Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 00 (2014) 000–000

Procedia Engineering

www.elsevier.com/locate/procedia

16th Conference on Water Distribution System Analysis, WDSA 2014

Commento: Elsevier to upda with volume and page numbers

Monitoring aquifer quality for artificial recharge within the WARBO project

Marco Pezzi[1], Milvia Chicca[1], Carmela Vaccaro[2], Daniel Gustavo Nieto Yàbar[3], Elisa Rota[1], Massimo Lanfredi[1], Salvatore Pepi[2] and Marilena Leis[1]*

[1]*Department of Life Science and Biotechnologies - University of Ferrara, L. Borsari 46 - 44121 Ferrara (Italy)*
[2]*Department of Physics and Earth Sciences - University of Ferrara, Saragat 1 - 44122 Ferrara (Italy*
[3]*OGS- Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Sgonico (TS) (Italy)*

Abstract

The macroinvertebrate community and physical-chemical parameters were monitored in a naturally flooded quarry (Copparo, Ferrara, Italy) chosen as an experimental site within WARBO project for aquifer artificial recharge. The biotic indices showed low species richness, diversity and evenness. Some species were abundant while others were detected only in autumn. Through canonical correspondence analysis, community dynamics resulted affected by changes in physical-chemical parameters. Since the aquifer quality was still unsuitable for artificial recharge, an attempt was made to lower the wetland temperature by phytodepuration and fast-growing local trees. Water quality will be monitored until the aquifer becomes suitable for WARBO.

Click here and insert your abstract text.

Peer-review under responsibility of the Organizing Committee of WDSA 2014.

Keywords: Artificial recharge of aquifers, biodiversity, macroinvertebrate community, temperature, phytodepuration

* Corresponding author. Tel.: ++39-532-455313; fax: ++39-532-249716.
E-mail address: marilena.leis@unife.it

Peer-review under responsibility of the Organizing Committee of WDSA 2014.

1. Introduction

The project WARBO LIFE+ (Water Re-Born - Artificial Recharge: New Technologies for sustainable management of water sources) was funded in 2011 by the European Community with the main purpose to reduce desertification and quality deterioration of natural water resources caused by saltwater intrusion into freshwater aquifers, and contribute to preserve water storage reserves against overexploitation due to increased demand. In Emilia-Romagna (Northern Italy) saltwater intrusion often occurs when saltwater pushes inland beneath the freshwater aquifer [1]. In many coastal areas it has been enhanced by human activities such as groundwater pumping from coastal freshwater wells, excessive water extraction and building of navigation, agricultural and drainage channels, which provide ways for saltwater to move inland, lowering the level of fresh groundwater. The ecological consequences are the disappearance of freshwater species and an increase of alophilic and salt-tolerant ones, followed by sterility of agricultural land. The WARBO project aims to provide artificial recharge of wells by injection of freshwater, the only successful method to hinder the increasing water shortage and drought. The quality of aquifers chosen for artificial recharge may be assessed by analysis of biodiversity and of bioindicators, animal, plant or fungal species sensitive to pollutants and thus suitable to monitor ecosystem health [2] [3]. In order to evaluate the quality of an aquifer for artificial recharge and environmental amelioration, we monitored the biodiversity (macroinvertebrate community) and the physical-chemical parameters in a naturally flooded quarry near Copparo (Ferrara, Italy) chosen as an experimental site for a WARBO project of artificial recharge in Northern Italy [4].

2. Materials and Methods

The community of macroinvertebrates and the physical-chemical parameters were monitored in 2012 and 2013 in an abandoned clay quarry (Cava Ponte San Pietro) in Copparo (Ferrara, Italy). The empty quarry, with a surface area about 10 ha, was naturally flooded in 2008 and in 2011 was chosen as a site for the experimental project of artificial recharge of aquifers within WARBO [4] [5] [6]. The Copparo area is a critical climate site because of recurrent droughts and large saltwater intrusions. Four sites were sampled in the study area at different distances from a piezometric well excavated for monitoring groundwater level (Fig. 1). Each site was sampled in triplicate at each time interval in July, October and November.

