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Life history and secondary production of the Chinese endemic damselfly *Euphaea opaca* (Odonata: Euphaeidae)

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Euphaea opaca Selys, 1853 is an endemic damselfly to China, but little is known about its biology and ecology. In this study, we investigated the life history and secondary production of *E. opaca* in a third order subtropical stream of Guangdong, China. Larvae were collected monthly from October 2010 to September 2011 using a Surber net with six replicates from riffle areas. The results show that *E. opaca* exhibited a univoltine life history in South China with recruitment from August to February of the following year; adults first appeared in late April and ended in early September, the flight period roughly coinciding with the rainy season. The mean nymphal density ranged from 1.85 individuals m^{-2} (July) to 81.48 individuals m^{-2} (January) during the study period. Estimated annual secondary production was 1240.4 mg DWm^{-2} $year^{-1}$, and annual production/biomass ratio (P/B) was 6.4.

Keywords: dragonfly; damselfly; *Euphaea;* life cycle; univoltine; subtropical stream

Introduction

The genus *Euphaea* Selys, 1840 occurs in tropical and subtropical Asia. Species of the genus are medium sized and rather robust. The majority of males possess colored wings, and color pattern of wings is usually a good character for distinguishing species. Females dive into fast-flowing water in the mid-channel of streams to oviposit underwater in submerged plant material (Reels and Dow, 2006; Reels and Wilson, 2009). There are two common *Euphaea* species occurring in South China: *E. opaca* Selys, 1853 is endemic to China, its distribution extending from the southern China into eastern China (Hämäläinen, 2004) and *E. decorata* Selys, 1853 occurs in most mountain streams throughout South China and Vietnam. The habitat of these two species, however, is quite different. The larvae of *E. opaca* inhabit medium to large-sized open streams with moderate to fast current in lowland areas, but often with shady areas along the banks (Figure 1a). The larvae of *E. decorata* are largely found in headwater or small well-shaded hill streams with relatively rapid flow (Figure 1b).

Life history refers to the variable events associated with the life cycle such as voltinism, development, and emergence patterns (Butler, 1984). Although life history is species-specific, it often exhibits variability in response to environmental conditions such as water temperature, pH or

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Figure 1. Larval habitats of two *Euphaea* species; a: *E. opaca* (in the present study site); b: *E. decorata* (in Guangzhou, China).

dissolved oxygen that can result in increased growth rates and number of generations produced annually (Butler, 1984). Secondary production is defined as the biomass produced by an animal population over a unit of time (Benke, 1979). It is ecologically important as it represents the energy available to higher trophic levels (Benke, Van Arsdall, Gillespie, & Parrish, 1984). An accurate estimation of production is a crucial requirement for energy flow analysis, because it can give answers to ecological riddles in freshwater ecosystems (Benke & Huryn, 2010). The magnitude of secondary production is influenced by life history features as well as by environmental parameters (Waters, 1979). Whereas the literature about life history of Odonata has grown considerably (Corbet, Suhling, & Soendgerath, 2006; Stoks and Códoba-Aguilar, 2012), there is little information on secondary production of Odonata. This is especially true for the genus *Euphaea*; the only report is of *E. decorata* in Hong Kong (Dudgeon, 1989a). This study aimed to provide information on the life history and secondary production of *E. opaca* with the aim to help conserve this species.

Materials and methods

The study site is located in two adjacent third order streams in the Hengshishui River that is a main tributary of the Beijiang River, Guangdong, China (Figure 2). The mean daily precipitation and air temperature in the study site during the sampling period is shown in Figure 3.

