Original Research Article

Charophyte community in the lowermost locality in the world near the Dead Sea, Israel

ABSTRACT

Aims: First study of the lowermost locality the Neot HaKikar with charophytes in the Dead Sea region of Israel has been implemented showing the algal diversity and ecological assessment of the water object environment.
Study design: We implemented diverse bio-indication methods.
Place and Duration of Study: Institute of Evolution, University of Haifa, Israel, Central Siberian Botanical Garden of the Siberian Branch of the Russian Academy of Sciences, Russia, between January 2012 and December 2014.
Methodology: Material for this study comes from 26 samples including 9 living and 9 fixed periphyton samples, 4 fixed samples of charophytes and 4 samples of water. We used bio-indication methods for the purpose of characterizing pool water quality and ecosystem sustainability. Index saprobity S and Index of aquatic ecosystem sustainability WESI were calculated.
Results: Altogether 39 species of algae, including macro-algae *Chara contraria* A.Braun ex Kützing (Charales, Charophyceae), were revealed in the Neot HaKikar pool. *Chara* was found in significant growth in the bottom and coastal part of the studied pool. Bio-indication and chemical variables characterized the charophyte site environment as mesotrophic to eutrophic with prevailing benthic types of organisms with an autotrophic type of nutrition, which are mostly attached to the substrate and preferred standing water, medium-enriched by oxygen, with temperate temperature, medium salinity, low alkalinity, and low-to-middle organic pollution, representing the Class III of water quality. Seasonality of the algal community and water quality showed organic and other contaminants of pollution during the winter period as a result of evaporation and an atmospheric dust impact. The Charophyte community is sharply limited in its development as a result of periodical anthropogenic desiccation of the pool. We found unique properties of *Chara contraria* in the renewed population after two years of desiccation.
Conclusion: We can recommend the Neot HaKikar pool for the monitoring of unique natural aquatic objects in the Dead Sea area, and *Chara contraria* as a climatic indicator of surviving under future climate warming.

Keywords: Charophytes, ecology, bio-indication, Dead Sea, Israel

1. INTRODUCTION

Diversity of algae in Israel has been studied sporadically during the last century, but from 2000 on we continued regular work in the rivers and other water bodies [1]. As a result, we studied known localities as well as finding new localities not only for algal diversity updates but also especially for revealing charophyte communities [2,3]. At the present time, we reveal 14 charophyte species (16 with infraspecific variety) that are known for Israel [4] from references and our own studies.

The charophytes prefer alkaline water environments, which form on the carbonates that are widely distributed in the studied region. Therefore, the Eastern Mediterranean environment gives us more chances to find new, unstudied aquatic objects in which charophyte algae can be identified. The altitude gradient plays the major role in historical species diversity forming process, which is [5] especially interesting in the Arava Valley, in the lowermost area of the world placed between the Red Sea and the Dead Sea. Biodiversity of the Arava Valley refers to the Saharo-Arabian Realm with a sharp arid climatic environment [6-8].

We assume that the diversity of this group of algae in Israel is still far from complete. Thus, the aim of our work was to find new habitats of charophytes and study their community and their environments, especially in the lowest place in the world that is affected by the shading of solar radiation of the dust layer – more than 500 meters thick.

2. MATERIAL AND METHODS

2.1. Description of study site

The Neot HaKikar pool is located in the northern part of the Arava Valley to the south of the Dead Sea at 30º57.221 N and 35º21.450 E with an altitude of 356 m below sea level (Fig. 1). The pool is permanent, about 10-12 m in diameter, about 0.5-0.7 m deep, and affiliated with the Israeli Mekorot Company as one of the freshwater sources in Kibbuz Ein Tamar. The area has a desert climate. Throughout the year, there is virtually no rainfall at Neot HaKikar. The average annual air temperature is about 24.1℃ [9].

The long-term average annual rainfall is 53 mm [9]. The driest month is August with 0 mm. Most precipitation falls in December, with an average of 12 mm but this occurs one time per 2-4 years. The warmest month of the year is August with an average air temperature of 31.4℃. In January, the average air temperature is 15.3℃. It is the lowest average temperature of the whole year.

Periodical year-round dust storms attack the area when sunlight is rather decreased. The main air dust content is at mid-day (Fig. 2) when UV radiation is lower than in the nearby high-altitude areas. The most impacted period is at mid-day, when dust concentration in the nearby city of Beer-Sheva rises up to 2-5 mg m^{-3} in March-May, and up to 5 mg m^{-3} in January-February and May depending on the sand storm generation area [10]. The air temperature increased significantly about 10℃ during the sand storm. Massive high temperature air with dust transportation covers an area of about 4,800 square kilometers in the Arava Valley [11].

Fig. 1. Study site in the Neot HaKikar pool, Arava Valley, Israel

Fig. 2. The Neot HaKikar area during the sandstorm, midday, in January 2012

2.2. Sampling and laboratory studies

Material for this study comes from 26 samples including 9 living and 9 fixed periphyton samples, 4 fixed samples of charophytes and 4 samples of water that were collected during two field trips on January 16 and June 12 of 2012 in the Neot HaKikar pool.

Algological samples were collected by substrate scratching and water scooping, placed in 15 ml plastic tubes, and partly fixed with 3% neutral formaldehyde solution, as well as some (duplicates) not fixed, and transported to the laboratory in an ice box.

Charophytes were treated with 2-3% HCl to remove calcium carbonate. After washing several times with distilled water, the material was studied with a Nikon stereomicroscope. The structure elements were observed with a Nikon digital camera (DC), a DinoLight camera, and light microscopes (LM) in the Institute of Evolution, University of Haifa (IEUH) and the Central Siberian Botanical Garden (NS) with help using international handbooks [12,13]. Herbarium specimens were deposited in the IEUH and NS.

