the enzyme treatment and no enzyme treatment, it seems that the mean value of weight loss was the same and that of mortality was very similar in spite of the difference in Ms (Table 3). However special attention should be paid to the deviation of enzyme treatment and no-enzyme treatment. The results of an *F*-test on both weight loss and

mortality suggested that the difference of deviation between the two treatments was significant (at the 5% level, both sides). Three of 5 blocks in the enzyme treatment showed higher mortality than the best of the no-enzyme treatment and the two of them showed 100% mortality. On the contrary, two of 5 blocks were lower comparing to the worst of the no-enzyme treatment. These data implied that the enzyme reaction did not happen uniformly among the 5 wood blocks. We believe that uniform reaction would increase the resistant performance against termites.

#### Observation and analysis of termite

The reason for the death of the termites remains unclear, but it seems important to discuss and understand the mechanism of this activity.

About 80% of the dead termites obtained after the bioassay in the enzyme treatment were black in color and the remainders were white. Both black and white termites are shown in Fig. 2. The blackened color was thought to be due to the ingestion of magnetic wood. Actually a positive correlation ( $r^2 = 0.8819$ ) between mortality of termites and weight loss of wood blocks was observed (Fig. 1). Then the termites were dissected and the intestine was removed to investigate the presence of magnetic wood. In the case of the blackened termites, the intestine was thick and it seemed to contain a lot of materials. On the contrary, in the case of the white termites the intestine was thin and empty. The contents of the intestine from blackened

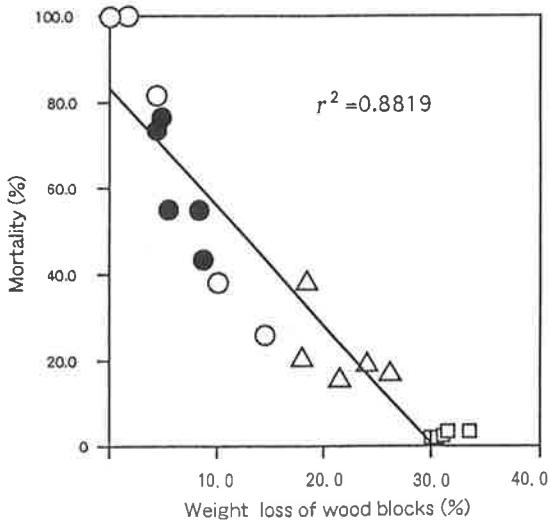


Fig. 1 The relationship between mortality of termites and weight loss of wood blocks after leaching treatment

○, ●, △ and □ indicate enzyme-treated, no-enzyme treated, iron (II) sulfate treated, and untreated woods.

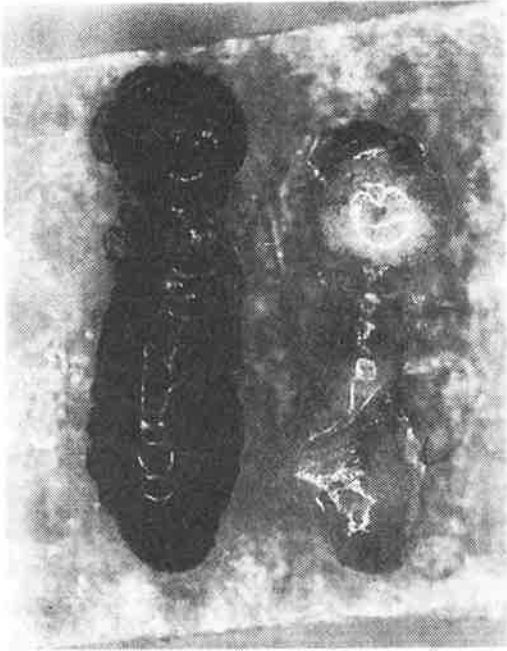


Fig. 2 The black and white termites fed the enzyme treated wood blocks.

termites were analyzed using a scanning electron microscope (Fig. 3). According to the data obtained by an X-ray microanalyzer, a high concentration of elemental iron was present in the intestinal contents (Fig. 4). Accordingly, it was indicated that the blackened termites died after ingesting the magnetic wood. On the other hand, the reason why 20% of the termites remained white must be considered as its ecdysis but they might have avoided magnetic wood and starved to death. In addition, the wood blocks of enzyme and no enzyme treatment before leaching treatment showed less weight loss than that of iron sulfate treatment after leaching test in spite of a similar mortality. This also implied the possibility that termites would avoid the magnetic wood.