Quantitative benthic samples were collected monthly from October 2010 to September 2011, at least six random replicates were taken using a Surber sampler (area 0.09 m^2, mesh size 250 μm) in riffle habitat, and all macroinvertebrate samples were preserved into vials containing 95% alcohol. Water physicochemical parameters were measured by a handheld multiparameter water quality meter (YSI-6600) and current velocity by flow meter (EW-FFLOW32101). In the laboratory, the head width of each specimen was measured under a stereoscopic microscope (Zeiss Stemi 2000-CS, Germany) equipped with a Photometrics CoolSNAP camera, then all larvae were divided into different size classes (based on head width) to construct size–frequency plots for life history determination. Damselfly larvae from each sample were dried to constant weight at 70°C and weighed in an electrobalance to the nearest 0.0001 mg. Secondary production was calculated using the size–frequency method (Benke, Van Arsdall, Gillespie, & Parrish, 1984; Hamilton, 1969; Hynes & Coleman, 1968; Menzie, 1980) as follows equation:

$$P = c \sum (N_j - N_{j+1})(W_j W_{j+1})^{0.5} 356/\mathrm{CPI} \quad (1)$$

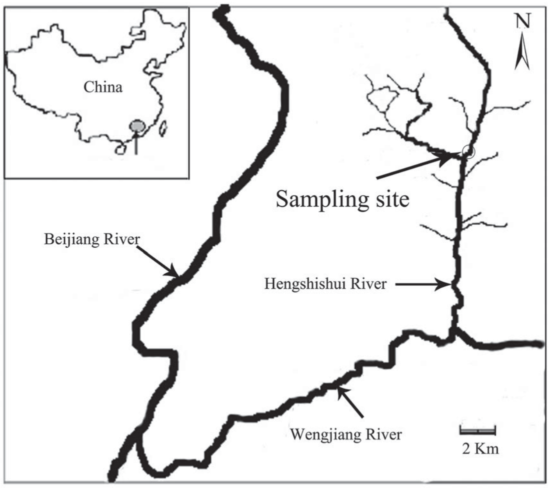

Figure 2. Map of the study area and the sampling site.

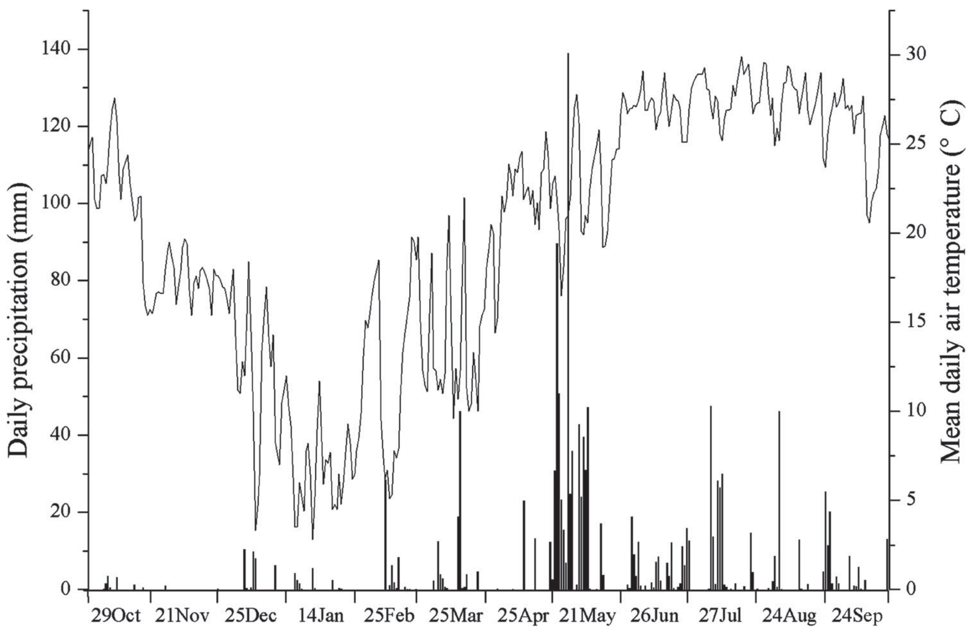

Figure 3. Mean daily precipitation and air temperature in study area during the sampling period (October 2010–September 2011).

where P is the annual production, c is the number of size classes ($j = 1$ to c), N_j is the mean number of individuals of size-class j during the year, W_j is the mean mass of size-class j. The cohort production interval (CPI) was estimated as the time from the first hatchings to the first emergences.

