CZECH MYCOLOGY 72(1): 43–70, MAY 29, 2020 (ONLINE VERSION, ISSN 1805-1421)

Biodiversity, spatial distribution and seasonality of heterotrophic straminipiles and true zoosporic fungi in two water bodies exposed to different effluents at Assiut (Upper Egypt)

ABDEL-RAOUF M. KHALLIL*, ESSAM H. ALI, ELHAGAG A. HASSAN,
SABREEN S. IBRAHIM

Botany and Microbiology Department, Faculty of Science, University of Assiut, EG-71515, Assiut, Egypt
*corresponding author: raouf59@gmail.com

Khallil A.M., Ali E.H., Hassan E.A., Ibrahim S.S. (2020): Biodiversity, spatial distribution and seasonality of heterotrophic straminipiles and true zoosporic fungi in two water bodies exposed to different effluents at Assiut (Upper Egypt). – Czech Mycol. 72(1): 43–70.

Patterns of frequency, biodiversity and seasonality of fungi-like organisms and true zoosporic fungi in relationship with some abiotic factors of two water bodies exposed to various effluents at Assiut Governorate (Upper Egypt) were investigated. Thirty-four species related to ten genera were isolated from the El-Zinnar irrigation canal and the El-Ibrahimia canal, which receive treated sewage water and the industrial effluents of a factory for oils and detergents, respectively, using the baiting technique during four seasons (from winter 2017 to autumn 2018).

The highest fungal diversity was recorded during winter, followed by autumn and spring, whereas summer was the lowest in species diversity. *Achlya*, *Dictyuchus*, *Allomyces* and *Pythium* were the prevalent genera, whereas *Brevilegnia* and *Pythiopsis* were the least frequent ones. Some fungal taxa were present throughout the year while others were highly restricted, occurring in only one season. The species composition and community structure of the heterotrophic straminipiles and true zoosporic fungi varied in spatial distribution and exhibited seasonal variations, probably influenced by particular abiotic water characteristics, sampling site and season.

Sites which directly receive either treated sewage water or industrial effluents were the poorest in straminipiles and true zoosporic fungi, and can be regarded as stressful environments where some abiotic parameters were excessive. Seasonality and biodiversity of the surveyed organisms are mainly dependent on water temperature, conductivity, most of the determined cations and anions, but pH did not exhibit any considerable impact. It is assumed that the existence of some fungal taxa at polluted sites may have a potential source of fungi beneficial for bioremediation and xenobiotic transformation.

Key words: aquatic ecosystems pollution, oomycetes, *Allomyces*, bioindicators.

Article history: received 16 January 2020, revised 12 April 2020, accepted 30 April 2020, published online 29 May 2020.

DOI: https://doi.org/10.33585/cmy.72104

Khallil A.M., Ali E.H., Hassan E.A., Ibrahim S.S. (2020): Biodiverzita, prostorové rozložení a sezonalita heterotrofních straminipil a zoosporických hub ve dvou kanálech s přítokem odpadních vod v okolí Asijútu (Horní Egypt). – Czech Mycol. 72(1): 43–70.

Práce přináší výsledky sledování frekvence výskytu, diverzity a sezonality houbám podobných organismů a pravých zoosporických hub ve vztahu k abiotickým faktorům ve dvou kanálech v Asijútském guvernorátu, kde jsou vystaveny působení různých odpadních vod. Technikou odběrů s využitím návnad byly v zavlažovacím kanálu El-Zinnar, kam ústí výtok z čistírny komunálních odpadních vod, a kanálu El-Ibrahimia, kam přitékají průmyslové odpady z továrny na výrobu olejů a čisticích prostředků, během čtyř ročních období (zima 2017 až podzim 2018) zjištěny celkam 34 druhy z 10 rodů.

Nejvyšší diverzita byla zjištěna v zimě, menší na podzim a na jaře, a druhově nejchudším obdobím je léto. Nejhojnější byli zástupci rodů *Achlya*, *Dictyuchus*, *Allomyces* a *Pythium*, naopak nejméně byla zastoupeny *Brevilegnia* a *Pythiopsis*. Zatímco výskyt některých druhů je rovnoměrný po celý rok, výskyt jiných je omezený v krajním případě i na jediné období. Druhové složení a struktura společenstev heterotrofních straminipil a zoosporických hub se mění v závislosti na prostorovém rozložení jejich výskytu a sezónních změnách; pravděpodobně se zde skládají vlivy abiotických vlastností vody, umístění odběrového místa a ročního období.

Nejchudší na straminipila a zoosporické houby jsou místa, kam přímo přitéká zpracovaná odpadní voda nebo průmyslové odpady; zde lze mluvit o stresovém prostředí, kde některé abiotické parametry dosahují nadměrných hodnot. Faktory, které výrazně ovlivňují sezonalitu a biodiverzitu sledovaných organismů, jsou zejména teplota vody, konduktivita, většina zjištěných kationtů a aniontů, zatímco pH nemá nikterak zjevný vliv. Na základě přítomnosti některých druhů i ve znečištěných místech lze předpokládat, že zde je možné hledat dobré bioindikátory a případně i houby využitelné pro bioremediaci a odbourávání cizorodých látek.

INTRODUCTION

Zoosporic fungi, which were all well known to Sparrow (1960), are not a monophyletic group and include taxa which are now known to have very diverse phylogenetic histories (Baldauf 2008, Gleason et al. 2017a). Based on cellular ultrastructure, molecular phylogeny, biochemicals, and physiological characteristics, Straminipila (Hyphochytriomycota, Oomycota, and Labyrinthulomycota) are not considered to be true fungi (Alexopoulos et al. 1996, Beakes et al. 2014), despite sharing many ecological functions, trophic strategies, morphological and physiological characteristics with true fungi and often inhabiting similar environments. Straminipila, which are different from true fungi, are treated as fungi-like organisms, whereas uniflagellate zoosporic fungi (chytrids and related groups) and the Opisthosporidia group (rosellids and aphelids) are treated as true fungi (Karpov et al. 2014). Anyway, in studies dealing with these groups together (aquatic oomycetes and true zoosporic fungi) the common term “zoosporic fungi” is used to cover both groups and simplify the terminology (Czeczuga & Muszyńska 2004).

Seventy-one percent of the earth's surface consists of water, but only 0.6% of it is freshwater. Freshwater resources are becoming increasingly scarce in many arid and semi-arid countries due to climate changes, economic growth, urbanisation and a growing human population. Consequently, utilisation of treated municipal wastewater and other effluents in irrigation of agricultural lands could be considered when its disposal is being planned particularly in arid and semi-arid regions. Besides sewage water which enters irrigation canals, also some industrial effluents characterised by a complex and diverse composition of organic and inorganic pollutants including strong acids, metallic ions, and polyaromatic hydrocarbons (PAHs) enter irrigation water (Selvarajan et al. 2019). The discharge of huge amounts of toxic heavy metals and organic pollutants into the aquatic environment resulting from human activities and industrial manufacturers has adverse impacts on aquatic ecosystems (Khallil & Abdel-Sater 1992, El-Hissy et al. 2001, Khallil et al. 2002, Turkar et al. 2011, Liu et al. 2017, Assress et al. 2019). These pollutants generally decline both the richness and activities of microbial species (Manahan 2000). Recently, awareness of the need to dispose of various wastes (e.g. municipal sewage water, industrial and agricultural wastes) beneficially and safely is rising. Aquatic ecosystems are subject to fluctuations in environmental parameters, mainly due to seasonal changes, agricultural, industrial and human activities. The changes in distribution, species composition and structure of the mycobiota assemblages in terms of ecosystem dynamics appear to be dependent on fluctuations in abiotic factors (Sparrow 1968, Shearer et al. 2007, Marano et al. 2011).

As a consequence, the use of various recycled industrial effluents and treated wastewater for irrigation is rising, particularly in urban areas of developing countries including Egypt. Physical, biological and chemical methods are necessary for treatment of sewage water and other effluents before they are reused and draining into irrigation systems to avoid serious environmental hazard. The fungal biodiversity of various water habitats is still a subject of ongoing research. The occurrence and diversity of fungi in wastewater and water bodies exposed to various effluents provide valuable insights regarding the adaptation and potential involvement of these organisms in bioremediation processes (Selvarajan et al. 2019). Several intensive studies concerning the incidence, periodicity and biodiversity of heterotrophic straminipiles and true zoosporic fungi in relation to non-polluted and polluted water characteristics have been published worldwide (e.g. Suzuki 1960, Sparrow 1968, Logvinenko 1970, Czeczuga et al. 1997, Shearer et al. 2007, Marano et al. 2008, Gleason et al. 2010a, 2010b, DiLeo et al. 2010, Nascimento et al. 2011, Wang et al. 2012, Niu et al. 2017, Khomich el al. 2017, Li & Wu 2018, Henderson el al. 2019).

In Egypt, although many investigations into zoosporic fungi occurring in the Nile system have been made (e.g. El-Hissy & Khallil 1989a, Khallil 1990, Khallil et al. 1993), insufficient attention has been paid to the biodiversity, spatial distribution and seasonal occurrence of zoosporic fungi in water areas exposed to different effluents (e.g. Khallil & Abdel-Sater 1992, El-Hissy et al. 2001, Khallil et al. 2002, Nasser et al. 2002, Ali 2007, Abd El-Zaher et al. 2017). Thus, the present investigation represents an attempt to bridge this gap and aims to monitor the biodiversity, spatial distribution and seasonal fluctuations of heterotrophic straminipiles (fungi-like organisms) and true zoosporic fungi inhabiting two water bodies receiving treated sewage water and industrial effluents from oils and detergents factory in relation to some physicochemical water characteristics.

MATERIAL AND METHODS

Study area and sampling sites. The Assiut wastewater treatment plant was constructed in 1957 and is located about 5 km southwest of the city of Assiut (about 365 km south of Cairo) near the village of Arab El-Madabegh. Its capacity is about 30,000 m^3/day. Domestic wastewater is discharged from houses, institutions, carwashes, commercial businesses and similar facilities. This discharge includes human and animal urine and faeces, and so-called grey water originating from washbasins and bathrooms. It is coloured, looks dirty and contains a certain amount of soluble or insoluble substances, organic and inorganic compounds. The wastewater is subjected to a series of successive treatment stages (includes physical, chemical and biological treatments as well as sludge removal) in the municipal plant and eventually the treated wastewater is collected in a basin and discharged into the El-Zinnar canal, which is a significant water resource for irrigation. Six surface water samples were collected seasonally from the El-Zinnar canal (Fig. 1A); one sample from the basin in which the treated sewage water is collected (ZN_1), and five samples from successive sites (ZN_2–ZN_6) of the main stream over c. 2 km (at approximately 500 m intervals). Two sites (ZN_2 and ZN_3) are located south of the plant, upstream, and can thus be considered as a control, one site (ZN_4) receives treated sewage water directly from the collection basin, and two sites (ZN_5 and ZN_6) are located north of the treatment municipal plant, downstream. At sites ZN_5 and ZN_6, discharged wastes are progressively diluted.

