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Relationships between clogging in irrigation systems and plankton community structure and distribution in wastewater reservoirs

Ana Milstein[a,*], Mordehai Feldlite[b]

[a] Agricultural Research Organization (ARO), Fish and Aquaculture Research Station Dor, M.P. Hof HaCarmel 30820 ISRAEL
[b] Israel Water Workers Association, Eyal, mid-Sharon 45480 ISRAEL

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ABSTRACT

The development of large populations of cladocerans and copepods in reservoirs that store wastewater for crop irrigation causes severe clogging in irrigation systems. In most reservoirs in Israel water is filtered at the banks of the reservoirs before being sent to irrigation. This avoids/reduces clogging in the irrigation systems transferring the problem to the storage reservoirs. To cope with this problem we studied relationships between clogging and particle size distribution in a range of secondarily treated wastewater reservoirs with different characteristics and water management. Since the reservoirs are deep and thermal stratification develops, measurements of the time required to clog 100 μm pore net filters and samples for physico-chemical and microscopic analyses were collected in the surface, deep epilimnion and hypolimnion. Factor analysis allowed identifying two independent sets of environmental conditions and planktonic species that lead to clogging of irrigation filters. The first set is related to thermal stratification and the development of a planktonic community with a complex web of feeding interactions in which the organisms capable of clogging filters are mainly copepods. The second set occurs in spring and fall, and includes planktonic organisms forming a short food chain in which the organisms capable of clogging filters are mainly cladocerans. A third factor was organic loading, mostly related to the entrance of fresh wastewater into the reservoirs during the irrigation season, which had a negative effect on nitrification and promoted blue green algae development and copepod reproduction. The analysis of potential management procedures to avoid filter clogging indicates that in these reservoirs manipulations of food web interactions in the planktonic community structure towards smaller organisms that do not clog filters would not be effective against copepods. A better option to decrease clogging events is to avoid pumping water out from the deep epilimnion, preferably pumping from the hypolimnion.

1. Introduction

The water column of lentic water bodies hosts a wide variety of particles of different types and sizes. In reservoirs that store water for irrigation those particles may cause severe clogging problems in irrigation systems, especially in the drip irrigation ones (over half of Israel's irrigated area is under drip irrigation, OECD, 2011). Clogging of filters, pipes and drippers produce inequality of water supply and shortage of water to the crops. Clogging depends on the interaction between the presence of clogging agents in the water of the irrigation reservoir, reservoir design and hydrology, and water management. Clogging agents may be rather large phyto- and zooplanktonic organisms, their decomposing rests, detritus and inorganic materials (sand, clay), which when combined often produce more serious clogging events (Juanicó et al., 1995).

In Israel the clogging problem originates in irrigation reservoirs of different size (5 ha–40 ha and 5 m–23 m maximum depth) that store waters of a wide range of qualities (from drinking water quality to different degrees of treated wastewater). Over 75% of the municipal wastewater of the country is reused, most of it for agricultural irrigation (The Water Agency - Israel, 2014). During the years different regulations requested better and better quality of the treated effluents, the major ones being the requirement for secondary treatment (BOD < 20 mg/l) in 1995 and for tertiary treatment (nutrient removal) in 2005 (Juanicó, 2008), the latter still being gradually implemented. The improvement of the quality of treated wastewater allowed increased zooplankton populations in the reservoirs, mainly copepods (length about 200–1000 μm) and cladocerans (length about 300–3000 μm), so that the clogging problem worsened mainly in the last 10–15 years as quality of treated wastewater improved. Some reservoirs deliver their water

* Corresponding author. Tel.: +972 4 6390651x108; fax: +972 4 6390652.
E-mail addresses: anamilstein@agri.gov.il (A. Milstein), motif@gan.org.il (M. Feldlite).

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directly to the irrigation systems, which at their head have filters of 130–200 μm pore. But in most reservoirs another 130–200 μm pore filter battery was added at the banks of the reservoirs and the filtered water is only then sent to irrigation. This avoids/reduces clogging in the irrigation systems transferring the problem to the storage reservoirs, which must overcome the problem to deliver the required amounts and quality of water.

The clogging problem created the need to find parameters easy to measure that enable predicting clogging hazards. The clogging potential meter (CPM), developed by the Israel Water Works Association (IWWA), enables to evaluate the potential of a water source to produce clogging episodes in irrigation systems. The earlier version of this instrument was described by Sagi et al. (1996) and the more advanced version by Feldlite and Yechiely (2011). The concept of this instrument is based on measuring the time it takes to partially clog a filter, when the examined irrigation water flows at a constant rate (10 liters per minute) with a differential pressure of 3 m across a small screen filter. Besides the measurement of clogging time, the material retained in the screen net can be collected and examined under stereoscope to identify the particles/organisms causing clogging. This, in turn, allows adopting appropriate management procedures against the specific clogging agent.

