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LIFE HISTORY OF AN ENDANGERED DRAGONFLY, *NANNOPHYA PYGMAEA* RAMBUR, IN KOREA (ANISOPTERA: LIBELLULIDAE)

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Aspects of the *N. pygmaea* life history, an endangered sp. in Korea, were studied at an abandoned paddy field in Mungyeong, Gyeongsangbuk-do, Korea. The larvae were sampled quantitatively at monthly intervals (every 2 weeks during the emergence period) from June 2006 to July 2007 and the adults were counted via a line-transect method. Based on the analyses of larval body length distribution, degree days (DD), and emergence time, the sp. is considered univoltine with an emergence period from mid-May to early August. The estimated sum of the thermal amount, effective to larval development during the study period, was 2468 DD. The relationship between the larval head width and wingsheath width, which is coincident with the temperature fluctuation pattern, shows that the population harbors at least 4 size groups (cohorts) in a generation.

INTRODUCTION

Nannophya pygmaea Rambur, a member of the dragonfly family Libellulidae is the smallest in the world in terms of body length (ca 13-14 mm) (ISHIDA et al., 1988; BAE, 1998). Although it is widely distributed throughout tropical and subtropical East Asia, the Korean population, which is regarded as an isolated population on the northernmost distributional border in continental Asia (36°33' N), is fragmentally distributed over southern portion of the Korean Peninsula. Thus far, only a few habitats have been reported in South Korea (KIM, 1997; BAE et al., 1999; LEE, 2001). It was, therefore, designated as an endangered species by the Ministry of Environment of Korea in 1988 (BAE et al., 1999) and

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is considered a flagship species in the wetland protection and conservation. In Japan, *N. pygmaea* is common and widespread, occurring up to 40°50' N in the Aomori prefecture (HAMADA & INOUE, 1985; SUGIMURA et al., 1999).

The understanding of voltinism is crucial to an appreciation of how the life cycles of organisms have adapted to certain environments inherent to different regions. Although the general Odonata life history aspects are relatively well known, those of *N. pygmaea* are poorly understood. The general biological characteristics of *N. pygmaea*, including habitat, distribution, and behavioral ecology, have been previously studied in both Japan and Korea (TSUBAKI, 1985; KIM, 1997; BAE et al., 1999).

With regard to the effects of environmental parameters on life history patterns, temperature may play a major role in a variety of aspects of Odonata biology, including oviposition, egg hatching, ecdysis, and developmental time (HASSALL et al., 2007). In this study, aspects of the life history of *N. pygmaea* are investigated with regard to accumulated degree days, voltinism, and larval cohorts on the basis of quantitative sampling and field observations.

MATERIAL AND METHODS

STUDY AREA AND TEMPERATURE MONITORING – Field studies were conducted in a wetland located in Mungyong-si, Gyeongsangbuk-do, Korea, between June 2006 and July 2007. This study site (36°33′15.9″ N, 128°00′20.2″ E, alt. 243 m a.s.l.), composed of 15 small stair-like wetlands, was a paddy field that had been abandoned for approximately three to five years. The water depth at the sampling points was approximately 5 to 10 cm. The substrate consists principally of silt and sand, with abundant organic detritus. The wetland vegetation includes *Juncus effusus* and *Persicaria thunbergii*.

The water temperature at the sampling area was monitored at 2-hour intervals with a water temperature data logger from the Onset Computer Corporation (Model: Optic StowAway® Temp, USA). The temperature recorder was installed on the surface of the bottom (ca 5 cm deep), and care was taken to avoid any direct sunlight at the monitoring point. The water temperature was converted to degree days (DD) via the rectangle method, demonstrated by the following equation (LEE et al., 1999):

$$\text{Rectangle DD} = (T_{max} + T_{min})/2 - T_b ,$$

where the T_{max} is daily maximum temperature, T_{min} is the daily minimum temperature, and T_b is the base temperature for larval development. The T_b value of 14.3°C, which was derived from a laboratory experiment on egg development (KIM et al., 2006), was utilized for *N. pygmaea* in this study.

SAMPLING – The larvae were sampled every two weeks during the emergence period but only at monthly intervals during the non-emergence period. Since this is an endangered species and despite the sampling permission was acquired from the Ministry of Environment of Korea, only a limited number of individuals could be sampled. Two quantitative samples were obtained using a hand net sampler (40×20 cm, mesh 0.25 mm). Two sampling points were selected at the side and middle of the wetland; all the organic material, including larvae, was sampled within a 40×100 cm area at each of the sampling points (4000×2 = 8000 cm^2 in total area). It was maintained in a 500 ml bottle and the larvae were sorted in the laboratory. Larval body length was assessed to determine the emergence time. The adults were counted using the line-transect (25×4 m) method. Larval body length and wing-sheath width were measured using a stereomicroscope (Zeiss Stemi 2000-C). All measurements were conducted with computer images captured under an image analyzer using the AxioVision Rel. 4.5 program. Larval body length classes were categorized in increments of 0.5 mm.