Algae and cyanobacteria were studied with the SWIFT, NIKON, and OLYMPUS dissecting microscopes under magnifications 40x–1000x from three repetitions of each sample and were photographed with digital cameras of the Leica stereomicroscope and Nikon Eclipse light microscope. The diatoms were prepared using the peroxide technique [14] modified for glass slides [15] and were placed in the Naphrax® resin from two repetitions of each sample. Charophyte and microscopic algae abundance were assessed as abundance scores according to a 6-score scale [16] (Tab. 1).

Tab. 1. Species frequencies according to 6-scores scale [1,16].

Score	Visual Estimate	Cell numbers of periphyton or plankton per slide (20 x 20 mm)
1	Occasional	1-5 cells per slide
2	Rare	10-15 cells per slide
3	Common	25-30 cells per slide
4	Frequent	1 cell over a slide transect
5	Very frequent	Several cells over a slide transect
6	Abundant	One or more cells in each field of view

Temperature was measured with a thermometer. Electrical Conductivity (EC), pH, and Total Dissolved Solids (TDS) were measured with HANNA HI 9813-0. Measurements were made in five repetitions by adding the probe into the water till the reading was stabilized. Chlorides and sodium percentages were determined with “Handheld Refractometers X-Series Sodium Chloride” with three repetitions. The concentration of N-NO_3 was measured with HANNA HI 93728 with five repetitions.

2.3. Bio-indication and indices calculation

The methods and indices that can be used for bio-indication of environment quality are based on the ecological point of view to the water and biota relationships [1,16]. The mutual influence of the diversity of freshwater algae and their habitat can be determined with the help of ecological preferences of the species developing in a studied community. This is a basic principle of bio-indication - compliance with the community composition to the parameters of its habitat.

Our ecological analysis has revealed a grouping of freshwater algae indicators to pH, salinity, and saprobity as well as for other habitat conditions [1,16]. Each group was separately assessed in respect to its significance for bio-indication. Those species that predictably responded to environmental variables can be used as bio-indicators reflecting the response of aquatic ecosystems to eutrophication, pH levels, salinity, organic pollutions, nutrition type, and trophic level.

Index saprobity S was calculated according to [17] using the species-specific saprobity index s of revealed taxa and its abundance scores (Tab. 1).

The calculated integral index of aquatic ecosystem sustainability (Aquatic Ecosystem State Index, WESI) is based on the water-quality classes [1,16] (Tab. 2) reflecting self-purification capacities for each of the sampling stations. Index WESI was calculated according to [1,16] as (1):

$$\text{WESI} = \text{Rank S} / \text{Rank N-NO}_3. \qquad (1)$$

Where: Rank S – rank of water quality on the Sladeček’s indices of saprobity; Rank N-NO_3 – rank of water quality on the nitric-nitrogen concentration (Tab. 2).

If WESI is equal to or larger than 1, the photosynthetic level is positively correlated with the level of nitrate concentration. If the WESI is less than 1, the photosynthesis is suppressed presumably according to toxic disturbances [1,16].

Tab. 2. Ecological water quality classification [1,16].

Water quality Class	Rank	NO_3^- mg N L^{-1}	Index saprobity S
I - very pure	1	< 0.05	<0.5
II - pure	2	0.05-0.20	0.5-1.0
II - pure	3	0.21-0.50	1.0-1.5
III - moderate	4	0.51-1.00	1.5-2.0
III - moderate	5	1.01-1.50	2.0-2.5
IV - polluted	6	1.51-2.00	2.5-3.0
IV - polluted	7	2.01-2.50	3.0-3.5
V - very polluted	8	2.51-4.00	3.5-4.0
V - very polluted	9	> 4.00	>4.0

2.4. Taxonomic analysis and classification

For taxonomic identification, the handbook series was used [13, 18-25]. Modern species names in our work come from algaebase.org [26] employing the common system nomenclature derived from T. Cavalier-Smith [27].

3. RESULTS

3.1. Chemical composition of the pool water

Chemical variables were measured two times in winter and summer seasons (Tab. 3). Environment variables are fluctuated in small ranges and reflected fresh to brackish, low alkaline, temperate temperature, and low polluted waters [1,16]. Index of saprobity S fluctuated in small ranges and reflects low levels of organic pollution, Class III of water quality. Sodium and chlorides content rather fluctuated between winter and summer. Remarkably, water conductivity, TDS, and chlorides are higher in summer whereas nitrates increase in winter.

Tab. 3. Chemical and biological variables in the Neot HaKikar pool in 2012.

Variables	Aver_summer	stdev	Aver_winter	stdev
Conductivity, mSm cm^{-1}	6.75	0.11	6.37	0.46
$N\text{-}NO_3$, mg L^{-1}	0.00	0.00	0.41	0.43
pH	7.13	0.20	7.14	0.30
Total Dissolved Solids (TDS), g L^{-1}	1.73	0.00	1.21	0.28
T, Cº	31.70	0.66	25.67	1.96
Cl, %	0.51	0.11	0.28	0.10
Na, %	0.51	0.11	0.28	0.10
No. of Species	24.00	1.15	24.00	1.00
Index saprobity S	1.80	0.21	1.79	0.18
Index WESI	1.00	0.00	1.21	0.46

3.2. Diversity and ecology of algae

We revealed 39 species of algae (Tab. 4) diversity which were rather constant during the sampling dates in summer (23) and winter (25) communities. The majority of species in winter was diatoms (15) whereas summer community enriched by greens also (10 and 10 respectively).

Tab. 4. Algal diversity with abundance scores and species ecological preferences (according to V. Sladeček [16], and H. Van Dam [28]) in the Neot HaKikar pool in January (Jan) and June (Jun) 2012, and in A. Ehrlich [29] (Hist).