To explain the termite resistance of magnetic wood, we have suggested two mechanisms. The main reason is the formation of harmful substances during the process of magnetite



Fig. 3 The contents of the intestine from blackened termites.

The blackened termite was dissected and the contents of the intestine were analyzed by a scanning electron microscope. ★ showed the analytical point by the X-ray microanalyzer.

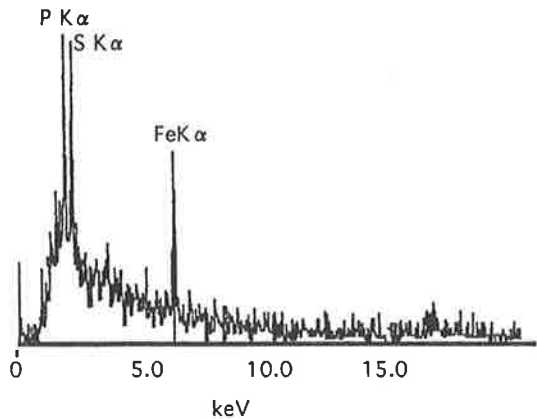


Fig. 4 Analysis of the contents of blackened termite by X-ray microanalyzer. High concentration of iron was present in the intestine of blackened termite.

formation and leaching treatment. Additionally, the starvation of termites due to their avoidance of the magnetic wood should be considered. The relationship between living organisms and magnetic fields is not clear at present. In the

future, the mechanisms of termite resistance should be examined in choice tests using preparations of magnetic woods which have different Ms. Anyway, there are many points that must be considered and further study is necessary.

As the magnetite is solid, so it is expected the magnetic wood would be resistant to rain. In addition the effect against termite attack was increased during leaching treatment. These unique characters could have synergy with chemical termiticides. In addition, magnetic wood is expected to provide a shielding effect against magnetic fields, as if it was wood containing a liquid magnet, as reported by OKA *et al* (1995). Field tests are necessary to estimate the ability for industrial use but we hope that the magnetic wood will have the status of a new kind of functional wood, like ceramic wood, acetylated wood, and wood-plastic combinations, in the near future.

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## Annual Species Appearance Patterns in a Local Butterfly Community during Early Growing Seasons

Masahiko KITAHARA

*Department of Animal Ecology, Yamanashi Institute of Environmental Sciences,  
Ken-marubi, Fujiyoshida, Yamanashi 403-0005, Japan*

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一地域チョウ類群集の春～初夏期間の各種の年次出現パターン 北原正彦 (山梨県環境科学研究所)

山梨県富士山麓西湖畔の様々な環境を含む約10haの場所で1985-89年の5年間、トランセクト法により集積したチョウ類群集のデータを用いて、春～初夏(4～6月)の成虫の出現パターンを解析した。4～6月のチョウ類は、ほぼ毎年(4～5年)記録された常出現種と僅かに1～2年しか記録されなかった寡出現種とから主に成り立っていた。1年間隔の種の回転率は29.1% (平均値) と高かったが、サンプリング誤差の影響も否定できない。群集の全体的属性(種数・総個体数・種類組成)は、5年間を通すと寡出現種の種数が多かったため、年毎に変動し、年次的な予測の程度は相対的に低かったが、群集の構成種レベルでの属性(各種の年毎の出現密度および群集内順位)は、解析の結果、年毎に大きな変動は無く、相対的に予測のきく状況を示していた。このチョウ類群集の内部構造特性と年次予測性およびその保全生物学への適用性について論議した。

