Geographical variation of pupal diapause in the great mormon butterfly, *Papilio memnon* L. (Lepidoptera: Papilionidae), in Western Japan

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(Received 30 September 1997; Accepted 16 January 1998)

Abstract

The distribution of the great mormon butterfly, *Papilio memnon* L., has been expanding to northeastern areas in the Kinki district in western Japan. To investigate the relationship between the phenomenon and characteristics of diapause of this species, the photoperiodic response of 4 Japanese populations including the subtropical and northernmost ones was examined. The critical photoperiod for inducing diapause at 20°C was 12 h 30 min in a subtropical population in Naze City (28°23'N), and about 13 h in temperate populations in Kagoshima (31°36'N), Wakayama (34°11'N), and Mino (34°54'N) Cities. Latitudinal variation was not found in diapause intensity (94–111 days) among the 3 temperate populations. However, diapause incidence at 13.5L–10.5D, which is slightly longer than the critical photoperiod, increased with latitude of the locality, and the deepest diapause was observed in some individuals in the Mino population. Nevertheless, the differences in critical photoperiod and diapause intensity among populations was smaller than that among broods in each population. As it appears to be difficult to explain the recent northward invasion of this species only by this slight change in diapause trait, the influence of climatic warming on the phenomenon is also discussed.

Key words: Pupal diapause, distribution, climatic warming, *Papilio memnon*, Japan

INTRODUCTION

In temperate regions, most insects enter winter diapause in response to seasonal cues such as short photoperiod and cool temperatures, and most widespread species show geographical variations in diapause. Insects inhabiting higher latitudes and/or altitudes tend to have longer critical photoperiods for inducing winter diapause and longer diapause periods. Variations in critical photoperiod and diapause intensity have been discussed in terms of adaptiveness to the climatic cline (e.g. Danilevsky, 1965; Danks, 1987).

The great mormon butterfly, *Papilio memnon* L. (Lepidoptera: Papilionidae), is distributed widely from tropical to temperate zones in the Oriental region, and the northern limit of its distribution lies in western Honshu, Japan. It was reported that under short day photoperiods at 25°C all individuals entered pupal diapause in a temperate population from Kagoshima, Japan (31.5°N) (Ishii, 1989), while no diapausing pupae were obtained in a trop-

ical population from Sabah, Malaysia (5.5°N) (Ishii, 1987). Thus, geographical variation of diapause is also apparent in this species.

Recently, changes in the distribution of insects including butterflies such as *Cacyreus marshalli* Butler (Sarto i Monteys, 1992; Anken and Pinto Bivar de Matos e Silva, 1996), *Danaus chrysippus* L. (Owen, 1991; Samraoui et al., 1992; Tennent, 1995), *D. eresimus* Cramer (Carhoun, 1996), *Leptotes marina* Reakirt (Gall and Andriele, 1994), and *Thymelicus lineola* Ochsenheimer (McKillop et al., 1992) have been reported worldwide. The distribution of *Papilio memnon* has also been expanding to northeastern areas in the Kinki district of western Japan (Fukuda et al., 1982; Shirôzu, 1985; Yoshio, 1994, 1995, Fig. 1). Ishii (1986) reviewed the geographical variation of pupal diapause in *Papilio* species distributed in eastern Asia including Japan, and hypothesized that the intensification or modification of pupal diapause is included in their northward invasion.

In the present study, we carried out several

experiments on the photoperiodic response of 4 Japanese populations of *P. memnon* including the northernmost one from 1993–1996 to examine this hypothesis. We report the results of the experiments and discuss the factors influencing the northward invasion of this species.

MATERIALS AND METHODS

Two series of experiments were done to investigate the photoperiodic response of the 4 populations of *P. memnon*, the Naze, Kagoshima, Wakayama and Mino populations.

In Series I, the response to photoperiods between 11 and 14 h was examined. Eggs of *P. memnon* were obtained from females collected at Naze City (28°23'N) in Amami Oshima Islands, Kagoshima Prefecture on 26 April 1993, at Kagoshima City (31°36'N) in Kagoshima Prefecture on 23 May 1993, at Wakayama City (34°11'N) in Wakayama Prefecture on 11 May 1993, and at Mino City (34°54'N) in Osaka Prefecture on 28 May 1993 (Fig. 1). Newly hatched larvae were reared under 4 photoperiodic conditions, 11L–13D, 12L–12D, 13L–11D and 14L–10D at $20 \pm 1.5^\circ\text{C}$.