Data were transformed as log10(x + 1) before performing statistical analyses. One-way analysis of variance (ANOVA) was used, followed by the Student–Newman–Keuls test (SNK) for comparing the temporal differences of larval density undertaken on SPSS Software 16.0 (SPSS Inc. Chicago, IL, USA).

Results

Water physicochemical parameters of habitat

During the study period, the sampling site water temperatures ranged from 11.6°C in January to 27.2°C in July. Dissolved oxygen was always near 100% saturation with minimum 6.52 mg l^{-1} in December. Values for pH averaged 7.3 within a range of 6.6–8.0. Mean conductivity (ms cm^{-1}) was 0.235 ± 0.060 (mean ± SD). Average water flow was 0.6 m s^{-1} within a range of 0.4–1.1 m s^{-1}. The stream width ranged from 10 to 15 m, and average depth was 0.30 m. The substrate was composed mainly of cobbles (90%), gravel (5%) and sand (5%).

Density and life history

Density of *E. opaca* larvae did not show temporal differences (n = 207, SNK: df = 5, F = 1.572, p = 0.182) from September to March except for maximum density (81.48 individuals m^{-2}) recorded in January (Figure 4), which was significantly higher than those densities recorded from May to August. Field observations indicated that emergence of adults began in late April, and ended in early September. A few adults persisted until October, suggesting that the flight period coincided with the rainy season in this region (Figure 3). The lowest larval density (all mature larvae with black wing pads ready to emerge) was recorded in July, and no mature larvae were found but a lot of newly hatched larvae were sampled in August, suggesting the new generation begins from August. *E. opaca* showed a univoltine life history in South China with recruitment from August to February of next year (Figure 5).

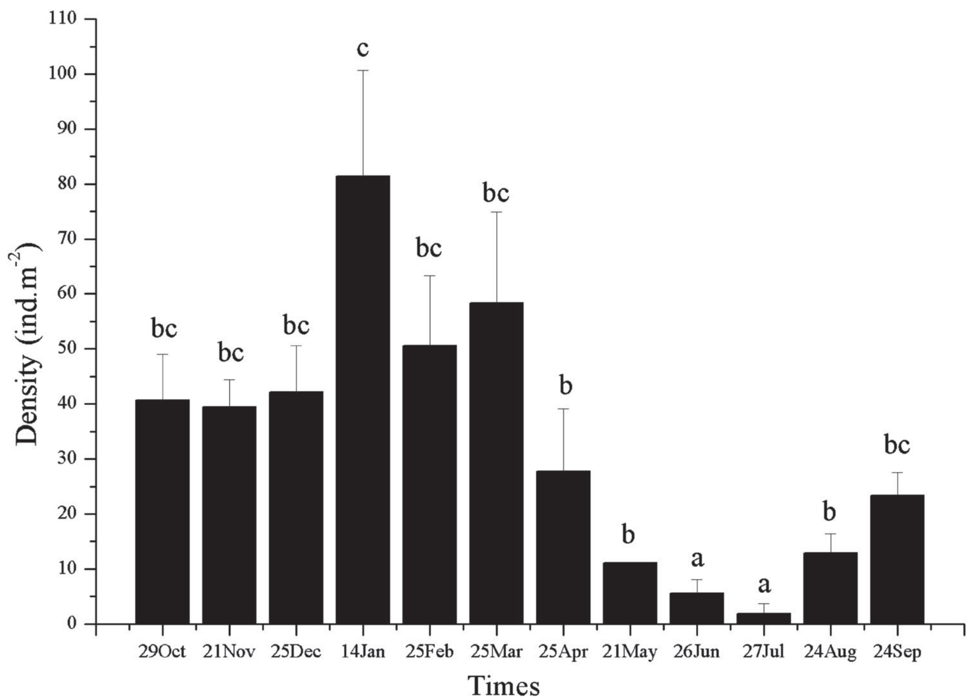

Figure 4. Seasonal changes of density of *Euphaea opaca* larvae during the study period. Note: The same letter means no significant difference at 5% level, all t-tests was performed after log10(x + 1) transformation.