Taxa	Hist	Jan	Jun	S	Hab	T	Reo	pH	Sal	Sap	D	Aut-Het	Tro	pH range
Cyanobacteria														
Anabaena sp.	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Anabaenopsis sp.	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Chroococcus turgidus (Kützing) Nägeli	-	1	2	0.8	P-B,S	-	aer	alf	hl	o	-	-	-	-
Coelomoron pusillum (Van Goor) Komárek	-	1	-	1.8	P	-	-	-	-	b	-	-	me	-
Limnococcus limneticus (Lemmermann) Komárková, Jezberová, O.Komárek & Zapomelová	+	-	3	1.5	P	-	-	-	-	o-b	-	-	o-m	-
Microcoleus autumnalis (Gomont) Strunecky, Komárek & J.R.Johansen	-	-	1	2.3	B,S	-	st-str	-	-	b	-	-	-	-
Oscillatoria sancta Kützing ex Gomont	-	4	-	2.7	P-B, S	eterm	st-str, aer	-	i	b-a	-	-	me	-

Phormidium breve (Kützing ex Gomont) Anagnostidis & Komárek	-	-	3	3.1	P-B, S	-	st	-	-	b-p	-	-	-	-
Planktothrix agardhii (Gomont) Anagnostidis & Komárek	-	-	4	2.2	P-B	-	st	-	hl	b-o	-	-	-	-
Pseudanabaena raphidioides (Geitler) Anagnostidis & Komárek	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Pseudanabaena redeckei (Goor) B.A.Whitton	-	3	6	2.1	P-B	H_2S	-	-	-	b-o	-	-	me	-
Romeria leopoliensis (Raciborski) Koczwara	-	-	2	1.5	P	-	st	-	-	o-b	-	-	e	-
Romeria minima (Lemmermann) Komárek	-	-	1	-	B	-	-	-	-	-	-	-	o	-
Ochrophyta														
Achnanthes thermalis (Rabenhorst) Schoenfeld	+	2	-	0.3	B	warm	st-str	ind	hl	o	-	-	-	-
Amphora pediculus (Kützing) Grunow ex A.Schmidt	-	-	3	1.7	B	temp	st	alf	i	o-a	sx	ate	e	8.0
Anomoeoneis sphaerophora E.Pfitzer	-	4	3	2.7	P-B	warm	st-str	alb	hl	x-b	-	ate	e	6.3-9.0
Brachysira vitrea (Grunow) R.Ross	+	-	-	0.5	B	-	-	ind	i	o-x	-	-	-	-
Caloneis amphisbaena (Bory de Saint Vincent) Cleve	-	2	-	2.3	B	-	st-str	alf	hl	o	-	ate	e	-
Caloneis macedonica Hustedt	+	-	-	-	B	-	st	alf	i	-	-	-	-	-
Cyclostephanos invisitatus (Hohn & Hellermann) Theriot, Stoermer & Håkasson	-	1	-	1.9	-	-	-	-	-	o-b	sx	-	-	-
Cyclotella meneghiniana Kützing	-	2	1	2.8	P-B	temp	st	alf	hl	o-a	sp	hne	e	5.5-9.0
Diploneis elliptica (Kützing) Cleve	+	-	-	0.6	B	temp	str	alf	i	o-a	sx	ats	m	-
Diploneis oblongella (Nägeli ex Kützing) Cleve-Euler	+	2	2	0.9	B	-	str	alf	i	o-a	sx	ats	-	-
Diploneis ovalis (Hilse) Cleve	-	1	-	0.9	B	-	str	alb	i	b	sp	ats	-	6.5-9.0
Gomphonema parvulum (Kützing) Kützing	+	-	-	2.3	B	temp	str	ind	i	x	es	hne	e	4.5
Halamphora acutiuscula (Kützing) Levkov	+	-	-	-	P-B	warm	-	alf	mh	-	sp	-	-	-

Halamphora subturgida (Hustedt) Levkov	+	-	-	-	B	-	-	alf	mh	-	-	-	-	-
Mastogloia aquilegiae Grunow	+	-	-	-	P	-	-	-	ph	-	-	-	-	-
Mastogloia braunii Grunow	-	3	6	-	P-B	-	-	alf	mh	-	-	-	-	-
Mastogloia lacustris (Grunow) Grunow	-	3	-	1.3	B	-	str	alf	hl	o	-	ats	e	-
Mastogloia smithii Thwaites ex W.Smith	-	2	-	1.3	B	-	-	alf	mh	b	sx	-	-	-
Navicula globulifera Hustedt	-	4	-	-	B	-	-	-	-	o	-	-	-	-
Navicula schroeteri Meister	+	-	-	-	B	-	str	alf	i	a-b	es	-	e	-
Navicula subrhynchocephala Hustedt	+	-	-	-	P-B	-	-	alf	i	-	sp	-	-	-
Navicymbula pusilla (Grunow) K.Krammer	+	-	4	-	B	-	-	alf	mh	-	es	-	-	-
Nitzschia amphibioides Hustedt	+	3	-	-	P-B	-	st-str	alf	i	-	-	-	-	-
Nitzschia elegantula Grunow	+	2	-	-	P-B	-	st	alf	hl	-	sx	-	-	-
Nitzschia fonticola (Grunow) Grunow	-	3	1	1.5	B	-	st-str	alf	oh	o-b	-	ate	me	7.7-7.95
Nitzschia microcephala Grunow	+	-	-	2.3	B	-	st-str	acf	hl	o-b	sx	hce	e	-
Nitzschia obtusa W.Smith	+	-	-	2.5	B	-	-	-	mh	b	es	-	-	-
Nitzschia palea (Kützing) W.Smith	-	-	3	2.8	P-B	temp	-	ind	i	o-x	sp	hce	he	7.0-9.0
Nitzschia scalpelliformis Grunow	+	-	-	-	B	-	-	-	hl	-	sp	-	-	-
Pinnularia ignobilis (Krasske) A.Cleve	-	-	4	-	-	-	-	-	-	-	-	-	-	-
Pinnularia kneuckeri Hustedt	+	-	-	-	B	-	-	-	-	-	-	-	-	-
Rhopalodia gibberula (Ehrenberg) Otto Müller	-	3	1	-	B	warm	str	ind	mh	-	es	-	-	4.8-9.0
Seminavis strigosa (Hustedt) Danieledis & Economou-Amilli	+	-	-	-	B	-	st	-	-	a-b	-	-	-	-
Surirella angustata Kützing	-	1	-	1.7	B	-	-	alf	i	b	-	-	-	-
Tryblionella hungarica (Grunow) Frenguelli	+	-	-	2.9	P-B	-	-	alf	mh	a-b	sp	ate	e	-
Euglenozoa														
Trachelomonas volvocina (Ehrenberg)	-	1	-	2.0	B	eterm	st-str	ind	i	b	-	-	-	4.4-8.4

