



HAL
open science

Extreme and Heterogeneous Conditions of the Desert Wetland Chott Ech Chergui (Algeria) Allow Isolating Halophilic, Alkalophilic and Thermophilic Bacteria

Aicha Mehrou Zouggar, Pascal Mirleau, Anne Chenuil, Françoise Denis, Aurore Caruso, Sidi Mohammed El Amine Abi Ayad, Sid Ahmed Chawki Lamara

► **To cite this version:**

Aicha Mehrou Zouggar, Pascal Mirleau, Anne Chenuil, Françoise Denis, Aurore Caruso, et al.. Extreme and Heterogeneous Conditions of the Desert Wetland Chott Ech Chergui (Algeria) Allow Isolating Halophilic, Alkalophilic and Thermophilic Bacteria. *Wetlands*, 2023, 43 (108), 10.1007/s13157-023-01757-5 . hal-04320473

HAL Id: hal-04320473

<https://hal.science/hal-04320473v1>

Submitted on 4 Dec 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Extreme and heterogeneous conditions of the desert wetland Chott Ech Chergui (Algeria) allow isolating**
2 **halophilic, alkalophilic and thermophilic bacteria.**

3
4 **Authors' name and ORCID number:**

5 Aicha Mehrou Zouggar^{1,2},

6 Pascal Mirleau^{2*}, ORCID N° 0000-0002-9654-6045

7 Anne Chenuil², ORCID N° 0000-0001-8141-7147

8 Françoise Denis^{3,4}, ORCID N° 0000-0002-0006-8238

9 Aurore Caruso⁴, ORCID N° 0000-0002-4327-543X

10 Sidi Mohammed El Amine Abi Ayad¹,

11 Sid Ahmed Chawki Lamara¹

12
13 **Affiliations:**

14 ¹ Laboratoire d'Aquaculture et Bioremédiation (AquaBior), Université Oran1 Ahmed Ben Bella, Algeria.

15 ² Aix Marseille Univ, Avignon Université, CNRS, IRD, IMBE, Marseille, France.

16 ³ UMR BOREA (Biologie des Organismes et Ecosystèmes Aquatiques), MNHN/CNRS

17 7208/IRD 207/UPMC, Muséum National d'Histoire Naturelle, Station de Biologie Marine de Concarneau,
18 29900, Concarneau, France.

19 ⁴ Laboratoire BIOSSE (Biologie des Organismes : Stress, Santé, Environnement), Le Mans Université Avenue
20 Olivier Messiaen, 72085, Le Mans Cedex 9, France.

21
22 *Corresponding author:

23 Email: pascal.mirleau@imbe.fr,

24 Tel.: +33 4 13 94 50 42

25 Fax: +33 4 91 28 86 68

26
27 **Acknowledgments**

28 We thank M. Rabahi and C. Mehali for their contribution to the field work, M. Meliani, S. Nil and the SEOR
29 ORAN compagnie for their help to measure water physicochemistry and to complete microbiological analyses.

30 We are grateful to the "Service Commun de Biologie Moléculaire" at IMBE for providing facilities and technical
31 assistance during DNA manipulation.

33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51

Abstract

Wetlands concentrate biodiversity, particularly in arid regions. Chott Ech Chergui (Algeria), one of the biggest wetlands of the north African desert, presents extreme temperatures and salinity conditions. We initiated a physico-chemical and microbiological survey at seven sites encompassing various conditions (salt lakes, freshwater lakes and hot springs), through a one-year monthly sampling campaign. Four sites under the influence of the spring showed little temporal physio-chemical variation. Three sites displayed higher variation and the aridity level, high from late spring until autumn, was a strong predictor of water chemistry. We evidenced extremophile bacteria. Among 320 bacterial isolates tested for thermo-, acido- and alcalino- tolerance, 39, affiliated to Firmicutes and Proteobacteria, were successfully maintained and underwent physiological, biochemical and molecular characterizations. Thermotolerance was recorded up to 100°C for a water isolate affiliated to *Geobacillus stearothermophilus*. Halotolerance was recorded up to 30% NaCl (w:v) for soil isolates affiliated to *Salinicola zeshunii*, *Chromohalobacter beijerinckii* and *Virgibacillus halodenitrificans*. Acido- and alcalo- tolerance were recorded for a pH range from 5 to 11 for several soil and water isolates affiliated to *Exiguobacterium*, *Bacillus*, *Salinicola* and *Chromohalobacter* genus. Our results comfort the interest of studying extremophile diversity in wetlands of the highly arid Sahara region.

Keywords: 16S rDNA, Aridity, Conservation value, Extremophile bacteria, Sahara.

52 **1. Introduction**

53 Wetlands account for about 40% of the overall value of ecosystem services worldwide (Gardner and Finlayson
54 2018). As source and reservoirs of water, they support a rich biodiversity through nutrient allocation and
55 resource provisioning. They also ensure protection from floods and droughts to surrounding people and globally,
56 they are important carbon sinks. However, they are severely endangered by global change, which is now
57 responsible for the loss of 21 percent of wetlands world's surfaces (Fluet-Chouinard et al 2023).

58 By contrast with temperate regions, wetlands of north Africa that are located at the door of arid deserts face
59 extreme conditions of dryness and elevated temperature that make them even more vulnerable to climate change,
60 with important consequences on biodiversity and ecosystem services they support. In Algeria, Chott Ech Chergui
61 (34°16'N 00°33'E), one of the largest African wetlands covers an area of 855,500 hectares (altitude 1000 m) at
62 the frontier of the Algerian desert between the north of the tellaric Atlas and the south of the Saharan Atlas. Its
63 water table is made up of three interconnected aquifers (Tertiary continental, Seneonic and Bajo-Bathon
64 aquifers) (Aoudia et al 2020) from which emerge natural thermal springs. These were exploited by drilling
65 between 1985 and 1990 to create an irrigated area of 2850 ha and to allow agricultural expansion in such an
66 inhospitable area. In parallel to increasing drought in the region, decrease of the hot springs flow was observed,
67 dropping from 600 L.s⁻¹ in 1960 to 80 L.s⁻¹ in 2019, which evidenced the decrease of the water table level
68 (Remini 2010; Direction Générale des Forêts Saïda, personal communication) and the vulnerability of such a
69 large wetland facing land-use change (Winkler et al 2021), especially since Chott Ech Chergui is a shallow flat-
70 bottomed depression locally called “sebkha”. Known to hold significant faunistic and floristic richness, Chott
71 Ech Chergui was included in the List of Wetlands of International Importance of the Ramsar Convention in 2001
72 (<http://www.ramsar.org>). However, besides studies on land use cartography and floristic diversity showing that
73 aridity and human activities threaten this ecosystem (Arabi and Mederbal 2016), the physicochemical
74 characteristics of Chott Ech Chergui surface water, and the biodiversity it holds have not yet been documented,
75 although these characteristics are essential to understand the wetland dynamics, its degradation and ultimately
76 define conservation strategies.

77 Given its location, Chott Ech Chergui is a possible reservoir of microorganism holding physiological and
78 biochemical characteristics typical of such arid environment that have high valorization potential in
79 biotechnologies. Such extremophile organisms have evolved the ability to thrive in environment showing
80 extreme values of temperature (>50°C), salinity (>5%, w:v) or pH (<6 or >8) such as in hot springs (Nabagye
81 and Yatuha 2022), geothermal area (Belilla et al 2019), salterns (Leoni et al 2020) or salt water (Saibi et al 2022;
82 Hassani et al 2022). In some situations, with overlaid environmental stresses, some microorganisms - that are
83 called “polyextremophile”, have acquired surprising capacities to withstand superimposed environmental
84 stresses (Egamberdieva et al 2018). Microbial communities living in such extreme conditions are given much
85 attention as potential early Earth ecosystem analogs and sources of new genes and metabolites valuable for
86 bioengineering (Ye et al 2023). Studies on such extreme microbial communities often combine cultivation and
87 molecular approaches (Belilla et al 2019).

