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ABIOTIC PARAMETERS IN TUNIS SOUTHERN LAGOON AFTER AN ENVIRONMENTAL RESTORATION AND STATUS OF MACROBENTHIC BIOCENOSIS (NORTHERN TUNISIA, CENTRAL MEDITERRANEAN SEA)

Khadija OUNIFI BEN AMOR & Mohamed Mourad BEN AMOR
Laboratoire de Biodiversité, Biotechnologie et Changements Climatiques, Faculté des Sciences de Tunis, Université Tunis El Manar, Tunis Tunisie. Institut National des Sciences et Technologies de la Mer, port de pêche, 2025 La Goulette, Tunisia

Jamila BEN SOUISSI
Institut National Agronomique de Tunisie, 43 Avenue Charles Nicolle, cité Mahrajène 1082, Tunis Tunisie.
e-mail: ounifikhadija@yahoo.com

ABSTRACT

Tunis Southern Lagoon was previously polluted by anthropogenic activities which needed a thorough environmental restoration, achieved during September 2001. The aim of the work is to reveal the positive changes of the abiotic parameters and their role on the biodiversity of the lagoon. Ecological measures carried out during a 24-months period (from October 2014 to September 2016) at 3 fixed stations, showed an improvement in water quality, confirming the positive impact of the restoration project. An overview of the macrobenthic biocenosis evolution is also discussed in the present work.

Key words: Eutrophication, restoration, improvement, water quality, biodiversity

PARAMETRI ABIOTICI NELLA LAGUNA MERIDIONALE DI TUNISI DOPO IL RESTAURO AMBIENTALE E STATO DELLA BIOCENOSI MACROBENTONICA (TUNISIA SETTENTRIONALE, MEDITERRANEO CENTRALE)

SINTESI

In passato la Laguna meridionale di Tunisi è stata contaminata da varie attività antropogeniche e pertanto necessitava di un accurato restauro ambientale, effettuato nel settembre 2001. L'articolo vuole evidenziare i cambiamenti positivi dei parametri abiotici e il loro ruolo sulla biodiversità della laguna. Le misure ecologiche effettuate nel corso di un periodo di 24 mesi (da ottobre 2014 a settembre 2016) in 3 stazioni fisse, hanno mostrato un miglioramento della qualità dell'acqua, confermando l'impatto positivo del progetto di restauro. Nel presente lavoro viene anche presentata una revisione dell'evoluzione della biocenosi macrobentonica.

Parole chiave: eutrofizzazione, restauro, miglioramento, qualità dell'acqua, biodiversità

INTRODUCTION

In the last decades, Tunis Southern Lagoon was polluted by local anthropic activities which induced dystrophic crises together with destruction of benthic communities (Ben Souissi, 2002; Chakroun, 2004), due to the fact that this lagoon poorly communicated with the sea. Water renewal was low, and a hyper-eutrophication and contamination by toxic heavy metals occurred in this brackish restricted area. An environmental rehabilitation of the lagoon was decided by Tunisian authorities to limit eutrophication and contamination by toxic industrial discharges. The project also aims to improve biodiversity and gradually restore fishery activities in the lagoon (Ben Souissi *et al*. 2015). The project of restoration was conducted between April 1998 and July 2001 by the Society for Research and Promotion of Tunis (SEPTS) and the consortium (LAC SUD 2000) (Vandenbroek and Ben Charrada 2001). The environmental restoration focused the enlargement the depth of the canal joining the lagoon to the sea and installing a hydraulic system allowing frequent renewal of the waters of the lagoon and the elimination of areas of water stagnation. The main objective of this study consists to analyze the new ecological status of this ecosystem based on 2 years of measurements locally carried out. An overview on its macrobenthic flora and the fishing interest fauna is discussed in this paper to point out the impact of ecological restoration on the biological environment.