The oils and detergents factory (Nile Company, Bani-Qurra) is located c. 40 km north of the city of Assiut (c. 325 km south of Cairo). The factory produces powder detergents (Savo-Randy), liquid detergents (Savonil-Desent), toilet soap, laundry soap, margarine, edible oils as well as different sorts of oil. The factory effluents are released directly into the main stream of the El-Ibrahimia irrigation canal (the longest irrigation canal in Egypt, extending about 360 km and representing the main source for irrigation in the central Egypt governorates). Five

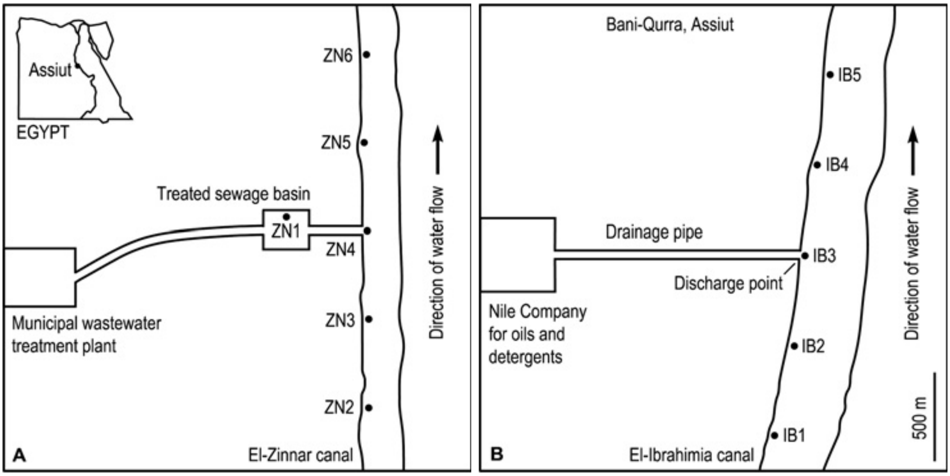

Fig. 1. Diagrams illustrating the sampling sites on El-Zinnar irrigation canal (**A**) receiving treated sewage water (Arab El-Madabegh, Assiut Governorate) and the sampling sites on El-Ibrahimia irrigation canal (**B**) receiving industrial effluents of the oils and detergents factory (Nile Company, Bani-Qurra, Assiut Governorate).

surface water samples were collected seasonally from five water sites (IB_1–IB_5) over a length of about 2 km (at c. 500 m intervals) on the El-Ibrahimia canal (Fig. 1B). Two sites (IB_1 and IB_2) were located south of the factory, upstream, one site (IB_3) receives factory effluents directly, and two sites (IB_4 and IB_5) are situated north of the factory, downstream. Thus, the two sites IB_1 and IB_2 can be considered as controls, the third site (IB_3) is directly polluted with industrial effluents and at the last two sites (IB_4 and IB_5), the discharged wastes are subject to progressive dilution.

Samples collection. Surface water samples were collected seasonally from the different sites in the two described study areas (El-Zinnar and El-Ibrahimia canals) during four seasons from winter 2017 to autumn 2018. Water samples were collected seasonally in 300 ml sterile glass bottles (three bottles for each site) containing sterilised sesame seeds serving as baits. For limnological characterisation of the water, surface water samples were collected concomitantly using a one-litre bottle. Water samples were directly taken to the laboratory and analysed for selected physical and chemical characteristics as well as for the recovery of heterotrophic straminipiles and true zoosporic fungi.

Physicochemical analysis of water samples. The water temperature was measured in situ using a laboratory thermometer (liquid mercury in glass tube), pH and water conductivity were measured ex situ using a combined pH and conductivity meter (Jenway Model 3450 conductivity/pH meter). The contents of organic matter were chemically estimated based on Jackson (1958). Sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), phosphate (PO_4^{3-}), nitrate (NO_3^-), sulphate (SO_4^{2-}) and bicarbonate (HCO_3^-) were determined according to APHA (1998).

Isolation and identification of heterotrophic straminipiles and true zoosporic fungi. Straminipiles and true zoosporic fungi (to simplify the term, both groups together are further referred to as zoosporic fungi or zoosporic taxa) were isolated from the collected water samples using the baiting technique (Sparrow 1960) with sesame seeds which had been proved to be the best bait in previous studies (Khallil 1990, El-Hissy & Khallil 1991). Surface water samples were poured under aseptic conditions into Petri dishes (9 cm in diameter) containing 10 sesame seeds each and then the Petri dishes (3 replicates) were incubated at 20 ± 2 °C for 24 hours (El-Hissy & Khallil 1989a). The colonised baits were transferred to other Petri dishes, supplemented with chloramphenicol (250 mg/l) to suppress bacterial growth (Roberts 1963). The dishes were incubated at 20 ± 2 °C and examined daily for the growth and identification of zoosporic taxa, then the colonised baits were transferred to new Petri dishes with sterilised distilled water to refresh the growth of the zoosporic fungi. For determination of fungal populations, the fungal species appearing in one water sample was counted as one colony (CFU). These organisms were grown on sterile culture media: GP (10 g glucose, 1 g peptone, 15 g agar and 1000 ml deionised water) with addition of 0.2 g penicillin, 0.1 g streptomycin sulphate and 0.02 g vancomycin after autoclaving). The recovered taxa were purified and preserved by multiple transfers to new substrates due to difficulties in culturing on agar media.

The identification of zoosporic fungal genera and species was performed based on morphological and culture characteristics according to Coker (1923), Johnson (1956, 1971, 1977), Waterhouse (1956, 1968), Sparrow (1960), Scott (1961), Seymour (1970), Karling (1977), Natvig (1987) and Johnson et al. (2002). Some fungal isolates did not form sexual reproductive structures and were therefore identified to the genus level. The fungal cultures were maintained on the previously mentioned media and stored at 8–12 °C and sub-cultured every 2–3 months. The number of isolation cases (NIC) and occurrence remarks (OR) of each recovered zoosporic taxon was calculated from the total number of collected water samples (44).

Canonical correspondence analysis. In order to reveal the correlation of the determined abiotic factors with particular species occurrence, Canonical Correspondence Analysis (Legendre & Legendre 1998) was used. CCA was applied using PAST (Paleontological Statistics) Software version 3 developed at the University of Oslo, Norway.

RESULTS AND DISCUSSION

PHYSICOCHEMICAL CHARACTERISTICS

The results of the physicochemical characteristics of the surface water samples collected from the two experimented water bodies are summarised in Tab. 1. Water temperature, conductivity, organic matter contents and major cations and anions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, PO_4^{3-}, SO_4^{2-} and NO_3^-) noticeably varied depending on water body, sampling site and season.

As shown in Tab. 1, the water temperature varied (from 19.0 °C to 33.1 °C) according to the sampling season, with the highest values during the summer whereas the lowest temperatures were measured in winter and spring. The pH values were slightly to moderately alkaline (fluctuated between 7.30 and 8.99) and did not show any variations according to the sampling season, water site or water body. The other parameters (Tab. 1) mostly had the highest values in water samples collected from either the main source of effluents or from the sites directly exposed to these effluents, regardless of sampling season or water body examined. These water sites were ZN_1 (collection basin of treated sewage water) and ZN_4 (receiving treated sewage water directly) in the case of El-Zinnar canal and IB_3 (receiving effluents of the oils and detergents factory) in the case of El-Ibrahimia canal. It seems that most of these effluents were diluted at the other sites downstream and did not differ much. The highest levels of the above-mentioned parameters at these sites may refer to the insufficient and imperfect processing which may cause adverse effects and pollution of irrigation water systems.

Assress et al. (2019) indicated that the concentrations of some metals were unevenly distributed over the wastewater treatment plants and showed relatively high concentrations of Ca^{2+}, Cu^{2+}, Mn^{2+}, Ni^{2+} and Zn^{2+} in the influent and Ca^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+} and Zn^{2+} in the effluent wastewater samples. Selvarajan el al. (2019) recorded relatively low values of some parameters (conductivity, Ca^{2+}, Mg^{2+}, Na^+, K^+, Si^{4+}, PO_4^{3-}, SO_4^{2-}, NO_3^-) in samples of wastewater collected from five industrial plants, among which a factory for the production of lead-acid automotive batteries. Variable results were obtained by several authors dealing with the same topic (Ferreira et al. 2010, Abd El-Zaher et al. 2017, Niu et al. 2017).

Tab. 1. Lowest values (L), highest values (H) and means (M) of some physicochemical features of water samples collected from six sites in El-Zinnar canal (ZN) and five sites in El-Ibrahimia canal (IB) during four seasons (from winter 2017 to autumn 2018).

Seasons	**Winter**						**Spring**					
Water bodies	**ZN**			**IB**			**ZN**			**IB**		
Parameters	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**
Temperature (°C)	20.0	21.5	21.0	21.0	23.0	22.0	19.0	20.0	19.3	20.0	21.0	20.5
pH	7.7	8.5	8.2	8.7	9.0	8.9	8.1	8.7	8.5	8.4	8.6	8.5
Conductivity (µS/cm)	357.0	1485.0	593.3	338.0	730.0	428.2	24.0	759.0	265.0	181.5	184.8	183.7
Organic matter (mg/l)	9.0	29.4	15.1	6.5	12.4	10.4	2.0	91.2	26.0	6.2	11.3	8.7
Na^+ (mg/l)	38.9	172.0	64.9	39.0	92.0	50.9	43.3	139.0	62.9	34.1	58.7	43.4
K^+ (mg/l)	2.2	30.5	10.3	4.0	4.8	4.4	6.9	27.7	16.1	5.1	218.0	52.7
Ca^{2+} (mg/l)	60.0	116.0	79.3	61.0	98.0	72.6	100.0	180.0	128.0	76.0	134.0	97.2
Mg^{2+} (mg/l)	12.2	97.2	64.0	34.0	60.8	48.1	36.5	79.0	55.3	48.6	69.3	57.6
Cl^- (mg/l)	105.0	227.5	150.2	96.3	168.0	118.7	175.0	371.0	258.0	140.0	248.0	181.0
HCO_3^- (mg/l)	420.9	844.9	502.2	366.0	610.0	466.7	162.7	329.4	206.0	135.5	183.0	160.8
NO_3^- (mg/l)	4.3	16.1	10.6	3.9	17.9	9.7	4.3	50.7	27.0	6.1	69.7	30.3
PO_4^{3-} (mg/l)	0.9	14.8	3.9	0.8	20.1	5.0	1.2	30.4	13.5	1.0	8.0	3.3
SO_4^{2-} (mg/l)	51.5	105.0	68.0	21.7	211.0	76.1	12.0	338.7	91.4	46.7	106.6	65.6

Seasons	**Summer**						**Autumn**					
Water bodies	**ZN**			**IB**			**ZN**			**IB**		
Parameters	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**
Temperature (°C)	33.0	33.1	32.9	32.8	33.1	32.9	31.4	32.5	32.1	31.8	32.8	32.3
pH	7.5	8.0	7.8	8.4	8.5	8.4	7.3	8.1	7.7	7.9	8.5	8.3
Conductivity (µS/cm)	323.0	1401.0	527.7	300.0	315.0	305.4	334.0	1152.0	549.8	327.0	485.0	363.8
Organic matter (mg/l)	3.8	71.0	27.5	15.0	33.0	22.8	7.9	53.2	22.1	2.9	18.7	9.2
Na^+ (mg/l)	36.0	150.0	61.8	36.8	44.0	40.3	29.4	111.0	51.1	25.3	45.4	31.0
K^+ (mg/l)	7.2	34.0	16.6	4.7	31.2	11.6	3.7	17.7	7.4	2.6	3.9	3.4
Ca^{2+} (mg/l)	52.0	114.0	65.3	42.0	62.0	50.4	60.0	126.0	81.2	66.7	112.0	91.8
Mg^{2+} (mg/l)	48.0	64.4	54.6	42.5	60.0	47.6	68.7	90.5	82.4	46.6	74.4	62.7
Cl^- (mg/l)	112.0	203.0	133.4	102.0	128.0	111.8	280.0	385.0	312.7	263.0	315.0	290.5
HCO_3^- (mg/l)	234.0	458.0	281.8	154.0	220.0	172.3	103.7	204.0	142.3	97.6	128.1	116.5
NO_3^- (mg/l)	9.2	67.9	29.3	3.7	9.2	6.4	25.1	37.9	31.2	24.5	38.0	31.1
PO_4^{3-} (mg/l)	0.3	39.9	7.9	0.2	36.0	10.8	13.4	33.4	22.0	18.9	36.7	23.4
SO_4^{2-} (mg/l)	4.5	349.0	73.2	49.7	87.0	71.0	142.3	291.0	184.2	136.9	183.6	153.5