To examine the between-year community predictability (constancy), I analyzed a published transect-count data set of a local butterfly community at the northern foot of Mt. Fuji in central Japan. The data set was obtained with the transect counting in an area of about 10 ha including arable fields, grassland, sparse woods including bushes, and secondary woodland. I used the transect-count data obtained from April to June for five years, 1985-1989. The analysis showed that the butterfly community was composed mainly of constant species that appeared in 4 or 5 of the years, and sporadic species that did only in 1 or 2 years. The mean value of species turnover rates for one-year intervals in the community was estimated to be 29.1%, though there may be a possibility that the transect-count data included sampling errors. The butterfly community was temporally unpredictable in the number of species, species composition, and total population abundances, mainly due to whether sporadic species appear or not, despite which the community also had a fairly stable aspect due to constant species. On the

other hand, the butterfly community showed a highly significant concordance in the rank order of species abundance over the 5 years. Also, all 9 correlations between log April-June abundances of species in possible pairs of years except for a pair of 1985 and 1987 showed lower  $P$  values ( $<0.05$ ). Thus, the abundance of each species was less variable among different years, and showed a high degree of temporal constancy. As a whole, the butterfly community had a predictable core of constant species with an unpredictable surface of sporadic species, and therefore, had a lower degree of temporal predictability. These results support the belief that even in unstable (high turnover) communities, there will be a mix of fugitive and stable species. How the analysis of community predictability may contribute to its conservation biology is discussed briefly.

**Key Words :** Temporal community predictability, Local butterfly community, Annual species appearance pattern, Early growing season, Constant and sporadic species

### Introduction

"To do science is to search for repeated patterns, not simply to accumulate facts." (MACARTHUR, 1972). A major objective of community ecology is to discern whether recurring predictable patterns of community structure exist (SEIFERT, 1984) and to explain the patterns by ecological inference (TAKEDA, 1987). In this respect, it is important to know whether there are repeated predictable temporal patterns in community structure (STRONG *et al.*, 1984; LAWTON and GASTON, 1989).

Up to now, most studies have been primarily concerned with temporal variation in population densities, while less data concerning temporal community variability exist (STRONG *et al.*, 1984; LAWTON and GASTON, 1989; BENGTSSON, 1994). LAWTON and GASTON (1989) emphasized the need for sound empirical data on the relative abundances of sets of component species measured over several generations. Few attempts have been made to examine the year to year dynamics of butterfly communities, except

for YAMAMOTO (1996).

In this study, I analyze a published data set (WATANABE, 1990) collected using transect counts on a local butterfly community surveyed successively for five years, 1985-1989. I explore four aspects of temporal community predictability: species composition, species richness, population abundance, and species rank order. I begin analyzing the temporal predictability in the species appearance patterns of a local butterfly community during the early growing seasons. Next, I explore the factors affecting the temporal predictability of the butterfly community. Finally, I briefly take into account the applicability of the studies of community predictability to modern conservation biology.

### Materials and Methods

#### *Data set analyzed*

I analyzed a data set of butterfly transect counts obtained by WATANABE (1990) in 1985-1989 in an about 10-ha area (about 920 m in altitude) at the northern foot of Mt. Fuji, Yamanashi Prefecture.

The fixed route (about 1.5 km) for the transect-

count was established in the area covering seven habitat types : grasslands, sparse woods, secondary forests, agricultural and open fields, housing sites, streams, and roads (Fig. 1). No major changes were observed in the environmental and landscape conditions or in land-use patterns in the area over the 5-year study period.

WATANABE (1990) did the transect count from April to June in 1985, to September in 1986, to June in 1987, to October in 1988, and to October in 1989. Therefore, in this paper, I analyzed the census data obtained from April to June in each of the 5 years. The period from April to June as an early growing season covers approximately one or at most two generations of each component species of the butterfly community. During April and June, the census was done for twelve days in 1985, nine days in 1986,

five days in 1987, five days in 1988, and six days in 1989 (WATANABE, 1990).

The transect counts were conducted along a fixed census route (see Fig. 1), within the period from about 9 : 00 to 12 : 00 (rarely from about 13 : 00 to 16 : 00) in fine weather. All butterflies sighted within 20 m of either side of the census route were identified and the number of individuals was recorded. The individuals that could not be identified by sight were captured by insect net, and released after identification. *Pieris melete* MÉNÉTRIÉS and *P. napi* LINNAEUS were treated as a single species.