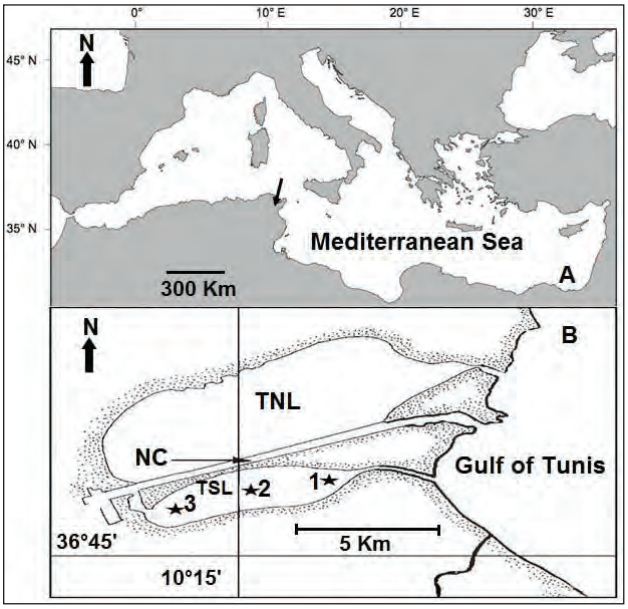

Fig. 1: A. Map of Tunisia pointing out the site of Tunis Southern Lagoon (TSL) located in the north. B. Tunis Northern Lagoon (TNL) separated from Tunis Southern Lagoon by a navigation channel (NC).1-3 sampling stations in TSL.
Sl. 1: A. Zemljevid Tunizije z označeno južno tuniško laguno (TSL) na severu. B. Severna tuniška laguna je od južne omejena s plovnim kanalom (NC). 1-3 Vzorčevalne postaje v TSL.

MATERIAL AND METHODS

The Lagoon of Tunis is separated in two areas by a navigation canal (Fig. 1). Tunis Southern Lagoon extends over an area of 720 ha with an almost regular depth of about 2.4 m. It appears as an ellipse stretching in a SW-NE direction, between 36°46'47"and 36°48'00"N and 10°12'22" and 10°16'41"E. Its shores have been excavated and protected by large rocky blocks. Three sampling stations are located in the lagoon and indicated by; Station 1 located to the east of the lagoon near the bay of Tunis, station 2 in the middle and station 3 in the west (Fig. 1). To access to these stations, a flat bottom boat suitable for navigation in the lagoon was used, the analyses consist of monthly measurements carried out *in situ* and in the laboratory during a 24 months from October 2014 to September 2016.

Temperature, salinity, pH, and dissolved oxygen were monthly measured at approximately 10 cm below the surface using a salinometer (WTW.LF 197), a pH meter (WTW. pH 197) and oximeter (WTW.OXI 197) calibrated beforehand. Turbidity was measured using a Secchi disk. In the laboratory, chemical analyzes of total nitrogen and phosphorus were analyzed in the laboratory by means of a photometric method which uses, as reagents, kits tests previously prepared by the supplier of the equipment. The basic tool of the photometric method is a photometer Photolab S12 type WTW equipped with a thermoreactor CR3000 type WTW. The chlorophyll-a was determined using the spectrophotometric method of Lorenzen (1967) and following Parsons *et al*. (1984), the analysis of the latter must be initiated rapidly (within 3 hours after sampling). The main results of two years of measurements are presented below. Data on macrobenthic fauna and flora were based on a compilation of published articles, thesis, surveys and our own observations in the last decade.

RESULTS

Temperature - The total average of 2 years of measurements is 20. 3 °C, the minima recorded vary between 9.8 and 11.8 °C and the maxima between 26.6 and 28 °C (Fig. 2). Temperatures recorded in station 1, near the Gulf of Tunis, show a slightly higher thermal gradient (1°C) compared to the other stations. This gradient is explained by the discharges of electric central near the water inlet to the lagoon, which discharge about 60 m^3s^{-1} of hot water. This difference is more appreciable in winter than in summer.