Fig. 1. Sampling sites in the flooded clay quarry (Cava Ponte San Pietro) near Copparo (Ferrara, Italy). The triangle indicates the position of a piezometric well.

Sampling for aquatic macroinvertebrates was performed by a standard aquatic D-ring net. The sampled material was washed, filtered and transferred by a funnel in 250 ml distilled water with 1.5% formaldehyde in a plastic carter. Observations and counting were performed in laboratory under a stereomicroscope Leica Zoom 2000 (Leica Microsystems, Wetzlar, Germany). Identification of organisms was conducted at the species level by taxonomic keys [7] [8]. The following biotic indexes were calculated: Shannon-Wiener index (species richness and number of individuals); Pielou index (species evenness); Margalef index (species diversity) [9]. The physical-chemical parameters were measured in the four sampling sites, in the same time intervals and in triplicate, by a Hanna HI

9828 multiparametric probe (HANNA Instruments, Smithfield, Rhode Island, USA), placed at about 3 m from the shoreline. The parameters measured were pH, conductance (uS/cm), salinity (Practical Salinity Units, PSU), oxidation reduction potential (ORP, mv), resistivity (OCM, ohm/cm), temperature (°C) and dissolved oxygen (ppm and %). The data on macroinvertebrate community and those obtained by the multiparametric probe were plotted by canonical correspondence analysis (CCA) analyzed by the software “Primer” version beta (McGraw-Hill Global Education Holdings, Milan, Italy). Sampling of flying insects and other land arthropod fauna was performed by a standard Malaise trap connected to a collection tube with ethanol 70°. For preservation and handling, specimens were transferred in ethanol 80° with 3% glycerol. Observations and counting were performed in laboratory under a stereomicroscope Leica Zoom 2000 equipped with a Canon PC1099 (Melville, New York, USA) Identification of flying organisms was conducted at the family level by specialized taxonomic keys [7] [8].

3. Results

The physical-chemical parameters detected in the four sampling sites are shown in Table 1.
The data concerning the invertebrate taxa detected in the quarry sampling sites are shown in Table 2, while the biotic indexes are shown in Table 3.

Table 1. Physical-chemical parameters measured by the multiparametric Hanna HI 9828 probe in the four sampling sites (see Fig. 1). Each datum is the average of three separate probe readings. The parameters are pH (± 0.02), conducibility (µS/cm ±1), salinity (Practical Salinity Units, PSU, ±0.01), Oxidation Reduction Potential (ORP, mV, ±1), atmospheric pressure (mbar, ±4), resistivity (Ωcm, ±1), temperature (°C, ±0.15), dissolved oxygen (DO, ppm and %, ± 1.5). Abbreviations: lug, July; ott, October; nov, November.

	pH	**µS/cm**	**PSU**	**ORP**	**mbar**	**Ωcm**	**°C**	**DO ppm**	**DO %**
lugA	6.46	3062	1.59	80.80	1216.60	327	24.31	4.54	54.27
lugB	6.74	3099	1.61	51.30	1016.53	323	24.44	4.91	59.90
lugC	6.53	2037	1.06	57.80	1018.20	491	26.72	5.10	63.70
lugD	7.01	3111	1.62	8.87	1047.76	285	24.67	4.99	60.47
ottA	9.01	3162	1.66	89.20	1021.70	316	18.19	6.94	73.70
ottB	8.68	3272	1.72	65.80	1021.80	306	18.38	6.71	71.50
ottC	8.79	3268	1.72	72.70	1021.70	306	18.24	6.83	72.60
ottD	9.40	3260	1.72	121.70	1021.50	307	18.60	6.70	71.80
novA	8.40	3265	1.72	26.10	1003.30	306	17.93	7.12	80.41
novB	8.44	3254	1.71	37.90	1003.30	307	17.60	7.09	80.30
novC	8.40	3275	1.72	29.60	1003.70	305	18.14	7.10	79.65
novD	8.42	3259	1.71	51.70	1003.80	307	18.61	7.08	80.39