RESULTS

WEATHER CONDITION

Annual precipitation in the study area in 2006 was 1352 mm (unpublished data from a local meteorological station); more than 66% (903 mm) of the precipitation occurred during the rainy season (July--August) (Fig. 1). The water level of ca. 5-10 cm was maintained during the study year.

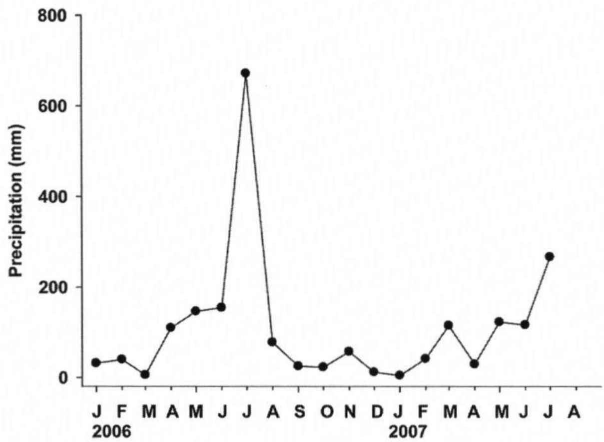

Fig. 1. Precipitation in the study area.

The mean water temperature detected during the study period was 16.01 ± 5.94°C (mean ± SD). The highest water temperature was recorded as 41.28°C (August 8 and 15, 2006) and the lowest was -3.31°C (December 29, in 2006). The temperature fluctuation pattern was influenced by the amount of rainy days (Fig. 2). The daily water temperature recorded between November 6 and April 8 did not exceed the base temperature (14.3°C) for the larval development of *N. pygmaea*; thus, no effective temperature was accumulated during that period. As a result, the estimated sum of the thermal amount, which was effective in terms of larval development over the study period, was 2468 degree days (Fig. 3). The water temperature was 3.81±2.93°C higher than the air temperature.

POPULATION DENSITY AND LIFE HISTORY

A total of 186 larvae was collected during the study period from June 2006 to July 2007. The collected number per sampling area (8000 cm^2) was largest on October 20, 2006 (n=31) and the smallest on July 7, 2006 (n=3) (Fig. 4). Figure 4 shows the frequency distribution of larval body length, ranging between 2.76-10.69 mm, during the study period.

As a result of the observation of adults using the line-transect method, more males (145) were observed than females (55) per sampling area (100 m^2) on June 17, 2006. This sex ratio pattern was similar to that recorded in 2007 (Fig. 5). The females appeared earlier than the males during the emergence period. Emergence begun

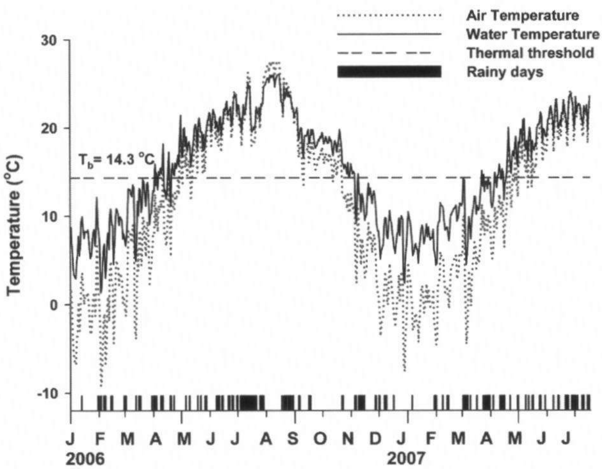

Fig. 2. Temperature in the study area. – [T_b = base temperature for larval development].

during mid-May and continued until early August. Its peak occurred during the period between late May and mid-June.

Figure 6 shows the relationship between larval head width and wingsheath width, the ranges of which are 1.05-3.15 mm and 0.00-2.75 mm, respectively. If the number of sampled larvae was sufficiently large enough (e.g., October 20, 2006), at least four larval size clusters or cohorts were recognized from this relationship.

DISCUSSION

The type-locality of *N. pygmaea* is not precisely known, although it was later identified as Borneo (STEINMANN, 1997). The distributional origin of the species is thus considered a tropical region. Local populations recorded from several locations in the southern part of the Korean Peninsula, belong to isolated populations on the northernmost continental distributional border in temperate region. The recent increase observed in the number of local populations on the Korean Peninsula can probably be attributed to the increase in wetland habitats, e. g., abandoned rice fields, as well as to global warming (BAE et al., 1999).