OCCURRENCE OF HETEROTROPHIC STRAMINIPILES AND TRUE ZOOSPORIC FUNGI

General overview

The obtained data (Tab. 2) elucidate the diversity, frequency and seasonal variations in heterotrophic straminipiles and true zoosporic fungi assemblages inhabiting two interesting aquatic habitats. Thirty-four species (28 identified species and six unidentified non-sexual ones) assigned to ten zoosporic genera (nine straminipile genera and only one genus of true zoosporic fungi) were gathered from the two water bodies during four seasons (from winter 2017 to autumn 2018). All the recovered zoosporic taxa recorded in the current investigation had been reported previously with different frequencies from various water areas in Egypt (e.g. El-Hissy and Khallil 1989a, Khallil 1990, Ali 2007) and in different geographical regions (e.g. Sparrow 1960, Karling 1977, Czeczuga & Proba 1987, Marano et al. 2008). Czeczuga et al. (1997) gathered 109 fungal species from 36 lakes and 4 rivers in the western Suwalki Lake District in Poland and correlated them with some abiotic factors. Czeczuga et al. (2007) isolated 88 species [41 true zoosporic fungal species and 47 fungus-like organisms (straminipiles)] on fruit tree petals floating in water. Ali (2007) isolated 34 species and five unidentified ones belonging to ten zoosporic fungal genera from 84 polluted water samples, collected randomly from various polluted water sites on the River Nile (Delta region, Lower Egypt). Nascimento et al. (2011) recovered 32 taxa of zoosporic fungi from 48 water samples collected from various water areas (Brazilian Cerrado). Our findings revealed that most of the monitored parameters exhibited a conspicuous positive or negative impact on occurrence, richness and species composition of straminipiles and true zoosporic fungi particularly at sites which receive the effluents directly.

Tab. 2. Seasonal variations and frequency of occurrence of straminipiles and true zoosporic fungi recovered from six sites in El-Zinnar canal (ZN) and five sites in El-Ibrahimia canal (IB) during four seasons (from winter 2017 to autumn 2018).
The occurrence is given as number of isolation cases (NIC), i.e. number of sampling sites at which the genus or species was recorded. Counts for genera represent numbers of sites with occurrence of the genus (regardless of the number of its species) at particular sites.
OR = Occurrence remarks: H = high occurrence, more than 40% of total number of samples; M = moderate occurrence, 20 to <40% of total number of samples; L = low occurrence, 10 to <20% of total number of samples; R = rare occurrence, less than 10% of total number of samples.

Seasons	**Winter**		**Spring**		**Summer**		**Autumn**		**Total NIC**	**OR**
Water bodies	**ZN**	**IB**	**ZN**	**IB**	**ZN**	**IB**	**ZN**	**IB**		
True zoosporic fungi										
Allomyces	4	0	2	3	3	4	0	1	17	M
A. anomalus Emers.	3	0	1	0	1	4	0	0	9	M
A. javanicus Kniep	0	0	1	2	1	1	0	0	5	L
A. macrogynus Emers. & Wilson	1	0	2	2	1	0	0	1	7	L

Seasons	**Winter**		**Spring**		**Summer**		**Autumn**		**Total NIC**	**OR**
Water bodies	**ZN**	**IB**	**ZN**	**IB**	**ZN**	**IB**	**ZN**	**IB**		
Straminipiles										
Achlya	6	0	4	2	2	1	3	5	23	H
A. americana Humphrey	0	0	0	2	0	0	0	0	2	R
A. dubia Coker	1	0	2	1	0	0	0	0	4	R
A. flagellata Coker	3	0	3	0	0	0	0	0	6	L
A. prolifera Nees	1	0	0	0	0	0	0	0	1	R
A. proliferoides Coker	3	0	1	0	2	1	2	3	12	M
Achlya sp.	3	0	1	0	2	1	3	5	15	M
Aphanomyces	2	0	2	0	4	1	0	1	10	M
A. laevis de Bary	2	0	2	0	2	1	0	1	8	L
Aphanomyces sp.	0	0	1	0	2	1	0	0	4	R
Aqualinderella fermentans Emers. & Weston	0	1	0	2	1	2	1	0	7	L
Brevilegnia sp.	0	0	0	0	0	1	1	0	2	R
Dictyuchus	1	4	3	3	3	1	2	3	20	H
D. carpophorus Zopf	0	0	0	0	0	0	0	1	1	R
D. magnusii Lindst.	0	1	0	0	1	0	0	1	3	R
D. monosporus Leitg.	0	0	1	1	0	0	0	0	2	R
D. sterilis Coker	1	4	3	2	3	1	2	2	18	H
Phytophthora	3	0	3	1	0	0	3	2	12	M
P. cactorum (Lebert & Cohn) Schröt.	0	0	0	0	0	0	1	0	1	R
P. fragariae Hickman	0	0	1	1	0	0	0	1	3	R
P. inflata Caros. & Tucker	2	0	1	0	0	0	1	0	4	R
Phytophthora sp.	1	0	2	0	0	0	1	2	6	L
Pythiopsis cymosa de Bary	0	0	0	0	0	0	0	1	1	R
Pythium	1	4	1	0	1	4	3	2	16	M
P. irregulare Buisman	0	1	1	0	0	2	2	1	7	L
P. rostratum E.J. Butler	0	1	0	0	0	0	1	0	2	R
P. thalassium Atkins	0	3	0	0	0	2	0	1	6	L
P. ultimum Trow	0	0	0	0	1	0	0	0	1	R
P. vexans de Bary	1	0	1	0	0	0	0	0	2	R
Pythium sp.	1	0	0	0	0	0	1	0	2	R
Saprolegnia	5	4	0	0	0	0	0	0	9	M
S. anisospora de Bary	1	0	0	0	0	0	0	0	1	R
S. diclina Humphrey	4	0	0	0	0	0	0	0	4	R
S. ferax (Gruith.) Kutz	4	1	0	0	0	0	0	0	5	L
S. furcata Maurizio	3	0	0	0	0	0	0	0	3	R
S. parasitica Coker	0	4	0	0	0	0	0	0	4	R
Saprolegnia sp.	2	2	0	0	0	0	0	0	4	R

Seasonal fluctuations

The highest biodiversity (24 species, 8 genera) was recorded during winter, followed by autumn (18 species, 9 genera) and spring (18 species, 7 genera), whilst during summer the lowest species diversity (14 species, 7 genera) was recorded. Our results revealed that water temperature was one of the main limiting factors governing the seasonal occurrence of zoosporic fungi. It is concluded that low or moderate temperatures are more favourable for zoosporic fungi.

This is in accordance to the findings by many authors (e.g. Klich & Tiffany 1985, El-Hissy & Khallil 1989a, 1991, Khallil et al. 1993, 1995, Osman 2004, Muhsin 2012), who indicated that temperature plays an important role governing the frequency, diversity and seasonal variations in aquatic fungi. In agreement with our results, Rattan et al. (1980) recorded maximum seasonal fluctuations of saprolegniaceous fungal taxa in winter whilst the minimum was in summer. In consistency with these suggestions, El-Hissy et al. (1982) also reported that the periods richest in zoosporic fungal genera and species were months with low or moderate temperatures while the summer months were the poorest. Within a water temperature range of 15–36 °C, Misra (1982) and Marano et al. (2008) also revealed that the highest frequency of zoosporic fungi was recorded at the lowest temperatures. In agreement with our results, the data by Lartseva (1987) evidence that the maximum diversity of saprolegnial fungi (except for *Achlya* species) was observed in a temperature range of 12.2 to 18.0 °C. Pires-Zottarelli (1990) revealed that the highest occurrence of *Saprolegniaceae* was in the dry season (with the lowest air temperatures). Voronin (2008) reported that temperature is an important factor governing the development and occurrence of zoosporic fungi and strongly influences the concentration of dissolved oxygen in water. With increasing temperature, the amount of dissolved oxygen decreases and consequently the fungal occurrence is impacted negatively. The rarity or disappearance of zoosporic fungi during summer is mainly due to an increase in water temperature and other related hydrological factors (Waterhouse 1942).

In contrast, Srivastava (1967) in India recorded a maximum abundance, distribution and diversity of water moulds during the summer season. Paliwal & Sati (2009) elucidated that the highest number of zoosporic fungal taxa was recorded during spring and rainy season (14.4–16.5 °C), whilst the lowest number of zoosporic taxa was recorded during winter (below 12 °C). However, Sparrow (1968) stated that water temperature seemed to be important for some zoosporic fungal species while the abundance of others appeared to be independent of temperature. Khulbe (1991) elucidated that higher temperatures during summer and low temperatures (below 15 °C) during winter were unfavourable for the majority of aquatic fungi. Our findings however do not entirely agree with the observation by Roberts (1963), who found two periods of water moulds incidence, one in autumn and another in spring. Dick & Newby (1961) found higher species diversity and seasonal occurrence of zoosporic fungi during the spring and autumn seasons. Nair & Bhat (2016) observed that the monsoon season is the best for recovering water moulds followed by the post monsoon and summer. This inconsistency may be ascribed to the difference in temperature of the various geographical regions investigated.

Considering that zoospores are probably involved in different food webs (Gleason et al. 2008), the number of competitors (due to a higher number of consumers such as rotifers, nematodes and protozoa) rise when temperature increases, which may be a possible explanation for the low abundance, species diversity and occurrence of zoosporic fungi recorded under these circumstances. Moreover, several investigations have suggested that the seasonal variations of *Saprolegniaceae* are correlated with temperature (Srivastava 1967, Alabi 1971, Misra 1982 and Nascimento et al. 2011). El-Hissy & Khallil (1989b) indicated that zoosporic fungi tolerate higher salt concentrations at lower temperatures. Some fungi are unable to colonise baits due to interspecific competition or the preferences of some species for substrates other than the baits present in the samples. Also. some fungal taxa are not easily recognizable or have not been characterised well as to bait preferences (Lozupone & Klein 2002).

Some genera (*Achlya*, *Allomyces*, *Aphanomyces*, *Dictyuchus* and *Pythium*) were represented throughout the year but others were highly restricted and appeared in only one season such as *Saprolegnia* (present only in winter) and *Pythiopsis* (present only in autumn). The same pattern was recorded for some other species (Tab. 2). Similarly, many authors suggest that the growth and development of zoosporic fungi depend on the season: some taxa develop mainly and predominate during cold seasons, but others during warm seasons (Sparrow 1968, El-Hissy & Khallil 1989a, 1991, Dasgupta & Rachel 1990). Milovtzova (1935) noted that species of *Saprolegnia* dominate during spring, whereas *Achlya* species predominate in autumn in water bodies situated in the vicinities of Kharkov. Roberts (1963) classified 27 recovered zoosporic taxa into three categories, Winter species (13 taxa), Summer species (6 taxa) and Constant species (8 taxa) which were represented throughout the year. Alabi (1971) indicated that some straminipile species were found in all seasons (e.g. *Achlya debaryana*) whereas others appeared in winter only (e.g. *Achlya orion*). In agreement with our findings concerning the variation in certain zoosporic taxa in dependence of temperature, Manoharachary (1981) classified zoosporic fungi into low-temperature species, moderate-temperature species, constant species and high-temperature species. Furthermore, Gupta and Mehrotra (1989) also divided zoosporic fungi into four groups according to their dependence on temperature: fungi preferring low temperatures of 14.2 to 18.0 °C, low to moderate temperatures of 14.2 to 30.0 °C, moderate to high temperatures of 21.4 to 34.8 °C, and eurythermic species (14.2

to 34.8 °C). According to both studies, most fungal taxa preferred low or moderate temperatures, while others were present throughout the year, and few appeared in summer in which the temperature was relatively high.