88 With the objective to gain knowledge on the physicochemical characteristics of Chott Ech Chergui wetland and
89 its yearly dynamics, we achieved a one-year monthly monitoring of water physicochemical characteristics at
90 several locations potentially uncovering distinct environmental situations as regards of temperature, salt and
91 nutrient concentrations. Expecting that to the typical environmental conditions of Chott Ech Chergui should

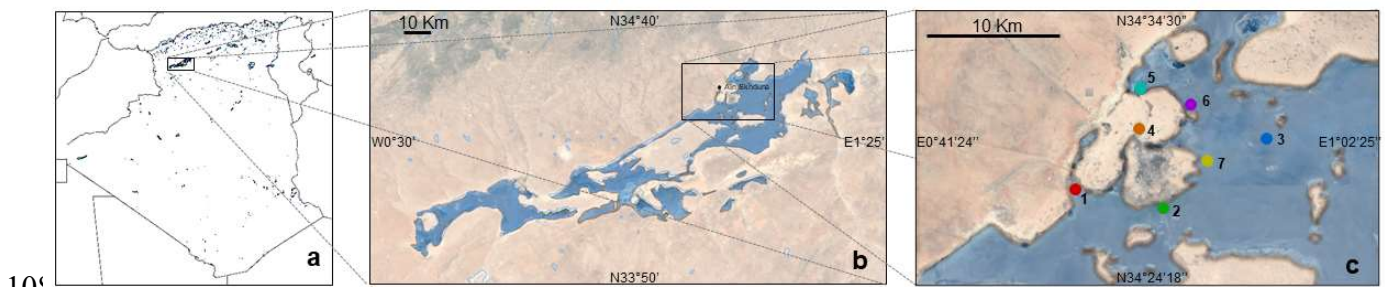
92 correspond typical microbial life, we established a culture collection of water extremophile bacteria that were
93 selected for particular thermo-, halo- or alkali- tolerance and we completed their phylogenetic identification.

94

95 2. Methods

96 2.1. Studied area and sample collection

97 Chott Ech Chergui presents several contrasted environmental conditions including thermal springs, freshwater,
98 and saltwater. To initiate the physicochemical and microbiological survey, locations showing regular water
99 availability and easy accessibility were chosen, leading to seven representative water sampling sites at proximity
100 of the major thermal spring of Chott Ech Chergui (Fig.1 and Table 1). All sampling sites and mapping data were
101 georeferenced using the mobile GPS GARMIN GPSmap 62. Cartography was generated using mapping software
102 ArcGis 10.1 and image superposition in Google Earth Pro 7.3. Sampling campaigns were conducted monthly
103 for one year from December 2018 to November 2019. At each site, samples of water and sediments were
104 collected in triplicate at a maximum of 10 cm depth for both sample type and under aseptic conditions, using
105 sterile 2.5 L opaque glass bottles for surface water and sterile 50 mL opaque glass bottles for sediments. Samples
106 were preserved at 4°C until laboratory analysis. Water samples were filtered through sterile 0.22 µm pore-
107 diameter filters (Whatman) before chemical analyses (except suspended matter and turbidity).



108 **Fig. 1** Geographical location of chott Ech Chergui and of sampling sites near Ain Skhoua.
109 Map of the Algerian hydrological network, **a**; representation of Chott Ech Chergui wetland, **b**; and location of
110 study sites, **c**. Study sites have been affected a number and a colour as follows: 1 (red), Source Zawia; 2 (green),
111 Chott Ech Chergui; 3 (deep blue), Large sebkha; 4 (orange), Source Ain Skhoua; 5 (light blue), Bassin; 6
112 (purple), Small sebkha; 7 (yellow), Oued (see Table 1 for site characteristics). Latitude and longitude are
113 displayed on the maps' borders.

114

115 2.2. Meteorology and hydrodynamics

116 Meteorological data were obtained from the Algerian website freemeteo (<https://dz.freemeteo.com/>). Rainfall
117 readings (mm) were used to calculate monthly and annual precipitations. The minimum and maximum air
118 temperature (°C) per day were used for descriptive statistics (monthly and annual, monthly maximum and
119 minimum average temperatures). An ombrothermic diagram was drawn to determine rainfall and temperature
120 variations during the year of field sampling (Fig. 2). To better understand the region's climatic characteristics,
121 monthly and annual aridity index were determined according to De Martonne's classification (Pellicone et al
122 2019). For each site and date, water depth (cm) was determined using a measuring tape.

123

125 **2.3. Physicochemical characteristics**

126 pH, temperature, and salinity were measured *in situ* with Hanna probes HI991001, HI93530, HI96822 (0-150
127 ppm) in the salt site at 1/10 dilution in MilliQ water, respectively; dissolved oxygen and conductivity were
128 measured with Hanna probes dedicated to extreme conditions, HI9145 and HI99301, respectively. The water
129 turbidity was determined with a MARTINI Mi415 turbidimeter (0-1000 NTU). Within 24 hours of sampling and
130 using the methods outlined in Rodier's technical manuals (Rodier et al. 2009, 2016). Ammonium, nitrate, nitrite
131 and orthophosphate concentrations were determined by spectrophotometry (METERTECH SP8001) using
132 indophenol blue, sodium salicylate, sulfanilamide and ammonium molybdate colorimetric methods, respectively.
133 The determination of the hydrometric titer and calcium and magnesium contents were carried out using the
134 EDTA titrimetric method. The water chloride concentration was determined with silver nitrates according to the
135 Mohr Method and the organic matter concentration was determined through the reduction of potassium
136 permanganate by the oxidable matter in the water. Mineralization was calculated from conductivity measures
137 based on the calculation table described in the Rodier technical manuals (Rodier et al. 2009, 2016). Sulfate and
138 bicarbonate contents were determined in January, April, July, October by volumetric titration (Metrohm 848
139 Titrino plus, Metrohm). Potassium and sodium contents were determined by atomic absorption
140 spectrophotometry using the PFP7 Flame Photometer (Jenway). In addition, pH, salinity, and dry matter in
141 sediments was measured each season by SEOR company.

142

143 **2.4. Microbiological cultures and isolation**

144 Following tests of several culture media, Nutrient Agar (NA) was chosen as the most suitable to isolate the
145 different types of extremophiles and to ensure cost-effectiveness for future biotechnological developments. of
146 Culture duration and incubation temperatures were chosen according to (Rainey and Oren 2006). Bacterial
147 isolation was performed using a serial dilution method up to 10^{-3} in 0.85% sterile saline solution followed by an
148 enrichment step in liquid NA (Elazzazy et al 2015), with pH adjusted to 7 at the exception of alkali-tolerant
149 isolation, for which pH was adjusted to 11. For halo-tolerant isolation, sodium chloride was set to 250 g.L⁻¹. The
150 mediums were distributed in test tubes and sterilized by autoclaving 120°C for 20 min. Culture tubes were then
151 inoculated with one gram of sampled sediment or one milliliter of sampled water, making five replicates per
152 sample. Culture enrichments were incubated at 35°C for a period of 48 hours for alkalitolerant, one week for
153 halo-tolerant and 48 h at 65°C for thermo-tolerant culture. Bacterial isolation was achieved following streaking
154 of the enrichment cultures on NA slants and incubated as previously. Bacterial isolates were kept on agar slants
155 by regular streaking on fresh medium and freeze-stored in a 40% glycerol solution at -80°C.

156

157 **2.5. Biochemical, physiological and tolerance studies of bacterial isolates**

158 Standard bacteriology methods were used to identify the isolated strains (Holt 1994; Collins et al 2004). The
159 microscopic approach combined with Gram and spore staining methods was used as phenotypic characterization
160 of bacterial cell. To examine halotolerance, bacterial growth was achieved at salt concentrations ranging from
161 0% to 30% (W/V), with 1% NaCl supplementation steps. To examine thermotolerance, bacterial growth was
162 evaluated at temperature ranging from 4°C to 120°C with 3°C intervals. To examine pH tolerance, bacterial
163 growth was measured at each pH unit from pH=3 to pH=12. Each bacterial isolate was subjected to the following

164 biochemical tests: amylase, lipase, citrate reductase, nitrate reductase, acetoin production, motility, mannitol,
165 glucose, galactose, fructose, catalase, oxidase, gas and H₂S production. The strains' ability to synthesize
166 enzymes was tested under appropriate salt, temperature, and pH optimal range conditions for each strain.
167