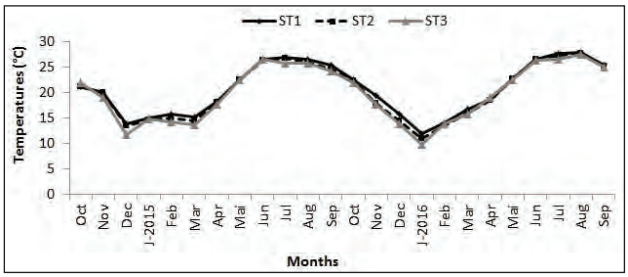

Fig. 2: Water temperatures in the Tunis southern lagoon (from October 2014 to September 2016)
Sl. 2: Temperatura vode v južni tuniški laguni (od oktobra 2014 do septembra 2016).

Salinity - The salinity in the lagoon is homogeneous. The mean value recorded during our study period is 37.5. The lowest exceptional salinities were 31.3 and 34.1 recorded respectively in September 2015 and February 2016 (Fig. 3). These values are recorded as a result of rainfall that caused storm water to enter the lagoon from the banks. The maximum salinity has reached a value of 39 recorded in July 2016 due to high temperatures that enhanced evaporation in the lagoon. With the exception of these values, salinity has varied with an annual gradient that usually does not exceed 1. This is mainly due to the rapid renewal of the lagoon water, which makes the effect of evaporation relatively low.

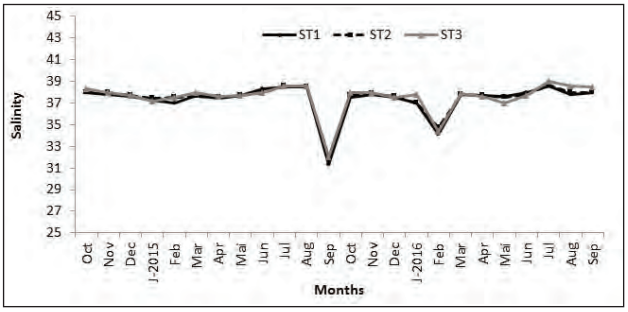

Fig. 3: Water salinity in the Tunis southern lagoon (from October 2014 to September 2016).
Sl. 3: Slanost v južni tuniški laguni (od oktobra 2014 do septembra 2016).

pH - The mean pH recorded in the southern lagoon over the period from October 2014 to September 2016 is 8.3, the maximum value is 9 while the minimum is 7.85 (Fig. 4). The relatively low values recorded in summer 2015 are mainly due to the exceptional warmth occurred during this period, which accelerate the fermentation and mortality of macroalgae inducing a relatively low pH. During the period of algal growth, the release of CO2 tends to increase this parameter.

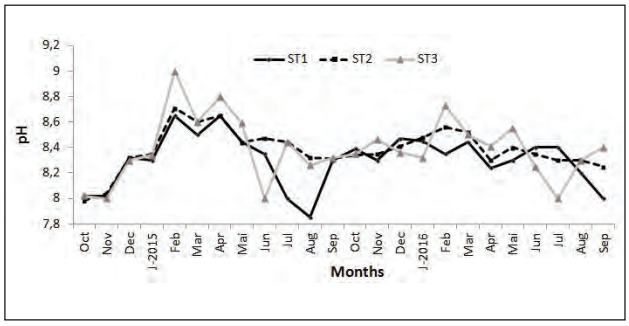

Fig. 4: Water pH in the Tunis southern lagoon (from October 2014 to September 2016).
Sl. 4: pH vode v južni tuniški laguni (od oktobra 2014 do septembra 2016).

Transparency - The average transparency of the water in the lagoon is about 2.0 m (Fig. 5). The lowest transparency values are recorded in station 1, which is largely influenced by the water in coming from the Gulf of Tunis. From station 2, the visibility conditions change and the influence of the gulf decreases considerably, the transparency is therefore better. The western part of the lagoon (ST3) represents the most transparent zone because it is less influenced by the gulf; moreover, it is constantly invaded by caulerpes, having roots sunk in the sediment, with a tendency to fix the materials on the bottom.