Occurrence and diversity of particular genera and species

Achlya (5 identified and 1 unidentified species), *Dictyuchus* (4 species), *Allomyces* (3 species) and *Pythium* (5 identified and 1 unidentified species) were the most prevalent genera (52.27%, 45.45%, 38.64% and 36.36% of total number of samples, respectively), whereas *Brevilegnia* and *Pythiopsis* (one species for each) had the least frequent occurrence (4.55% and 2.27% of total number of samples, respectively). The remaining genera (*Phytophthora*, *Aphanomyces*, *Saprolegnia* and *Aqualinderella*) showed a moderate or low seasonal occurrence (15.91–27.27% of total number of samples). In contrast, El-Hissy et al. (2001) reported that *Saprolegnia* was the most prevalent genus at sites receiving industrial effluents of the Kima fertiliser factory (Aswan, Upper Egypt). Yanna et al. (2002) found *Saprolegnia*, *Dictyuchus*, *Achlya* and *Aphanomyces* to be dominant genera in Hong Kong. Osman (2004), also in contrast to our results, reported that *Pythium* and *Aqualinderella* were the most prevalent genera at sites polluted with sewage. Voronin (2008) recorded that *Achlya*, *Saprolegnia* and *Dictyuchus* had the highest seasonal occurrence. Conversely, several authors who studied the incidence of water moulds (straminipiles and true zoosporic fungi) in freshwater habitats of the River Nile system (El-Hissy et al. 1982), in brackish water habitats of several Egyptian lakes (El-Hissy et al. 2004) and in polluted waters with industrial fertiliser effluents (El-Hissy et al. 2001) revealed that *Saprolegnia* was one of the most prevalent genera. In some lotic aquatic ecosystems (Buenos Aires Province, Argentina), Marano & Steciow (2006) reported that *Achlya*, *Aphanomyces*, *Dictyuchus*, *Olpidiopsis*, *Phytophthora*, *Pythium*, *Rhizophlyctis* and *Saprolegnia* were the most prevalent genera.

Achlya, *Saprolegnia* and *Pythium* exhibited the broadest species spectra (each was represented by five identified species and unidentified isolates) whereas *Aqualinderella*, *Brevilegnia* and *Pythiopsis* had the narrowest species spectra (each was represented by only one species). Similarly, El-Hissy and Khallil (1989a) reported that *Achlya* and *Saprolegnia* frequently had the highest species spectra in various water bodies. In disagreement with our results, Ali (2007) reported that *Achlya* did not have the highest species spectrum and elucidated that *Pythium* (8 species) had the broadest spectrum of species diversity. However, in accordance with our results, he reported that *Saprolegnia* (7 species) was among the genera with the broadest spectrum of species diversity and *Aqualinderella* (only one species, *A. fermentans*) had the narrowest spectrum in polluted water drainages across the Nile Delta region (Lower Egypt).

Regarding particular species, *Dictyuchus sterilis* (40.91% of total number of samples), and *Achlya proliferoides* (27.27% of total number of samples) were the prevalent species, exhibiting the highest frequency of occurrence among the identified species and also emerged from both experimented water bodies irrespective of sampling season. The remaining species recovered (Tab. 2) had moderate, low or rare frequencies (2.27–20.45% of total number of samples). On the contrary, Ali (2007) recorded that *Saprolegnia delica* and *Dictyuchus carpophorus* were the commonest zoosporic fungal taxa particularly in hyper-polluted waters with heavy metals. Czeczuga et al. (2007) reported that *Rhizophydium cornutum*, *R. globosum* (true zoosporic fungi), *Aphanomyces irregularis*, *A. laevis*, *Saprolegnia litoralis*, *Pythium butleri*, *P. inflatum*, *P. tardicrescens* and *P. ultimum* (straminipila) were the commonest species. Moreover, Kiziewicz (2012) recovered 21 species related to 8 genera of zoosporic fungi from river springs (Poland), and indicated that *Achlya apiculata*, *Aphanomyces laevis*, *Catenophlyctis variabilis*, *Dictyuchus monosporus*, *Pythium debaryanum* and *Saprolegnia ferax* were the prevalent taxa.

INFLUENCE OF ENVIRONMENTAL FACTORS

General assessment

The water samples collected from sites ZN_1 and ZN_4 in El-Zinnar canal and IB_3 in El-Ibrahimia canal were the poorest in fungal occurrence, abundance and diversity. The frequency and dominance of zoosporic fungi were conspicuously reduced in these stressful environments as compared with other less polluted sites. The low diversity of zoosporic fungi at these sites may be explained by changes in some ecological factors of these water sites resulting from the increase of water salinity levels and relatively high values of most other abiotic parameters determined (e.g. water conductivity, concentrations of Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, PO_4^{3-}, SO_4^{2-} and NO_3^-). These sites can be regarded as stressful or extreme environments in which the values of one or more abiotic factors are much higher than those considered normal for the growth and survival of zoosporic fungi.

Many authors (e.g. Ali 2007, Godlewska et al. 2009, 2012, Gleason et al. 2010a) have supported this suggestion. These polluted sites were the poorest in zoosporic fungi. Similarly, Godlewska et al. (2009, 2012) and Ali (2007) indicated that less polluted sites seemed to have a higher species diversity than moderately to heavily polluted ones. El-Hissy & Khallil (1989a) and Gleason et al. (2010a) reported that most water moulds are unable to grow and survive in extreme environmental conditions because wall-less zoospores are susceptible to osmotic, mechanical and temperature shocks, and depend on water for dispersal (Gleason et al. 2008). In consistence with our results, Marano et al. (2008) revealed that trends in frequency, abundance and distribution of zoosporic organisms displayed a correlation with temperature, nitrite, nitrate, ammonia, sulphate and phosphorus. Nascimento et al. (2011) recorded that some physicochemical parameters such as temperature, calcium and phosphorus were found to be correlated with distribution, species composition and abundance of zoosporic fungi, and consequently, spatial changes and seasonality of these parameters can also affect community structure (Srivastava 1967, Misra 1982, Czeczuga & Proba 1987). Conversely, several studies have indicated and suggested that some zoosporic fungi are adaptable to stressful and extreme environmental conditions and are able to survive for many years (e.g. Gleason et al. 2012). In this respect, some zoosporic fungi have a stress-tolerant strategy under stressful environmental circumstances and rather than facing extinction, they have the capability to grow slowly and reproduce for at least part of their life history (Gleason et al. 2010a).

Influence of organic matter contents

The organic matter contents of the collected water samples ranged from 2.0 to 91.2 mg/l, with the highest levels frequently at sites which receive effluents directly. These sites were the poorest in zoosporic fungi. Our results are entirely in contrast with the findings by many authors, who reported that water samples rich in organic matter contents were almost the richest in zoosporic fungi (Sparrow 1960, Karling 1977, Misra 1982, El-Hissy & Khallil 1989a, Shearer et al. 2007, Ali 2007, Voronin 2008). This inconsistence may be attributed to interactions with other limiting abiotic factors such as high water temperature, high salinity levels and high concentrations of some cations and anions. In this respect, Kirk et al. (2001; cit. sec. Voronin 2008: 342) stated that levels of dissolved organic matter represent an important factor influencing the abundance and occurrence of zoosporic fungi, and revealed that with the increase of organic matter contents, the number of fungal taxa also increases but only if salinity and temperature are relatively low. The high levels of organic matter which accompany pollutions reduce the abundance and diversity of water moulds even to full extinction (Harvey 1952, Tan & Lim 1984). However, Kiziewicz & Kurzątkowska (2004) stated that when the content of pollutants exceeds the range of tolerance for the respective taxa of zoosporic fungi, it delimits their occurrence. This is probably the reason why the lowest number of zoosporic fungi was found to grow in eutrophic water.

Influence of pH

The pH values of the water samples did not exhibit any regular pattern according to seasons or locality and were generally slightly to moderately alkaline, exhibiting a relatively narrow range (between 7.30 and 8.99). So, pH did not exhibit any considerable influence on seasonality and biodiversity of straminipiles and true zoosporic fungi, at least in the present study. This is in accordance with results recorded in various water bodies by El-Hissy et al. (1982) and El-Hissy & Khallil (1989a). Similarly, Gupta & Mehrotra (1989) observed that pH was an insignificant factor concerning the abundance and occurrence of water moulds. Ali (2007) stated that the pH values of polluted water (8.36–11.15**)** had no influence on the species composition and occurrence of water moulds. Zoosporic fungi have been recovered frequently growing on different substrates in water habitats of extremely low pH but never in habitats of extremely high pH values (Sparrow 1960, Gleason et al. 2010b). Conversely, Khulbe (1980) concluded that the incidence of water moulds was related to pH values and recorded a rich fungal population in some lakes of the Nainital region (India) with a pH of 7.3 to 8.8. Several water moulds can tolerate an increase or decrease in pH by forming dormant structures (Sparrow 1968, Gleason et al. 2010b, 2017b). Consistently, Voronin (2008) revealed that zoosporic fungi may be recovered from water bodies with variable pH values. In contrast to our finding, Lund (1934) distinguished water moulds inhabiting water environments into five groups, from highly acid to constantly alkaline with a wide pH range (from 3.5 to 8.4). Suzuki (1960) concluded that acidic waters contain fewer zoosporic fungal taxa. DiLeo et al. (2010) stated that pH seemed to be the primary driver of water mould abundance in the field, and the abundance of zoosporic fungi was significantly reduced with increasing pH of the naturally acid water of the pine barrens and a reduction in the pH of the impacted water improved the conditions, consequently raising fungal abundance. It has been reported that pH has a complex impact not only on mycelial growth, reproduction, enzyme activity and zoospore activity, but also affects the availability of calcium, potassium, phosphorus, iron, copper and zinc salts (such as copper sulphate and zinc sulphate) and the form in which nitrogen is present (Smith et al. 1984). Furthermore, the pH values of the River Teign upstream (pH 5.4–6.0) exhibited an impoverished mycobiota compared to the less acidic (pH 7.0–7.2) downstream section (Shearer & Webster 1985). However, in Turkey, Dubey (1990) found that alkaline waters are favourable for more genera and species of zoosporic fungi. Moreover, Dubey et al. (1994) isolated more taxa of zoosporic fungi from six streams with a high pH than from those with a low pH.

Influence of water conductivity and contents of some cations and anions

Water conductivity, which is directly related to the concentration of ionic solutes, exhibited great variations and fluctuated between 24 and 1485 µS/cm depending on water body, sampling site and season (Tab. 1). The highest values of water conductivity were recorded at sites ZN_1 and ZN_4 in El-Zinnar canal and IB_3 in El-Ibrahimia canal (which receive wastes and industrial effluents directly). Similarly, slightly lower or higher conductivity values were recorded in effluent wastewater samples in Turkey (Tanyol & Demir 2016), in South Africa (Assress et al. 2019), and in China (Wang et al. 2012).