168 **2.6. Phylogenetic characterization of bacterial isolates**

169 The bacterial cells were recovered from 1.5 mL culture subsamples following centrifugation at 1500 g for 20
170 min. Bacterial cell lysis was achieved following resuspension of the culture pellet in 200 mL buffer TE (Tris 10
171 mM, EDTA 1 mM pH 8), addition of 50 mL lysozyme (80 mg/mL) and incubation at 37° for 4 h. The mixture
172 was then crushed with glass beads for 90 s at 30 Hz using the TissueLyser (Qiagen). Following centrifugation for
173 30 s at 11000 g, the supernatant was collected in 2 mL tubes, and the pellet was washed in 250 mL of TE buffer
174 before being crushed and centrifuged once more. Both supernatants were combined and 30 µl of 10 mg/mL
175 RNase was added and the mixture was incubated at 50°C for 1h30. 25 µl of 2X lysis buffer (1% SDS, 20 mM
176 NaCl, 20mM Tris pH 8, 20 mM EDTA) and 2.5 µl of Proteinase K (20 mg/mL), followed by incubation at 50°C
177 for 2 h. The DNA was then precipitated with sodium acetate and ethanol (0.1 V sodium acetate pH = 8 at 3 M
178 and 3 V ethanol 100% at -20 °C). After overnight incubation at -20°C, the mixture was centrifuged at 16 000 g
179 for 20 min at 4°C. The supernatant was discarded and the pellet was rinsed with 100 µl of 70% ethanol (-20°C)
180 and soft manual stirring four times. Following centrifugation at 16000 g for 20 min at 4°C, the supernatant was
181 discarded and the DNA containing pellet was eluted in 50 µl TE buffer after total evaporation of the ethanol.
182 Nucleic acid assay and purity testing were performed using the NanoDrop™UV-visible spectrophotometer
183 (Thermo Scientific).

184 PCR amplification of the bacterial 16S rDNA was achieved using forward primer 16S 27F:
185 AGAGTTTGATCMTGGCTCAG (modified of Fd1 primer after (Winker and Woese 1991) and reverse primer
186 16S 1547 Rd1: AAGGAGGTGATCCAGCC (Winker and Woese 1991). PCR reactions were conducted in a
187 volume of 50 µl, with 0.2 mM each dNTP (PCR nucleotide Mix, Promega), 0.1 µM of each primer, 5 µl 10X
188 Buffer, 0.025 U/µL of DreamTaq DNA polymerase (ThermoScientific) and 10 pg to 1 µg genomic DNA was
189 added to the reaction mixture. After initial denaturation at 95°C for 2 min, we ran 40 cycles of denaturation at
190 95°C for 30s, followed by annealing at 55°C for 30s, elongation at 72°C for 1 min and a final elongation at 72°C
191 for 10 min. Amplicons were visualized following agarose (2%) gel electrophoresis and ethidium bromide
192 staining under UV light transilluminator (Molecular Imager® Gel Doc™). Amplicons of ~1500 nt were Sanger-
193 sequenced (Eurofins Genomics©).

194 16S rDNA sequences were manually edited using the BioEdit program (Hall et al 2011) based on visual
195 examination of chromatograms. 16S rDNA query sequences were submitted to the Genbank database and
196 provided with an accession number via the National Center for Biotechnology Information (NCBI; Table S1).
197 Most similar reference sequences were retrieved using the BLAST program and were joined to our new Sanger
198 sequences for phylogenetic reconstruction using the Mega X software (Kumar et al 2018). Query and reference
199 sequences were aligned using the CLUSTALW program (Thompson et al 2003), and phylogenetic trees were
200 reconstructed by the maximum composite likelihood method (Saitou and Nei 1987). Bootstrap test (500
201 replicates) was achieved to calculate the percentage of replicate trees in which the associated taxa clustered
202 together, and the evolutionary distances were computed using the Maximum Composite Likelihood method
203 (Tamura et al 2004).

204

205 **2.7. Statistical analyses**

206 Physicochemical data were analyzed using JMP 9.0 (SAS Institute Inc.) for univariate analysis and PRIMER v7
207 program and (Primer-E Ltd, Plymouth, United Kingdom; Clarke and Gorley 2015) for multivariate analysis.
208 Canonical analysis of principal coordinates was achieved using the CAP routine of the PERMANOVA+ program
209 (Primer-E Ltd, Plymouth, United Kingdom) and the variability of physicochemical data across sampling sites,
210 captured on CAP1 and CAP2 eigenvalues, was tested using between pair student t tests.

211 In addition, the distribution of the points representing the anions and cations characterizing the chemical
212 structure of the water of the Chott Ech Chergui was determined according to the piper diagram and using the
213 Diagram software. The chemical facies of the waters of each sampling site at the Chott Ech Chergui level was
214 illustrated from the average concentrations of calcium chloride, magnesium, sodium, potassium, sulphate,
215 bicarbonates and nitrates after their classification by the Schoeller Berkloff diagram using the Diagram
216 software.

217

218 **3. Results**

219 **3.1. Local meteorology and hydrodynamics**

220 The metrological data provided by Station Rghuis showed that mean monthly temperature varied between 11°C
221 and 28°C. The highest temperature recorded in the area was 48°C in July, and the lowest temperature was 0°C in
222 January. Large variations in the amount of rainfall were observed throughout the year, with ~60 mm recorded in
223 January, April, and November and ~26 mm spike recorded in September following a three-month drought
224 summer period (Fig. 2A). The aridity index displayed three peaks, mirroring the dynamics of precipitation
225 throughout the year (Fig. 2B). Water depth varied consequently during the sampling year with higher values
226 measured during rainy periods and lower values measured during the dry summer season (Fig. 2C). Among
227 sampling sites, the highest water depth (~32 cm) was measured on sites n°2 and n°5, in the vast freshwater
228 depression and at the beginning of a river fed by the second thermal source, respectively; the lowest values was
229 recorded during the driest months of July and August, with full drying out at site n°3 in the vast arid depression
230 fed by the 1st thermal spring and rainfalls.

231

232 **3.2. Temporal variation of water physicochemistry**

233 Most water parameters measured at site n°3 (Fig. 3) showed highest values and variability across sampling dates
234 (i.e. Salinity ~ 80g/L , Hardness ~2000 mg.L⁻¹ , Conductivity ~100000 µSm³, Organic Matter. ~17 mg.L⁻¹ ,
235 Mg⁺⁺ ~250 mg.L⁻¹ , Ca⁺⁺ ~600 mg.L⁻¹ , Cl⁻ ~2400 mg.L⁻¹ and NO₃⁻~40 mg.L⁻¹), which must be put in relation
236 with sediments with high salinity content (Table S1) and the succession of drying – rewetting periods that
237 prevented from correct water sampling in December 2018, July and August 2019. Also, sites n°1 and 4, that are
238 in the direct stream of the thermal sources showed an average temperature of ~35°C all year. However, for all
239 other sites, the temporal variation of water physicochemical parameters revealed seasonal patterns.

240

241
 242
 243
 244

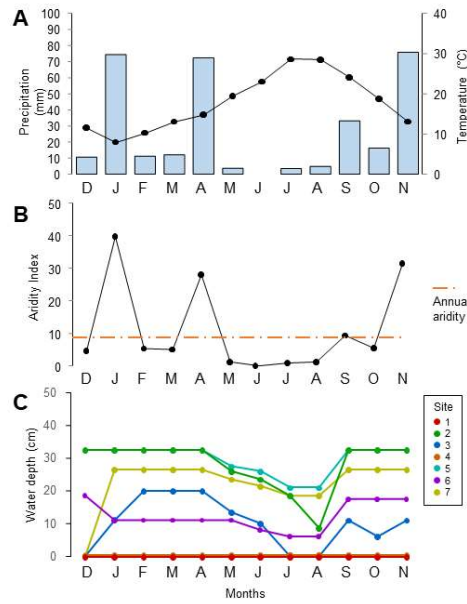


Fig. 2 Meteorology of the region of Ain Skhoua and hydrological dynamics of the study sites during the sampling campaign (December 2018 to November 2019): Ombrothermic diagram, **a**; variation of the aridity index, **b**; variation of water depth at each study site, **c**.