#### Methods of analysis

I first calculated the monthly abundance (i. e., the monthly total number of individuals observed/the research frequencies only when the species were found in a month) for each species during the early growing season (from April

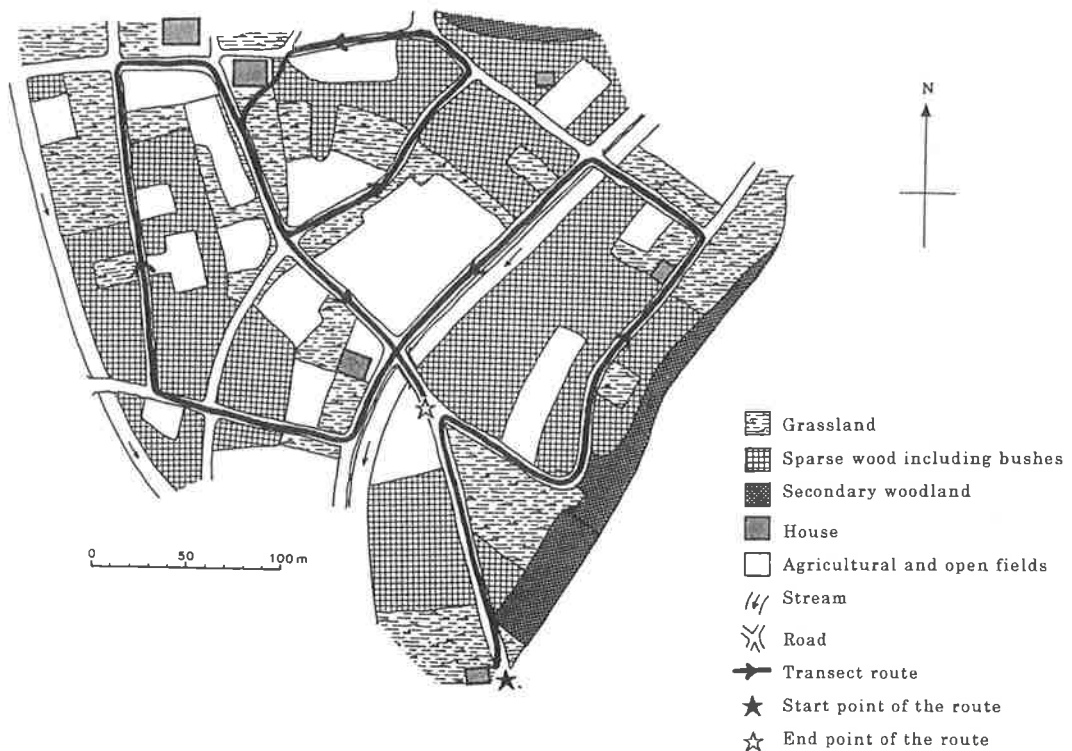


Fig. 1 Descriptive map of the vegetation and environmental component in the study site (WATANABE, 1990).

until June). Then, I summed up the all monthly abundances to get a total of April, May, and June's monthly abundances in each year (hereafter called April-June abundance). The April-June abundance and its rank order of each component species are shown in the Appendix. Exceptionally, I used data in the observation of May 1 for calculating the monthly abundance in the April in 1988, because of the lack of regular observations.

Species turnover rate (i. e., relative turnover rate, SCHOENER (1986)) over a unit time (one-year) interval,  $t_2 - t_1$ , in the species appearance patterns of the butterfly community monitored was calculated as

$$100 \times \frac{(Sd + Sa)}{(St_1 + St_2)}$$

Where  $Sd$  is the number of species that disappeared,  $Sa$  is the number of species that newly appeared,  $St_1$  is the number of species at  $t_1$ , and  $St_2$  is the number of species at  $t_2$  (DIAMOND, 1969; WILLIAMSON, 1981; SCHOENER and SPILLER, 1987). Relative turnover is a better measure for comparisons between kinds of systems (SCHOENER, 1986). In this study, I treated the species recorded in year  $t_1$  but not in  $t_2$  as those that disappeared (genuine or apparent extinctions). The species recorded in year  $t_2$  but not in  $t_1$  were treated as those that newly appeared (genuine or apparent invasions).

