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Composition and distribution of planktonic ciliates from ponds of different salinity in the solar saltwork of Sfax, Tunisia

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Abstract

The planktonic ciliated protozoa of 14 ponds of increasing salinity were investigated in the saline of Sfax, Tunisia. Taxa of the classes of Spirotrichea and Heterotrichea were the numerous ciliates. Abundance of the community ranged from 0.0 to 11.8×10^4 ciliates per litre. Values decrease significantly with salinity gradient, as species richness does. Based on the range of salinity over which ciliate taxa appeared, we distinguished three groups of ciliates. The first group is mainly composed of oligotrichs and choreotrichs that are commonly found in marine coastal waters. Small ciliates belonging to the order Prostomatida were found in a large range of salinity values, but their densities also decreased with salt concentration. In contrast, large-size species of heterotrichous ciliates were found in ponds with high salinity values only. In these ponds, the presence of prey appeared as an important factor in controlling the abundances of these halotolerant ciliates. Our data also suggest that *Fabrea salina*, a common halophile ciliate, acts as a competitor of the brine shrimp *Artemia salina* in the saline of Sfax. Salinity, prey availability, and the presence of competitors seem to be the main factors for the distribution of ciliate taxa in this hypersaline environment.

Keywords: solar saltwork; salinity gradient; ciliates; protozoa; halophile

1. Introduction

Ciliated protozoa are a ubiquitous component of aquatic food webs in both lacustrine (Carrias et al., 1998; Macek et al., 2001) and marine (James and Hall, 1995; Pérez et al., 1997, 2000; Dolan et al., 1999; Petz, 1999) environments. Ciliates may be important in secondary production (Reckermann and Veldhuis, 1997; Brown et al., 2002) and as food resource for zooplankton (Arndt, 1993; Sanders and Wickham, 1993; Jürgens, 1994). Thus they are considered as important mediators of energy transfer from pico- and nanoplanktonic production to higher trophic levels (Wiadnyana and Rassoulzadegan, 1989; Stoecker and McDowell-Cappuzzo, 1990; Dolan, 1991; Gifford, 1991; Legendre and Rassouldezgan, 1995; Sime-Ngando et al., 1995).

Over the past 20 years, the role of ciliates in pelagic food webs has been the focus of numerous studies. These studies covered the abundance, the composition, the seasonal and spatial distribution (Montagnes et al., 1988; Laybourn-Parry, 1994; Pitta and Giannakourou, 2000; Johansson et al., 2004), and growth rates and production of ciliate communities (Müller and Geller, 1993; Carrias et al., 2001; Yasindi and Taylor, 2003). These works have also indicated that pelagic ciliates constitute a highly diverse community capable of exploiting a wide range of food resources including picoplankton, protozoa, phytoplankton and even some metazooplankton species.

Although there is a good understanding of planktonic ciliate ecology and their role in the microbial loop, there have

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been no detailed studies of their importance in extreme environments such as solar salterns. To our knowledge, the only available data on planktonic ciliates in extreme saline environments come from salted lakes in Antarctica (Laybourn-Parry and Perris, 1995; Bell and Laybourn-Parry, 1999). Saline lagoons have a very wide range of salinities: from that of coastal waters ($S = 35$) up to the lagoons saturated with sodium chloride ($S = 330$). Studies on the organisms occurring in saline lagoon have mainly dealt with the halotolerant taxa, such as the anostracan *Artemia salina* (Persoone et al., 1980; Sorgeloos, 1988; Barata et al., 1995), the alga *Dunallelia salina* (Giordano et al., 1994; Moreno-Garrido and Cañavate, 2001), the ciliate *Fabrea salina* (Yufera, 1985; Pandey and Yeragi, 2004) and the bacteria and Archaea (Cornée, 1984; Oren, 1999, 2000; Oren and Rodriguez-Valera, 2001; Gasol et al., 2004). It is only recently that planktonic communities such as phytoplankton (Campbell and Davis, 2000; Estrada et al., 2004; Ayadi et al., 2004), zooplankton (Quintana et al., 1998; Thièry and Puente, 2002; Quintana, 2002; Toumi et al., 2005) and bacteria and Archaea within microbial food chain (Pedrós-Alió et al., 2000; Gasol et al., 2004) have been studied. It seems that microbial food webs in salines tend to become simpler as the salt concentration increases. The general trend of a decrease of the abundance, species richness and diversity of aquatic organisms as the salt concentration increases has been notified by several authors (Busson, 1982; Williams, 1998; Pedrós-Alió et al., 2000). Only few species, the most salt tolerant, survive at the highest salt concentrations. Despite recent interest in the functional role of microorganisms along salinity gradient, there have been no detailed studies of ciliate community in these ecosystems. In general, relatively few studies have been sufficiently comprehensive to characterize the composition and the degree to which protistan species are known and the description varies tremendously within the major groups present in salt marshes. The saline of Sfax (Tunisia) provides an additional advantage for this type of investigation. Due to the semi-arid climate and the strict operating conditions imposed by the salt producing company, the physical–chemical variables of each pond are very stable over the years (Toumi et al., 2005).