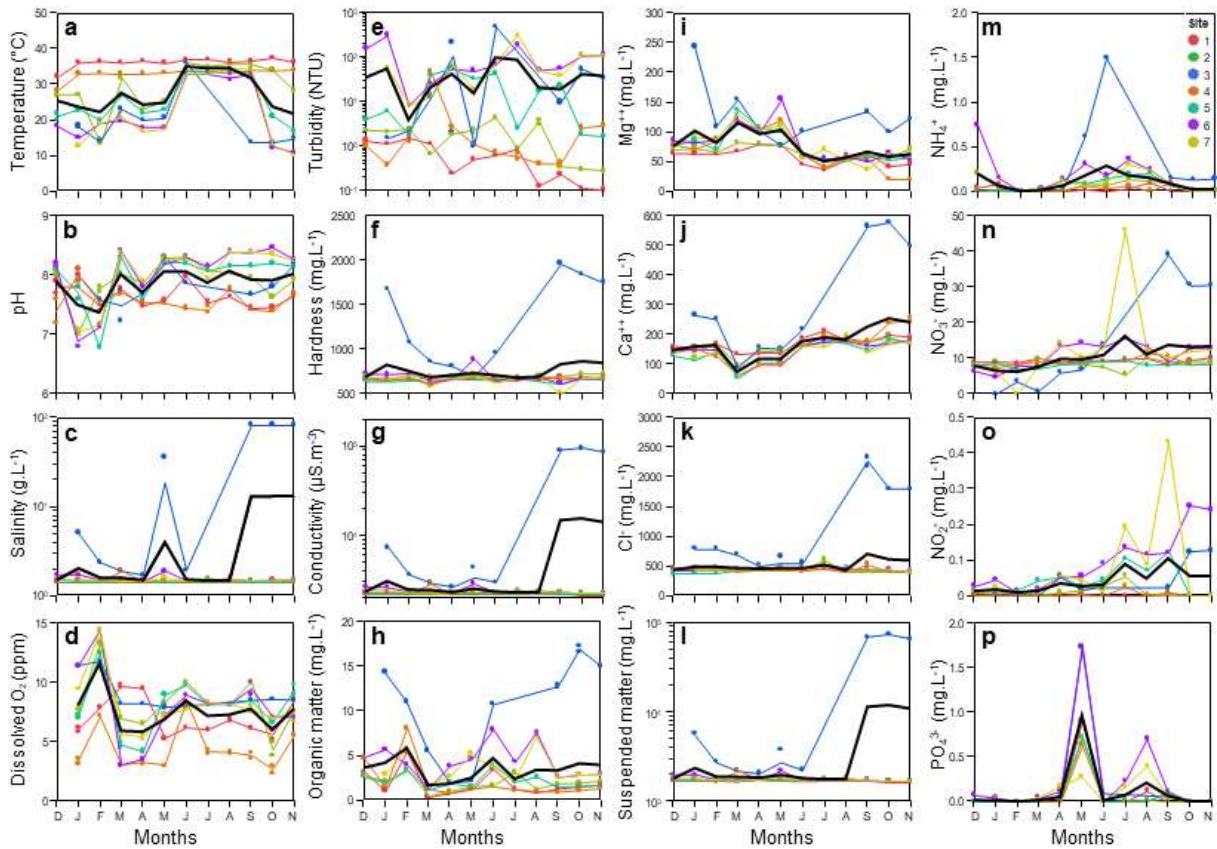


Fig. 3 Dynamics of water physicochemical parameters at the various sampling sites of Chott Ech Chergui between December 2018 and November 2019: temperature, **a**; pH, **b**; salinity, **c**; dissolved Oxygen, **d**; turbidity **e**; hardness **f**; conductivity, **g**; organic matter **h**; magnesium content, **i**; calcium content, **j**; chloride content, **k**; suspended matter, **l**; ammonium content, **m**; nitrate content, **n**; nitrite content, **o**; orthophosphates, **p**. Capital letters indicate successive sampling months on the X-axis. For convenience color legend of the sites is displayed in graph **m**. The thick black lines show across sites average values.

252 Winter was marked by low water temperature $\sim 23^{\circ}\text{C}$, with lower points at $\sim 12^{\circ}\text{C}$ locally). This was associated
253 with neutral pH values (~ 7.5), the highest values of dissolved oxygen (~ 12 ppm) and organic matter contents (~ 5
254 $\text{mg}\cdot\text{mL}^{-1}$). The arrival of spring came along with the slow increase of temperature (up to the maximum value of
255 $\sim 32^{\circ}\text{C}$ in June) and pH (reaching $\text{pH}\sim 8$ in May), while dissolved oxygen dropped importantly (down to ~ 6 ppm
256 in April) before rising up to a secondary peak late spring (~ 8 ppm in June). The organic matter content followed
257 a similar pattern as that of oxygen, with an important decrease early spring (down to ~ 2 $\text{mg}\cdot\text{L}^{-1}$ in April) and a
258 secondary peak late spring (~ 5 $\text{mg}\cdot\text{L}^{-1}$ in June). The magnesium content reached its highest value (~ 100 $\text{mg}\cdot\text{L}^{-1}$ in
259 May) in contrast to the calcium content that reached its lowest value (~ 80 $\text{mg}\cdot\text{L}^{-1}$ in March). Also, spring was
260 characterized by a peak value of phosphate content (~ 1 $\text{mg}\cdot\text{L}^{-1}$ in May).

261 From the late spring to early autumn, water temperature rises to the maximum value that characterize
262 permanently site n°1 and 4 ($\sim 32^{\circ}\text{C}$), at all other sites. This was associated with almost stable alkaline conditions
263 ($\text{pH}\sim 8$), low and stable oxygen content (~ 7.5 ppm) and a weak increase of the organic matter content. While
264 magnesium maintain at its lowest throughout summer (~ 50 $\text{mg}\cdot\text{L}^{-1}$), the calcium contents increased to reach its
265 maximum value early fall (~ 200 $\text{mg}\cdot\text{L}^{-1}$ in October). Interestingly, the nitrogen cycle was marked by successive
266 rises of ammonium content (rising up to ~ 0.25 $\text{mg}\cdot\text{L}^{-1}$ in June), nitrates contents (rising up to ~ 15 $\text{mg}\cdot\text{L}^{-1}$ in July)
267 and nitrites (rising up to ~ 0.1 $\text{mg}\cdot\text{L}^{-1}$ between July and September). Also, summer was marked by a secondary
268 peak value of phosphate (~ 0.2 $\text{mg}\cdot\text{L}^{-1}$ in August).

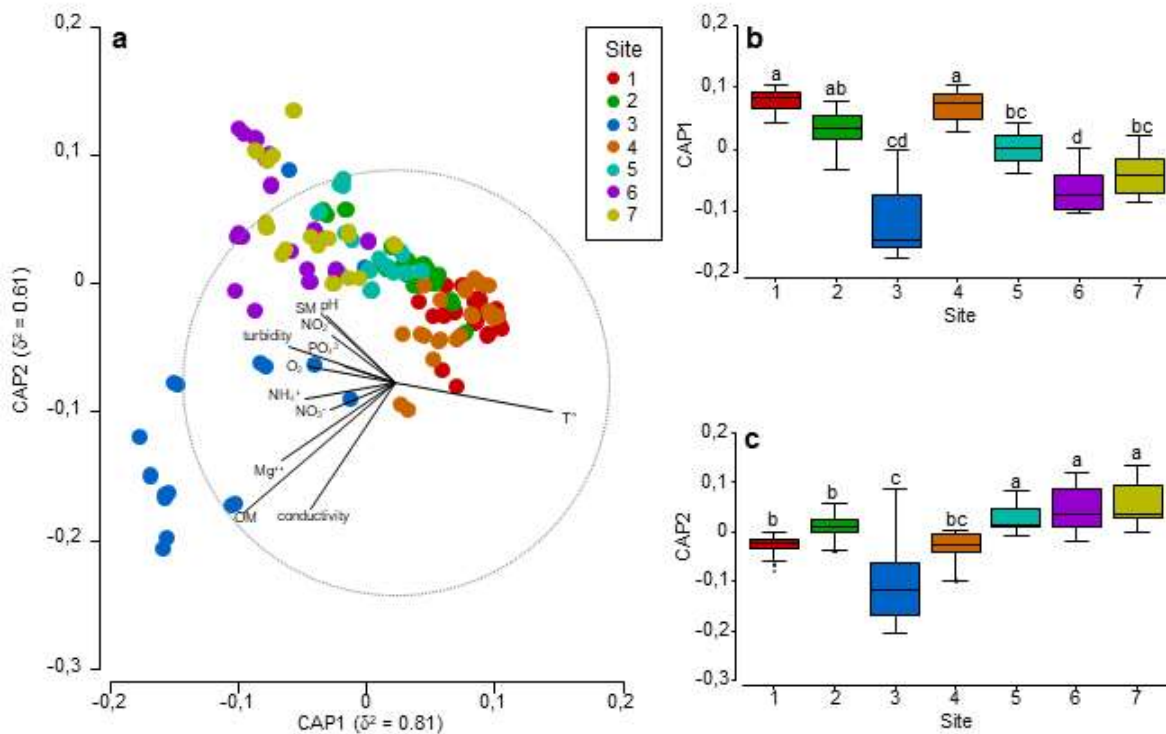
269 The third period of autumn was marked by water temperature dropping (down to $\sim 20^{\circ}\text{C}$), lowest values of
270 magnesium content (~ 50 $\text{mg}\cdot\text{L}^{-1}$) and highest value of calcium content (rising up to ~ 200 $\text{mg}\cdot\text{L}^{-1}$ in October and
271 November).