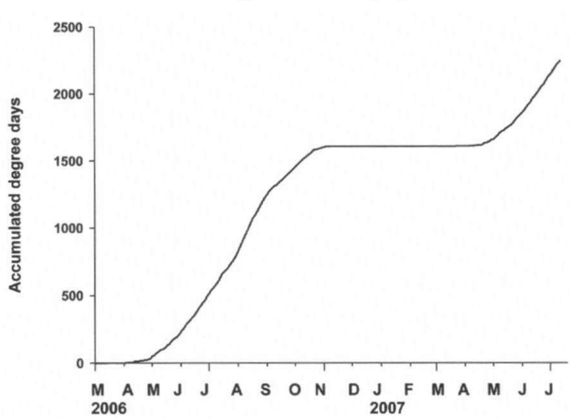

Fig. 3. *Nannophya pygmaea*: accumulated degree days (DD) during larval development.

Generally, the tropical libellulids are multivoltine and have a larger number of generations in a year than those in the temperate zone dragonflies (HECKMAN, 1979; SALMAH et al., 2006). As shown in this study, the Korean *N. pygmaea* population is univoltine, with adult emergence in late spring to early summer. According to CORBET (1999), the Odonata are generally divided into "spring species" and "summer species". The fully grown larvae of the spring species undergo a diapause, and also have a short hatching period from the spring to the early summer. Considering that *N. pygmaea* emerged from mid-May to early August, they are believed to be a spring species, and the fully grown larvae occur during the winter, as shown in Figure 4.

The degree days method takes into consideration the average daily temperature accumulations that influence insect development (TOKESHI, 1985). As it goes from a rearing experiment conducted by the authors (KIM et al., 2009), *N. pygmaea* larvae require approximately 133 degree days to grow 1 mm. Considering that dragonflies normally require two to three weeks to reach sexually maturity (YAMAMOTO, 1968), we can estimate that oviposition begins approximately in late May, the eggs hatch quickly, and the larval growth requires approximately 1460 degree days until in November they reach the final stage. On the basis of the larval body length distribution and growth rate, the first cohort emerges in

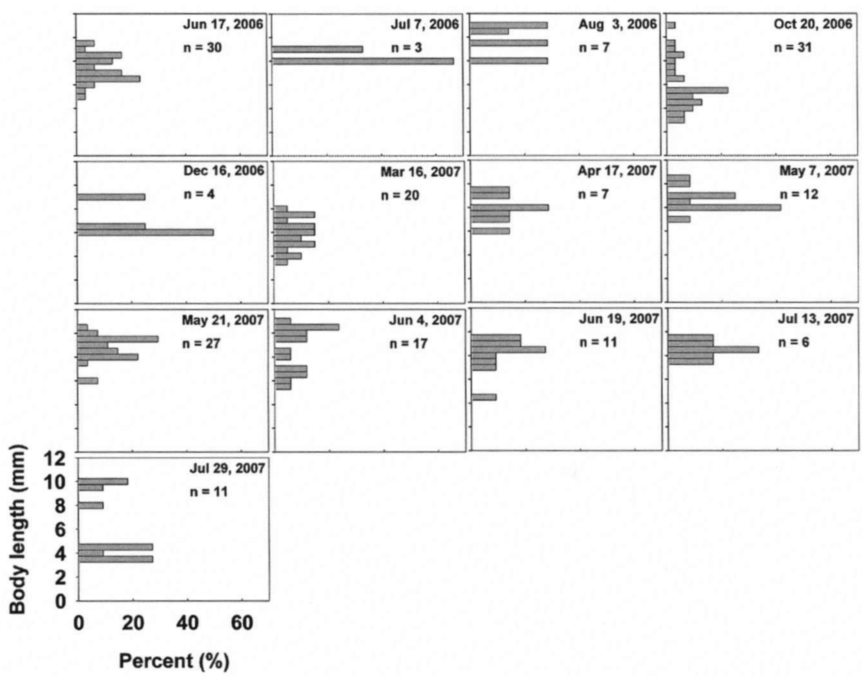

Fig. 4. *Nannophya pygmaea*: larval body size distribution from June 2006 to August 2007.