Ehrenberg														
Chlorophyta														
Eudorina elegans Ehrenberg	-	-	2	2.3	P	-	st-str	-	i	b	-	-	-	-
Gemellicystis imperfecta (Korsh.) Lund	-	1	-	1.2	-	-	-	-	-	-	-	-	-	-
Scenedesmus apiculatus (West & G.S.West) Chodat	-	1	1	-	P	-	st-str	-	-	-	-	-	-	-
Charophyta														
Chara contraria A.Braun ex Kützing	-	3	2	1.1	B	-	st-str	alf	i	o-b	-	-	-	-
Cosmarium laeve Rabenhorst	-	6	6	1.9	B, P-B, aer	-	st-str	ind	i	o-a	-	-	me	5.4-9.4

Note: S (S): species-specific index saprobity. Ecological types (Hab): P, planktonic; B, benthic; P–B, planktonic-benthic, S, soil. Temperature (T): temp, temperate waters inhabitant; eterm, eurythermic inhabitant; warm, warm-water inhabitant; H_2S, anoxia indicators. Streaming and Oxygenation (Reo): str, streaming waters inhabitant; st-str, low streaming waters inhabitant; st, standing waters inhabitant; aer, aerophytic inhabitant. pH (pH): ind, indifferent; alf, alkaliphil; acf, acidophil; alb, alkalibiont. Halobity (Sal): i, oligohalobious-indifferent; hl, oligohalobious-halophilous; mh, mesohalobious; ph, polyhalobious. Saprobity (D): es, eurysaprob; sx, saproxen; sp, saprophil. Saprobity (Sap): o, oligosaprob; o-a, oligo-alpha-mesosaprob; x-o, xeno-oligosaprob; x-b, xeno-betamesosaprob; b, betamesosaprob; b-o, beta-oligosaprob; o-b, oligo-beta-mesosaprob; b-p, beta-meso-polysaprob a-b, alpha-beta-mesosaprob; b-a, beta-alpha-mesosaprob; x, xenosaprob. S: species-specific Index saprobity according [17]. Nitrogen uptake metabolism (Aut-Het) [28]: ats, nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen; ate, nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen; hne, facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen; hce, nitrogen-heterotrophic taxa, needing elevated concentrations of organically bound nitrogen. Trophic state (Tro) [28]: me, meso-eutraphentic; e, eutraphentic; m, mesotraphentic; ot, oligotraphentic; o-m, oligo-mesotraphentic; he, hypereutraphentic.

One of the species that were found in the Neot Hakikar was the macrophyte alga *Chara contraria* (Fig. 3). Structural elements and the thallus habitat showed that our samples fell within the typical diagnosis ranks [13].

The strongly incrusted fragile thalli were 4–8 cm in length (Fig. 3). The stem cortex was diplostichous, tylacanthous or nearly isostichous. The spine-cells were solitary, papillose. The short ellipsoid stipulodes were in double rows. The branchlets were up to 12 mm in length and consisted of 2-3 corticate segments and ecorticate segment mostly broken off within studied specimens. The branchlet cortex was diplostichous and complete (the five tubes were seen). The bract-cells were unilateral, the posteriors were rudimental and the anteriors were 0.8-1.2-times longer than the oogonium. The gametangia were solitary and conjoined. The black ripe oospores were present in studied specimens.

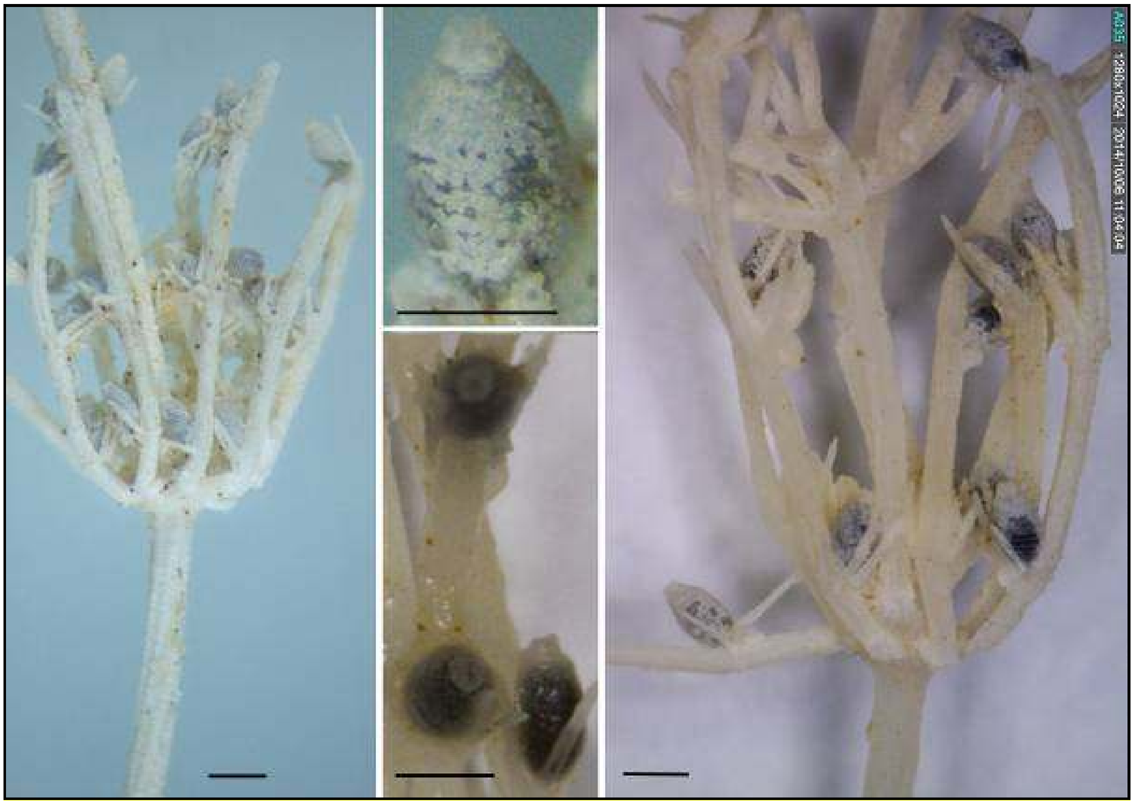

Fig. 3. *Chara contraria*: 1 – axis with stipulodes, base of whorl, axial cortex, and oogonia; 2, 3 – oogonia; 3 – axis with branchlets and oogonia. Scale bar 1 mm