Fig. 1. Change in the northeastern boundary of distribution of *Papilio memnon* in Japan. Closed circles indicate localities where females of this species were collected for this study. The distribution boundary in 1940 was drawn from Shirôzu (1985), those in 1945, 1950 and 1981 from Fukuda et al. (1982), and that in 1995 from Yoshio (1995).

In Series II, the response to photoperiods near the critical photoperiods for inducing diapause was examined. Eggs were obtained from females collected at Naze City on 25 September 1994, at Kagoshima City on 1 May 1994, at Wakayama City on 9 May 1994 and 13 May 1995, and at Mino City on 25 May and 1 June 1995. For the Naze population, the F_1 generation was used. In this series larvae were reared under 12L–12D, 12.5L–11.5D, 13L–11D and 13.5L–10.5D at $20 \pm 1.5^\circ\text{C}$.

Larvae were reared on fresh leaves of a citrus, *Citrus* sp., in 1993 and 1994, and on the artificial diet of Yoshio and Ishii (1996) in 1995. Rearing of larvae on citrus leaves was done as follows: Three to five larvae were reared in a 200-ml clear plastic cup during the 1st and 2nd instars. After the 3rd instar, larvae were individually reared in a 200-ml cup and the 5th (final) instar larvae in a 500-ml clear plastic cup. Rearing on the artificial diet was according to Yoshio and Ishii (1996), in which we reported that there was no significant difference in larval development and diapause incidence between groups reared on citrus leaves and the artificial diet.

The pupae thus obtained were kept under the same conditions as the larval stage until adult emergence. Since the pupal stage was 25 days or less under long days at 20°C in all 4 populations, individuals whose pupal stage lasted more than 25 days were regarded as diapausing. The period from pupation to adult emergence was defined as diapause intensity in diapausing individuals. Egg, larval, and pupal stages were recorded individually.

In Series II, both the critical photoperiod and mean diapause intensity were calculated on the basis of the data for all individuals belonging to each population and for all progenies of the same parents (referred to as “brood” below).

RESULTS

Egg, larval and pupal stages

Mean egg, larval, and pupal stages did not differ significantly among groups reared under different photoperiods in the 4 populations of *P. memnon* (by Tukey test, $p > 0.05$). Mean egg stage was about 7 days and mean pupal stage of non-diapausing individuals was 17–18 days at

Table 1. Mean egg, larval, and pupal stages (mean $\pm$ S.D. days) of 4 populations of *Papilio memnon* reared at 20°C. As mean larval, and pupal stages were not significantly different among groups reared under different photoperiods in the 4 populations, all data were pooled

Population	Egg stage	Larval stage	Pupal stage	
			Diapause	Non-diapause
Naze	6.6 $\pm$ 1.0 a (44)	27.6 $\pm$ 3.5 a (44) ^a	97.2 $\pm$ 16.9 a (15)	16.8 $\pm$ 1.6 a (22)
Kagoshima	6.7 $\pm$ 0.7 a (38)	28.9 $\pm$ 3.7 ab (50)	111.4 $\pm$ 11.8 b (35)	17.7 $\pm$ 2.3 a (15)
Wakayama	6.8 $\pm$ 0.5 a (45)	30.0 $\pm$ 2.7 b (45)	97.8 $\pm$ 15.6 a (32)	16.5 $\pm$ 1.1 a (13)
Mino	6.7 $\pm$ 0.8 a (34)	29.3 $\pm$ 3.9 ab (60)	109.6 $\pm$ 22.8 b (40)	17.3 $\pm$ 1.0 a (20)

Means followed by the same letter in the same column are not significantly different by Tukey test ($p > 0.05$). Numbers in parentheses indicate sample size.

^aThe figure includes 7 individuals which died from failure to pupate.

20°C, and there was no significant difference in these means among the 4 populations ($p > 0.05$, Table 1). As for larval stage, the mean of the Naze population (27.6 days) was significantly shorter than that of the Wakayama one (30.0 days, $p < 0.05$).