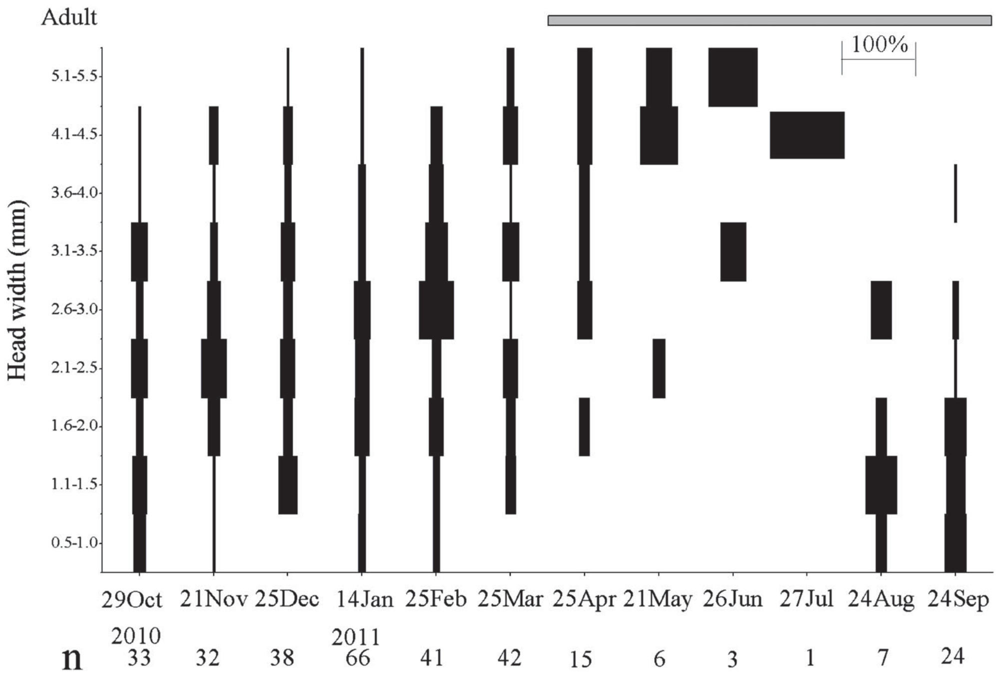

Figure 5. Size-frequency distribution of *Euphaea opaca* larvae from October 2010 to September 2011 in Hengshishui River. Note: width of bars represent percentage of larvae in each size class on a given sampling date. Gray solid horizontal line indicates the emergence time of the adult.

Secondary production

Based on the head width, all larvae were divided into nine size classes in the study. Mean head capsule width and dry mass values for the nine size classes of *E. opaca* from all sampling dates

Table 1. Annual production (mg DW m^{-2} y^{-1}) and annual P/B ratio of *Euphaea opaca* estimated by size-frequency method in Hengshishui River during the study period.