Table 2. Taxa identified in the flooded quarry. n.i., not identified

Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**
Porifera	Demospongiae	Haplosclerida	Spongillidae	*Spongilla*	*S. lacustris*
Annelida	Clitellata	Haplotaxida	Lumbricidae	*Lumbricus*	*L. terrestris*
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus*	*G. pulex*
Arthropoda	Branchiopoda	Cladocera	Daphniidae	*Daphnia*	*D. pulex*
Arthropoda	Entognatha	Collembola	Sminthuridae	*Sminthurides*	*S. acquaticus*
Arthropoda	Insecta	Rhynchota	Corixidae	*Corixa*	*C. punctata*
Arthropoda	Insecta	Diptera	Chironomidae	*Chironomus*	*C. plumosus*
Arthropoda	Insecta	Diptera	Culicidae	*Culex*	*C. pipiens*
Arthropoda	Arachnida	Acarina	Hydracarina	n.i.	A
Arthropoda	Arachnida	Acarina	Hydracarina	n.i.	B

Table 3. Biotic indices for each sampling site and time interval. H': Shannon index; J': Pielou index; d: Margalef index. Letters and numbers indicate the sampling sites (see Fig. 1) and the replicas. Abbreviations as in Fig. 1.

	H'	J'	d
lugA	0.06	0.06	0.26
lugB	0.77	0.53	0.55
lugC	0.51	0.33	0.46
lugD	0.67	0.31	0.42
ottA	0.26	0.19	0.32
ottB	0.19	0.14	0.38
ottC	0.31	0.28	0.32
ottD	0.18	0.12	0.39
novA	1.26	0.86	0.56
novB	1.03	0.66	0.58
novC	1.05	0.76	0.56
novD	1.09	0.71	0.56

The community is characterized by low species richness, diversity and evenness. Some species were very abundant in any season, such as the crustacean *Daphnia pulex*. Other frequent species were another crustacean, *Gammarus pulex*, and two insects, the hemipteran *Corixa punctata* and the dipteran *Culex pipiens*. The species most sensitive to salinity, such as the freshwater sponge *Spongilla lacustris* and the springtail *Sminthurides aquaticus*, were detected as a few individuals only in autumn, when water temperature and salinity were optimal. No significant differences were detected in community composition among the sampling sites.
The CCA map in Fig. 2 shows the relationships between each taxon and the explanatory variables (arrows) representing the physical-chemical parameters measured by the probe. According to these data, the distribution of some taxa appears to be affected by the seasonal parameter variations. In lotic environments *D. pulex* is considered a good bioindicator [10] but the community in the quarry appears generally affected by the changes in water parameters mainly due to climate changes.