Critical photoperiod for inducing pupal diapause

The photoperiodic response curves of the 4 populations are shown in Fig. 2. All 4 populations showed a long-day response: All individuals developed into adults with no arrest of development under a long day of 14L-10D, while all or most individuals entered diapause in the pupal stage under short days of 11L-13D and 12L-12D. The critical photoperiod for inducing pupal diapause in the Naze population was

Fig. 2. Incidence of pupal diapause in 4 populations of *Papilio memnon*, the Naze (■), Kagoshima (○), Wakayama (□) and Mino (●) populations, reared under various photoperiods at 20°C.

about 12 h 30 min, which was shorter than those of the other 3 populations by about 30 min. Under 12L-12D and 11L-13D, about a fourth of the individuals averted diapause in the Naze population, while almost all individuals in the other 3 populations entered diapause. Although there were significant differences in diapause incidences under 12L-12D and 11L-13D

Fig. 3. Frequency distribution of the pupal stage of 4 populations of *P. memnon*. The data of individuals reared under various photoperiods at 20°C were pooled. Gray and black columns indicate non-diapausing and diapausing individuals, respectively.

among these 4 populations (by χ^2 -test, d.f.=3, $p<0.05$), no significant difference was found in those among the Kagoshima, Wakayama, and Mino populations (by χ^2 -test, d.f.=2, $p>0.05$).

Diapause intensity

Since no significant difference was observed among mean pupal stages of diapausing individuals reared under different photoperiods (by Tukey test, $p>0.05$), all data from the pupal stage were pooled and are shown in Fig. 3. Pupal stages of diapausing individuals ranged from about 2 to 5 months in the Naze, Kagoshima and Wakayama populations, while the Mino population included individuals whose pupal stages lasted both less than 2 months and more than 5 months. Mean diapause intensities, i.e. mean pupal stages for diapausing individuals, were 97, 111, 98 and 110 days, respectively, in the Naze, Kagoshima, Wakayama and Mino populations (Table 1). There was no significant difference in mean

diapause intensity between the Naze and Wakayama populations and between the Kagoshima and Mino populations (by Tukey test, $p>0.05$), but the means of the Naze and Wakayama populations were significantly shorter than those of the Kagoshima and Mino populations ($p<0.05$, Table 1).

Variation of critical photoperiod within a population

Figure 4 shows the photoperiodic response curve for each population and each brood within each of the 4 populations. Although all individuals entered pupal diapause under 12L–12D in the Naze population in this series, the photoperiodic response for each population showed the same tendency as seen in Series I: The critical photoperiods for the populations were also about 12 h 30 min and about 13 h in the Naze and the 3 other populations, respectively. There was no significant difference in the incidence of diapause under 13L–11D among

Fig. 4. Incidence of pupal diapause of 4 populations of *P. memnon* reared under various photoperiods at 20°C. Open and closed circles indicate incidences of pupal diapause for brood and population, respectively.

the Kagoshima, Wakayama, and Mino populations (by χ^2 -test, d.f.=2, $p>0.05$). However, the diapause incidences under 13.5L-10.5D were significantly different among these 3 populations: 16 and 36% of pupae entered diapause in the Wakayama and Mino populations, respectively, while all individuals averted pupal diapause in the Kagoshima population. No significant difference was found in the ratio of diapausing and non-diapausing individuals under 13.5L-10.5D between the Kagoshima and Wakayama populations, while the Mino population showed the highest diapausing incidence among the 3 populations (by χ^2 -test, d.f.=2, $p<0.05$).

The photoperiodic response of each brood varied within every population. All of the 2 broods responded to photoperiods almost uniformly in the Naze and Kagoshima populations, while each brood showed a different photoperiodic response in the Wakayama (by χ^2 -test, d.f.=3, $p<0.05$) and Mino (d.f.=1, $p<0.05$) populations. It is noteworthy that the diapause incidence varied from 0 to 90% under 13L-11D in the Wakayama population. In this population, about 20% of individuals averted diapause under a short day of 12.5L-11.5D in 2 of 4 broods examined, while about 30% of individuals entered diapause even under a long day of 13.5L-10.5D in 1 of 3 broods. In the Mino population, 1 of 2 broods examined showed about 70% pupal diapause even under a long day of 13.5L-10.5D, while all individuals in the other brood completely averted the diapause under the same photoperiod.

Variation of diapause intensity within a population

Figure 5 shows the mean diapause intensity for each population and its broods. Mean diapause intensities for the populations were 94, 106, 103, and 111 days, respectively, in the Naze, Kagoshima, Wakayama, and Mino populations. Pupal diapause was maintained longer in the Kagoshima population than in the Wakayama population (by Tukey test, $p<0.05$), while no significant difference was shown in the mean diapause intensity between the Kagoshima and Mino populations. In the Wakayama population, the mean diapause in-

Fig. 5. Mean diapause intensity of the 4 populations of *P. memnon* at 20°C. Open and closed circles indicate mean diapause intensities for brood and population, respectively. Horizontal line indicates standard deviation. Means of broods with same letters in each population are not significantly different by *t*-test except the Wakayama population tested by Tukey test ($p>0.05$). Sample sizes are also given in the figure.

tensity for the 4 broods examined varied from 93 to 110 days, which shows that this population consists of broods whose diapause intensity was as long as the Mino population and as short as the Naze one.