272

273 **3.3. Spatial variability of water physicochemistry**

274 The first two axes of the CAP analysis of water physicochemical parameter allowed categorizing the sampling
275 sites into three groups, showing their contrasted environmental conditions (Fig. 4). The superimposed correlation
276 circle summarizes the variables that describe the factors explaining the variation across sites. Sites 1 and 4,
277 corresponding to source Zaiwa and source Ain Skouna, respectively, were driven by elevated water temperature
278 and low values for much of the considered environmental parameters, which point out the oligotrophy and low
279 oxygenation of the thermal water resurging from the belowground water table. Sites 5, 6 and 7 and to a lower
280 extend site 2, opposed to the sites 1 and 4 on the CAP 1 axis partly due to contrasted water temperature regime,
281 but also because these sites showed high values of pH, suspended matter, nitrites, orthophosphate, turbidity and
282 oxygen content, which typify these sites as eutrophic and alkaline. Site 3, corresponding to the vast arid
283 depression of the Large Sebkha also opposed on the CAP 1 axis to the sources site. But site 3 opposed to site 5,
284 6, 7 and 2 on the CAP 2 axis as it showed high values of ammonium, nitrate, magnesium, organic matter and
285 conductivity (regrouping salinity, hardness, calcium content and chloride content). This latter site can thus be
286 qualified as eutrophic and saline.

287

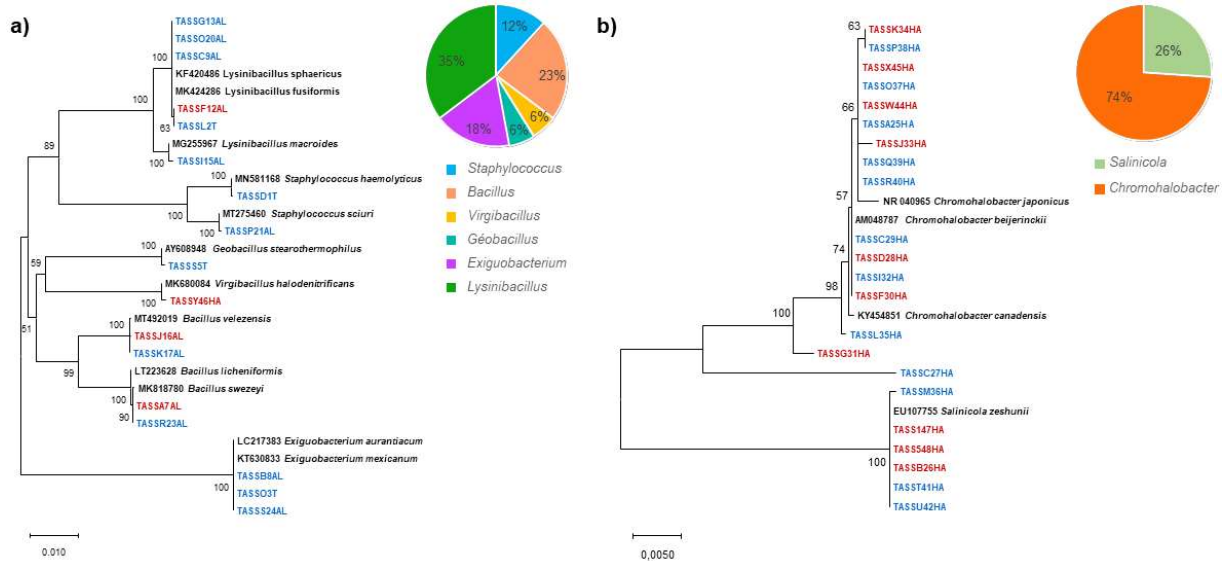


288
 289 **Fig. 4** Constrained ordination from the canonical analysis of principal coordinates (CAP analysis) discriminating
 290 the various sampling sites of Chott Ech Chergui according to the water physicochemical parameters measured
 291 from December 2018 to November 2019 (a). The superimposed Pearson correlation circle show correlations
 292 vectors of individual physicochemical parameters: temperature (T°), pH, dissolved oxygen (O_2), turbidity,
 293 organic matter (OM), magnesium content (Mg^{++}), suspended matter (SM), ammonium content (NH_4^+), nitrate
 294 content (NO_3^-), nitrite content (NO_2^-), orthophosphates (PO_4^{3-}) and conductivity. The latter vector is
 295 representative for variation of salinity, hardness, calcium content and chloride content, showing correlation
 296 coefficient $r > 0.84$. Comparison of the physicochemical variability across sampling sites is shown on the two
 297 most discriminant axis CAP1 and CAP2 (b and c, respectively). Values affected with a different letter are
 298 significantly different for $p < 0.05$.

300 3.4. Isolation and characterization of bacterial extremophile isolates

301 Following microbiological analyses, 320 bacterial isolates from soil and sediments samples were tested for
 302 thermo-, acido- and alcalino- tolerance. Among them, only 39 were maintained in a culture collection (Table S1).
 303 Following sequencing of the 16S rRNA genes and phylogenetic affiliation with subject sequences retrieved from
 304 the NCBI GenBank, 17 isolates were affiliated to the phylum Firmicutes, class Bacilli, order Bacillales, family
 305 *Bacillaceae* within genus *Bacillus*, *Lysinibacillus*, *Virgibacillus*, *Geobacillus*, *Exiguobacterium*, and family
 306 *Staphylococcaceae* within genus *Staphylococcus* (Fig. 5A); 22 isolates were affiliated to the phylum
 307 Proteobacteria, class gamma-Proteobacteria, order Oceanospirillales, family Halomonadaceae within genus
 308 *Chromohalobacter* and *Salinicola* (Fig. 5B). Two isolates (OM301605 and OM301582) did not have closely
 309 related subject sequence in the database. Isolate OM301582 had a particularly weak percentage identity with the
 310 closest reference sequence in the NCBI database (<94%), which weaken its formal affiliation to the
 311 *Chromalobacter* genus.

312



313
 314 **Fig. 5** Taxonomic affiliation of bacterial isolates through phylogenetic reconstruction of their 16S rRNA
 315 sequences with closest relative sequences collected from the NCBI GeneBank database. Phylogenetic
 316 reconstruction is shown separately for firmicutes **(a)** and for proteobacteria **(b)**. For each bacterial group, pie
 317 charts show the proportional distribution of strains within genus.
 318

319 The various surveyed water and sediment sites revealed contrasted phylogenetic affiliation across sites, so that
 320 bacteria affiliated to the Proteobacteria were only recovered at sites 3 (Large Sebkh) and 6 (Small Sebkh),
 321 while those affiliated to the Firmicutes were isolated at all sites to the exception of site 7 (Oued). The 16
 322 bacterial isolates affiliated to the phylum Firmicutes could grow in the absence of salt but could tolerate 5 to
 323 15% salt in the culture medium, these are considered “halotolerant”; and 23 bacterial isolates affiliated to the
 324 phylum Firmicutes (genus *Virgibacillus*) and to the phylum Proteobacteria that could not grow without salt, had
 325 a minimum requirement of 5% salt content in the culture medium, and could still grow at a high salt
 326 concentration of up to 30%, these are considered “halophilic.” All isolates showed the ability to thrive in both
 327 acidic and alkaline conditions, but 10 isolates could support only low alkalinity (pH 9), while 29 isolates could
 328 still thrive at high alkalinity (up to pH 10 and 12), these are considered “alkalitolerant” and “alkaliphilic”,
 329 respectively. Similarly, the 27 isolates showing the ability to grow at pH 5 are considered “acidotolerant”. All
 330 isolates had the ability to grow above 45°C and remarkably, one isolate required high temperature to grow
 331 (ranging from 50°C up to 100°C), these are considered “thermophilic”. Contrastingly, five isolates showed the
 332 ability to thrive in large temperature range (ranging from 4°C to 60°C), these are considered “psychro-
 333 thermotolerante”.