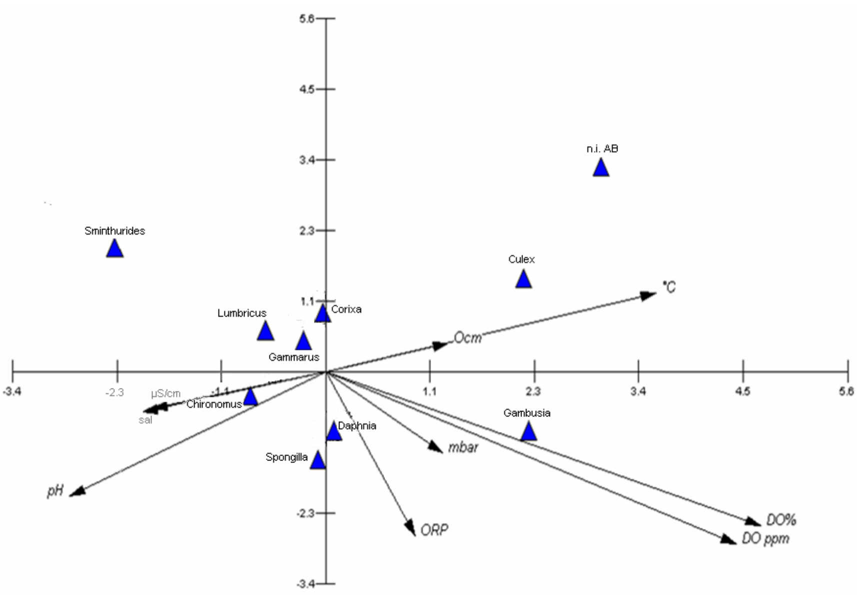

Fig. 2. Effects of physical-chemical parameters measured by the multiparametric probe and the macroinvertebrate community structure (taxa distribution) analyzed by canonical correspondence analysis (CCA). The parameters measured are from left to right: pH, conducibility (μS/cm), salinity (PSU, sal), redox potential (ORP, mV), atmospheric pressure (mbar), resistivity (Ocm, ohm cm), temperature (°C), dissolved oxygen (DO, ppm and %) (see Table 1). Each taxon (blue triangle) is identified by its genus name; ni.AB, unidentified genera of the family Hydracarina (see Table 2).

Concerning flying insects and other land arthropod fauna, a total of 7 insect taxa were collected and identified at the family level in the flooded quarry. The most abundant families were Carabidae (Coleoptera) and Formicidae (Hymenoptera), closely related to vegetation and each amounting to 26% of the capture.

Table 4. Biotic indices for land arthropod taxa, shown as in Table 3.

H'	1.73	2.36	2.59
J'	0.89	0.82	0.90
d	2.04	4.39	4.64

4. Conclusions

The most abundant bioindicator taxa in the Copparo quarry are the crustacean *Daphnia pulex* and *Gammarus pulex*, and the hemipteran *Corixa punctata*. These results can be considered positive because flooded quarries often exhibit a low quality environment unsuitable to sensitive bioindicators. No significant differences in species composition were detected among the sampling sites: moreover, the community shows a low biodiversity probably because the quarry is a rather recent habitat. Some taxa are very abundant; others, such as *Corixa punctata*, represented by a high number of individuals, are apparently unaffected by local changes in the physical-chemical parameters but rather by seasonal changes, less expected to affect community structure. The presence of a saltwater intrusion, as confirmed by data on groundwater level (30 m) collected by the piezometric well, does not apparently affect biodiversity because for each taxon changes were detected in abundance but not in taxonomic richness. These results and the finding of a sensitive freshwater species such as *Spongilla lacustris* support the hypothesis that the saltwater intrusion has not yet significantly affected the community equilibrium. Concerning the land arthropod fauna, this community is characterized by a low level of biodiversity and no taxa clearly indicating environmental stress were detected.

These data are the first concerning the macroinvertebrate and land arthropod fauna obtained in the naturally flooded quarry (Cava Ponte San Pietro, Copparo, Ferrara), monitored as an experimental site for the WARBO project. According to our data, the quality of the aquifer in the quarry is not yet suitable to be employed as a WARBO recharge. An attempt to improve the aquifer quality was therefore initiated by phytodepuration with traditional ways, such as by planting *Phragmites communis* and fast-growing local trees such as *Salix rubra* and *S. alba*. The phytodepuration is expected to mitigate local temperature especially in summer, therefore improving the aquifer quality and biodiversity. The water quality will be continuously monitored through the invertebrate communities and the physical-chemical parameters, until the quarry aquifer will become suitable for the WARBO artificial recharge. Nevertheless, in the long run the degree of biodiversity detected in the Copparo quarry seems positive for both WARBO artificial recharge and the project of environmental amelioration of the entire area established by the

Copparo Municipality. Continuous sampling will be required to evaluate the long-term effects of the project and of others involving recovery and renaturalization of local agricultural land. The final results and the success of the project in terms of biodiversity, ecological qualification and water quality improvement will be assessed only after several years of monitoring.