Concordance for species abundances was calculated on the rank orders of April-June population abundances, shown in the Appendix. The degree of concordance was assessed by using KENDALL's coefficient of concordance (non-parametric multisample rank correlation statistic, SIEGEL, 1956; MARTIN and BATESON, 1993):

$$W = \frac{s}{\frac{1}{12} k^2 (N^3 - N)}$$

where  $s = \sum (R_i - \frac{\sum R_i}{N})^2$ ,  $R_i$  is the total of rank orders of each component species during the study period,  $k$  is the number of years studied, and  $N$  is the number of all component species ranked. In this study, the species not recorded in a given year were included in the calculation of  $W$  as tied maximum ranks within the year. In addition, the correlation coefficient was calculated between log transformed April-June abundances of each species of butterfly in two different years.

The voltinism and adult flight period used in the analysis were estimated from the literatures (UNNO and AOYAMA, 1981; FUKUDA *et al.*, 1982, 1983, 1984 a, b), and also from the actual data of seasonal changes in the observed number of individuals of each species in this data set (WATANABE, 1990).

## Results

### *The evaluation of the differences in the number of census days among the 5 years of study*

The number of days in which the census was done in each year (see the section of "Data set analyzed") was not significantly correlated with the number of butterfly species observed in each year ( $r_s = -0.205$ ,  $P > 0.05$ ,  $N = 5$ ), and also with the total number of individuals observed (total population abundance) in each year ( $r_s = -0.564$ ,  $P > 0.05$ ,  $N = 5$ ). From these results, it is considered that the differences in the number of census days among the years had almost no effect on the parameters of the butterfly community such as the number of species.

### *Taxonomic composition and apparent turnover rate of the butterfly community*

All butterfly species observed in the transect counts and the numbers of years in which the species were observed are shown in the Appendix. Figure 2 shows the frequency distribution of component species against the number

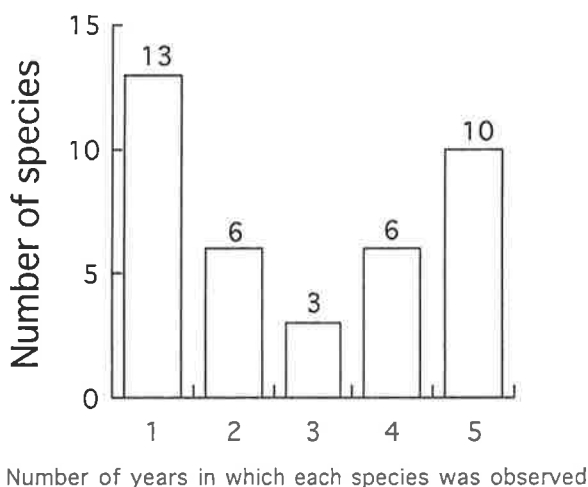


Fig. 2 Frequencies with which butterfly species were observed in different numbers of years between 1985 and 1989. The numeral above each bar indicates the number of butterfly species in different numbers of years in which the species was observed.

of years in which each species was observed during the study period. The frequency distribution is bimodal, with a peak in 4 or 5 years and with the other peak only in 1 or 2 years. For convenience' sake, the former constantly appearing group is hereafter referred to as "constant species", and the latter occasionally appearing group as "sporadic species".

Table 1 shows the estimated voltinism and adult flight period of the respective sporadic species in this habitat. According to the adult flight period, the univoltine sporadic species are divided into two types: (1) adults emerge only in early summer (including 3 spp.); (2) overwintering adults produce the first flight in spring, and new adults emerge in early summer (including 2 spp.). The bivoltine sporadic species are divided into two types: (1) the first adult flight occurs in late spring-early summer, the second in mid summer (including 6 spp.); (2) overwintering adults produce the first flight in spring, new adults emerge in early and mid summer, and the last flight occurs in late summer-fall (including 1 sp.). The multivoltine

sporadic species are divided into two types: (1) the first adult flight occurs in spring-early summer, the second in mid summer, and the third in fall (including 4 spp.); (2) overwintering adults produce the first flight in spring, new adults emerge in early summer, and the subsequent flights occur in summer-fall (including 3 spp.). From these results, there is little possibility that the species classified as "sporadic" in this study were yearly and occasionally observed during early growing seasons, because they had either univoltinism and adult emergence time in summer-fall seasons, or multivoltinism and main adult flight period in summer-fall seasons, except for a few species such as *Neptis philyra* MÉNÉTRIÉS, *Brenthis daphne* DENIS et SCHIFFERMÜLER, and *Parnara guttata* BREMER et GREY.