334 The screening for enzymatic activities showed that all isolates expressed their activities in pH, salt- and
 335 temperature- ranges they were cultivated in. Over all isolates, 20 isolates from the genus *Chromohalobacter* and
 336 *Salinicola* could reduce citrate, 17 isolates affiliated to the genus *Staphylococcus*, *Bacillus*, *Exigubacterium*,
 337 *Chromohalobacter*, *Salinicola* and *Virgibacillus* synthesize acetoin, 15 isolates affiliated to the genus
 338 *Staphylococcus*, *Lysinibacillus*, *Exigubacterium*, *Geobacillus*, *Bacillus*, *Chromohalobacter* and *Salinicola* reduce
 339 nitrates, 11 strains bacteria isolates affiliated to the genus *Staphylococcus*, *Geobacillus*, *Bacillus*, *Lysinibacillus*,
 340 and *Chromohalobacter* produce lipase, and 14 isolates affiliated to the genus *Lysinibacillus*, *Exigubacterium*,
 341 *Geobacillus* and *Bacillus* synthesize amylase. 32 isolates utilized sugar (mannose, glucose, fructose), and 11

342 used mannitol as main carbon source. 23 isolates were oxidase-positive, 31 had antioxidant catalase and
343 interestingly, most of the enzyme producers were affiliated to the firmicutes, not to the proteobacteria.

344

345 **4. Discussion**

346 Several wetlands with extreme environmental conditions, have been the focus of extensive research to describe
347 microbial diversity and biotechnological potential. The arid and hypersaline Chott El Jerid (Tunisia), with
348 hypersaline conditions, was studied to screen bacteria and archaea isolates for the accumulation of
349 polyhydroxyalkanoates inclusions (Ben Abdallah et al 2020). The hypersaline geothermal area of Dallol in the
350 desert of Danakil (Ethiopia), holding chaotropic conditions related to Mg^{++}/Ca^{++} -dominated brines, hyperacidity
351 and elevated temperatures allowed identifying exceptionally diverse and abundant ultrasmall archaea (Belilla et
352 al 2019). In Algeria, the salty to moderately salty wetland dayat Morsli, near Oran, facing many years of
353 anthropogenic pollution, was investigated for physicochemical and biological yearly dynamics in the view of
354 rehabilitation possibilities (Ben Bayer et al 2019); recent investigation of The Great Sebkhia of Oran, a
355 hypersaline lake, allowed characterizing 17 halotolerant bacterial isolate as promising sources of important
356 molecules (Saibi et al 2022); and the hypersaline Saharian chott Zehrez-Chergui was investigated using a
357 combination of cultivable and non-cultivable method in search of soil halophilic archaea (Hassani et al 2022).

358 The present study constitutes the first investigation of Chott Ech Chergui (Algeria) that aimed to provide one of
359 the largest wetlands of the north African desert with physico-chemical and bacteriological characteristics. Water
360 deficiency is thus the main constraint of this wetland, which occurs seasonally in some areas or constitutes a
361 chronic stress in others, leading to dried out sites that prevented from appropriate sampling. At the exception of
362 site n°3 (Large Sebkhia), that showed high level of organic matter contents, the surface waters of Chott Ech
363 Chergui are generally oligotrophic and observed changes in water chemistry are mainly related to meteorological
364 factors. The water nutrient dynamic is affected by soil leaching that follows periods of rainfalls (Loudière and
365 Gourbesville 2020), and also by water evaporation at the dry summer season that concentrate nutrients (nitrate,
366 nitrite, orthophosphate) as previously reported by the United Nation report (Hazzab 2011; Ouali et al 2018).

367 Our study distinguishes four key habitats in the Chott Ech Chergui wetland based on contrasted physicochemical
368 parameters. The first are the hot springs (sites n°1 and n°4), which have a constant water temperature of 37-40°C
369 throughout the year, a high oligotrophy level with low contents of organic matter, nitrogen, and phosphorus.
370 According to the classification of Skopljak (Skopljak et al 2006), these thermal waters are dominated by
371 chlorides and calcium and, unlike other thermal springs in the region (Hazzab 2011; Ouali et al 2018), they also
372 show elevated contents of sulfate and sodium. Among the eight thermal springs relevant of the public sector in
373 Algeria, only one thermal spring (Hammam Charef, located ~200 km east of Chott Ech Chergui) has the most
374 similar water chemistry (Ouali et al 2018; Fig. S1 and S2). This extreme habitat, characterized by high
375 temperatures and by oligotrophic conditions, imposes strong physiological constraints that should limit bacterial
376 metabolism, growth and multiplication. The second habitat is hypersaline (site n°3) showing high salinity levels
377 in the sediment (up to 380 g.L⁻¹; Table S2) that drive elevated but fluctuating salt contents in water (reaching 80
378 g.L⁻¹) in relation to regular supply with freshwater, hot springs and rain. In this habitat, high concentrations of
379 chloride, magnesium, calcium, nitrites, nitrates, orthophosphates, and ammonium should favor bacterial growth
380 and sustain diversification of thermo- and halo- tolerant microbiota. In comparison to other hypersaline habitats
381 of north Africa, the three permanent arid salt lakes in the Oued Righ valley (northeastern Algeria) showed the

382 same type of chlorinated and calcium sulphate waters (Gouasmia et al 2016); while the four arid salt lakes of
383 Tunisia showed differences of water minerality and nutrient content, in relation to chlorides and
384 sodium/potassium dominance (Kbir-Ariguib et al 2001). The third habitat (sites n°6 and n°7), in addition to
385 hypersaline characteristics of both water and sediments (Table S2), is characterized by elevated pH values,
386 suitable for the development of alkaliphile microorganisms. The fourth habitat (sites n°2 and n°5) given its
387 condition at the confluence of all three previous habitats, showed average levels of nutrient, pH, salinity and
388 temperature values, making of it the most hospitable habitat of Chott Ech Chergui that should hold abundant and
389 diversified microbial life.

390 The relationship between the environmental constrain of the habitats defined above and microbial diversity
391 should be addressed in further studies using new generation DNA sequencing technics. However, our sampling
392 campaign successfully allowed the bacteriological, biochemical and molecular characterization of several
393 extremophile isolates in relation to the key environmental constraints of Chott Ech Chergui. These were
394 affiliated to the Proteobacteria (Table S1), with several strains regrouped to genus *Chromohalobacter* and
395 *Salinicola* and to the Firmicutes, with several strains regrouped to genus *Bacillus*, *Geobacillus*, *Staphylococcus*,
396 *Exigubacterium*, *Lysinibacillus* and *Virgibacillus*. Such bacterial taxa were also isolated from saline ecosystems
397 of northeastern Algeria (Menasria et al 2019), from salterns in Korea (Lee et al 2012), from various saline
398 habitats in India (Kumar et al 2012), from saline and hypersaline lakes in the Qinghai Province of China (Jiang et
399 al 2018) and more closely, in The Great Sebkha of Oran (Saibi et al 2022).

400 All these bacterial isolates had the ability to thrive at alkaline pH and high salt concentrations. The bacterial
401 isolates affiliated to the Firmicutes formed a group of halotolerant bacteria, to the exception of the *Virgibacillus*
402 strain OM301613 considered halophilic, like all bacterial isolates affiliated to the Proteobacteria. According to
403 the classification of alkaliphile (Mevada et al 2022), thirty bacterial isolates were considered facultative
404 alkaliphiles, while nine were considered alkalitolerant.

405 Three bacterial isolates affiliated to the genus *Exigubacterium* (strains OM301601, OM301581 and OM301607)
406 can thrive at temperatures ranging from 4°C to 60°C and are thus considered psychro-thermotolerant. One
407 bacterial isolate affiliated to the genus *Geobacillus* (strain OM301608) is considered thermophilic as it shows the
408 ability to grow at 100°C, while all other bacterial isolates are considered meso-thermotolerant as they show
409 abilities to grow at temperature ranging from 15°C to 60°C. The recovery of thermotolerant bacteria affiliated to
410 the genus *Bacillus* and *Geobacillus* is not surprising as they have often been described as abundant members of
411 microbial community living in thermal environments (Amin et al 2018; Narsing Rao et al 2018; Panosyan et al
412 2018; Xian et al 2018; Belilla et al 2019 and Saghatelyan et al, 2021).