DISCUSSION

Critical photoperiod for inducing pupal diapause

It was clear that the photoperiodic response of the 4 populations of *P. memnon* was the long-day type, like other *Papilio* species inhabiting the temperate zone (e.g. Oliver, 1969; Hidaka and Hirai, 1970; Ichinose, 1974; Ishii, 1977, 1989; Ichinose and Negishi, 1979; Ichinose and Iwasaki, 1979; Sims, 1980; Shimada, 1983; James, 1988). The photoperiodic response of the Naze population in Series I was also similar to that of subtropical *Papilio* butterflies (Ae, 1978; Ichinose and Negishi, 1979), and slightly different from those of the other 3 populations (Kagoshima, Wakayama and Mino): Not all individuals entered dia-

pause in the pupal stage even under short days of 12L–12D and 11L–13D in the Naze population in Series I. Naze City is located in the subtropical zone, so that the adaptive significance of diapause for the Naze population may not entirely correspond to that for the temperate populations. As functions of pupal diapause in subtropical *Papilio* species, escape from dry seasons (Ae, 1978) and reduction of damage by typhoons (Uesugi, 1992) were pointed out.

In the Kagoshima, Wakayama, and Mino populations, the diapause incidence under 13.5L–10.5D increased with higher latitudes, which suggests that a geographical differentiation in photoperiodic response for inducing diapause has occurred in these temperate populations. It is interesting that variation in the photoperiodic response among broods was wide in the Wakayama and Mino populations which occupy the regions near the northeastern boundary of the species' distribution. Ichinose and Iwasaki (1979) suggested that there are 2 distinct strains in the Tokyo population of *Papilio protenor demetrius* Cramer with respect to the photoperiodic response of diapausing pupa. Since *P. memnon* is inferred to invade the Kinki district by several routes, it is reasonable to expect a mixture of genetically different strains there. In the Wakayama population, some broods showed shorter critical photoperiods, while the others had longer ones. This may be due to the mixture of individuals from southern Wakayama, where the climate is mild under the influence of the Black Current, and those from a northern population.

In the Mino population, one brood showed the longest critical photoperiod among all broods from the 4 populations examined, which may suggest that the northern population has experienced selection favoring a longer critical photoperiod for inducing pupal diapause.

Diapause intensity

Among the 4 populations, mean diapause intensity was shortest in the Naze population and longest in the Mino population. It is interesting that the mean diapause intensity of the Kagoshima population was as long as that of the Mino population and longer than that of the Wakayama population. However, since the

difference in the mean diapause intensity between the Kagoshima and Wakayama populations was only 3 days, it is possible that the 3 temperate populations are still substantially similar to each other in this physiological trait. The major significance of winter diapause may be to prevent the restart of development before the depth of winter (e.g. Danks, 1987). Considering that the critical photoperiod is about 13 h, most individuals will enter pupal diapause by early October in the 3 populations. As shown in Fig. 3, with the exception of individuals such as the one which emerged 32 days after pupation in the Mino population, almost no individuals would emerge as adults for about 2 months after pupation. Therefore, it is considered that adult eclosion would not occur in most individuals before December when the mean temperature decreases to less than 10°C at the 3 localities. However, in the Mino population, if the timing to enter diapause becomes earlier due to a slight increase in the critical photoperiod (Fig. 4), it will be difficult to maintain diapause until the winter comes. Some individuals showed deeper diapause in the Mino population (Fig. 3). Under such conditions, selection would favor individuals that maintained diapause for longer periods.

Environmental factors

Geographical variation of diapause was observed not only between subtropical and temperate populations but also among temperate populations in this species, however, the difference was rather small. In most Japanese *Papilio* species inhabiting the Kinki district and more northern areas, both the critical photoperiod for induction of pupal diapause and the diapause intensity are longer than *P. memnon* of the Mino population. For example, the critical photoperiod was reported as 13 h 30 min in the Kyoto populations (35°N) of *P. helenus niconicolens* Butler and *P. macilentus* Janson (Ishii, 1989). As for diapause intensity, Ichinose (1974) and Ichinose and Iwasaki (1979) reported that some individuals maintained diapause for more than 260 and 200 days in the Tokyo populations (35.5°N) of *P. maackii tutanus* Fenton and *P. protenor demetrius*, respectively. In other words, the recent northward inva-

Fig. 6. Change in mean temperatures of the coldest month at Kagoshima and Osaka Cities from 1960 to 1995 (from Japan Meteorological Agency, 1960–1996).

sion of *P. memnon* has occurred without substantial changes in the diapause trait. In fact, the difference in photoperiodic response among broods was larger than that among populations in this species. Thus, it may be difficult to explain the change in the distribution of this species from only the intensification of diapause.