The poorest samples of zoosporic fungi collected from aquatic sites were found to have higher values of either conductivity or the cations and anions measured. Our results indicate an adverse impact of high salinity levels on diversity, abundance and seasonal occurrence of zoosporic fungi. This is in agreement with findings by several other authors (El-Hissy & Khallil 1989a, Ali 2007). In this respect, El-Hissy & Khallil (1989b) and other physiological studies revealed that high salinity levels progressively reduced mycelial growth rate, zoospore germination, sexual reproduction and respiration rate of water moulds. However, Gleason et al. (2006) reported that several species of true zoosporic fungi (Chytridiomycota) could survive various salt contents. Voronin (2008) stated that fungi tolerate higher salt concentrations at lower temperatures. Some investigations revealed that the number of zoosporic fungi could be influenced by sulphate concentration (Czeczuga & Muszyńska 2004). Czeczuga et al. (2002) revealed that the species diversity of zoosporic and Ingoldian fungi depends on sulphates, calcium and to a lesser degree on the concentration of chlorides, and reported that both sulphates and chlorides occur in large amounts in polluted and polytrophic waters. Similarly, Czeczuga et al. (2007) stated that the concentration of sulphates represents a major environmental factor influencing the abundance and occurrence of zoosporic fungi in freshwater habitats (negative relation irrespective of water habitats studied). Of straminipilous organisms, only 12 species of *Saprolegniales* were recovered from surface waters with sulphate values ranging from 20.98 to 46.89 $mg.l^{-1}$, whereas a relatively large group of representatives of *Pythiales* (32 *Pythium* spp. and 1 *Phytophthora* sp.) were recorded (Czeczuga et al. 2007). Similarly, El-Hissy & Khallil (1989a) reported that saprolegniaceous fungi are more sensitive to water salt levels in comparison with pythiaceous fungi. Many authors described that pH, salinity, temperature, dissolved organic matter, total nitrogen, electrical conductivity, NO_3^- and total phosphorus are factors driving the structure of microbial communities in different habitats (Wang et al. 2012, Chan et al. 2017, Khomich et al. 2017, Li & Wu 2018). High values of some pollutants have the potential to exert selective adverse impact on fungal diversity and abundance. Some studies suggest similar conclusions

(Somboonna el al. 2012, Lee et al. 2017). Czeczuga & Proba (1987) recorded a positive correlation between the abundance and species diversity of water moulds and Mg, but other investigations did not support such a relationship (Misra 1982, Czeczuga et al. 1990). Nascimento et al. (2011) revealed that values of total fungal abundance varied depending on season, recording the highest occurrences during the dry season; this is in accordance with other studies from tropical regions (Alabi 1971, Pires-Zottarelli 1990). This is probably due to remarkably the lowest values of temperature, chloride content and conductivity, and high values of dissolved oxygen. Chróst & Siuda (2006) and Godlewska et al. (2009) reported that water samples with low levels of ammonium, organic nitrogen, phosphates, chlorides and sulphates were the richest in zoosporic fungi. Muszyńska et al. (2014) found that the species diversity of zoosporic fungi depended largely on such hydrochemical parameters as CO_2, nitrites, nitrates, ammonium nitrogen and phosphates, showing a negative correlation, whereas pH and O_2 correlated positively with the diversity of the studied microorganisms.

Correlation between abiotic factors of stressed sites and species occurrence

The physicochemical parameters of water samples varied depending on water body, sampling site and season. Most of the abiotic parameters (Tab. 1) had the highest values at sites which receive effluents directly, regardless of sampling season or the water body examined and these sites were consequently almost the poorest in zoosporic fungi. From this it follows that the richness and species composition of zoosporic fungi were negatively influenced by most of these parameters. It is interesting to note that we isolated some zoosporic species from stressful sites receiving effluents, therewith having the highest recorded values of conductivity as well as cations and anions. In this respect, *Pythium vexans* and *Pythium* sp. were isolated from site ZN_1 (collection basin of treated sewage) in El-Zinnar canal, whereas *Dictyuchus monosporus* and *Pythiopsis cymosa* were isolated from site IB_3 in El-Ibrahimia canal (receiving effluents of the oils and detergents factory). The occurrence of these fungal species at polluted sites provides valuable insights regarding their adaptation and their potential in bioremediation processes. These species could have a predictive role as bioindicators of aquatic ecosystem pollution and might play important roles in pollutant degradation, organic decomposition, and transformation of xenobiotic compounds.

Some studies have correlated the distribution and occurrence of zoosporic fungi and other water-inhabiting fungi with the characteristics of some water bodies exposed to either wastewater or various industrial effluents and provided nearly similar results. In this respect, Khallil & Abdel-Sater (1992) recorded the highest values of conductivity, total soluble salts, phosphate, sulphate, chloride, calcium and magnesium at sites which are directly exposed to industrial effluents of the Manquabad Superphosphate Factory (Assiut, Egypt). Nasser et al. (2002) recorded similar findings in water samples collected from sites exposed to effluents of the Kima fertiliser factory (Aswan, Upper Egypt). Similarly, the data assembled by Kirgizbaeva (1976) showed that some zoosporic fungi were very poorly represented in polluted water areas. Stjerma-Pooth (1957) recorded that *Achlya prolifera* was the dominant in wastewater from a manufactory of wood fibre wallboard. Harvey (1952) recorded some representatives of *Aphanomyces* in heavily fouled Ohio streams and *Brevilegnia diclina* was collected from the same watercourse following dilution by rains. Johnson et al. (2002) stated that some members of straminipiles can tolerate such unfavourable habitats. Wurtz (1956) stated that members of *Saprolegnia* (unidentified *Saprolegnia* species) were abundant in sewage water courses polluted by wastes from sugar and food processing plants. Furthermore, Suzuki (1960) revealed that water bodies polluted by municipal wastes harboured several zoosporic fungi and reported that an unidentified *Saprolegnia* sp. was abundant along 350 metres of a river receiving sugar refinery wastes. Cooke & Bartsch (1959) isolated 15 species related to *Achlya*, *Dictyuchus* and *Saprolegnia* in waters containing high levels of domestic and industrial wastes. Cooke & Matsuura (1969) isolated some unidentified zoosporic fungal species from several locations at a waste stabilisation pond and adjacent areas: raw sewage, sludge and pond water receiving sewage. Logvinenko (1970) recorded some representatives of zoosporic fungi in five processing stages of a waste treatment plant but *Achlya* species were completely missing in the wastewater.

Relationship of abiotic factors with particular species occurrence

It is worth mentioning that the recovered straminipiles and true zoosporic fungal species showed different responses to some physicochemical characteristics of water (Figs. 2, 3).

The physicochemical parameters of surface water samples collected from El-Zinnar irrigation canal (Fig. 2) revealed that Na^+ and NO_3^- had influence on the occurrence of *Allomyces macrogynus*, *Phytophthora cactorum*, *Phytophthora inflata*, *Phytophthora* sp., *Pythium irregulare*, *Pythium rostratum*, *Pythium vexans* and *Pythium* sp., whereas *Allomyces anomalus*, *Brevilegnia* sp., *Dictyuchus magnusii*, *Saprolegnia anisospora*, *Saprolegnia diclina*, *Saprolegnia ferax*, *Saprolegnia furcata* and *Saprolegnia* sp. correlated with Ca^{2+}, HCO_3^- and pH. Temperature and pH exhibited a clear relationship with the occurrence of *Achlya dubia*, *Achlya prolifera*, *Achlya flagellata*, *Achlya proliferoides*, *Achlya* sp., *Aphanomyces laevis*, *Aphanomyces* sp., *Allomyces javanicus*, *Dictyuchus monosporus*, *Dictyuchus sterilis* and *Phytophthora fragariae*.

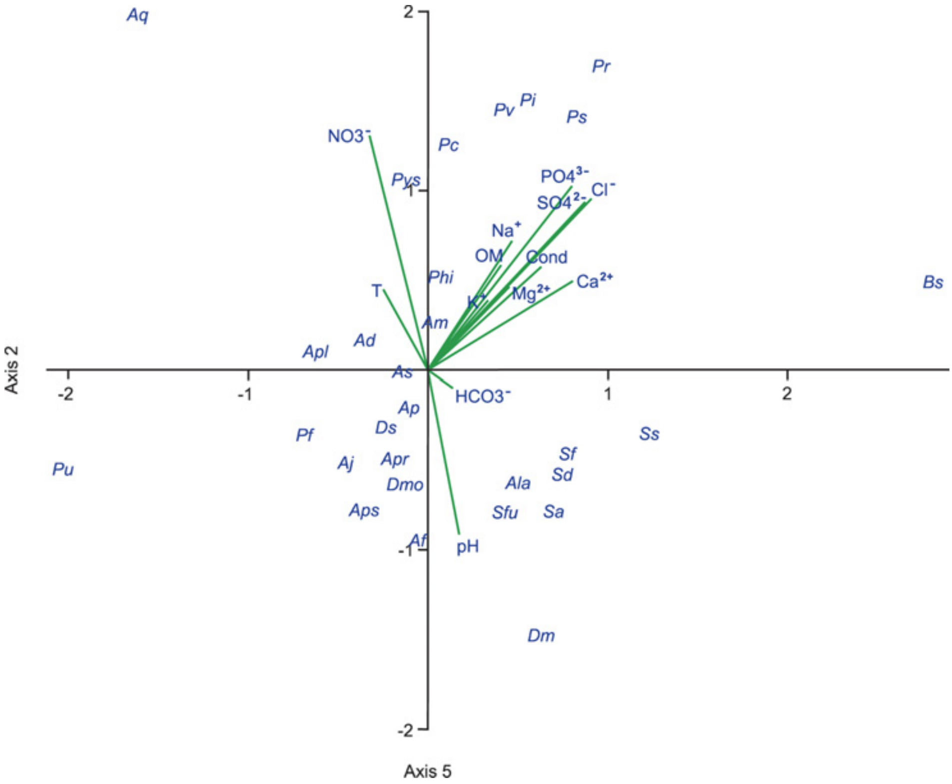

Fig. 2. Interaction of physicochemical parameters and zoosporic fungal composition (CCA) in El-Zinnar canal (near the village of Arab El-Madabegh).
Parameter abbreviations: Cond = conductivity, OM = organic matter content, T = temperature.
Species abbreviations: *Ad* = *Achlya dubia*, *Af* = *A. flagellata*, *Ap* = *A. prolifera*, *Apr* = *A. proliferoides*, *As* = *Achlya* sp., *Ala* = *Allomyces anomalus*, *Aj* = *A. javanicus*, *Am* = *A. macrogynus*, *Apl* = *Aphanomyces laevis*, *Aps* = *Aphanomyces* sp., *Aq* = *Aqualinderella fermentans*, *Bs* = *Brevilegnia* sp., *Dm* = *Dictyuchus magnusii*, *Dmo* = *D. monosporus*, *Ds* = *D. sterilis*, *Pc* = *Phytophthora cactorum*, *Pf* = *P. fragariae*, *Phi* = *P. inflata*, *Ps* = *Phytophthora* sp., *Pi* = *Pythium irregulare*, *Pr* = *P. rostratum*, *Pys* = *Pythium* sp., *Pv* = *P. vexans*, *Pu* = *P. ultimum*, *Sa* = *Saprolegnia anisospora*, *Sd* = *S. diclina*, *Sf* = *S. ferax*, *Sfu* = *S. furcata*, *Ss* = *Saprolegnia* sp.