413 Although all bacterial isolates were polyextremophile, their site of origin determines their degree of tolerance to
414 the three main constraint of Chott Ech Chergui wetland (temperature, alkalinity and salinity). For instance,
415 strains that can grow at high salt concentrations were found in the second and third habitats (sites 3 and 6)
416 characterized by salinity and alkalinity, respectively; and those that can grow at high temperature were found in
417 the first habitat (sites 1 and 4) characterized by elevated temperatures and in the fourth habitat (sites 2 and 5)
418 showing intermediate conditions. However, alkaliphilic and alkaline-tolerant strains were found in all four
419 habitats.

420 Several bacterial isolates of our collection were shown to express enzymatic activities valuable in biotechnology
421 (such as lipases and amylases) in a large range of temperature or salt concentrations. These initial bacteriological

422 test open perspective of biochemical investigation of the corresponding bioactive molecules these bacterial
423 isolates produce (Boyadzhieva et al 2018; Qiu et al 2021; Pham et al 2021) and highlights the biotechnological
424 potential of Chott Ech Chergui wetland as a reservoir of polyextremophile bacterial isolates.

425

426 **5. Conclusion**

427 This study provides the first report of the physicochemical conditions of the Chott Ech Chergui wetland and a
428 typification of the water habitats with extreme conditions it holds, including seasonal aridity, elevated thermal
429 gradient, high salinity and high alkalinity. As a first step in the way to describe the biodiversity this unique
430 ecosystem supports, we successfully isolated and identified halophilic, alkalophilic and thermophilic bacteria,
431 some of which, polyextremophile, combine all three characters. This study constitutes the base of future
432 programs of biodiversity monitoring of Chott Ech Chergui wetland and offers promising perspectives of
433 valorization in biotechnologies as conservation values for wetlands with extreme environmental conditions. The
434 remarked decrease of the watered surface at the dry summer season are primary symptoms of a more general
435 drying up of Chott Ech Chergui wetland that is likely to emphasize with climate change and call for the
436 improvement of management practices and the control of surrounding human activities.

437 **6. References**

- 438 Amin A, Ahmed I, Khalid N, et al (2018) Insights into the Thermophile Diversity in Hot Springs of Pakistan. In:
439 Egamberdieva D, Birkeland N-K, Panosyan H, Li W-J (eds) Extremophiles in Eurasian Ecosystems:
440 Ecology, Diversity, and Applications. Springer Singapore, Singapore, pp 1–28
- 441 Aoudia M, Issaadi A, Bersi M, et al (2020) Aquifer characterization using vertical electrical soundings and
442 remote sensing: A case study of the Chott Ech Chergui Basin, Northwest Algeria. *J. African Earth Sci*
443 170:103920. doi: 10.1016/j.jafrearsci.2020.103920
- 444 Arabi Z, Mederbal K (2016) Intégration des données multi-sources dans un Système d'Information
445 Géographique pour l'étude de la diversité floristique au niveau de la zone humide du Chott Ech
446 Chergui, Saida. *J Bioresour Valori*. 1: 16-22.
- 447 Belilla J, David Moreira, Ludwig Jardillier, et al (2019) Hyperdiverse archaea near life limits at the polyextreme
448 geothermal Dallol area. *Nature ecology & evolution* 3:1552–1561. doi: 10.1038/s41559-019-1005-0.
- 449 Ben Abdallah M, Karray F, Sayadi S (2020) Production of Polyhydroxyalkanoates by Two Halophilic Archaeal
450 Isolates from Chott El Jerid Using Inexpensive Carbon Sources. *Biomolecules* 10:109. doi:
451 10.3390/biom10010109
- 452 Ben Bayer W, Casse N, Baba Hamed MB, et al (2019) First characterization of physicochemical and biological
453 variables of the salt wetland dayat Morsli in Oran (Algeria). *J. African Earth Sci* 160:103652. doi:
454 10.1016/j.jafrearsci.2019.103652
- 455 Boyadzhieva I, Tomova I, Radchenkova N, et al (2018) Diversity of Heterotrophic Halophilic Bacteria Isolated
456 from Coastal Solar Salterns, Bulgaria and Their Ability to Synthesize Bioactive Molecules with
457 Biotechnological Impact. *Microbiol* 87:519–528. doi: 10.1134/S0026261718040033
- 458 Clarke KR, Gorley RN (2015) Getting started with PRIMER v7. PRIMER-E: Plymouth, Plymouth Marine
459 Laboratory, 20(1).
- 460 Collins CH, Collins CH, Lyne PM (eds) (2004) Collins and Lyne's microbiological methods, 8. ed. Arnold,
461 London
- 462 Egamberdieva D, Birkeland N-K, Panosyan H, Li W-J (eds) (2018) Extremophiles in Eurasian Ecosystems:
463 Ecology, Diversity, and Applications. doi: 10.1007/978-981-13-0329-6
- 464 Elazzazy AM, Abdelmoneim TS, Almaghrabi OA (2015) Isolation and characterization of biosurfactant
465 production under extreme environmental conditions by alkali-halo-thermophilic bacteria from Saudi
466 Arabia. *Saudi J Biol Sci* 22:466–475. doi: 10.1016/j.sjbs.2014.11.018
- 467 Fluet-Chouinard E, Stocker BD, Zhang Z, et al (2023) Extensive global wetland loss over the past three
468 centuries. *Nature* 614:281–286. doi: 10.1038/s41586-022-05572-6
- 469 Gardner RC, Finlayson M (2018) Global wetland outlook: State of the world's wetlands and their services to
470 people 2018. Secretariat of the Ramsar Convention, Switzerland
- 471 Gouasmia G, Amarouayache M, Frihi H, Hichem Kara M (2016) Caractérisation physico-chimique de trois lacs
472 salés permanents de la vallée d'Oued Righ (Sahara septentrional, Algérie nord-est). *Revue d'Ecologie,*
473 *Terre et Vie* 71:330–341.
- 474 Hall T, Hall T, Alzohairy DAM (2011) BioEdit: An important software for molecular biology. *GERF Bulletin of*
475 *Bioscience* 2(1), 60-61

- 476 Hassani II, Quadri I, Yadav A, et al (2022) Assessment of diversity of archaeal communities in Algerian chott.
477 *Extremophiles* 27:2. doi: 10.1007/s00792-022-01287-8
- 478 Hazzab A (2011) Eaux minérales naturelles et eaux de sources en Algérie. *Comptes Rendus Geoscience* 343:20–
479 31. doi: 10.1016/j.crte.2010.11.007
- 480 Holt JG (1994) *Bergey's Manual of Determinative Bacteriology*. Lippincott Williams & Wilkins
- 481 Jiang H, Huang J, Yang J (2018) Halotolerant and Halophilic Microbes and Their Environmental Implications in
482 Saline and Hypersaline Lakes in Qinghai Province, China. In: Egamberdieva D, Birkeland N-K,
483 Panosyan H, Li W-J (eds) *Extremophiles in Eurasian Ecosystems: Ecology, Diversity, and Applications*.
484 Springer Singapore, Singapore, pp 299–316
- 485 Kbir-Ariguib N, Chehimi DBH, Zayani L (2001) Treatment of Tunisian salt lakes using solubility phase
486 diagrams. *Pure and Applied Chemistry* 73:761–770. doi: 10.1351/pac200173050761
- 487 Kumar S, Karan R, Kapoor S, et al (2012) Screening and isolation of halophilic bacteria producing industrially
488 important enzymes. *Brazilian Journal of Microbiology* 43:1595–1603. doi: 10.1590/S1517-
489 83822012000400044
- 490 Kumar S, Stecher G, Li M, et al (2018). MEGA X: Molecular Evolutionary Genetics Analysis across computing
491 platforms. *Mol Biol Evol* 35:1547-1549
- 492 Lee S-J, Lee Y-J, Jeong H, et al (2012) Draft Genome Sequence of *Virgibacillus halodenitrificans* 1806. *J*
493 *Bacteriol* 194:6332–6333. doi: 10.1128/JB.01280-12
- 494 Leoni C, Volpicella M, Fosso B, et al (2020) A Differential Metabarcoding Approach to Describe Taxonomy
495 Profiles of Bacteria and Archaea in the Saltern of Margherita di Savoia (Italy). *Microorganisms* 8:936.
496 doi: 10.3390/microorganisms8060936
- 497 Loudière D, Gourbesville P (2020) Rapport mondial des Nations Unies sur la mise en valeur des ressources en
498 eau 2020 - L'eau et les changements climatiques. *La Houille Blanche* 76–81. doi: 10.1051/lhb/2020024
- 499 Menasria T, Monteoliva-Sánchez M, Benammar L, et al (2019) Culturable halophilic bacteria inhabiting
500 Algerian saline ecosystems: A source of promising features and potentialities. *World J Microbiol*
501 *Biotechnol* 35:132. doi: 10.1007/s11274-019-2705-y
- 502 Mevada VA, Beladiya UH, Gandhi HR, et al (2022) Alkalophiles: Environmental Distribution, Taxonomy,
503 Physiology, Bioenergetics, Survival Mechanism, and Enzymes. In: Gunjal AB, Thombre R, Parray JA
504 (eds) *Advances in Environmental Engineering and Green Technologies*. IGI Global, pp 35–64
- 505 Nabagye A, Yatuha J (2022) Physico-chemical Parameters and Species' Distribution Patterns of Extremophilic
506 Bacteria in Kitagata and Ihimbo Hot Springs in South Western Uganda. *ASRJETS* 86:157–173.
- 507 Narsing Rao MP, Liu L, Jiao J-Y, et al (2018) Hot Springs of India: Occurrence and Microbial Diversity. In:
508 Egamberdieva D, Birkeland N-K, Panosyan H, Li W-J (eds) *Extremophiles in Eurasian Ecosystems:*
509 *Ecology, Diversity, and Applications*. Springer Singapore, Singapore, pp 29–55
- 510 Ouali S, Hadjiat MM, Ait-Ouali A (2018) Cartographie et caractérisation des ressources géothermiques de
511 l'Algérie. *J. Renewable Energies*, 21(1), 54-61.
- 512 Panosyan H, Margaryan A, Poghosyan L, et al (2018) Microbial Diversity of Terrestrial Geothermal Springs in
513 Lesser Caucasus. In: Egamberdieva D, Birkeland N-K, Panosyan H, Li W-J (eds) *Extremophiles in*
514 *Eurasian Ecosystems: Ecology, Diversity, and Applications*. Springer Singapore, Singapore, pp 81–117