3.3. Bio-indication of the studied pool environment

Bio-indication methods characterized pool water quality and ecosystem sustainability on the basis of the identified species (Tab. 4). The majority of taxa represent the inhabitants of benthos (37), which corresponds to the small size of the pool. Temperature indicators represent not only temperate species (5) but also warm water inhabitants (4). One species of cyanobacteria *Pseudanabaena redeckei* is an indicator of anoxia and sulfides, which come from the bottom sediments as a result of organic matter degradation. As a whole, the pool community contains more species that are indicative of medium oxygen enrichments (11). A wide range of groups, from acidophilic to alkalibionthic, represent indicators of water pH, and alkaliphilic species strongly prevailed (20). It is remarkable that the spectrum of salinity indicators shift to the high-salinity group such as mesohalobes (8) and even polyhalobes (1), but the group of oligohalobious-indifferent species number prevailed (17). Indicators of organic pollution in [17,30] demonstrated wide ranks of species from 11 groups of saprobity from which indicators of Class II and III prevailed. Watanabe's system indicators (D) were represented by diatoms only and reflect medium organic enrichments. Indicators of nutrition type [28] that preferred the revealed algal species shows a shift to the autotrophic groups that used photosynthetic ways of protein synthesis. As a result, the trophic indicators [28] reflecting that pool environment corresponded to a eutrophic ecosystem state.

A comparison of the seasonal dynamics shows increases in high-temperature groups in winter (Fig. 4.1). Substrate preferences (Fig. 4.2), salinity (Fig. 4.3) and pH indicators (Fig. 4.4), were distributed over the same groups in similar proportions in both seasons. Nutrition type indicators mostly show species of autotrophic nutrition in winter and species with heterotrophic ability in summer (Fig. 4.5). Indicators of trophic states were more diverse in summer and reflect mesotrophic and eutrophic states of the pool in both seasons (Fig. 4.6). Only one species, *Pseudanabaena redeckei*, was an indicator of anoxia and sulfides in both seasons (Tab. 4).

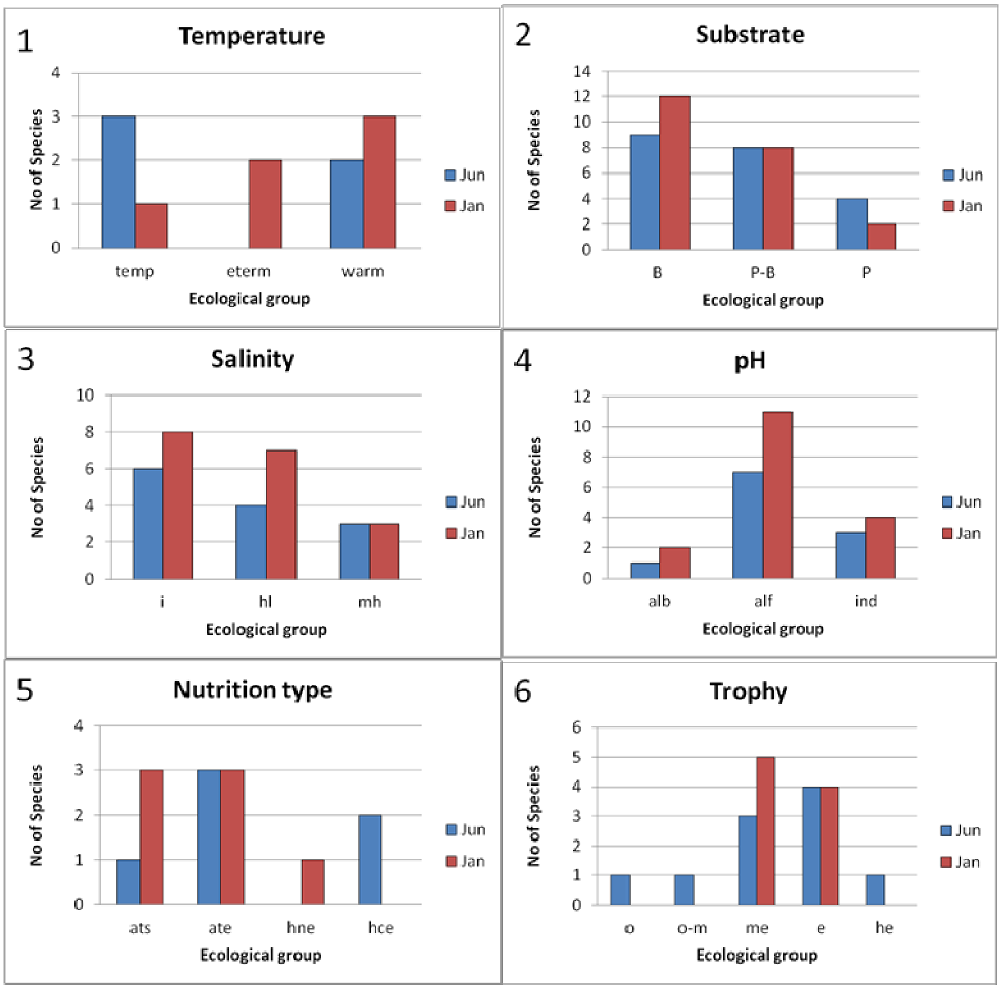

Fig. 4. Bio-indication of the Neot HaKikar pool. Ecological group in each histogram are follow in the indication variable increasing.