During this study, the abundance and the composition of ciliated protists were analyzed in 14 lagoons of increasing salinity, in order to answer the following questions:

(1) Does the species richness and abundance of ciliated protozoa decrease along the salinity gradient? (2) Are there halotolerant forms? and (3) How are the ciliates distributed in relation to the other planktonic communities (nanoplankton, phytoplankton and zooplankton) and especially the extremophiles such as *Artemia* and *Dunallelia*?

2. Materials and methods

2.1. Study site

The study was conducted in the solar saltern of Sfax (central-eastern coast of Tunisia, about 34° 39′N and 10° 42′E), an artificial system formed of interconnecting ponds of different salinity, from that of seawater up to sodium chloride saturation. The lagoon extends over an area of about 1500 ha to the south of the town of Sfax, on a peninsula situated between the port zone and the village of Gargour. The saltern, separated from the sea by an artificial seawall, consists of a series of shallow ponds (20–70 cm deep) whose area varies from about 10 to several hundred hectares. The input of seawater and the circulation between the various ponds are entirely controlled depending on the meteorological conditions in order to ensure an annual yield of about 300,000 tonnes of halite and 25,000 tonnes of bittern brine. The detailed characteristics of the various ponds have been described by Ayadi et al. (2002).

2.2. Sampling

Fourteen ponds of salinity ranging from 45 to 395 were sampled on 22 January and 16 May 2003. Water samples were collected 1 m above the outfall of each pond and between 5 and 20 cm below the surface using a 10-L Van Dorn bottle. The zooplanktonic organisms retained by filtering 10 L of water through a 100-μm-mesh net were transferred to a sterile 125-ml flask and fixed with formaldehyde (4% final concentration). Two 200 ml samples of water were fixed in acid Lugol's iodine to study phytoplankton and ciliates. A sample was prepared without fixative to examine and count large-sized ciliates. A 100 ml sample was fixed with formalin to preserve nanoplankton. Temperature and pH were measured immediately after sampling using a mercury glass thermometer graduated in 0.1 °C and a Met Röhm® type pH meter.

2.3. Laboratory analysis

Salinity as total dissolved salts (TDS) was estimated by the dry residue method, which consists of evaporating a 50-ml sample (24 h, 120 °C) in a previously sterilised crystallizing dish (by heating at 550 °C for 1 h), and calculating the salt content from the difference in weight before and after evaporation. The total weight of major ions generally constitutes over 99% of the total salinity (Wetzel and Likens, 2000). Based on seasonal studies (Toumi et al., 2005; Elloumi, unpublished data), salinity of each pond had a CV < 6% around the seasonal mean value, indicating the great stability of this parameter in the saltwork. Concentrations of suspended matter were determined by measuring the dry weight of the residue after water filtration through a Whatman GF/C membrane.

Zooplankton was identified and counted under a binocular microscope in Dolffus chambers. In addition, appropriate body dimensions of 30–40 individuals of each taxa or stage were measured using a micrometer and biovolume was calculated using simple geometric shapes. The biovolume was then directly converted into carbon content according to Alcaraz et al. (2003) using biovolume–carbon relationship.

Phytoplankton and ciliate counts were made under an inverted microscope using Utermöhl's (1958) method. At least 200 ciliates were counted for each sample and were identified to genus or species level by consulting the works of Petz (1999), Alder (1999) and Strüder-Kypke and Montagnes