Fig. 3 indicates the relationship between physicochemical parameters of surface water samples collected from El-Ibrahimia canal and occurrence of zoosporic fungal species recovered. HCO_3^- and K^+ correlated directly with dominance of *Aqualinderella fermentans*, *Brevilegnia* sp., *Dictyuchus monosporus*, *Pythium rostratum*, *Pythium thalassium*, *Saprolegnia ferax*, *Saprolegnia parasitica* and *Saprolegnia* sp. On the other hand, the temperature, dissolved organic matter, Cl^- and PO_4^{3-} exhibited a relationship with the occurrence of *Achlya proli-*

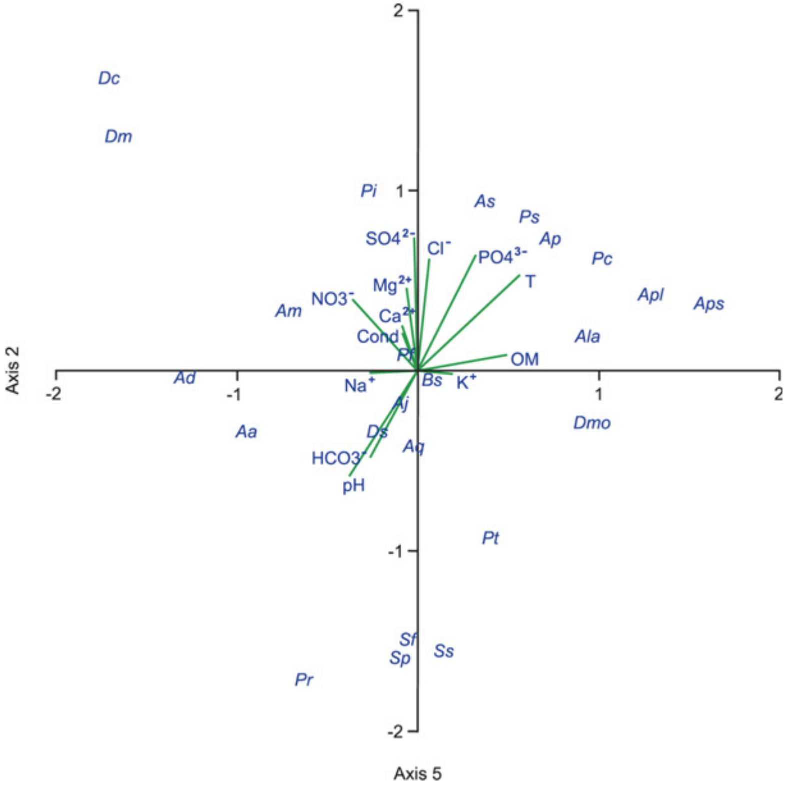

Fig. 3. Interaction of physicochemical parameters and zoosporic fungal composition (CCA) in El-Ibrahimia canal as affected by industrial effluents of the oils and detergents factory (Nile Company, Bani-Qurra).

Parameter abbreviations: Cond = conductivity, OM = organic matter content, T = temperature.

Species abbreviations: *Aa* = *Achlya americana*, *Ad* = *A. dubia*, *Ap* = *A. proliferoides*, *As* = *Achlya* sp., *Ala* = *Allomyces anomalus*, *Aj* = *A. javanicus*, *Am* = *A. macrogynus*, *Apl* = *Aphanomyces laevis*, *Aps* = *Aphanomyces* sp., *Aq* = *Aqualinderella fermentans*, *Bs* = *Brevilegnia* sp., *Dc* = *Dictyuchus carpophorus*, *Dm* = *D. magnusii*, *Dmo* = *D. monosporus*, *Ds* = *D. sterilis*, *Pf* = *Phytophthora fragariae*, *Ps* = *Phytophthora* sp., *Pc* = *Pythiopsis cymosa*, *Pi* = *Pythium irregulare*, *Pr* = *Pythium rostratum*, *Ps* = *Pythium* sp., *Pt* = *P. thalassium*, *Sf* = *Saprolegnia ferax*, *Sp* = *S. parasitica*, *Ss* = *Saprolegnia* sp.

feroides, *Achlya* sp., *Allomyces anomalus*, *Aphanomyces laevis*, *Aphanomyces* sp., *Phytophthora fragariae*, *Phytophthora* sp. and *Pythiopsis cymosa*. Moreover, the occurrence of *Achlya americana*, *Achlya dubia*, *Allomyces javanicus* and *Dictyuchus sterilis* was affected by pH and Na$^+$, while conductivity and some water-soluble ions (Na$^+$, Ca^{2+}, Mg^{2+} and NO$_3^-$) showed a correlation with the frequency of *Allomyces macrogynus*, *Dictyuchus carpophorus*, *Dictyuchus magnusii* and *Pythium irregulare*.

Zoosporic taxa variations in both water areas examined

Fungal diversity and occurrence differed between the water bodies examined. In this respect, *Achlya* (62.5% of total number of samples, 4 species and one unidentified taxon) and *Allomyces* (37.5% of total number of samples, 3 species) exhibited the highest occurrence in water samples collected from El-Zinnar canal, whereas *Dictyuchus* (55% of total number of samples, 4 species) and *Pythium* (50% of total number of samples, 3 species) had the highest occurrence in El-Ibrahimia canal. *Achlya proliferoides* (33.33% of total number of samples) had the highest seasonal occurrence in El-Zinnar canal, whereas *Dictyuchus sterilis* (45% of total number of samples) had the highest frequency of occurrence in El-Ibrahimia canal. Ten fungal species (*Achlya flagellata*, *A. prolifera*, *Phytophthora cactorum*, *P. inflata*, *Pythium ultimum*, *P. vexans*, *Saprolegnia anisospora*, *S. diclina*, *S. ferax* and *S. furcata*) were only recovered from El-Zinnar canal, but were completely missing in El-Ibrahimia canal. Conversely, five species of zoosporic fungi (*Achlya americana*, *Dictyuchus carpophorus*, *Pythiopsis cymosa*, *Pythium thalassium* and *Saprolegnia parasitica*) appeared exclusively in El-Ibrahimia canal water samples. Some genera and species showed a variable seasonal occurrence (Tab. 2) in both water bodies. These variations may be ascribed to the difference in the nature of the effluents and in fungal adaptability.

CONCLUSIONS

The response of the fungal community structure and activity could have a predictive role in bioindication of aquatic ecosystem pollution. It is concluded that the presence of some zoosporic taxa or related microbial taxa in some polluted waters provides valuable insights regarding their adaptation and their potential in bioremediation processes. These zoosporic species could be applied in pollutant degradation, organic decomposition, and transformation of xenobiotic compounds. Continued research on heterotrophic straminipiles (fungus-like organisms) and true zoosporic fungi is important for increased awareness, understanding and unveiling of their function and ecosystem stability, particularly in this period of rapid climate change and of aquatic system pollution that may result from industrial production and other human activities. Further investigations in this field should be encouraged and interest in this topic stimulated.

REFERENCES

ABD EL-ZAHER E.H.F., ABOU-ZEID A.M., MOSTAFA A.A., ARIF D.M. (2017): Industrial oil wastewater treatment by free and immobilized *Aspergillus niger* KX759617 and the possibility of using it in crop irrigation. – Rendiconti Lincei 28(1), 93–103. DOI: https://doi.org/10.1007/s12210-016-0578-7

ALABI R.O. (1971): Seasonal periodicity of *Saprolegniaceae* at Ibadan, Nigeria. – Transactions of the British Mycological Society 56: 337–341. DOI: https://doi.org/10.1016/S0007-1536(71)80127-4

ALEXOPOULOS C.J., MIMS C.W., BLACKWELL M. (1996): Introductory mycology, 4th ed. – 869 pp., J. Wiley & Sons, New York.

ALI E.H. (2007): Biodiversity of zoosporic fungi in polluted water drainages across Niles' Delta region, Lower Egypt. – Acta Mycologica 42(1): 99–111. DOI: https://doi.org/10.5586/am.2007.010

AMERICAN PUBLIC HEALTH ASSOCIATION (APHA) (1998): Standard methods for the examination of water and wastewater, 20th ed. – Washington.

ASSRESS H.A., SELVARAJAN R., NYONI H., NTUSHELO K., MAMBA B.B., MSAGATI T.A.M. (2019): Diversity, co-occurrence and implications of fungal communities in wastewater treatment plants. – Scientific Reports 9: 14056. DOI: https://doi.org/10.1038/s41598-019-50624-z

BALDAUF S.L. (2008): An overview of the phylogeny and diversity of eukaryotes. – Journal of Systematics and Evolution 46: 263–273.

BEAKES G.W., HONDA D., THINES M. (2014): Systematics of the Straminipila: Labyrinthulomycota, Hyphochytriomycota, and Oomycota. Systematics and Evolution. – In: McLaughlin D.J., Spatafora J.S., eds., The Mycota, Vol. 7^{a}, pp. 39–97. Springer Verlag, Berlin/Heidelberg.

CHAN C.S., CHAN K., EE R., HONG K., URBIETA M.S., DONATI E.R., SHAMSIR M.S., GOH K.M. (2017): Effects of physiochemical factors on prokaryotic biodiversity in Malaysian circumneutral hot springs. – Frontiers in Microbiology 8: 1252. DOI: https://doi.org/10.3389/fmicb.2017.01252

CHRÓST R.J., SIUDA W. (2006): Microbial production, utilization, and enzymatic degradation of organic matter in the upper trophogenic water layer in the pelagial zone of lakes along a eutrophication gradient. – Limnology and Oceanography 51: 749–762. DOI: https://doi.org/10.4319/lo.2006.51.1_part_2.0749

COKER W.C. (1923): The *Saprolegniaceae* with notes on other water molds. – 201 pp., University of North Carolina Press, Chapel Hill. DOI: https://doi.org/10.5962/bhl.title.6494

COOKE W.B., BARTSCH A.F. (1959): Aquatic fungi in water with high waste loads. – Sewage and Industrial Wastes 31: 1316–1322.

COOKE W.B., MATSUURA G.S. (1969): Distribution of fungi in a waste-stabilization pond system. – Ecology 50: 689–694. DOI: https://doi.org/10.2307/1936261

CZECZUGA B., PROBA D. (1987): Studies of aquatic fungi VII. Upper part of the River Narew and its tributaries in a differentiated environment. – Nova Hedwigia 44: 151–161.

CZECZUGA B., MUSZYŃSKA E. (2004): Aquatic zoosporic fungi from baited spores of cryptogams. – Fungal Diversity 16: 11–22.

CZECZUGA B., BRZOZOWSKA K., WORONOWICZ L. (1990): Studies of aquatic fungi. XIII. Mycoflora of the river Czarna Hancza and its tributary, the river Marycha. – Internationale Revue der Gesamten Hydrobiologie und Hydrographie 75: 245–255. DOI: https://doi.org/10.1002/iroh.19900750210

CZECZUGA B., ORLOWSKA M., WORONOWICZ I. (1997): Fungi in water reservoirs of the Western Suwalki Lake district and in some adjacent basins. – Roczniki Akademii Medycznej w Białymstoku 42(1): 41–61.

CZECZUGA B., KIZIEWICZ B., ORŁOWSKA M. (2002): Zoosporic and conidial fungi within the Podlasie stretch of the river Bug. – Annales Academiae Medicae Bialostocensis 47: 40–57.

CZECZUGA B., MAZALSKA B., GODLEWSKA A., MUSZYŃSKA E., KUC K. (2007): Fungi and fungus-like organisms (Straminipila) on fruit tree petals floating in water. – Biological Letters 44(1): 41–50.

DASGUPTA S.N., RACHEL J. (1990): Additions to our knowledge of the zoosporic fungi. – Indian Phytopathology 43(4): 564–567.

