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The influence of fundamental design parameters on ciliates community structure in Irish activated sludge systems

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Abstract

The protozoan community in eleven activated sludge wastewater treatment plants (WWTPs) in the greater Dublin area has been investigated and correlated with key physio-chemical operational and effluent quality parameters. The plants represented various designs, including conventional and biological nutrient removal (BNR) systems. The aim of the study was to identify differences in ciliate community due to key design parameters including anoxic/anaerobic stages and to identify suitable bioindicator species for performance evaluation. BNR systems supported significantly different protozoan communities compared to conventional systems. Total protozoan abundance was reduced in plants with incorporated anoxic and anaerobic stages, whereas species diversity was either unaffected or increased. *Plagiocampa rouxi* and *Holophrya discolor* were tolerant to anoxic/anaerobic conditions and associated with high denitrification. Apart from process design, influent wastewater characteristics affect protozoan community structure. *Aspidisca cicada* was associated with low dissolved oxygen and low nitrate concentrations, while *Trochilia minuta* was indicative of good nitrifying conditions and good sludge settleability. *Trithigmostoma cucullulus* was sensitive to ammonia and phosphate and could be useful as an indicator of high effluent quality. The association rating assessment procedure of Curds and Cockburn failed to predict final effluent biological oxygen demand (BOD_5) indicating the method might not be applicable to treatment systems of different designs.

Keywords: Protozoa; Indicator; Wastewater treatment; BNR systems; Anoxia; Anaerobia

Introduction

Protozoa are potentially important indicators of process performance and efficiency (Madoni 2003; Curds and Hawkes 1975). Curds and Cockburn (1970a) who carried out a comprehensive study of the protozoal population of 56 activated sludge plants in the UK found a rich protozoan community related to effluents of high quality while a community with only few species in small numbers was associated with low-quality effluent. Since then a series of plant studies has been carried out to further explore the relationship between the protozoan community structure, effluent quality and plant operating conditions, including the indicator values of certain protozoan species or groups (Martín-Cereceda et al. 1996; Madoni et al. 1993; Al-Shahwani and Horan 1991; Esteban et al. 1991). Performance indices have also been developed based on ciliate diversity and abundance as indicators of activated sludge performance (Jiang and Shen 2003; Burgess et al. 2002; Madoni 1994; Curds and Cockburn 1970b).

Abbreviations: BNR, biological nutrient removal; BOD_5, biological oxygen demand (for 5 days); DO, dissolved oxygen; HRT, hydraulic retention time; MLSS, mixed liquor suspended solids; NH_4-N, ammoniacal nitrogen; NO_3-N, nitrate nitrogen; ORP, oxidation reduction potential; PO_4-P, phosphate phosphorus; SBI, Sludge Biotic Index; SBR, sequencing batch reactor; SRT, sludge retention time; SSVI, specific sludge volume index; TN, total nitrogen; TOC, total organic carbon; TP, total phosphorus; WWTP, wastewater treatment plant.

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However, in many studies process operation and efficiency has been limited to measuring the final effluent BOD_5 concentration (Lee et al. 2004; Salvado et al. 1995; Al-Shahwani and Horan 1991; Curds and Cockburn 1970b) while a limited number of studies have included ammoniacal nitrogen concentrations and studied the association of protozoan species to nitrifying conditions (Liu et al. 2008; Madoni et al. 1993; Poole 1984). With the introduction of the EU Urban Wastewater Treatment Directive (91/271/EEC) (Council of the European Communities 1991) and a greater understanding of the role of nutrients in promoting eutrophication in rivers, wastewater treatment is now increasingly including biological nutrient removal (BNR), which involves both anaerobic and anoxic stages (Akin and Ugurlu 2003). There is currently very little information on the effect of BNR systems and the use of different redox conditions on the protozoan community and whether this affects the current use of indicator systems employed with protozoa in activated sludge. Liu et al. (2008) are the first researchers to include BNR systems in a study to determine whether the protozoan communities are related to treatment processes and how they are affected. They found that different systems with the same process principles exhibit similar protozoan community structures with more diverse communities in systems with anaerobic, anoxic and aerobic stages. However they only studied the association of protozoan as functional groups with operational parameters and effluent quality and not at species level.