We use Tab. 4 with Index saprobity S values that were calculated on the basis of species abundance scores (Tab. 1) and species-specific index s after the Sládeček [17,30] model, and nitrate concentration (Tab. 3) data for ecosystem state index WESI calculation. Despite the Index Saprobity S values that show low-organic matter concentration, the index WESI fluctuated from 1.00 to 1.33, which can characterize the studied site's ecosystem as high capacity to self-purification.

3. DISCUSSION

The studied site (Neot HaKikar) is unique, not only because it is the lowermost locality in the world but also because it is subjected to the impact of sand storms. As a result, the sunlight intensity decreases for 20-25 percent [31] from Beer-Sheva at about 300 m above sea level down to Neot HaKikarat about 356 m below sea level, altogether about 650 m of air thickness.

Environmental variables fluctuated in small ranges, which reflect the relative stability of the environment. Tab. 3 shows that summer chemical variables (excluding nitrates) are higher than winter variables. We assume that this finding could be the result of evaporation under high temperatures in summer that impacted the first stage of the dissolved solids [1,8,16]. Nitrate concentration that usually correlated with organic pollution is higher in winter, which can be a result of dust from sand storms that contained organically enriched particles and chlorides [10,11,32,33]. Nitrate formation in the Mediterranean region air correlated with sea-salt particle enrichments during the dust storm and increased with UV radiation up to five times [34]. As a whole, this dynamic of chemical variables and chlorides and nitrates in particular can be the result of the impact of a sharp arid climate that has been revealed in the water bodies of the Arava Valley [35,36], Central Asia [36], and Southern Ukraine [37].

Diversity of algae in the Neot HaKikar was studied from 1995 by A. Ehrlich [29] and represented by 20 taxa of diatoms only. We revealed 39 species in which diatoms prevail but other species are represented by cyanobacteria, euglenoids, and green and charophyte algae. Only five species from Ehrlich's list and our finding overlapped. Moreover, we did not find the 15 species that were represented in Ehrlich's book [29], but found 33 more species of cyanobacteria, euglenoids, green algae, and the very abundant charophyte *Cosmarium* than Ehrlich [29] listed. Altogether, the algal species list now includes fifty-four species in which diatoms prevail (Tab. 4). Species abundance fluctuated between seasons and in divisional level taxa. Therefore, the most abundant species included cyanobacteria (*Pseudanabaena redeckei*) and diatoms (*Mastogloia braunii*) that were abundant in winter, and charophytes (*Cosmarium laeve*) were well developed in both seasons. *Chara contraria* was not abundant but were represented in both summer and winter communities.

Chara contraria is widely distributed in the Mediterranean countries and in some similar dry climate regions and is cosmopolitan [38]. Species distribution is known from the sea level up to 2000 m a.s.l. in Central Europe [39]. It seems that the lowermost altitude for charophytes had not been assessed at all. Previously, we had shown that the species of the genus *Chara* in Israeli populations are well separated from one another according to Amplified fragment length polymorphism (AFLP) analysis [40] including *Chara contraria*. The *Chara contraria* community was dominated by diatoms (Tab. 4) that attach to macro-alga as well as to stones and plants in the pool bottom. Unfortunately, periodic reconstructing of the area causes the pool to dry up. During several field trips in 2002-2014 we couldn't find the pool, but it was periodically renewed. As a result of periodic desiccation, the charophyte plants died, but they can be renewed after one-two years after a dry period. We assume that survival of *Chara contraria* in this dry land site can be possible with oospores stored in the pool sediments. It is very important to note that the studied populations of *Chara* demonstrated high tolerance to desertification despite the ecological consequences of climate change [32] in the region [41]. Our exploration of Israeli charophytes shows that oospores can survive for at least two years that we know of [3] but possibly even longer.

Halobity groups' alignment with brackish-water indicators suggests long-term effects of salinity increases in the long process of diversity developing in the pool in excessively arid environments. As has been revealed [31,43], the natural water streams in the Arava Valley, and the Neot HaKikar in particular, have a permanent trend in decreasing in water content under the impact of an arid climate. On the other hand, the source of chlorides in the Arava Valley comes from atmospheric dust, which combines with nitrates during the dust storms [34].

As can be seen in Tab. 4, the water quality defined by bio-indication is the same that is shown by the chemical components of the water (Tab. 3). In conclusion, we can characterize the studied pool as mesotrophic to eutrophic with prevailing benthic types of organisms with an autotrophic type of nutrition, which are mostly attached to substrates and prefer standing water with medium oxygen enrichment water, temperate temperature, moderate salinity, low alkalinity, and low-to-middle organic pollution.

Few species of filamentous cyanobacteria and euglenoids (Tab. 4) can confirm that the charophyte site is impacted by organic and other contaminants mostly in winter. This situation is similar to that of the Upper Jordan River previously examined by us [42], where the pollution coming from the catchment area pollutes the water more in winter than in summer. The source of nitrates in the Arava Valley is from atmospheric dust, which brings chloride particles during the dust storms on which nitrates forming from the atmospheric gases are helped by UV radiation [34].

We can assume that there are only a few polluting factors that influence the water quality at Neot HaKikar pool and its algal community. Because the pool is under Mekorot company protection, there is no strong pollution impact. But we can see that the anthropogenic influence comes from periodic reconstruction of the pool area, which we in particular observed during 2012-2013. Unfortunately, the studied pool is still under climatic impact also, which provokes increases in salinity and nitrates [34,41], and therefore algal species richness will change [44,45].

On the other hand, this area is under decreasing sunlight during the sandstorms that periodically come from the Sahara Desert, from the Arabian Desert across the Negev Desert [10]. Massive dust transportation not only covers large deserted areas [11], such as the Arava Valley, but also decreases in sunlight intensity during the day. It is especially important in the lowermost area near the Dead Sea in which light intensity decreased 25% [31] as a result of the dust layer thickness, which is more than 250 m.