DICK M.W., NEWBY H.V. (1961): The occurrence and distribution of *Saprolegniaceae* in certain soils of south-east England. I. Occurrence. – Journal of Ecology 49: 403–419. DOI: https://doi.org/10.2307/2257273

DILEO K., KIMBERLY D., MIN-VENDITTI A., DIGHTON J. (2010): A correlation between chytrid abundance and ecological integrity in New Jersey pine barrens waters. – Fungal Ecology 3: 295–301. DOI: https://doi.org/10.1016/j.funeco.2009.11.004

DUBEY T. (1990): Studies on seasonal occurrence of aquatic fungi of Hanumantal Pond, Jabalpur (India). – Proceedings of the West Virginia Academy of Science 62: 17.

DUBEY T., STEPHENSON S.L., EDWARDS P.J. (1994): Effect of pH on the distribution and occurrence of aquatic fungi in six West Virginia mountain streams. – Journal of Environmental Quality 23: 1271–1279. DOI: https://doi.org/10.2134/jeq1994.00472425002300060021x

EL-HISSY F.T., KHALLIL A.M. (1989a): Studies on aquatic fungi in Delta region (Egypt). – Zentralblatt für Mikrobiologie 144: 421–432. DOI: https://doi.org/10.1016/S0232-4393(89)80059-9

EL-HISSY F.T., KHALLIL A.M. (1989b): Combined effects of salinity and temperature on some morphological aspects of four zoosporic fungi. – Journal of Basic Microbiology 29(5): 281–289. DOI: https://doi.org/10.1002/jobm.3620290511

EL-HISSY F.T., KHALLIL A.M. (1991): Distribution and seasonal occurrence of aquatic phycomycetes in water and submerged mud in El-Ibrahimia canal (Upper Egypt). – Journal of lslamic Academy of Sciences 4: 311–316.

EL-HISSY F.T., MOUBASHER A.H., EL-NAGDY M.A. (1982): Seasonal fluctuations of freshwater fungi in River Nile (Egypt). – Zeitschrift für Allgemeine Mikrobiologie 22: 521–527. DOI: https://doi.org/10.1002/jobm.19820220803

EL-HISSY F.T., NASSER M.S.M., KHALLIL A.M., ABDEL-MOTAAL F.F. (2001): Aquatic fungi recovered from water and submerged mud polluted with industrial effluents. – Journal of Biological Sciences 1: 854–858. DOI: https://doi.org/10.3923/jbs.2001.854.858

EL-HISSY F.T., ALI E.H., ABDEL-RAHEEM A. (2004): Diversity of zoosporic fungi recovered from the surface water of four Egyptian lakes. – Ecohydrology & Hydrobiology 4: 77–84.

FERREIRA V., GONÇALVES A.L., PRATAS J., CANHOTO C. (2010): Contamination by uranium mine drainages affects fungal growth and interactions between fungal species and strains. – Mycologia 102(5): 1004–1011. DOI: https://doi.org/10.3852/09-248

GLEASON F.H., MIDGLEY D.J., LETCHER P.M., MCGEE P.A. (2006): Can soil Chytridiomycota survive and grow in different osmotic potentials? – Mycological Research 110: 869–875. DOI: https://doi.org/10.1016/j.mycres.2006.04.002

GLEASON F.H., KAGAMI M., LEFEVRE E., SIME-NGANDO T. (2008): The ecology of chytrids in aquatic ecosystems: roles in food web dynamics. – Fungal Biology Reviews 22: 17–25. DOI: https://doi.org/10.1016/j.fbr.2008.02.001

GLEASON F.H., SCHMIDT S.K., MARANO A.V. (2010a): Can zoosporic true fungi grow or survive in extreme or stressful environments? – Extremophiles 14: 417–425. DOI: https://doi.org/10.1007/s00792-010-0323-6

GLEASON F.H., DAYNES C.N., MCGEE P.A. (2010b): Some zoosporic fungi can grow and survive within a wide pH range. – Fungal Ecology 3: 31–37. DOI: https://doi.org/10.1016/j.funeco.2009.05.004

GLEASON F.H., CRAWFORD J.W., NEUHAUSER S., HENDERSON L.E., LILJE O. (2012): Resource seeking strategies of zoosporic true fungi in heterogeneous soil habitats at the microscale level. – Soil Biology and Biochemistry 45: 79–88. DOI: https://doi.org/10.1016/j.soilbio.2011.10.011

GLEASON F.H., SCHOLZ B., JEPHCOTT T.G., VAN OGTROP F.F., HENDERSON L., LILJE O., KITTELMANN S., MACARTHUR D.J. (2017a): Key ecological roles for zoosporic true fungi in aquatic habitats. – Microbiology Spectrum 5(2): FUNK-0038-2016. DOI: https://doi.org/10.1128/microbiolspec.FUNK-0038-2016

GLEASON F.H., MARANO A.V., LILJE O., LANGE L. (2017b): What has happened to the "aquatic phycomycetes" (sensu Sparrow)? Part I: A brief historical perspective. – Fungal Biology Reviews 32(1): 26–33. DOI: https://doi.org/10.1016/j.fbr.2017.09.001

Godlewska A., Kiziewicz B., Muszyńska E., Mazalska B. (2009): Fungi and straminipilous organisms found in ponds in Białystok. – Polish Journal of Environmental Studies 18(3): 369–376.

Godlewska A., Kiziewicz B., Muszyńska E., Mazalska B. (2012): Aquatic fungi and hetertrophic straminipiles from fish ponds. – Polish Journal of Environmental Studies 21(3): 615–625.

Gupta A.K., Mehrotra R.S. (1989): Seasonal periodicity of aquatic fungi in tanks at Kurukshetra, India. – Hydrobiologia 173(3): 219–229. DOI: https://doi.org/10.1007/BF00008969

Harvey J.V. (1952): Relationship of aquatic fungi to water pollution. – Sewage and Industrial Wastes 24: 1159–1164.

Henderson L., Marano A.V., Truszewski E., Gleason F.H., Lilje O. (2019): Copper (II), lead (ll) and zinc (ll) reduce the rate of attachment in three zoosporic true fungi from soils of NSW, Australia. – Nova Hedwigia 108(3–4): 435–447. DOI: https://doi.org/10.1127/nova_hedwigia/2018/0512

Jackson M.L. (1958): Soil chemical analysis. – 498 pp., Prentice-Hall, Englewood Cliffs.

Johnson T.W. Jr. (1956): The genus *Achlya*: morphology and taxonomy. – 180 pp., University of Michigan, Ann Arbor.

Johnson T.W. Jr. (1971): Aquatic fungi of Iceland: *Pythium*. – Mycologia 63: 517–536. DOI: https://doi.org/10.1080/00275514.1971.12019132

Johnson T.W. Jr. (1977): Aquatic fungi of Scandinavia: Species of *Brevilegnia*. – Mycologia 69: 287–298. DOI: https://doi.org/10.1080/00275514.1977.12020060

Johnson T.W. Jr., Seymour R.L., Padgett D.E. (2002): Biology and systematics of *Saprolegniaceae*. – University of North Carolina, Wilmington.

Karling J.S. (1977): Chytridiomycetarum Iconographia. – 414 pp., J. Cramer, Vaduz.

Karpov S.A., Mamkaeva M.A., Aleoshin V.V., Nassonova E., Lilje O., Gleason F.H. (2014): Morphology, phylogeny, and ecology of the aphelids (Aphelidea, Opisthokonta) and proposal for the new superphylum Opisthosporidia. – Frontiers in Microbiology 5: 112. DOI: https://doi.org/10.3389/fmicb.2014.00112

Khallil A.M. (1990): Mycoflora associated with some freshwater plants collected from Delta region (Egypt). – Journal of Basic Microbiology 30(9): 663–674. DOI: https://doi.org/10.1002/jobm.3620300909

Khallil A.M., Abdel-Sater M.A. (1992): Fungi from water, soil and air polluted by the industrial effluents of Manquabad superphosphate factory (Assiut, Egypt). – International Biodeterioration and Biodegradation 30: 363–386. DOI: https://doi.org/10.1016/0964-8305(92)90040-U

Khallil A.M., El-Hissy F.T., Abdel-Raheem A. (1993): Monthly variations of Oomycetes (zoosporic fungi) and aquatic Hyphomycetes at Sohag (Upper Egypt). – Acta Societatis Botanicorum Poloniae 62: 67–73. DOI: https://doi.org/10.5586/asbp.1993.012

Khallil A.M., El-Hissy F.T., Ali E.H. (1995): Seasonal fluctuations of aquatic fungi recovered from Egyptian soil (Delta Region). – Journal of Basic Microbiology 35: 93–102. DOI: https://doi.org/10.1002/jobm.3620350206

Khallil A.M., Nassar M.S., El-Hissy F.T., Abdel-Motaal F.F. (2002): Zoosporic fungi recovered from water and submerged mud polluted with industrial effluents of Kom Ombo sugar cane factory (Upper Egypt). – In: Proc. 2nd International Conference on Biological Sciences, Fac. Sci., Tanta Univ., Egypt, 27–28 April 2002, Vol. 2, pp. 341–355.

Khomich M., Davey M.L., Kauserud H., Rasconi S., Andersen T. (2017): Fungal communities in Scandinavian lakes along a longitudinal gradient. – Fungal Ecology 27: 36–46. DOI: https://doi.org/10.1016/j.funeco.2017.01.008

Khulbe R.D. (1980): Occurrence of water moulds in relation to hydrogen ion concentration in some lakes of Nainital, India. – Hydrobiologia 69: 3–5.

Khulbe R.D. (1991): An ecological study of water molds of forest soils of Kumaun Himalaya, India. – Tropical Ecology 32: 127–135.

Kirk P.M., Cannon P.F., David J.S., Stalpers J.A. (2001): Ainsworth et Bisby's Dictionary of the Fungi, 9th ed. – CABI Bioscience, Wallingford.

KIRGIZBAEVA K.M. (1976): Vodnye griby v zagryaznennykh vodoemakh tashkentskoi oblasti. Alʹgoflora i mikoflora Srednei Azii [Aquatic mushrooms in the polluted reservoirs of the Tashkent region. Algoflora and Mycoflora of Central Asia]. – 305 pp., Fan, Tashkent.

KIZIEWICZ B. (2012): Frequency and distribution of zoosporic true fungi and heterotrophic straminipiles from river springs. – Polish Journal of Environmental Studies 21(4): 923–927.

KIZIEWICZ B., KURZĄTKOWSKA A. (2004): Aquatic fungi and fungus-like organisms isolated from surface waters situated near Białystok in Podlasie Province of Poland using the insect *Notonecta glauca* as bait. – Mycologia Balcanica 1: 117–123.

KLICH M.A., TIFFANY L.H. (1985): Distribution and seasonal occurrence of aquatic *Saprolegniaceae* in northwest Iowa. – Mycologia 77: 373–380. DOI: https://doi.org/10.1080/00275514.1985.12025114

LARTSEVA L.V. (1987): Profilaktika i terapiya saprolegnioza ikry osetrovykh i belorybitsy pri iskusstvennom ikh razvedenii [Prophilaxis and therapy of saprolegnioses of sturgeon and conny eggs at their artificial propagation]. – Extended Abstract of Cand. Science (Biology) Dissertation, Moscow.

LEE Z.M.P., PORET-PETERSON A.T., SIEFERT J.L., KAUL D., MOUSTAFA A., ALLEN A.E., ELSER J.J. (2017): Nutrient stoichiometry shapes microbial community structure in an evaporitic shallow pond. – Frontiers in Microbiology 8: 949. DOI: https://doi.org/10.3389/fmicb.2017.00949

LEGENDRE P., LEGENDRE L. (1998): Numerical ecology, 2nd English ed. – 853 pp., Elsevier, Amsterdam.

