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Cyclicity of Long-Term Population Dynamics in Dragonflies of the Genus *Sympetrum* (Odonata, Anisoptera) in the Basin of Lake Chany

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Abstract—This work is directed at continuous studies of cyclicity of long-term (1980–2010) population dynamics of odonates in the basin of Lake Chany (in the south of Western Siberia). Four sympatric species of the genus *Sympetrum* have been investigated by spectral analysis method. The cycle spectra of population dynamics have been constructed for each species; the basic parameters of these cycles (period, phase, and power) have been calculated. Special number cycles have been found for each species. Interspecies differences increased in the direction from high to low frequencies of the spectrum. In the cases of similar cycles, interspecies differences have been shown in the ratio of cycle powers and/or phases: identical phases can indicate the ability of species to increase their number synchronously with any of close species; different phases can indicate the possibility of a small-numbered species to reach its maximum number against the minimum number of numerous species. A comparison of sympatric species spectra of the genera *Coenagrion* and *Sympetrum* has led to the conclusion that, the more similarity there is in environmental standards among species inside a genus (as for *Sympetrum*), the more specific the species frequency spectra are. All species of the genus *Sympetrum* can synchronize their number fluctuations with 2- to 3 and 4- to 5-year fluctuations of the local climate. Also specific synchronization with important nature-climatic rhythms was found for each species: for *S. danae*, with an 18-year rhythm of the level of Lake Chany and with a 16-year rhythm of June temperatures; for *S. flaveolum,* with a 24-year Brickner cycle, with an 8-year cycle of rainfall, and with a 28-year cycle of April and May temperatures; for *S. vulgatum,* with a 40- to 42-year cycle of the level of Lake Chany, with 12-year cycle of rainfall, and with a 7-year cycle of April and June temperatures; and for *S. sanguineum*, with a 7-year cycle of April and June temperatures. Perhaps the adaptation mechanism of species to each other and to environments is enclosed in the cyclicity of long-term fluctuations of species number.

Keywords: Odonata, *Sympetrum* spp., long-term population dynamics, population cycles, spectral analysis, Western Siberia, Lake Chany basin, Barabinsk forest steppe

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INTRODUCTION

The number dynamics are directly or indirectly associated with environmental factors (abiotic and biotic), as well as with processes that spontaneously take place within the population itself (Bigon et al., 1989; Sinclair, 1973; Symonides, 1979). The variability of the population size can be considered an adaptive response to the existence conditions of the species (Nikol'skii, 1965). Insect populations are also subject to number fluctuations (Varley and Gradwell, 1968; Harcourt, 1971; Poole, 1974).

Odonates, as amphibious insects, have water (egg and larval) and terrestrial (imaginal) development stages in their life cycles. With such a complex life cycle, it is very difficult to isolate the factors affecting the number of the local population of odonates (Corbet, 1999; Stoks and Córdoba-Aguilar, 2012). Only abiotic factors universal for all odonates could be emphasized: climate (Popova, 2001a; Hickling et al., 2005; Hassall and Thompson, 2008; *Monitoring climatic*..., 2010) and weather conditions (Belyshev et al., 1989; Dingemanse and Kalkman, 2008; Suhling et al., 2015). All phases of the odonate life cycle are closely related. Thus, quantitative and qualitative parameters of egg laying determine larval development (Hottenbacher and Koch, 2006; Remsburg, 2011). The conditions and characteristics of aquatic larvae development affect the life of terrestrial imago, for example, their number (Popova, 2010; Popova and Haritonov, 2010; McCoy et al., 2009; Stoks et al., 2005) and dispersal capacity (Conrad et al., 2002; Benard and McCauley, 2008; Haritonov and Popova, 2011). In foreign environmental literature, such an indirect link

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between the aquatic and terrestrial components of the taxocene is called carry-over effects (McPeek and Peckarsky, 1998).