The apparent species turnover rates were 24.4, 30.4, 26.5, and 35.1% yr<sup>-1</sup> (respective one-year intervals from 1985 to 1989) (mean = 29.1, S. D. = 4.71). These values might be partly affected by the sampling error of the transect counting. But they are not very different from those reported by SCHOENER and SPILLER (1987) (32.5% for island orb spiders) and by DIAMOND (1969) (35.9% for island birds), which are known for high turnover rates, although these values are calculated based almost entirely on island genuine extinctions and invasions.

These results imply that the species composition is highly variable, mainly due to whether sporadic species appear or not, and therefore, the community had a temporal unpredictable species composition.

#### *Dynamics in species richness and total population abundance*

Figure 3 shows the year-to-year dynamics in the species richness. The number of species observed during the early growing season (from April to June) varied across the years. The constant species predominated in the butterfly

Temporal Predictability of a Local Butterfly Community

Table 1. The estimated voltinism and adult flight period of the sporadic butterfly species in the studied habitat. The estimation was done using the literature and the actual number of individuals of each species in this data set (see text)

Species	Voltinism*	Adult flight period
<i>Choaspes benjaminii</i>	2	late May-June, late July-Aug.
<i>Thoressa varia</i>	2	late May-June, late July-Aug.
<i>Parnara guttata</i>	3	mid May-June, July-Aug., Sept.-Oct.
<i>Papilio xuthus</i>	3	May-early June, July-Aug., Sept.-Oct.
<i>Papilio macilentus</i>	2	mid May-mid June, late July-Sept.
<i>Papilio maackii</i>	2	mid May-mid June, late July-Sept.
<i>Eurema hecabe</i>	3	overwintering adults in spring, new brood in early summer, continuous brood in summer-fall.
<i>Gonepteryx aspasia</i>	1	overwintering adults in spring, new brood in early July.
<i>Rapala arata</i>	2	mid May-June, late July-Aug.
<i>Celastrina argiolus</i>	3	late April-May, July-Aug., Sept.-Oct.
<i>Plebejus argus</i>	1	mid June-mid July
<i>Brenthis daphne</i>	1	mid June-July
<i>Limenitis camilla</i>	3	June, late July-Aug., mid Sept.-Oct.
<i>Neptis philyra</i>	1	late June-July
<i>Araschnia burejana</i>	2	mid May-June, mid July-Aug.
<i>Polygonia c-aureum</i>	2 - 3	overwintering adults in spring, new brood in early summer, continuous brood in summer-fall.
<i>Kaniska canace</i>	2	overwintering adults in spring, new brood in July-Aug., the second brood in late summer-fall.
<i>Nymphalis xanthomelas</i>	1	overwintering adults in spring, new brood in late June.
<i>Cynthia cardui</i>	3 ≤	overwintering adults in spring, new brood in early summer, continuous brood in summer-fall.

\* : number of generations per year. 1 : univoltines, 2 : bivoltines, 3 and 3 ≤ : tri- and multivoltines.

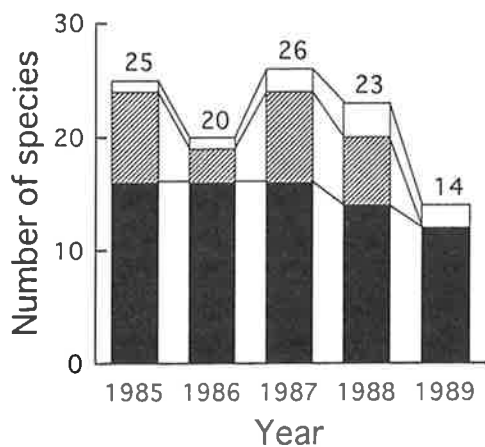


Fig. 3 Year to year changes in the number of butterfly species recorded in 4 or 5 years (■), those in 1 or 2 years (▨), those in 3 years (□), and all butterfly species recorded (numeral above each bar) during the study period from 1985 to 1989.

community in every year during the 5-year study period (mean proportion of the numbers of constant species in the 5-years = 70.4%, range 60.9%-85.7%), keeping nearly stable numbers of species. However, the second most abundant species in the proportion were those which appeared only in 1 or 2 years (sporadic species) and showed variable species numbers across the years, and the species appearing at 3 years showed the lowest abundance in the butterfly community. As a result, the year-to-year variation in the total number of species and taxonomic composition was strongly dependent on that in the number and composition of sporadic species.