Size class	Head width (mm) (range)	*n*, m[−2a]	DW, mg[b]	B, mg m[−2c]	Δin n[d]	DW at loss[e]	DW loss[f]	× 9, mg m[−2g]
I	0.48	11.8	0.044	0.521	2.1	0.075	0.159	1.429
II	0.66 (0.63–0.69)	9.7	0.105	1.021	2.1	0.208	0.440	3.957
III	0.98 (0.75–1.15)	7.6	0.311	2.352	1.6	0.592	0.940	8.458
IV	1.43 (1.22–1.59)	6.0	0.873	5.224	0.9	1.359	1.274	11.467
V	1.88 (1.63–2.06)	5.0	1.844	9.310	0.8	2.825	2.168	19.513
VI	2.45 (2.10–2.78)	4.3	3.805	16.288	0.6	5.784	3.712	33.410
VII	3.18 (2.82–3.57)	3.6	7.764	28.253	0.5	11.505	5.964	53.678
VIII	4.07 (3.68–4.45)	3.1	15.246	47.576	0.5	23.237	10.924	98.315
IX	5.29 (4.98–5.55)	2.7	31.228	82.766	2.7	31.228	82.766	744.898
Total	—	—	—	193.311	—	—	—	930.301

Biomass = 193.3; Cohort P = 930.3; Cohort P/B = 4.8
Annual production = Cohort P × (365/CPI) = 930.301 × (12/9) = 1240.4 mg DW m^{-2} y^{-1}
Annual P/B = Cohort P/B × (12/9) = 6.4

[a]Number present per square meter of each size class.
[b]Mean dry mass (in milligrams) of individuals of each size class.
[c]Total mean annual biomass of each size class.
[d]Change in number of individuals present between size classes.
[e]Mean dry mass of individuals of each size class when lost from the population (calculated as $DM^{x} + DM^{x+1}/2$).
[f]Total dry mass (milligrams) lost with each size class.
[g]Dry mass loss × the number of size classes gives mean annual production for each size class.

are given in Table 1. A simple linear regression of ln dry weight (y, mg) and ln head width (x, mm) showed a significant relationship ($n = 156$, $r^2 = 0.8594$, $F = 4.786$, $p < 0.01$). The linear relationship between dry weight (y) and head width (x) can be described by the equation:

$$\ln y = 2.7347 \ln x - 1.1143 \tag{2}$$

In this study, the first F0 larvae and adults were found in April, thus, the CPI of *E. opaca* was nine months (August–April). The annual secondary production of *E. opaca* was 1240.4 mg DW m^{-2} y^{-1} with an annual production/biomass ratio (P/B) of 6.4 (Table 1).

Discussion

Voltinism is an important life history trait that varies with the environment (Corbet et al., 2006). According to the overview in Corbet et al. (2006) univoltine is the most common type of life cycle among euphaeid species, and Dudgeon (1989a) also suggests that univoltine life histories are typical of odonates that inhabit perennial tropical monsoon streams. According to Winterbourn (2003) it is expected that congeneric species have similar life cycles. Our results agree with the above viewpoints. *Euphaea opaca* exhibited a univoltine life history in the subtropical stream of Guangdong, southern China, like the congeneric *E. decorata* in Hong Kong (Dudgeon, 1989a). Adults of *E. opaca* emerge at the onset of the rainy season and the flight period is roughly synchronized with the summer monsoons. Larvae live in open and perennial lotic habitat, but the young larvae do not appear until the rainy season is over. Such traits are also exhibited by *E. decorata* in Hong Kong (Dudgeon, 1989a), and may be related to the avoidance of flash floods that damage or wash out the young larvae.