515 Pellicone G, Caloiero T, Guagliardi I (2019) The De Martonne aridity index in Calabria (Southern Italy). *Journal*
516 *of Maps* 15:788–796. doi: 10.1080/17445647.2019.1673840

517 Pham VHT, Kim J, Shim J, et al (2021) Purification and Characterization of Strong Simultaneous Enzyme
518 Production of Protease and α -Amylase from an Extremophile-Bacillus sp. FW2 and Its Possibility in
519 Food Waste Degradation. *Fermentation* 8:12. doi: 10.3390/fermentation8010012

520 Qiu J, Han R, Wang C (2021) Microbial halophilic lipases: A review. *J Basic Microbiol* 61:594–602. doi:
521 10.1002/jobm.202100107

522 Rainey FA, Oren A (2006) *Extremophile Microorganisms and the Methods to Handle Them*. Academic Press, pp
523 1–25

524 Remini B (2010) La problématique de l’eau en Algérie du nord. *Larhyss Journal*. P-ISSN 1112-3680 E-ISSN
525 2521-9782

526 Rodier J, Legube B, Merlet N (2009) *L’analyse de l’eau (9e édition)*. Eaux naturelles, eaux résiduaires, eau de
527 mer. Dunod, 564-571

528 Rodier J, Legube B, Merlet N (2016) *L’analyse de l’eau (10e édition)*. Dunod

529 Saghatelian A, Margaryan A, Panosyan H et al (2021). Microbial Diversity of Terrestrial Geothermal Springs in
530 Armenia and Nagorno-Karabakh: A Review. *Microorganisms*, 9(7):1473.
531 <https://doi.org/10.3390/microorganisms9071473>

532 Saibi ANE, Nas F, Arab M, et al (2022) Antimicrobial and Enzymatic Profiling of Halophilic and Halotolerant
533 Bacteria from a Hypersaline Lake ‘The Great Sebkhah of Oran, Northwestern Algeria.’ *Geomicrobiol J*
534 39:816–831. doi: 10.1080/01490451.2022.2079777

535 Saitou N, Nei M (1987) The neighbor-joining method: A new method for reconstructing phylogenetic trees. *Mol*
536 *Biol and Evol* 4:406-425

537 Skopljak F, Bašagić M, Škripić N (2006) Hydrogeological characteristics of the “Olympija” source, Sarajevo.
538 *RMZ Mater Geoenviron*, 53: 483.

539 Tamura K, Nei M, Kumar S (2004) Prospects for inferring very large phylogenies by using the neighbor-joining
540 method. *Proc Natl Acad Sci U.S.A.* 101:11030-11035.

541 Thompson JD, Gibson TobyJ, Higgins DG (2003) Multiple Sequence Alignment Using ClustalW and ClustalX.
542 *Current Protocols in Bioinformatics*. doi: 10.1002/0471250953.bi0203s00

543 Winker S, Woese CR (1991) A Definition of the Domains Archaea, Bacteria and Eucarya in Terms of Small
544 Subunit Ribosomal RNA Characteristics. *Syst Appl Microbiol*, 14(4), 305–310.
545 [https://doi.org/10.1016/S0723-2020\(11\)80303-6](https://doi.org/10.1016/S0723-2020(11)80303-6)

546 Winkler K, Fuchs R, Rounsevell M, Herold M (2021) Global land use changes are four times greater than
547 previously estimated. *Nat Commun*, 12(1), 2501. <https://doi.org/10.1038/s41467-021-22702-2>

548 Xian W-D, Narsing Rao MP, Zhou E-M, et al (2018) Diversity of Thermophiles in Terrestrial Hot Springs of
549 Yunnan and Tibet, China. In: Egamberdieva D, Birkeland N-K, Panosyan H, Li W-J (eds)
550 *Extremophiles in Eurasian Ecosystems: Ecology, Diversity, and Applications*. Springer Singapore,
551 Singapore, pp 57–79

552 Ye JW, Lin YN, Yi XQ et al, (2023) Synthetic biology of extremophiles: a new wave of biomanufacturing.
553 *Trends Biotechnol* 41(3), 342–357. <https://doi.org/10.1016/j.tibtech.2022.11.010>

554

555 **7. Statements and Declarations**

556 **Funding**

557 This work was supported by Campus France and the France - Algeria Hubert Curien partnership “Tassili” under
558 Grant Agreement No 42200XF.

559 **Competing Interests**

560 The authors have no relevant financial or non-financial interests to disclose.

561 **Author Contributions**

562 • Conceptualization: Abi Ayad Sidi Mohammed El Amine, Lamara Sid Ahmed Chawki, Mehrou Zouggar
563 Aicha, Denis Francoise, Caruso Aurore; Methodology: Mehrou Zouggar Aicha, Pascal Mirleau, Chenuil Anne;
564 Formal analysis and investigation: Mehrou Zouggar Aicha, Pascal Mirleau, Chenuil Anne; Writing - original
565 draft preparation: Mehrou Zouggar Aicha, Pascal Mirleau; Writing - review and editing: Mehrou Zouggar
566 Aicha, Pascal Mirleau, Chenuil Anne, Denis Francoise; Funding acquisition: Chenuil Anne, Abi Ayad Sidi
567 Mohammed El Amine; Resources: Pascal Mirleau, Chenuil Anne, Abi Ayad Sidi Mohammed; Supervision:
568 Pascal Mirleau, Chenuil Anne.

569 **Data Availability**

570 The datasets generated during and/or analysed during the current study are available from the corresponding
571 author on reasonable request.

572

573 **8. Tables**

574

575 **Table 1.** Name, location and characteristics of the sampling sites in the wetlands Chott Ech Chergui.

Site	Name	Latitude	longitude	Brief description
1	Source Zawia	34°28'2.21"N	0°49'7.93'' E	First thermal source main point of the Chott Ech Chergui supply
2	Chott Ech Chergui	34°30'0.96 ''N	0°50'39.88''E	Vast freshwater depression
3	Large Sebkha	34°27'13.80"N	0°50'33.21"E	Vast arid depression salty soil fed by the 1st thermal spring and rain waters
4	Source Ain Skhouana	34°30'8.14 ''N	0°50'44.50''E	Second thermal source and second feeding point of the Chott Ech Chergui
5	Bassin	34°30'0.96 ''N	0°50'39.88''E	Beginning of a river fed by the second thermal source
6	Small Sebkha	34°29'42.12 ''N	0°50'54.36''E	Basin fed by the second thermal spring and rainwater forming a brackish lake
7	Oued	34°29'46"N	0°53'27''E	feeding point on the east side of the Chott Ech Chergui forming the continuation of the river

576

577