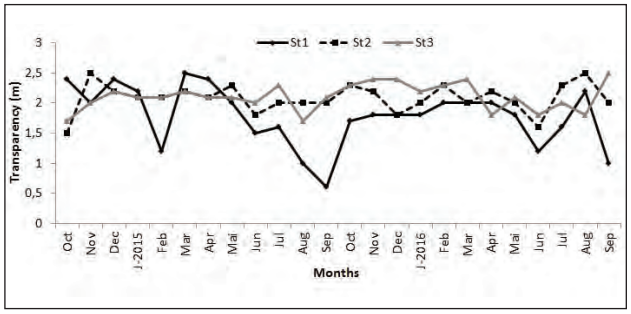

Fig. 5: Monthly fluctuations of Transparency (m) in the Tunis southern lagoon (from October 2014 to September 2016).
Sl. 5: Mesečna nihanja prozornosti (m) v južni tuniški laguni (od oktobra 2014 do septembra 2016).

Dissolved Oxygen - The dissolved oxygen contents range from 70 to 130%. The average of the two years of measurements in the lagoon is 90% (Fig. 6). The maximum values observed are due to the production of oxygen by photosynthesis of macroalgae and the minimum values observed are probably due to the mineralization of organic matter resulting from the mass mortality of nitrophilic algae.

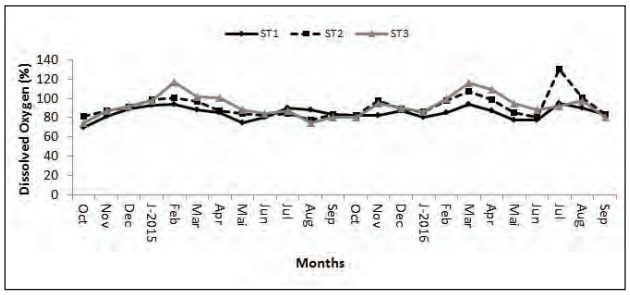

Fig. 6: Monthly fluctuations of dissolved Oxygen (%) in the Tunis southern lagoon (from October 2014 to September 2016).
Sl. 6: Mesečna nihanja koncentracij raztopljenega kisika (%) v južni tuniški laguni (od oktobra 2014 do septembra 2016).

Total Nitrogen - The average total nitrogen concentration over the two years is 674 µg/l. An extreme value of 1378 µg/l was recorded in November 2015 (Fig. 7). This rate coincided with the massive mortality of macroalgae in this month since the organic form of nitrogen constitutes about 89% of total nitrogen.

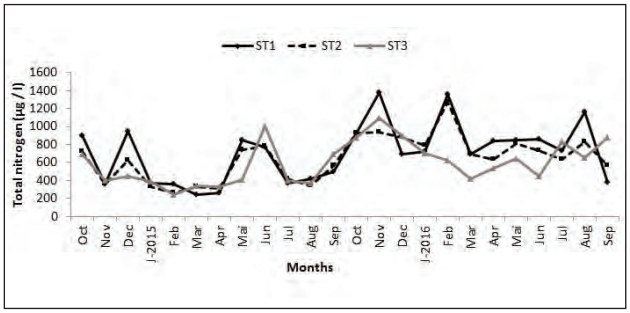

Fig. 7: Monthly fluctuations of total nitrogen (µg/l) in the Tunis southern lagoon (from October 2014 to September 2016).
Sl. 7: Mesečna nihanja koncentracij celokupnega dušika (µg/l) v južni tuniški laguni (od oktobra 2014 do septembra 2016).

Total phosphorus - The total phosphorus content range from 9 to 93 µg/l with an average of 32.7 µg/l (Fig. 8). The peaks are due either to the mortality of the macroalgae or to the action of the floods and rains that preceded the periods of these peaks and which brought large quantities of phosphate nutrients into the lagoon.

Chlorophyll-a - The Chlorophyll-a allow us to assess the degree of eutrophication of the water, in the Tunis southern lagoon, chlorophyll-a concentration varies from 0.28 to 14.88 µg/l (Fig. 9). The average of the two years relatively low at 2.5 µg/l.