The study of larval populations of different odonate species revealed many factors determining their numbers. These factors include the properties of the reservoir, both hydrological (Popova, 2001, 2010) and biotopical (Popova and Smirnova, 2010; Popova and Haritonov, 2014a), and food resources (Corbet, 1999; McPeek, 2008; Sahlén et al., 2008). Biotic interactions are also important. They include territorial intra- and interspecific competition (Ryazanova, 1998; Dronzikova, 2010; Pierce and Crowley, 1985), as well as the stress susceptibility and mortality of larvae caused by interaction with predators (McPeek and Peckarsky, 1998; Baker et al., 1999; Stoks et al., 2005; Katayama, 2013) and parasites (Serbina and Haritonov, 2001; Baker et al., 2007; Wildermuth and Martens, 2007). Our field experience with adult odonates, as well as literature data (Belyshev et al., 1989; Haritonov, 1991; Corbet, 1999; Conrad et al., 2002; Remsburg and Turner, 2009; Harabiš and Dolný, 2010; Remsburg, 2011), suggest that all the factors listed above for larvae are relevant for adults, only with the difference that adults have terrestrial biotopes instead of water ones. In addition to these factors, the already-mentioned larval heritage also influences the number characteristics of the odonate adult population. As a result, the number of imago odonates, consisting of different components, is a complex; integrated; and, accordingly, very informative population indicator, especially in its temporal dynamics. One adequate characteristic of the temporal organization of the biological system is the spectrum of its periods, or cycles (Martynyuk et al., 2007).

Cycles of population dynamics have been described for many populations of animals; their characteristics have been determined (Chernyavskii and Lazutkin, 2004; Duvanova et al., 2009; Erdakov, 2011; Kiselev and Yamborko, 2014; Telepnev and Erdakov, 2014; Bjørnstad et al., 1998; etc.). We did not know any publications on odonate cycling. We have previously investigated the long-term cyclicity of population variations in several species of damselflies (suborder Zygoptera) of the genus *Coenagrion* in Lake Chany basin (Popova et al., 2016a). In the present work, we examined dragonflies (suborder Anisoptera) of the genus *Sympetrum* inhabiting the same territory and in the same multiyear sampling as *Coenagrion* spp. Representatives of the genus *Sympetrum* play an important role in biocenosis of the temperate belt due to their high numbers and specific ecological features (Sukhacheva et al., 1988; Popova, 1999; Popova and Haritonov, 2014b; Corbet, 1999).

We chose the objects according to their following characteristics: (1) close relation (the species belong to the same genus), (2) sympatricity (species inhabit the investigated territory), and (3) relative stability of abundance (throughout the time of observation, the species more or less retained their number category). With all their close relations, these species coexist quite amicably in practically the same space and time.

The aim of this study is to reveal the regularities of the cyclicity of the multiyear course of abundance of four species of the genus *Sympetrum*.

The research tasks are as follows: construct the spectrum of population rhythms, calculate the periods and powers of the harmonic components (cycles or rhythms) in the dynamic spectrum of each species, analyze chronograms and spectra taking into account the ecological features of the species, and elucidate natural time sensors that support the rhythms of the odonate number.

In order to avoid overloading the text with frequently recurring Latin, we found it possible to use the Latin name of the genus *Sympetrum*, sympetrum, already adopted by odonatologists and, accordingly, to call the odonates of this genus "sympetrums."

METHODS AND MATERIALS

Research Site

The investigations were carried out in the southeast of Western Siberia, in the Barabinsk forest steppe, in the basin of Lake Chany. The research site (54°32′–54°39′ N, 78°06′–78°19′ E) is located in Novosibirsk oblast.

Study Object and Its Ecological Characteristics

Four sympatric species of odonates of the genus *Sympetrum* Newman, 1833: *S. danae* (Sulzer, 1776), *S. flaveolum* (Linnaeus, 1758), *S. sanguineum* (Müller, 1764), and *S. vulgatum* (Linnaeus, 1758) were studied. These species have wide ranges: three are trans-Eurasian (*Sympetrum flaveolum*, *S. sanguineum*, and *S. vulgatum*) and one is circumboreal (*S. danae*). Odonates are of medium size: wingspan is 50–60 mm, length of the rear wing is 25–40 mm, and body length, 30–50 mm. The largest species of these four is *S. vulgatum* and the smallest is *S. danae*. Due to the large intraspecific variabilities, the dimensional characteristics of all species overlap quite well. In the temperate zone, the sympetrums belong to the summer–autumn phenological group. The flight time for these species coincides: from the middle of June to the beginning of October.

Topical preferences of the species can be traced: *S. flaveolum* and, especially, *S. sanguineum* are *woodside* species, preferring ecotones on the border of arboreal and shrubby vegetation and open spaces; *S. vulgatum* is a *steppe* species, inclined to open biotopes; and *S. danae* is a *forest* one, associated with tree and shrub vegetation (Popova, 1999). The larvae have a fairly similar set of requirements: they develop in semiflow and stagnant water bodies with abundant