In recent years, the influence of climatic warming, especially around cities, on plants and animals including insects has been discussed (Kiritani, 1997). Figure 6 shows the change in mean temperature of the coldest month at Kagoshima and Osaka Cities from 1960 to 1995 (Japan Meteorological Agency, 1960–1996). Mean temperatures of the coldest month have been rising with fluctuation from year to year, and the mean at Osaka City in 1993 was as warm as the means at Kagoshima City in the 1960's. Moreover, it has not dropped below 5°C since 1987 and the tendency for the winter temperatures to increase is still continuing. Scriber (1994) reported that an invasion of several insects from the south to Michigan occurred during the warmer period from 1987 to 1991, but the insects failed to survive the hard frost of 1992. The climatic warming, especially rising winter temperatures, may also be included in the northward expansion of distribution in *P. memnon*.

ACKNOWLEDGEMENTS

We are grateful to Mr. A. Nomura of the Osaka Prefectural Experiment Station of Citrus Fruits, Dr. H. Tanaka of the Osaka Prefectural Agricultural and Forestry Research Center, and Dr. R. Mochioka of Osaka Prefecture University for supplying citrus leaves. Our thanks are also due to Mr. Y. Nakagami of the Environmental Technology Association of Kagoshima Prefecture and Mr. H. Fukuda of the Lepidopterological Society of Japan for collecting adults of the Kagoshima and Naze populations of *P. memnon*.

REFERENCES

- Ae, S. A. (1978) A study on the immature stages and diapause of papilionid and other butterflies of the Philippines. *Tyô to Ga* 29: 227–235.
- Anken, R. H. and M. H. Pinto Bivar de Matos e Silva (1996) Further remarks on the occurrence of the southern African butterfly *Cacyreus marshalli* (Butler, 1898) (Lepidoptera: Lycaenidae) on the European mainland. *Entomologist's Gaz.* 47: 151–155.
- Carhoun, J. V. (1996) Conquering soldiers: The successful invasion of Florida by *Danaus eresimus* (Lepidoptera: Nymphalidae). *Holarctic Lepid.* 3: 7–18.
- Danilevsky, A. S. (1965) *Photoperiodism and Seasonal Development of Insects* (English ed.). Oliver & Boyd, Edinburgh and London (Translated from Russian by J. Jhonson assisted by N. Waloff).
- Danks, H. V. (1987) *Insect Dormancy: An Ecological Perspective*. Biological Survey of Canada, Ottawa.
- Fukuda, H., E. Hama, T. Kuzuya, A. Takahashi, M. Takahashi, B. Tanaka, H. Tanaka, M. Wakabayashi and Y. Watanabe (1982) *The Life Histories of Butterflies in Japan (I)*. Hoi-kusha, Tokyo, pp. 114–117 (in Japanese).
- Gall, W. K. and R. F. Andrie (1994) Significant range extension of *Leptotes marina* (Lepidoptera: Lycaenidae) into New York State. *Great Lakes Entomol.* 26: 319–320.
- Hidaka, T. and Y. Hirai (1970) Effect of non-24-hour photoperiod and light interruption of the dark phase on diapause de-