LI S., WU F. (2018): Diversity and cooccurrence patterns of soil bacterial and fungal communities in seven intercropping systems. – Frontiers in Microbiology 9: 1521.
DOI: https://doi.org/10.3389/fmicb.2018.01521

LIU J., LI J., TAO Y., SELLAMUTHU B., WALSH R. (2017): Analysis of bacterial, fungal and archaeal populations from a municipal wastewater treatment plant developing an innovative aerobic granular sludge process. – World Journal of Microbiology and Biotechnology 33: 14.
DOI: https://doi.org/10.1007/s11274-016-2179-0

LOGVINENKO L.I. (1970): Fikomitsety v stichnikh vodakh Bezlijudivs'kikh ochisnikh sporud [Phycomycetes in the sewage water of the Bezludovsk water purifying plant]. – Journal of Microbiology 32: 317–322. [in Ukrainian]

LOZUPONE C.A., KLEIN D.A. (2002): Molecular and cultural assessment of chytrids and *Spizellomyces* populations in grassland soils. – Mycologia 94: 411–420.
DOI: https://doi.org/10.1080/15572536.2003.11833206

LUND A. (1934): Studies on Danish freshwater Phycomycetes and notes on their occurrence particularly relative to the hydrogen concentration of the water. – Mémoires de l'Academie (Royale) des Sciences Denmark, Section des Sciences, 6: 1–97.

MANAHAN S.E. (2000): Environmental chemistry, 7th ed. – Lewis Publishers, CRC Press, Boca Raton.

MANOHARACHARY C. (1981): The taxonomy and ecology of freshwater Phycomycetes from India. – Indian Review of Life Sciences 1: 3–21.

MARANO A.V., STECIOW M.M. (2006): Frequency and abundance of zoosporic fungi in some lotic environments of Buenos Aires Province (Argentina). – Journal of Agricultural Technology 2(1): 17–28.

MARANO A.V., BARRERA M.D., STECIOW M.M., DONADELLI J.L., SAPARRAT M.C.N. (2008): Frequency, abundance and distribution of zoosporic organisms from Las Cañas stream (Buenos Aires, Argentina). – Mycologia 100: 691–700. DOI: https://doi.org/10.3852/07-198

MARANO A.V., BARRERA M.D., STECIOW M.M., GLEASON F.H., PIRES-ZOTTARELLI C.L.A., DONADELLI J.L. (2011): Diversity of zoosporic true fungi and heterotrophic straminipiles in Las Cañas stream (Buenos Aires, Argentina): assemblages colonizing baits Agostina. – Fundamental and Applied Limnology 178(3): 203–218. DOI: https://doi.org/10.1127/1863-9135/2011/0178-0203

MILOVTZOVA M. (1935): Vodni hryby Kharkova ta yoho okolyts [Aquatic phycomycetes from Kharkov and its environs]. – Trudy Instytutu Botaniky, Kharkivs'kyi Derzhavnyi Universytet [Traveaux de l'Institut Botanique, Université de Kharkov] 1: 28–37. [in Ukrainian with English summary]

Misra J.K. (1982): Occurrence, distribution and seasonality of aquatic fungi as affected by chemical factors in six alkaline ponds of India. – Hydrobiologia 97: 185–191. DOI: https://doi.org/10.1007/BF00011973

Muhsin T.M. (2012): Aquatic fungi of Iraq: A review. – Marsh Bulletin 7(1): 39–47.

Muszyńska E., Kiziewicz B., Godlewska A., Milewski R. (2014): Fungi and straminipilous organisms growing in the Narew River and its chosen tributaries in NE Poland. – Polish Journal of Environmental Studies 23(2): 401–408.

Nair K.S., Bhat D.J. (2016): Diversity and seasonal appearance of aquatic fungi in three streams of Western Ghat forests of Goa, India. – Biodiversity Journal 7(2): 215–222.

Nascimento C.A., Gomes E.P.C., Pires-Zottarelli C.L.A. (2011): Occurrence and distribution of zoosporic organisms in water bodies from Brazilian Cerrado. – Mycologia 103(2): 261–272. DOI: https://doi.org/10.3852/10-139

Nasser M.S., Khallil A.M., El-Hissy F.T., Abdel-Motaal F.F. (2002): Terrestrial fungi from water and submerged mud polluted by the industrial effluents (Aswan, Egypt). – Journal of Biological Sciences 2(2): 124–129. DOI: https://doi.org/10.3923/jbs.2002.124.129

Natvig D.O. (1987): *Aqualinderella fermentans*. – In: Fuller M.S., Jaworsky A., eds., Zoosporic fungi in teaching and research, pp. 78–79. Southeastern Publishing Corporation, Athens.

Niu L., Li Y., Xu L., Wang P., Zhang W., Wang C., Cai W., Wang L. (2017): Ignored fungal community in activated sludge wastewater treatment plants: diversity and altitudinal characteristics. – Environmental Science and Pollution Research 24(4): 4185–4193. DOI: https://doi.org/10.1007/s11356-016-8137-4

Osman R.A. (2004): Some ecological and physiological studies on fungi inhabiting sewage and sludge. – M.Sc. thesis, 312 pp. [depon. in Botany and Microbiology Department, Assiut University, Egypt].

Paliwal P.C., Sati S.C. (2009): Distribution of aquatic fungi in relation to physicochemical factors of Kosi River in Kumaun Himalaya. – Nature and Science 7(3): 70–74.

Pires-Zottarelli C.L.A. (1990): Levantamento dos fungos zoospóricos da Represa do Lobo ("Broa"), São Carlos, SP, Brasil. – Master thesis, 175 pp. [depon. in Universidade Estadual Paulista, São Paulo].

Rattan S.S., Muhsin T.M., Ismail A.L.S. (1980): Notes on the occurrence and seasonal periodicity of *Saprolegniaceae* in Shatt Al-Arab (Iraq). – Kavaka 8: 41–46.

Roberts R.E. (1963): A study of the distribution of certain members of the Saprolegniales. – Transactions of the British Mycological Society 46: 213–224. DOI: https://doi.org/10.1016/S0007-1536(63) 80077-7

Sadeghi F., Samsampour D., Seyahooei M.A., Bagheri A., Soltani J. (2019): Diversity and spatiotemporal distribution of fungal endophytes associated with *Citrus reticulata* cv. Siyahoo. – Current Microbiology 76(3): 279–289. DOI: https://doi.org/10.1007/s00284-019-01632-9

Scott W.W. (1961): A monograph of genus *Aphanomyces*. – Virginia Agricultural Experiment Station Technical Bulletin 151: 1–95.

Selvarajan R., Sibanda T., Sekar S., Nel W.A. (2019): Industrial effluents harbor a unique diversity of fungal community structures as revealed by high-throughput sequencing analysis. – Polish Journal of Environmental Studies 28(4): 2353–2362. DOI: https://doi.org/10.15244/pjoes/90791

Seymour R.L. (1970): The genus *Saprolegnia*. – Nova Hedwigia (Beiheft) 19: 1–124.

Shearer C.A., Webster J. (1985): Aquatic hyphomycete communities in the River Teign, Devon, England: I. Longitudinal distribution patterns. – Transactions of the British Mycological Society 84: 489–501. DOI: https://doi.org/10.1016/S0007-1536(85)80011-5

Shearer C.A., Descals E., Kohlmeyer B., Kohlmeyer J., Marvanová L., Padgett D., Porter D., Raja H.A., Schmit J.P., Thorton H.A., Voglmayr H. (2007): Fungal biodiversity in aquatic habitats. – Biodiversity and Conservation 16: 49–67. DOI: https://doi.org/10.1007/s10531-006-9120-z

Smith S.N., Armstrong R.A., Rimmer J.J. (1984): Influence of environmental factors on zoospores of *Saprolegnia diclina*. – Transactions of the British Mycological Society 82: 413–422. DOI: https://doi.org/10.1016/S0007-1536(84)80004-2

SOMBOONNA N., ASSAWAMAKIN A., WILANTHO A., TANGPHATSORNRUANG S., TONGSIMA S. (2012): Metagenomic profiles of free-living archaea, bacteria and small eukaryotes in coastal areas of Sichang Island, Thailand. – BMC Genomics 13(7): S29. DOI: https://doi.org/10.1186/1471-2164-13-S7-S29

SPARROW F.K. JR. (1960): Aquatic Phycomycetes. – xxv + 1187 pp., University of Michigan Press, Ann Arbor.

SPARROW F.K. JR. (1968): Ecology of freshwater fungi. – In: Ainsworth G.C., Sussman A.S., eds., The fungi: an advanced treatise, Vol. 3 The fungal population, pp. 41–93. Academic Press, London.

SRIVASTAVA G.C. (1967): Some species of Saprolegniaceae collected from Gorakhpur, India. – Hydrobiologia 30: 281–292. DOI: https://doi.org/10.1007/BF00034598

STJERMA-POOTH I. (1957): *Achlya prolifera* als Abwasserpilz in einem mittelschwedischen Wasserlauf. – Report No. 38, Institute for Freshwater Research Drottningholm, pp. 247–266.

SUZUKI S. (1960): Distribution of aquatic phycomycetes in a river polluted by municipal wastes. – Journal of Waterworks & Sewage Association (Tokyo) 312: 51–54.

TAN T.K., LIM G. (1984): A comparison of fungi from polluted water. – Environmental Pollution Series A 35: 57–65. DOI: https://doi.org/10.1016/0143-1471(84)90130-2

TANYOL M., DEMIR V. (2016): Correlations between some operation parameters and efficiency evaluation of domestic wastewater treatment plant in Tunceli (Turkey). – Desalination and Water Treatment 57: 28115–28121. DOI: https://doi.org/10.1080/19443994.2016.1182082

TURKAR S.S., BHARTI D.B., GAIKWAD G.S. (2011): Various methods involved in waste water treatment to control water pollution. – Journal of Chemical and Pharmaceutical Research 3(2): 58–65.

VORONIN L.V. (2008): Zoosporic fungi in freshwater ecosystems. – Inland Water Biology 1(4): 341–346 [original Russian text published in Biologiya Vnutrennikh Vod 4: 33–38]. DOI: https://doi.org/10.1134/S1995082908040056

WANG X., HU M., XIA Y., WEN X., DING K. (2012): Pyrosequencing analysis of bacterial diversity in 14 wastewater treatment systems in China. – Applied and Environmental Microbiology 78: 7042–7047. DOI: https://doi.org/10.1128/AEM.01617-12

WATERHOUSE G.M. (1942): Some water moulds of the Hogsmill River collected from 1937 to 1939. – Transactions of the British Mycological Society 25: 315–325. DOI: https://doi.org/10.1016/S0007-1536(42)80021-2

WATERHOUSE G.M. (1956): The genus *Phytophthora*. Diagnoses (or descriptions) and figures from the original papers. – Miscellaneous publication 12, 120 pp., Commonwealth Mycological Institute, Kew.

WATERHOUSE G.M. (1968): The genus *Pythium* Pringsheim. Diagnoses (or descriptions) and figures from the original papers. – Mycological Papers 110, 71 pp., Commonwealth Mycological Institute, Kew.

WURTZ A. (1956): Champignons, bactéries et algues des eaux polluées. – Bulletin Français de Pisciculture 182: 5–25.

YANNA, HO W.H., HYDE K.D. (2002): Fungal succession on fronds of *Phoenix hanceana* in Hong Kong. – Fungal Diversity 10: 185–211.