Total population abundance fluctuated across

the years (Fig. 4). Minima and maxima of the total population abundances were observed in 1989 and in 1988, respectively.

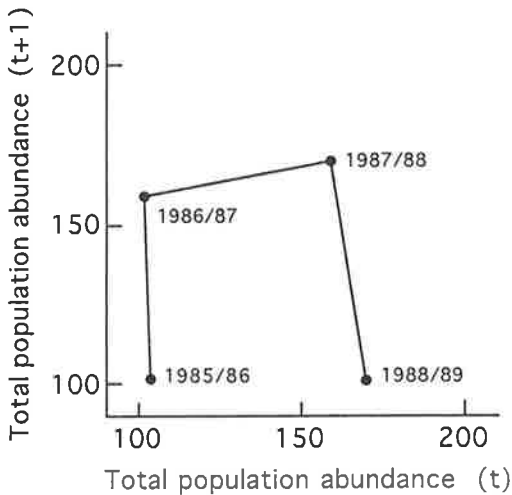


Fig. 4 Plots of the total butterfly population abundance in year  $t+1$  with that of year  $t$ . The total population abundances are obtained by summing the April-June abundances of all component species observed in each year.

These results suggest that the butterfly community had a temporal unpredictable aspect in both species richness and total population abundance, although the community also had a fairly stable aspect due to the presence of constant species.

#### Concordance in the rank order of species abundance

This butterfly community showed a significant concordance in the rank order of April-June population abundance over the 5 years 1985-89 ( $W = 0.651$ ,  $\chi^2 = 120.44$ , d. f. = 37,  $P < 0.001$ ). However, it is known that rare species have a disproportionate effect on the value of  $W$  (JOERN and PRUESS, 1986). There was a tendency for the species that were recorded in less than 3 years to be less abundant (KITAHARA and FUJII, unpublished). Thus, I further calculated  $W$  except for such species recorded in less than 3 years, and its value was still significant ( $W =$

0.555,  $\chi^2 = 49.95$ , d. f. = 18,  $P < 0.001$ ). These results suggest that the butterfly community showed a high degree of temporal constancy in rank order of species abundance.

#### Correlations between yearly abundances of component species

Figure 5 shows the correlation coefficients calculated between log transformed April-June abundances of each component species in two different years. All possible pairs of years between 1985 and 1989 were compared, and therefore, the maximum number of years between observations was four (1985 with 1989). Figure 6 shows four examples selected from those ten correlations in all possible pairs of years shown in Fig. 5. All of the correlations except for a pair of 1985 and 1987 had lower  $P$

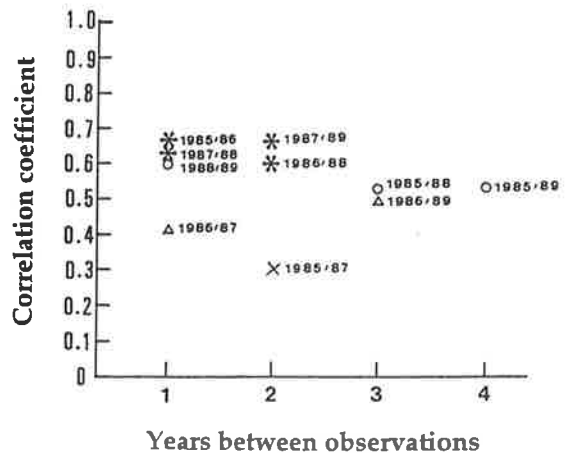


Fig. 5 Correlation coefficients between log transformed April-June abundances of each butterfly species in two different years. Points show the values of the correlations between all possible pairs of years between 1985 and 1989 (\* :  $P < 0.001$ , O :  $0.001 \leq P < 0.01$ , Δ :  $0.01 \leq P < 0.05$ , X :  $P > 0.05$ ). Each correlation coefficient was calculated for species present in both or either of the two years.

values ( $< 0.05$ ). This suggests that abundant species have remained abundant, and rare species have remained rare throughout the five years of study.