- termination in *Papilio xuthus* L. *Proc. Jpn. Acad.* 46: 541–545.
- Ichinose, T. (1974) Pupal diapause in some Japanese papilionid butterflies, with special reference to the difference in photoperiodic response between the diapausing pupae of *Papilio maackii tutanus* Fenton and *P. xuthus* Linnaeus. *Kontyû* 42: 439–450.
- Ichinose, T. and N. Iwasaki (1979) Pupal diapause in some Japanese papilionid butterflies III. The difference in the termination of diapause between the two subspecies of *Papilio protenor* Cramer. *Kontyû* 47: 272–280.
- Ichinose, T. and H. Negishi (1979) Pupal diapause in some Japanese papilionid butterflies II. The difference in the induction of diapause between the two subspecies of *Papilio protenor* Cramer. *Kontyû* 47: 89–98.
- Ishii, M. (1977) Photoperiodic reaction of the Hokkaido population of *papilio bianor dehaanii* C. et R. Felder (Lepidoptera: Papilionidae). *Tyô to Ga* 28: 115–116.
- Ishii, M. (1986) Papilionids—change in the distribution to northward and the adaptation for climate. In *Nihon no Kontyû* (K. Kiritani ed.). Tokai University Press, Tokyo, pp. 24–32 (in Japanese).
- Ishii, M. (1987) Diapause potential in tropical papilionids (Lepidoptera: Papilionidae). *Appl. Entomol. Zool.* 22: 114–115.
- Ishii, M. (1989) Seasonality in papilionid butterflies. *Nature Insects* 24: 6–10 (in Japanese).
- James, D. G. (1988) Induction of pupal diapause in *Papilio aegeus aegeus* Donovan and *Graphium sarpedon choredon* (C. & R. Felder) (Lepidoptera: Papilionidae). *Aust. Ent. Mag.* 15: 39–44.
- Japan Meteorological Agency (1960–1996) *Annual Report of the Japan Meteorological Agency*. The Japan Meteorological Agency, Tokyo.
- Kiritani, K. (1997) The low development threshold temperature and the thermal constant in insects, mites and nematodes in Japan. *Miscell. Publ. Natl. Inst. Agro-Environ. Sci.* 21: 1–72 (in Japanese with English summary).
- McKillop, W. B., W. B. Preston and A. R. Westwood (1992) Range extension for the European skipper, *Thymelicus lineola* (Ochsenheimer), 1808 (Lepidoptera: Hesperidae), in Manitoba. *Can. Entomol.* 124: 993–994.
- Oliver, C. G. (1969) Experiments on the diapause dynamics of *Papilio polyxenes*. *J. Insect Physiol.* 15: 1579–1589.
- Owen, D. F. (1991) Can *Danaus chrysippus* (L.) (Lepidoptera: Danaidae) establish itself in Europe? *Entomologist's Gaz.* 42: 37–39.
- Samraoui, B., S. Benyacoub and R. Menai (1992) *Danaus chrysippus* (L.) in Algeria: Possible breeding status and new sightings (Lepidoptera, Danaidae). *Nota Lepid.* 14: 348–350.
- Sarto i Monteys, V. (1992) Spread of the southern African Lycaenid butterfly, *Cacyreus marshalli* Butler, 1898, (LEP: Lycaenidae) in the Balearic Archipelago (Spain) and considerations on its likely introduction to continental Europe. *J. Res. Lepid.* 31: 24–34.
- Scriber, J. M. (1994) Climatic legacies and sex chromosomes: Latitudinal patterns of voltinism, diapause, size, and host-plant selection in two species of swallowtail butterflies at their hybrid zone. In *Insect Life-Cycle Polymorphism* (H. V. Danks ed.). Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 133–171.
- Shimada, K. (1983) Photoperiodic induction of diapause in normal and allatectomized precocious pupae of *Papilio machaon*. *J. Insect Physiol.* 29: 801–806.
- Shirôzu, T. (1985) Change in the distribution of butterflies in recent years in Japan. In *The Works of T. Shirôzu*. Executive Committee to Commemorate the Retirement of Prof. T. Shirôzu, Fukuoka, pp. 26–28 (in Japanese).
- Sims, S. R. (1980) Diapause dynamics and host plant suitability of *Papilio zelicaon* (Lepidoptera: Papilionidae). *Am. Midl. Nat.* 103: 375–384.
- Tennent, J. (1995) *Danaus chrysippus* Linnaeus, 1758; a review of records and present status in the Maghreb countries of Morocco, Algeria and Tunisia (Lepidoptera, Danaidae). *Nota Lepid.* 17: 201–216.
- Uesugi, K. (1992) Polymorphism and mimicry in *Papilio polytes*. *Insectarium* 29: 168–174 (in Japanese).
- Yoshio, M. (1994) Change in distribution of the great mormon, *Papilio memnon* L. in northern Kinki district, Japan. *Nature Insects* 29: 26–31 (in Japanese).
- Yoshio, M. (1995) Change in the distribution of the great mormon, *Papilio memnon* L. in northern Kinki districts, Japan. Part 2. *Nature Insects* 30: 20–22 (in Japanese).
- Yoshio, M. and M. Ishii (1996) Rearing larvae of the great mormon butterfly, *Papilio memnon* L. (Lepidoptera: Papilionidae), on artificial diet. *Jpn. J. Ent.* 64: 30–34.