As a protected mechanism, algal cells formed special compounds [46] as a response to the UV-radiation impact [47] on the one hand, and negatively reacted to sunlight inhibition. Increasing UV-radiation effects include inhibition of photosynthesis, inhibition of growth, and DNA damage. As a result, algae have developed a mechanism of avoidance as well as adaptation to light intensity fluctuation during its evolutionary process. It especially relates to the charophyte species definition.

Well known is that *Chara vulgaris* and *C. contraria* are two cosmopolite species that are sometimes difficult to distinguish one from another [48]. Moreover, these species often occupied the same habitat, as we revealed in the Negev Desert stream Ein Avdat [32,40]. Because each charophyte species evolved in the presence of UV radiation, a multitude of adaptive strategies have been developed, which allowed them to exist under sunlight exposure (*C. vulgaris*) or in less exposed places (*C. contraria*) [13], and the repair of DNA damage as a result of developing a major mechanism of UV adaptation [47]. As at was found in our research for the Avdat stream, with the AFLP analysis the charophyte populations is divided into clusters corresponding to the levels of light intensity over the shadow gradient in this deep canyon in the Central Negev. Therefore, we can assume that environmental preferences of both morphologically similar species of *Chara* are entrenched in the process of evolution as a result of repairing injured DNA by ultraviolet radiation and subsequent consolidation of other features. As a result, we are seeing the shade-tolerant *C. contraria* in the Arava Valley inhabiting the lowest place in the world that is affected by the shading of the dust layer more than 500 meters thick.

5. CONCLUSION

The new unique locality, the Neot HaKikar pool in the Arava Valley, is a protected area near the Dead Sea and is the lowermost habitat of charophytes in the world that is located at an altitude of about 350 m below sea level. The pool's environment can be characterized as natural, brackish, low alkaline with low-to-middle organic polluted waters that are inhabited by 39 (54 with references [29]) algal species from which the charophyte *Chara contraria* and diatoms dominated. The charophyte *C. contraria*, which is distributed all over the world, after one-two years of periodic desiccation can be renewed with the help of oospores buried in bottom sediments. This unique property of *C. contraria* can help charophytes survive in the Eastern Mediterranean region, which is under desertification with the impact of periodic sandstorms that decrease photosynthetic radiation intensity about 25% as a result of high dust concentration and regional climate change.
Therefore, the Neot HaKikar pool as a unique charophytes habitat, ecosystem of which have high capacity to self-purification, can be protected for anthropogenic reconstruction, as well as its water quality and algal communities can be studied and monitored for more detailed characteristics of diversity that we have presented here mostly for the first time, and in indicating various climate change parameters.

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REFERENCES

1. Barinova S. Algal diversity dynamics, ecological assessment, and monitoring in the river ecosystems of the eastern Mediterranean. NY, USA: Nova Science Publishers; 2011a.
2. Barinova S, Romanov R. A new Chara locality in the protected area of the Galilee Mountains, Israel. Nat Res Conserv. 2014a;2(5):80-85, DOI: 10.13189/nrc.2014.020502.
3. Barinova S, Romanov R. Unique locality with charophytes in the Mount Arbel National Park, Israel. Elixir Bio Diver. 2014b; 77:28932-36.
4. Romanov RE, Barinova SS. The charophytes of Israel: historical and contemporary species richness, distribution, and ecology. Biodiv Res Conserv. 2012;25:57–64.

5. Barinova S. The effect of altitude on distribution of freshwater algae in continental Israel. Current Topics in Plant Biol. 2011b;12:89–95.
6. Amiram DHK, Rosenan N, Kadmon N, Elster J, Gilead M, Paran U, eds. Atlas of Israel. Jerusalem: Ministry of Labour, and Amsterdam: Elsevier Publishing Co.; 1970.
7. Galun M. The lichens of Israel. Jerusalem: The Israel Academy of Science and Humanities; 1970.
8. Barinova S, Nevo E. Climatic and pollution impact on algal diversity of the freshwater ecosystems in Eurasia. In: Climate Change and Impacts. WY, USA: Academy Publish; 2012.
9. Climate data for cities worldwide. Accessed 02 January 2015. Available: http://en.climate-data.org/location/201911/
10. Krasnov H, Katra I, Koutrakis P, Friger MD. Contribution of dust storms to PM10 levels in an urban arid environment. J Air Waste Manag Ass. 2014;64(1):89-94, DOI:10.1080/10962247.2013.841599.
11. Bruins HJ, Lithwick H. Solar Energy in Arid Frontiers: Designing a Photovoltaic Power Plant for Kibbutz Samar, Israel. The Arid Frontier: Interactive Management of Environment and Development. Netherlands; 1998. Google Books. Kluwer Academic Publishers.
12. John DM, Whitton BA, Brook AJ, editors. The freshwater algal flora of the British Isles: an identification guide to freshwater and terrestrial algae. Cambridge: Cambridge University Press; 2011.
13. Krause W. Charales (Charophyceae). Süßwasserflora von Mitteleuropa, 18. Stuttgart: Gustav Fischer Verlag; 1997.
14. Swift E. Cleaning Diatom Frustules with Ultraviolet Radiation and Peroxide. Phycologia. 1967;6(2-3):161–63.
15. Barinova SS. Morphology of connective spines in diatom algae of the genus Aulacoseira Thwaites. Paleontological J. 1997;31(2):239–45.
16. Barinova SS, Medvedeva LA, Anissimova OV. Биоразнообразие водорослей-индикаторов окружающей среды (Diversity of algal indicators in environmental assessment). Tel Aviv: Pilies Studio; 2006. Russian.
17. Sládeček V. Diatoms as indicators of organic pollution, Acta Hydroch Hydrob. 1986;14:555–66.
18. Komárek J, Anagnostidis K. Cyanoprokaryota. Teil 1. Chroococcales. Süsswasserflora von Mitteleuropa, 19/1. Jena, Stuttgard, Lübeck, Ulm: Gustav Fisher Verlag; 1998.
19. Komárek J, Anagnostidis K. Cyanoprokaryota. Teil 2. Oscillatoriales. Süsswasserflora von Mitteleuropa, 19/2. München: Elsevier; 2005.
20. Komárek J, Fott B. Chlorophyceae (Grünalgen), Chlorococcales. T. 7. Das Phytoplankton des Süsswassers. Systematik und Biologie. Stuttgart: E. Schweizerbartische Verlagsbuchhandlung; 1983.
21. Krammer K, Lange-Bertalot H, Teil. 3. Centrales, Fragillariaceae, Eunotiaceae. Die Süsswasser flora von Mitteleuropa. 2/3. Stuttgart, Jena: Gustav Fisher Verlag; 1991a.
22. Krammer K, Lange-Bertalot H. Bacillariophyceae. Teil 4. Achnanthaceae, Navicula und Gomphonema. Süßwasserflora von Mitteleuropa, 2/4. Stuttgart, Jena: Gustav Fisher Verlag; 1991b.
23. Krammer K, Lange-Bertalot H, Bacillariophyceae. Teil 1. Naviculaceae. Süsswasserflora von Mitteleuropa. 2/1. Jena, Stuttgart, Lübeck, Ulm: Gustav Fisher; 1991a.
24. Krammer K, Lange-Bertalot H, Bacillariophyceae. Teil 2. Bacillariaceae, Epithemiaceae, Surirellaceae. Süsswasserflora von Mitteleuropa, 2/2. Jena, Stuttgart, Lübeck, Ulm: Gustav Fisher; 1991b.
25. Starmach K. Euglenophyta – Eugleniny. In: Starmach K, Siemińska J., editors. Freshwater flora of Poland, 3. Warszawa, Kraków: Państowe Wydawnictwo Naukowe; 1983. Polish.
26. Guiry MD, Guiry GM. AlgaeBase, World-wide electronic publication. Galway: National University of Ireland Press; 2013.
27. Cavalier-Smith T. Only six kingdoms of life. Proc R Soc Lond B. 2004;271:1251–62.
28. Van Dam H, Martens A, Sinkeldam J. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands J. Aquatic Ecol. 1994;28:117–33.
29. Ehrlich A. Atlas of the inland-water diatom flora of Israel. Jerusalem: Israel Academy of Science and Humanities; 1995.
30. Sládeček V. System of water quality from the biological point of view. Ergeb Limnol. 1973;7: 1–128.