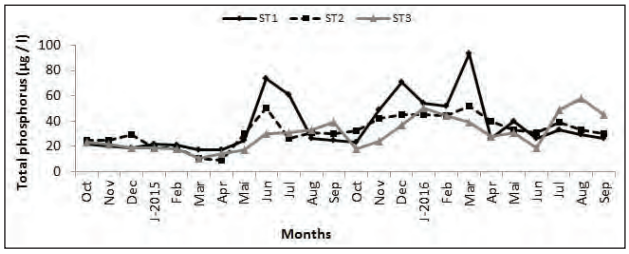

Fig. 8: Monthly fluctuations of total phosphorus (µg/l) in the Tunis southern lagoon (from October 2014 to September 2016).
Sl. 8: Mesečna nihanja koncentracij celokupnega fosforja (µg/l) v južni tuniški laguni (od oktobra 2014 do septembra 2016).

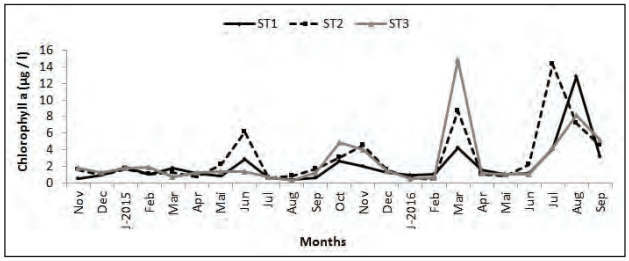

Fig. 9: Monthly fluctuations of Chlorophyll a (µg/l) in the Tunis southern lagoon (from October 2014 to September 2016).
Sl. 9: Mesečna nihanja koncentracij klorofila a (µg/l) v južni tuniški laguni (od oktobra 2014 do septembra 2016).

DISCUSSION

Prior the lagoon's ecological rehabilitation, the average monthly salinity ranged between 31 and 48.9 (Ben Souissi 2002), between 37 and 38.3, after environmental restoration. This comparison indicated that the euryhalin character of the lagoon is changed into "marinization" *sensu* Zaouali and Baeten (1983). High levels of dissolved oxygen in water trend towards an eutrophication, and to date since the end of environmental restoration, no dystrophic crisis was observed; the dissolved oxygen levels oscillate around the saturation point (Hermi & Aissa (2002); Chakroun, 2004). Monthly pH averages were saw-tooth fluctuations between 8.11 and 9.49 and may even reach very alkaline pH values as a result of spills of various chemical pollutants (Ben Souissi 2002). This parameter currently has a spatiotemporal stability since the minimum value did not drop below 8 and the maximum value did not exceed 8.4.

Based on the key parameters of eutrophication indicators: total phosphorus and chlorophyll-a, expressed as annual averages, the eutrophication status of the Tunis Southern Lagoon waters can be outlined. The report of

these concentrations on the abacus following the model proposed by the OCDE (1982) showed that the waters of the Tunis southern lagoon are mesotrophic with a probability of 54% *versus* the hypereutrophic state observed before the restoration with a probability of 70% (Jouini *et al.,* 2005).

The restoration of the lagoon displayed a high increase of biodiversity, with occurrence of species of phanerogams and seaweed of marine origin. Among new established vegetation in the lagoon were found the endemic caulerpe *Caulerpa prolifera* **(**Forsskål) J.V.Lamouroux, 1809, and the brown algae *Cystoseira barbata* (Stackhouse) C.Agardh, 1820 indicator of a healthy ecosystem (Ben Souissi *et al*., 2015). Prior to restoration, the benthic macroflora was exhibited a very low biodiversity characteristic from eutrophic euryhalin and eurytherm facies dominated by *Ulva rigida* C.Agardh, 1823, typical of lagoon environments (Ben Souissi, 2002; Shili *et al*., 2002).

The lagoon azoic during its restoration was progressively invaded by several species, among them were found immigrants from Indo-Pacific origin established since autumn 2001 in the area with the start-up of locks and the restoration of communication with the sea (Gulf of Tunis) and the lagoon itself (Ben Souissi *et al.,* 2003).