Corbet et al. (2006) summarized the voltinism of Odonata for 275 species and subspecies which were categorized into five types: partivoltine, semivoltine, univoltine, bivoltine and multivoltine. Secondary production has been estimated for only a few species of Odonata (Benke, 1976; Benke & Wallace, 2015; Dudgeon, 1989a, 1989b; Gaines, 1987; Phillips, 2001; Wallace, Cuffney, Lay, & Vogel, 1987). *E. opaca* and *E. decorata* both had the same life cycle pattern, but their secondary production and annual P/B were quite different. In the present study, the estimated annual secondary production (1240.4 mg DW m^{-2} $year^{-1}$) of *E. opaca* was much higher than those of *E. decorata* (ranging from 131.7–167.1 mg DW m^{-2} $year^{-1}$) reported by Dudgeon (1989a), the resulting P/B ratio (6.4) of *E. opaca*, inhabiting an open third order stream, was also higher than the values (3.9–5.0) of *E. decorata* from a shaded forest headwater stream in Hong Kong (Dudgeon, 1989a). Likewise, Dudgeon (1989b) estimated production of two gomphid species (*Heliogomphus scorpio* and *Onychogomphus sinicus*) in the same stream, and found that their production was 182.0–236.0 mg DW m^{-2} $year^{-1}$. More recently, the annual production of snag predators Odonata was estimated at 2100–1500 mg DW m^{-2} $year^{-1}$ in a Coastal Plain river of USA (Benke and Wallace, 2015). In general, the high levels of secondary production will occur when growth rates are rapid and biomass is high (Benke, 1979); therefore, any factor that reduces growth rates or biomass of macroinvertebrates will also reduce their production, for example, low food quality and quantity, competition and low temperature, etc., can reduce growth rates or biomass (Huryn & Wallace, 2000). The annual production of the gomphid *Progomphus obscurus* in Texas, USA was estimated as high as 6842.0 mg DW m^{-2} $year^{-1}$, for which one reason may be that *P. obscurus* is the only abundant invertebrate predator in that sandy stream (Phillips, 2001). The gut content analysis showed that the prey of *E. decorata* in Hong Kong forest streams were predominantly chironomids, mayflies and caddisflies (Dudgeon, 1989a). Unfortunately, in the present study, all larval materials of *E. opaca* were dried for calculating biomass and secondary production and devoid of the diet information. However, based on the surveys by Chi, Zhao, Guan, Wang, and Tong (2010), a total of 51 macroinvertebrate taxa with high density were found and *E. opaca* was one of few predators in our study site. The production of *E. opaca* was much higher than that of *E. decorata*, which may be related to *E. opaca* having less competition for food and more available prey than *E. decorata* (the above-mentioned two predatory gomphids, *H. scorpio* and *O. sinicus*, also co-occurred in the same stream). Of course, general trends for comparison between continents or interspecies are difficult to make because only few estimates of production have been published in Odonata.

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References

Benke, A. C. (1976). Dragonfly production and prey turnover. *Ecology*, *57*, 915–927. doi:10.2307/1941057

Benke, A. C. (1979). A modification of the Hynes method for estimating secondary production with particular significance for multivoltine populations. *Limnology and Oceanography*, *24*, 168–171. doi:10.4319/lo.1979.24.1.0168

Benke, A. C., & Huryn, A. D. (2010). Benthic invertebrate production – facilitating answers to ecological riddles in freshwater ecosystems. *Journal of the North American Benthological Society*, *29*, 264–285. doi:10.1899/08-075.1

Benke, A. C., Van Arsdall, T. C., Jr., Gillespie, D. M., & Parrish, F. K. (1984). Invertebrate productivity in a subtropical Blackwater River: The importance of habitat and life history. *Ecological Monographs*, *54*, 25–63. doi:10.2307/1942455

Benke, A. C., & Wallace, J. B. (2015). High secondary production in a Coastal Plain river is dominated by snag invertebrates and fuelled mainly by amorphous detritus. *Freshwater Biology*, *60*, 236–255. doi:10.1111/fwb.12460

Butler, M. G. (1984). Life histories of aquatic insects. In V. H. Resh, & D. W. Rosenberg (Eds.), *Ecology of aquatic insects* (pp. 24–55). New York: Prager.