Since 2002 the Israel Water Works Association is carrying out a water quality monitoring program weekly performed in over 70 irrigation reservoirs throughout the country. Among other parameters, the program includes CPM measurements with 150 μm pore nets to detect early development of clogging agents and adopt appropriate procedures to avoid or control clogging episodes. Through this work much experience accumulated and many questions arose in the search for long-term solutions to avoid clogging and short-term solutions to solve already happening clogging events. As a first step towards the long-term solutions approach we studied relationships between clogging and particle size distribution in a range of secondarily treated wastewater reservoirs with different characteristics and water management. The objective of the study was to better understand the functioning of the reservoir ecosystem in order to evaluate potential management procedures to avoid filter clogging, including from which water level to pump water out and manipulations of food web interactions in the planktonic community structure towards smaller organisms that do not clog filters.

2. Material and methods

2.1. Field work

In Israel irrigation reservoirs are deep water bodies in which rain water is collected during the rainy winter while treated wastewater may enter all the year round. Before the outset of the irrigation season reservoirs are generally full. During spring thermal stratification develops leading to strong vertical gradients of environmental conditions: a warm, oxygen rich, upper 3–5 m deep layer where photosynthesis prevails (epilimnion), a 1–2 m deep transition layer where temperature steeply decrease (thermocline), and a cold anoxic deeper layer where decomposition processes prevail (hypolimnion). As water is pumped out for irrigation water depth decreases, at a higher rate during the dry warm period. In some reservoirs water is pumped out from near the reservoir bottom, while in most reservoirs a floating monk allows choosing the pumping depth from the upper 4–6 m water layer.

The research was carried out in 9 irrigation reservoirs that receive wastewater after secondary treatment. In all these reservoirs wastewater enters into the upper reservoir water layers and the water passes through 130 μm pore filters before it is sent to the irrigation systems. Reservoirs differed in dimensions, bottom type and water management (Table 1).

Sampling was carried out during the 2011 and 2012 irrigation seasons after the rainy winter was over and regular irrigation activities started. Samples were collected always during the mid and late morning hours. From April to early July 2011 water samples were collected in the reservoirs' banks from the irrigation pipes before the filtering system; the depth of the water column from which that water was pumped out was recorded. Afterwards, water samples were collected in the reservoirs near the monk, from a boat. In this case temperature and dissolved oxygen were measured each 0.5 m from surface to bottom of the water column. Water samples were then collected according to those measured profiles, at least at surface and hypolimnion and if relevant also above the transition zone (deep epilimnion over the thermocline).

In each sampling point (before irrigation filters and in each reservoir depth) water was collected for chemical analyses: pH, nitrogen in ammonium (TAN) nitrate (N_NO_3) and organic matter (N_org), total phosphorus (TP), total suspended solids (TSS). A Clogging Potential Meter (CPS) with net filters of 150 μ, 100 μ, 60 μ and 33 μ was used to measure time to clog each net. If clogging did not occur after 5–7 min filtration was stopped. Good water quality for irrigation is considered when clogging time of the 150 μm and 100 μm nets was at least 5 min. The CPS was also used to collect the particles retained by each filter for suspended solids analysis and for microscopic identification and counting of phyto- and zooplankton. The samples for chemical analyses were sent to specialized laboratories. The microscopic analyses were performed by the authors.

2.2. Statistical analyses

The management, chemical and plankton data of all the reservoirs and sampling days during 2011 and 2012 were combined in a single data matrix. Plankton counts were log transformed to normalize. The 'time to clog nets' data were entered as decimals (minutes.seconds) and used as a decimal variable to meet format requirements of the statistical procedures applied. Differences of each variable among water layers were tested with Scheffe's mean multicomparison test after performing ANOVA. Relationships among variables were explored with the multivariate technique of factor analysis. Both were run using the Statistical Analysis System (SAS) package version 9.2 (SAS, 2008).

Factor analysis was run to identify ecological processes related to filter clogging that account for the main variability of the measured variables (Milstein, 1993). The purpose of factor analysis is to explain the relationships among a set of variables in terms of a limited number of new variables (factors), which are assumed to be responsible for the covariation among the observed variables. From the several available techniques to extract factors, principal components calculated from the correlation matrix among variables was used. The first factor extracted is the linear combination of the original variables that accounts for as much of the variation contained in the samples as possible. The second factor is the second linear function of the original variables that accounts for most of the remaining variability, and so on. The factors are independent of one another, have no units and are standardized variables (normal distribution, mean = 0, variance = 1). The coefficients of the linear functions defining the factors are used to interpret their meaning, using the sign and relative size of the coefficients as an indication of the weight to be placed upon each variable. In each factor the variables with the same sign present high positive correlation among them, being both groups negatively correlated between them. In Table 3, the coefficients of the variables considered for interpretation of the factors are presented in bold.