Another study that has been published recently focused on three plants that employ biological nitrogen removal with different levels of removal efficiencies (Pérez-Uz et al. 2010). In these plants protozoan populations showed lower abundances but a higher diversity than those found in conventional systems. Supported by their results that protist communities are different in N-removal systems the authors pointed out that it is becoming increasingly clear, that bio-indicator indices must be adapted to the type of treatment process (Pérez-Uz et al. 2010). These latest findings support the opinion that results from previous studies on conventional activated sludge plants cannot be directly extrapolated to new wastewater treatment plants (WWTPs) and thus further research in this field is needed.

The objectives of this study are, by measuring a wide range of design and operational/management factors: (i) to determine the typical ciliates inhabiting different Irish activated sludge plants; (ii) to study the relationship between effluent quality, operational factors, physico-chemical parameters and the ciliates present in the plants and (iii) to verify whether different plant designs, especially conventional and BNR systems, support different protozoan communities. The results of this study should help to find bio-indicator species for process performance and sludge quality that are suitable for the broad use in all treatment plants designs and specifically for BNR systems.The hypotheses tested were:

1. The species structure of the protozoan population in activated sludge is related to the final effluent BOD_5.
2. Anaerobic and anoxic stages reduce total protozoan abundance.
3. Anaerobic and anoxic stages reduce protozoan diversity and complexity.
4. Conventional and BNR systems support different protozoan community.

Material and Methods

Sampling sites

Eleven activated sludge plants located in the greater Dublin area were selected for inclusion in the study (Table 1). This comprised 2 sequencing batch reactors (SBRs), 3 conventional plug flow systems, 3 completely mixed and 3 extended aeration units. Compared to the completely mixed systems where the loading is uniformly distributed within the aeration tank, a temporal and spatial BOD_5 gradient is created in SBRs and plug flow reactors, respectively (Gray 2005). Extended aeration systems are usually operated under a lower sludge loading (BOD_5 loading related to the volume of biomass) which results in the process being food limited (Gray 1990). Five plants incorporated anoxic stages to perform nitrogen removal through denitrification. Nine plants employed phosphorus removal with 6 using chemical precipitation, 1 biological removal and 2 combining both methods. For the biological phosphorus removal anaerobic stages are integrated in the treatment process. The largest plant is Ringsend WWTP serving central Dublin with a population equivalent of 1.9 million treating municipal (58% domestic, 42% industrial) sewage. The other plants are medium or small-sized works treating mainly domestic wastewater. Leixlip II was the only plant included in the study which had a significant industrial loading (70%). Samples of primary settled sewage, mixed liquor and final effluent were taken during the Spring/Summer of 2008, with the mixed liquor samples collected from the end of the aerobic zone.

Physico-chemical and operational parameters

The plants provided information about operating parameters such as hydraulic retention time (HRT), sludge retention time (SRT), organic loading and sludge loading (Table 1). When samples were taken dissolved oxygen (DO) and pH were measured on-site using a multimeter (Hanna HI 9828) equipped with a galvanic dissolved oxygen (DO) sensor and a gel filled pH/ORP electrode. Influent and effluent samples were collected for the analysis of the biological oxygen demand (BOD_5), chemical oxygen demand (COD), total organic carbon (TOC), total phosphorus (TP), orthophosphate, total nitrogen (TN), ammonium, nitrate and nitrite. The BOD_5 was measured respirometrically using the Oxitop® system (Reuschenbach et al. 2003) with means of 2–4 replicates used for statistical analysis. Nitrification in the BOD test was suppressed by the addition of 0.5 mg L^{-1}