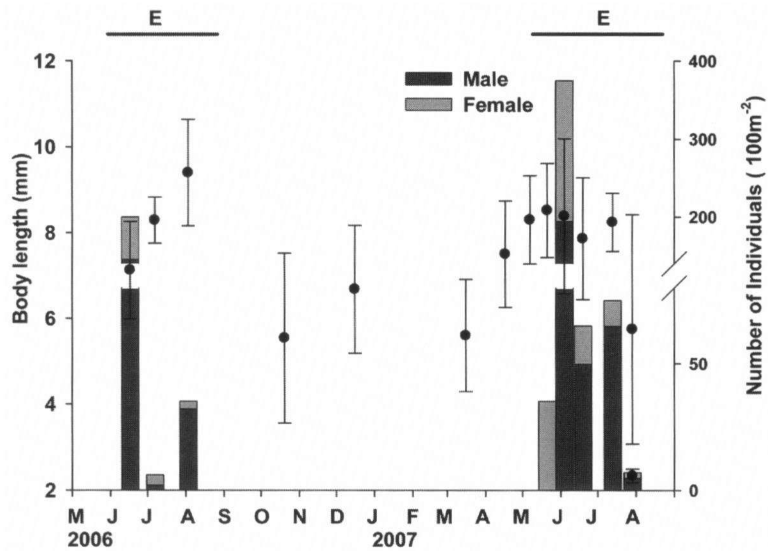

Fig. 5. *Nannophya pygmaea*: hypothetical life history pattern proposed from the information on larval body size distribution, change in the sex ratio of the adults, and on the periods of emergence. – [Vertical bars mean standard deviation. E = Emergence].

mid-May, and their offspring, after a diapause at the final larval instar, becomes the early emergence cohort in the following year (Fig. 5).

TSUBAKI & ONO (1987) suggested that mating success could be attributed to weather conditions associated with the number of sunny days during the reproductive period. As shown in this study, during the time of oviposition, the high temperature peak and non-rainy days were matched (Fig. 2). The relationship between larval head width and wingsheath width, which also nearly coincides with the temperature fluctuation pattern, shows that the Korean population of *N. pygmaea* harbors at least four size groups throughout the year (Fig. 6). The intermittent rainfalls from June to July could influence the oviposition which may result in different larval size groups within a generation.

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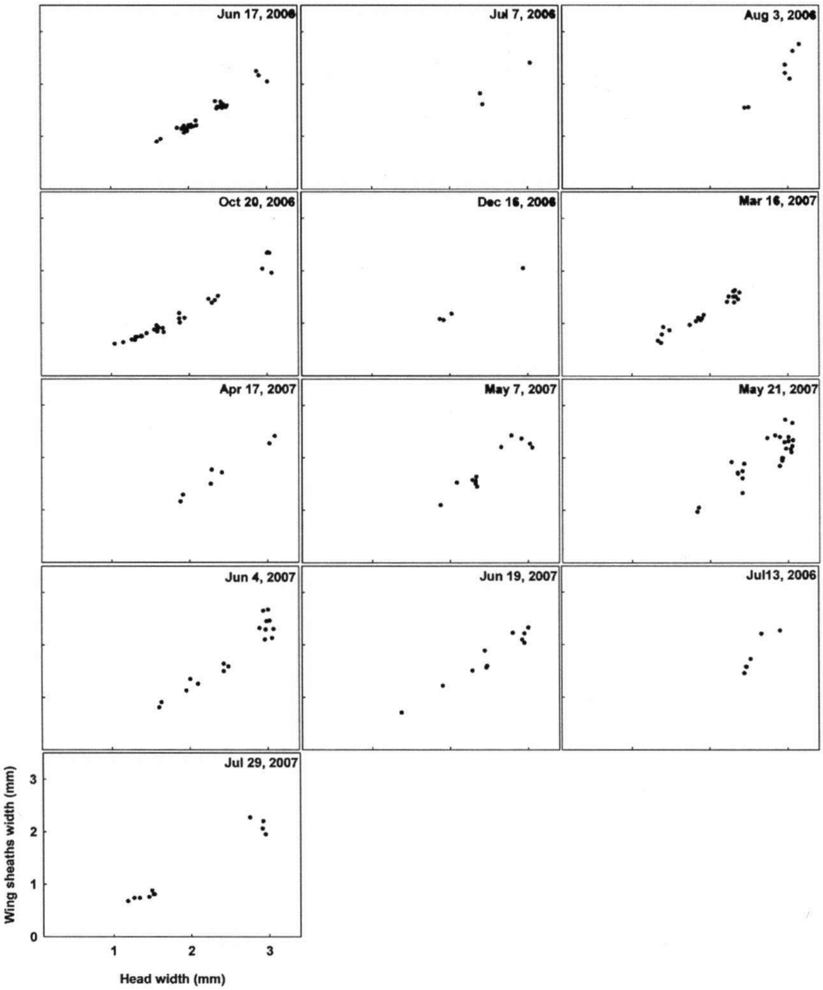

Fig. 6. *Nannophya pygmaea*: relationship between head width and wingsheath width in larvae during the study period.

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