The project WARBO LIFE+ (Water Re-Born - Artificial Recharge: New Technologies for sustainable management of water sources) was funded in 2011 by the European Community with the main purpose to reduce desertification and quality deterioration of natural water resources caused by saltwater intrusion into freshwater aquifers, and contribute to preserve water storage reserves against overexploitation due to increased demand. In Emilia-Romagna (Northern Italy) saltwater intrusion often occurs when saltwater pushes inland beneath the freshwater aquifer [1]. In many coastal areas it has been enhanced by human activities such as groundwater pumping from coastal freshwater wells, excessive water extraction and building of navigation, agricultural and drainage channels, which provide ways for saltwater to move inland, lowering the level of fresh groundwater. The ecological consequences are the disappearance of freshwater species and an increase of alophilic and salt-tolerant ones, followed by sterility of agricultural land. The WARBO project aims to provide artificial recharge of wells by injection of freshwater, the only successful method to hinder the increasing water shortage and drought. The quality of aquifers chosen for artificial recharge may be assessed by analysis of biodiversity and of bioindicators, animal, plant or fungal species sensitive to pollutants and thus suitable to monitor ecosystem health [2] [3]. In order to evaluate the quality of an aquifer for artificial recharge and environmental amelioration, we monitored the biodiversity (macroinvertebrate community) and the physical-chemical parameters in a naturally flooded quarry near Copparo (Ferrara, Italy) chosen as an experimental site for a WARBO project of artificial recharge in Northern Italy [4].

Acknowledgements

We owe thanks to the staff of the WARBO project and to the municipality of Copparo (Ferrara, Italy) for kind collaboration and support.

References

[1] Giambastiani BMS, Antonellini M, Oude Essink GHP, Stuurman RH. Saltwater intrusion in the unconfined coastal aquifer of Ravenna (Italy): A numerical model. *J Hydrol* 2007; 340:91-104.

[2] McKenzie DH, Hyatt D, McDonald VJ. *Ecological indicators*. New York USA: Elsevier; 1990.

[3] Grillas P. Identification of indicators. In: Tomas Vives P, editor. *Monitoring Mediterranean Wetlands: A Methodological Guide*. Slimbridge UK: Med Wet Publication; Wetlands International; 1996.

[4] Dal Prà A, Mezzalira G, Niceforo U. Esperienze di ricarica della falda con aree forestali di infiltrazione. *L'Acqua* 2010; 2:77-78.

[5] Nieto Yàbar D, Accaino F, Affatato A, Barbagallo A, Baradello L, Coren F, Paganini P, Vaccaro C, Abu Zeid N, Leis M, Santarato G, Farina S, Gruppioni M. Innovative technologies for the sustainable management of water resources: the WARBO (WAter Re-BOrn) project. *Boll Geofis Teor Appl* 2012; 53:253-260.

[6] LIFE07 ENV/IT/000475. Technical report on Techniques for Management of Artificial Recharge (MAR). Final report, 31 December 2011. http://www.lifetrust.it/cms/

[7] Minelli A, Ruffo S, La Posta S. *Checklist delle specie della fauna italiana*. Bologna Italia: Edagricole; 1995.

[8] Tremblay E. *Entomologia applicata*. *Volume IV*. Napoli Italia: Liguori Editore Srl; 2000.

[9] Pereira HM, Ferrier S, Walters M, Geller GN, Jongman RHG, Scholes RJ, Bruford MW, Brummitt N, Butchart SHM, Cardoso AC, Coops NC, Dulloo E, Faith DP, Freyhof J, Gregory RD, Heip C, Höft R, Hurtt G, Jetz W, Karp DS, McGeoch MA, Obura D, Onoda Y, Pettorelli N, Reyers B, Sayre R, Scharlemann JPW, Stuart SN, Turak E, Walpole M, Wegmann M Essential biodiversity variables. *Science* 2013; 339:277-278.

[10]. Badea AB, Gagyi-Palffy A, Stoian LC, Stan G. Preliminary studies of quality assessment of aquatic environments from Cluj suburban areas, based on some invertebrates bioindicators and chemical indicators. *AACL Bioflux* 2010; 3:35-41.

Web sites:
http://www.warbo-life.eu/
http://www.arpa.emr.it