31. Boykiw E. The effect of settling dust in the Arava Valley on the performance of solar photovoltaic panels. The Senior Thesis in Department of Environmental Science Allegheny College Meadville, Pennsylvania, USA, April, 2011, 36 pp.
32. Barinova SS, Yehuda G, Nevo E. Comparative analysis of algal communities of northern and southern Israel as bearing on ecological consequences of climate change. J Arid Env. 2010;74:765-76. doi:10.1016/j.jaridenv.2009.03.001
33. Grishkan I. Schlesinger P, Mamane Y. Influence of dust storms on concentration and content of fungi in the atmosphere of Haifa, Israel. Aerobiologia. 2012;28:557–64.
34. Mamane Y, Gottlieb J. Nitrate formation on sea-salt and mineral particles - A single particle approach. Atmospheric Env. 1992;26A(9):1763–69.
35. Barinova SS, Tsarenko PM, Nevo E. Algae of experimental pools on the Dead Sea coast, Israel. Israel J Plant Sci. 2004;52(3):265-75.
36. Barinova SS, Bragina TM, Nevo E. Algal species diversity of arid region lakes in Kazakhstan and Israel. Community Ecol. 2009;10(1):7-16.
37. Klymiuk V, Barinova S, Lyalyuk N. Diversity and Ecology of Algal Communities from the Regional Landscape Park "Slavyansky Resort", Ukraine. Research and Reviews: J Bot Sci. 2014;3(2):9-26.
38. Corillion R. Les Charophycées de France et d'Europe Occidentale. Trav Lab Fac Sc Angers. 1957;11–12:7–499. French.
39. Haas JN. First identification key for charophyte oospores from central Europe. Eur J Phycol. 1994;29(4):227–35.
40. Yehuda G, Barinova SS, Krugman T, Pavlicek T, Nov Y, Nevo E. Microscale adaptive response of charophytes of the Negev Desert, Israel: species divergences by AFLP. Nat Res Conserv. 2013;1(3):55-64. DOI: 10.13189/nrc.2013.010301.
41. Perry AS, Perry RY. Effects in arid regions. In: Ecotoxicology and Climate. SCOPE: Published by John Wiley and Sons Ltd.;1989.
42. Barinova SS, Nevo E. The Upper Jordan River algal communities are evidence of long-term climatic and anthropogenic impacts. J Wat Res Prot. 2010;2:507–26.
43. Bruins HJ, Sherzer Z, Ginat H, Batarseh S. Degradation of springs in the Arava Valley: anthropogenic and climatic factors. Land Degrad Develop. 2012;23:365–83. DOI: 10.1002/ldr.2149
44. Dor I, Ehrlich A. The effect of salinity and temperature gradients on the distribution of littoral microalgae in experimental solar ponds, Dead Sea Area, Israel. Mar Ecol. 1987;8:193-205.
45. Barinova SS, Tsarenko PM, Nevo E. Algae of experimental pools on the Dead Sea coast, Israel. Isr J Plant Sci. 2004;52(3):265-75
46. Karsten U, Garcia-Pichel F. Carotenoids and mycosporine-like amino acid compounds in members of the genus Microcoleus (cyanobacteria): a chemosystematic study. Syst Appl Microbiol. 1996;19(3):285–94.
47. Klish M, Sinha RP, Hader D-P. UV-absorbing compounds in algae. Curr Topics Plant Biol. 2002;3:113-20.
48. Grant MC, Proctor VW. Chara vulgaris and C. contraria: patterns of reproductive isolation for two cosmopolitan species complexes. Evolution. 1972;26(2):267–81.