Chi, G. L., Zhao, Y., Guan, Z. Y., Wang, J. W., & Tong, X. L. (2010). Relationship between macroinvertebrate and environmental variables in Hengshishui River, Guangdong, China. *Acta Ecologica Sinica*, *30*, 2836–2845. Retrieved from http://en.cnki.com.cn/Article_en/CJFDTotal-STXB201011005.htm

Corbet, P. S., Suhling, F., & Soendgerath, D. (2006). Voltinism of Odonata: a review. *International Journal of Odonatology*, *9*, 1–44. doi:10.1080/13887890.2006.9748261

Dudgeon, D. (1989a). Life cycle, production, microdistribution and diet of the damselfly *Euphaea decorata* (Odonata: Euphaeidae) in a Hong Kong forest stream. *Journal of Zoology*, *217*, 57–72. doi:10.1111/j.1469-7998.1989.tb02474.x

Dudgeon, D. (1989b). Gomphid (Odonata: Anisoptera) life cycles and production in a Hong Kong forest stream. *Archiv für Hydrobiologie*, *114*, 531–536. Retrieved from http://cat.inist.fr/?aModele = afficheN&cpsidt = 19702910

Gaines, W. L. (1987). Secondary production of benthic insects in three cold-desert streams. *Technical Report PNL-6286/UC-11*, Battelle Pacific Northwest Laboratory, Richland, Washington 99352.

Hämäläinen, M. (2004). Caloptera damselflies from Fujian (China), with description of a new species and taxonomic notes (Zygoptera: Calopterygoidea). *Odonatologica*, *33*, 371–398. Retrieved from http://natuurtijdschriften.nl/record/592487

Hamilton, A. L. (1969). On estimating annual production. *Limnology and Oceanography*, *14*, 771–782. doi:10.4319/lo.1969.14.5.0771

Huryn, A. D., & Wallace, J. B. (2000). Life history and production of stream insects. *Annual Review of Entomology*, *45*, 83–110. doi:10.1146/annurev.ento.45.1.83

Hynes, H. B. N., & Coleman, M. J. (1968). A simple method of assessing the annual production of stream benthos. *Limnology and Oceanography*, *13*, 569–573. doi:10.4319/lo.1968.13.4.0569

Menzie, C. A. (1980). A note on the Hynes method of estimating secondary production. *Limnology and Oceanography*, *25*, 770–773. doi:10.4319/lo.1980.25.4.0770

Phillips, E. C. (2001). Life history, food habits, and production of *Progomphus obscurus* (Odonata: Gomphidae) in Harmon Creek Texas. *Texas Journal of Science*, *53*, 19–28. Retrieved from http://www.freepatentsonline.com/article/Texas-Journal-Science/128674059.html

Reels, G. T., & Dow, R. (2006). Underwater oviposition behaviour in two species of Euphaea in Borneo and Hong Kong (Odonata: Euphaeidae). *International Journal of Odonatology*, *9*, 197–204. doi:10.1080/13887890.2006.9748278
Reels, G. T., & Wilson, K. (2009). Observations of the oviposition behaviour of four species of *Euphaea* Selys (Zygoptera: Euphaeidae). *Agrion*, *13*, 80–83. Retrieved from http://worlddragonfly.org/?page_id = 125
Stoks, R., & Códoba-Aguilar, A. (2012). Evolutionary ecology of Odonata: A complex life cycle perspective. *Annual Review of Entomology*, *57*, 249–265. doi:10.1146/annurev-ento-120710-100557
Wallace, J. B., Cuffney, T. F., Lay, C. C., & Vogel, D. (1987). The influence of an ecosystem-level manipulation on prey consumption by a lotic dragonfly. *Canadian Journal of Zoology*, *65*, 35–40. doi:10.1139/z87-006
Waters, T. F. (1979). Influence of benthos life history upon the estimation of secondary production. *Journal of the Fisheries Research Board of Canada*, *36*, 1425–1430. doi:10.1139/f79-208
Winterbourn, M. J. (2003). Habitats segregation and nymphal life history of two *Nesalemletus* species (Ephemeroptera: Nesameletidae) in a mountain stream. *Aquatic Insects*, *25*, 41–50. doi:10.1076/aqin.25.1.41.14028