The current malacological fauna of the lagoon is comprised 50 species of molluscs, 2 Polyplacophora, 28 gastropods (especially nudibranchs), 17 bivalves and 3 cephalopods *versus* only 29 species recorded before restoration (Eteres *et al*. 2011). Of these 50 species, 5 are allochthonous having an Indo-Pacific origin. The best instance is *Fulvia fragilis* (Forsskål & Niebuhr, 1775), which colonized and invaded the entire lagoon, with presence of juveniles and specimens up to 60 mm in width (Rifi *et al*., 2011; 2013).

Therefore, new activities have been developed such as the collection of mussel on artificial rocky banks of the lagoon and fishery of cephalopod species such as common cuttlefish *Sepia officinalis* Linnaeus, 1758 and musky octopus *Eledone moschata* (Lamarck, 1758).

A diversity of carcinological fauna was displayed in the lagoon comprising 44 crustacean species (19 decapods, 11 isopods, 10 amphipods, 3 barnacles and a single stomatopod) were recorded *versus* 29 before the ecological rehabilitation of the lagoon. Of these 44 species, 31 are autochthonous and 13 allochthonous (Ounifi Ben Amor *et al*. 2017). The presence of some species seems not to be transient since several of them were well established in the area (Ounifi Ben Amor *et al*., 2015; 2016a; 2016b).

The ichthyofauna is also much diversified and concomitantly allowed the resumption of fishing activities in area. Eight species of elasmobranch and more than 70 teleost species are recorded in the lagoon (Méjri *et al*., 2004; Ben Souissi *et al*., 2005). A survey carried out in 2014 among fishermen operating regularly in the lagoon shows that the local ichthyofauna included more than 90 species (Ben Souissi *et al*. 2015).

The physicochemical and trophic analyzes carried out before and after the restoration of Tunis southern lagoon, display a high water quality, stability and an improvement in edaphic environment of the lagoon. This homogenization observed after the ecological restoration is the consequence of an important exchange between the lagoon and the Gulf of Tunis. Such exchange and the absence of water stagnation in some areas have led to a marked disappearance of nitrophilous algae *versus* the reappearance of marine species. The successful settlement of these latter in Tunis southern lagoon revealed the evident improvement of the lagoon waters.

ABIOTSKI PARAMETRI V TUNIŠKI JUŽNI LAGUNI PO OKOLJSKI OBNOVI IN STATUS MAKROBENTOŠKIH BIOCENOZ (SEVERNA TUNIZIJA, OSREDNJE SREDOZEMSKO MORJE)

Khadija OUNIFI BEN AMOR & Mohamed Mourad BEN AMOR
Laboratoire de Biodiversité, Biotechnologie et Changements Climatiques, Faculté des Sciences de Tunis, Université Tunis El Manar, Tunis Tunisie. Institut National des Sciences et Technologies de la Mer, port de pêche, 2025 La Goulette, Tunisia

Jamila BEN SOUISSI
Institut National Agronomique de Tunisie, 43 Avenue Charles Nicolle, cité Mahrajène 1082, Tunis Tunisie.
e-mail: ounifikhadija@yahoo.com

POVZETEK

Južna tuniška laguna se je soočala z onesnaženjem zaradi antropogenih dejavnosti, zato je prišlo septembra 2001 do okoljske obnove. Namen tega prispevka je obelodaniti pozitivne spremembe v abiotskih dejavnikih in njihovo vlogo glede biodiverzitete v laguni. Ekološke meritve, ki so potekale v 24-mesečnem obdobju (od oktobra 2014 do septembra 2016) na 3 stalnih postajah, so pokazale izboljšanje kvalitete vode in s tem potrdile pozitivni učinek projekta obnove. Avtorji v delu razpravljajo tudi o makrobentoških biocenozah.

Ključne besede: evtrofikacija, obnova, izboljšanje, kvaliteta vode, biodiverziteta

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