The life cycle of *Cyclops vicinus* in Lake Søbygård: new aspects derived from sediment analyses

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Received 21 November 2002; in revised form 27 May 2003; accepted 20 June 2003

**Key words:** *Cyclops vicinus*, copepod, life cycle, diapause, sediment

**Abstract**

*Cyclops vicinus* is the only copepod species in the pelagic zone of Lake Søbygård and can be found there all year round. We studied the population dynamics of this copepod over a one-year period. In contrast to earlier studies we included the copepods in the pelagic zone as well as the copepods resting in the sediment. *Cyclops vicinus* was found not only in the open water, but also in the sediment throughout the year. From the fluctuations of the abundances in both habitats we suggest that the life cycle is more complex than known so far: different diapause pattern appear within the population and the induction of diapause is different than in other populations. We assume that these features contribute to the predominance of *C. vicinus* in Lake Søbygård.

**Introduction**

Organisms living in aquatic habitats experience considerable fluctuations of biotic and abiotic conditions. In the lakes periods of abundant food allow juvenile development and reproduction, whereas food limitation, predation or deteriorating abiotic conditions endanger the organisms living there (Sommer et al., 1986). In order to survive in seasonally deteriorating environments, organisms have evolved strategies, which guarantee synchronization in time and space between growth and reproduction and favorable environmental conditions.

In copepods diapause either as eggs or as copepodids provides an efficient adaptation to a fluctuating environment. Diapause of cyclopoid copepods occurs at distinct ontogenetic stages during the juvenile development, which includes 6 naupliar and 6 copepodid stages.

*Cyclops vicinus* Uljanin is one of the most common and most studied planktonic cyclopoid copepods in Central Europe (Kiefer, 1978; Einsle, 1993; Santer, 1998). It is found in many mesotrophic and eutrophic lakes. The life cycle of this copepod is usually characterized by a diapause starting in early summer (Einsle, 1964; George, 1976; Maier, 1989; Santer & Lampert, 1995). The fourth or fifth copepodid stages stop feeding, accumulate lipids, sink down to the lake bottom and burrow into the sediment, where they survive even under anoxic conditions for a long time. The copepods emerge from the sediment in autumn (Santer & Lampert, 1995) or remain in diapause until the following spring (George, 1976; Maier, 1989). In some lakes, the population is completely absent from the open water during diapause (Einsle, 1967; Santer & Lampert, 1995) while in other lakes only a part of the population undergoes diapause, whereas another part of the population stays in the pelagial and exhibits summer generations (George, 1976; Maier 1989, 1996; Einsle, 1996).

It has been suggested that diapause in *Cyclops vicinus* is an adaptation to avoid food competition between juvenile copepod stages and Daphnids (Santer & Lampert, 1995) and mortality by fish pred-
The induction of diapause is considered to be induced by day length (Einsle, 1964; Spindler, 1971), which allows the population to escape from the pelagial before the conditions become harmful, i.e. food becomes limiting and fish predation strong. Circulation of the lake and oxygenation of the sediment was hypothesized to terminate diapause (Einsle, 1967).

In Lake Søbygård, a small and shallow hyper-eutrophic lake located in mid-Jutland, Denmark, *C. vicinus* is the only copepod in the pelagic zone and appears in high densities (Hansen & Jeppesen, 1992; Hansen, 1996). It is found in the pelagial all year round, with high abundances in summer. From the decrease in the abundances of fourth copepodid stages in late spring, Hansen & Jeppesen (1992) proposed that a part of the population entered summer diapause, but the sediment had never been examined to prove this assumption.

The present study combines for the first time the analyses of the seasonal abundances of *Cyclops vicinus* in the sediment and in the open water of Lake Søbygård over a one-year period. It was set up in order to provide a complete description of the life cycle of *C. vicinus* in Lake Søbygård. We considered this attempt to be very important, since the this lake has been studied for many years (Jeppesen et al., 1998) and the knowledge of the life cycle of the predominating copepod might be useful for further analyses of the interactions within this system. The major aim of this study however, was to understand the persistence of *C. vicinus* as the sole copepod in Lake Søbygård.

**Methods**

The abundances of *C. vicinus* in the open water and in the sediment of Lake Søbygård (for details about the lake see Jeppesen et al., 1998) were recorded during a one-year period from April 1997 to May 1998. Plankton and sediment samples were taken at 1–4 weeks intervals at a single mid-lake station of 1.5 m water depth. Samples were collected weekly during May 1997, when *C. vicinus* was expected to enter summer diapause (Hansen, 1996). During summer the copepods were sampled biweekly and every 3rd to 4th week during autumn and winter, except for periods with thin ice cover.

Plankton samples were collected at noon from two depths (subsurface and 1 m) with a 5.1-l plankton sampler, pooled, filtered through a 55-μm-mesh net and preserved in 70% ethanol. Two replicate samples were taken on each sampling date. Subsamples were taken from each replicate and the number of nauplii and copepodids was counted under a dissecting microscope. Copepodid stages (C1–C6) were counted separately, whereas naupliar stages (N1–N6) were pooled. At least 200 nauplii and 100 copepodids of each stage were counted per sample. To receive densities the counted numbers were recalculated into individuals per square meter.

Three sediment cores (inner diameter of 5.2 cm) were taken with a Kajak sampler (Kajak et al., 1965). In the laboratory, the overlying water was siphoned off and the upper 22–28 cm of the sediment cores were sliced at 2 cm intervals. Sediment cores shorter than 22 cm were omitted. Each sediment slice was rinsed with tap water on a 250-μm-mesh net to remove as much fine sediment as possible. *C. vicinus* copepodids of one sediment core were counted immediately (i.e. alive); the copepods of the two sediment cores were preserved in 70% ethanol and counted later. Abundances of diapausing *C. vicinus* in the sediment were calculated as numbers per square meter of sediment surface.

To demonstrate the vertical distribution of the diapausing copepodids in the sediment the 25th, 50th, 75th and 100th percentile depths (i.e. depths in the sediment above them 25, 50, 75 and 100% of the diapausing copepodids were found) were calculated for each date (for explanation see also Figure 2).

**Results**

*The life cycle of Cyclops vicinus*

*C. vicinus* was found in the open water as well as in the sediment throughout the year (Figs 1 and 2). The resting individuals were in general fourth copepodid stages; they were motionless with swimming legs directed forward, antennae stretched closely along the body, debris adhering to the lateral sides of the cephalothoraxes and with empty digestive tracts. Occasionally dead copepodids were found, but only in low density (<2% of resting copepodids).

The temporal variations in the abundances of the different stages of *C. vicinus* indicate that several generations were produced during one year. At the beginning of the investigation period in spring 1997, the abundances of copepods in the open water as well