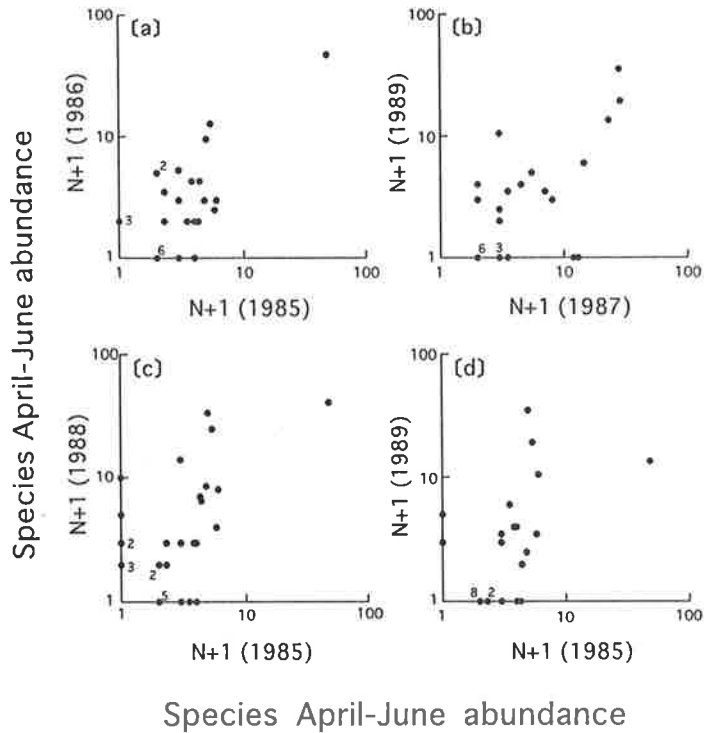


Fig. 6 Four examples of the relationship between the log transformed April-June abundance (+1) of each butterfly species in different pairs of years (a : year 1985 and 1986 :  $r=0.667$ ,  $t=4.565$ ,  $P<0.001$ , b ; 1987 and 1989 :  $r=0.660$ ,  $t=4.304$ ,  $p<0.001$ , c ; 1985 and 1988 :  $r=0.528$ ,  $t=3.405$ ,  $0.001 \leq P < 0.01$ , d ; 1985 and 1989 :  $r=0.535$ ,  $t=3.166$ ,  $0.001 \leq P < 0.01$ ), for species present in both or either of the two years, which were selected from among ten relations in all possible pairs of years shown in Fig. 5. Numerals beside the dots indicate repeated observations.

## Discussion

### *Temporal predictability of the butterfly community*

This study suggests that, in the butterfly community, the whole community attributes such as species number, total population abundance, and species composition were temporally unpredictable over the 5-year study period, but the component population's attributes such as the rank order of abundance of each species were more temporally predictable over the period. It is generally accepted that temporal community predictability varies greatly among different sorts of organisms

and habitat templates (e. g., MACARTHUR and WILSON, 1967 ; PIANKA, 1970, 1988 ; MACARTHUR, 1972 ; SOUTHWOOD, 1977, 1988). For example, a high degree of temporal constancy, especially in species-relative abundances, has been shown for several animal groups : insects (STRONG *et al.*, 1984 ; JOERN and PRUESS, 1986 ; TAKEDA, 1987 ; EVANS, 1988) ; fishes (MOYLE and VONDRACEK, 1985) ; and birds (DUNNING, 1986 ; WILLIAMSON, 1987). On the other hand, a low degree of temporal community predictability has been demonstrated for a number of animal groups : leaf-hoppers (WALOFF and THOMPSON, 1980) ; fishes (ROSS *et al.*, 1985 ; GROSSMAN *et al.*, 1985) ; and birds (WIENS, 1984). In a habitat dimension,