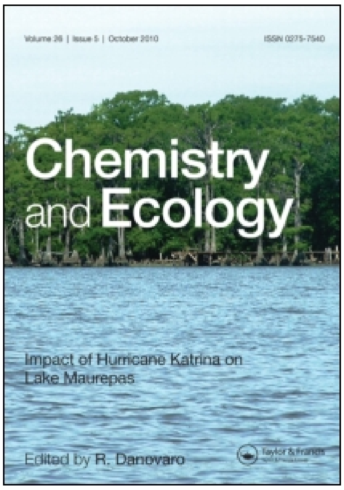

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Marcella Ruta[a]; Milva Pepi[a]; Enrica Franchi[a]; Monia Renzi[a]; Margherita Volterrani[a]; Guido Perra[a]; Cristiana Guerranti[a]; Angiola Zanini[b]; Silvano E. Focardi[a]
[a] Dipartimento di Scienze Ambientali, Università degli Studi di Siena, Siena, Italy [b] Dipartimento di Scienze Geologiche, Università degli Studi di Catania, Catania, Italy

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RESEARCH ARTICLE

Contamination levels and state assessment in the lakes of the Oliveri-Tindari Lagoon (North-Eastern Sicily, Italy)

Marcella Ruta[a]*, Milva Pepi[a], Enrica Franchi[a], Monia Renzi[a], Margherita Volterrani[a], Guido Perra[a], Cristiana Guerranti[a], Angiola Zanini[b] and Silvano E. Focardi[a]

[a]*Dipartimento di Scienze Ambientali, Università degli Studi di Siena, Siena, Italy;* [b]*Dipartimento di Scienze Geologiche, Università degli Studi di Catania, Corso Italia, Catania, Italy*

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The Oliveri-Tindari Lagoon, located in North-Eastern Sicily (Italy) and composed of six lakes, is subject to continuous environmental changes. An integrated study focusing on sediment features and levels of contamination was carried out for three of the six lakes, which are of ancient origin: Verde, Mergolo della Tonnara and Marinello. A high primary production (26.89 $\mu g\,l^{-1}$) was detected at Lake Verde; texture classification showed a typical grain size in the sediments of all lakes; the study of macronutrients highlighted 17.08 of total carbon in sediments from Lake Mergolo della Tonnara; toxic elements were detected at higher concentrations in the sediments of Lake Marinello in comparison to the others, while arsenic was found in high concentrations in all the samples tested, especially in Lake Verde, with a mean value of 17.25 $mg\,kg^{-1}$ dry weight (d.w.). All the organic contaminants, except *4,4′*-dichlorodiphenyldichloroethylene, were below the detection limits in the sediments. Minimal microbiological contamination was found in both water and sediment samples. In the latter, we isolated several bacterial strains thriving in the presence of arsenic, which play a role in the biogeochemical cycle of arsenic. These preliminary results, obtained for the first time using a multidisciplinary approach, provide general information about the Oliveri-Tindari Lagoon area.

Keywords: water parameters; heavy metals; organic contaminants; microbial ecology; Oliveri-Tindari Lagoon

1. Introduction

The Oliveri-Tindari Lagoon is a natural reserve including six small coastal lakes, three of which (Verde, Mergolo della Tonnara and Marinello) are of ancient origin and the others (Nuovo, which is covered by sand, Fondo Porto and Porto Vecchio) are of recent formation. As reported in a Military Geographic Institute map of 1856, this lagoon system originated about 140 years ago, when the first three of the current six lakes were present. Due to the high level of variability in this area, the amount of research into it has increased through the years.

The first morphological and physico-chemical studies, conducted in 1955 [1], highlighted a tendency to extreme changes due to the combined activity of the wind and sea. The whole area

*Corresponding author. Email: ruta@unisi.it

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is subject to variance due to the constant influence of typical marine, terrestrial and atmospheric processes [2]. This zone comprises various environments and is characterised in particular by a humid brackish area between the mainland and marine waters [3,4]. Studies on nutrient salts and involving the determination of several metabolic bacterial groups were carried out during a period characterised by limited anthropogenic impact, in the form of tourism [5,6]. Subsequent physico-chemical and biological analyses demonstrated that this lagoon system has variations and bodies of water with similar characteristics to marine environments, except for Lake Marinello, which is isolated from the sea and has freshwater characteristics [7]. The possibility of installing an aquaculture plant in the area has been suggested, partly due to the presence of a link with the sea [8]. Other studies of the area have revealed the markedly brackish character of the lake waters, and the presence of low anthropogenic pressure [8]. A study of the distribution of phanerogams was also carried out, showing a direct relationship between fluctuations in sedimentary inputs and the evolution of phanerogam meadows [9].

The analysis of lagoons and protected areas plays a pivotal role in environmental conservation [2]. Following the above evaluations, the Lake Marinello Natural Reserve was founded in 1998, and this area is currently of great importance from a naturalistic and environmental point of view. However, although they have provided important results, previous studies carried out in this area have dealt with individual aspects and an overall view of this ecological system is lacking.

We conducted a preliminary study, using a multidisciplinary approach, in order to assess the contamination levels and the environmental conditions of the Oliveri-Tindari Lagoon (North-Eastern Sicily, Italy).

2. Materials and methods

2.1. *Study area and sampling*

The study area was the Oliveri-Tindari Lagoon, located in North-Eastern Sicily (38°08′134″N; 15°03′366″E) at Cape Tindari, 280 meters above sea level. This lagoon covers an area of 420,435 m^2. The area includes the Marinello Natural Reserve (Figure 1). Sampling was carried out in October 2005. Superficial water samples were collected for nutrient analyses from undisturbed areas at three sites: central (top and bottom) and another two diametrically opposite points. Sediment samples (0–10 cm) were collected manually using Plexiglas tubes (10 cm i.d.). Three corers per lake (a central one and two diametrically opposite) were brought back to the laboratory. Sterile sub-samples of both water and sediment samples were collected, respecting the rules of sterility and processed for microbiological analysis within 12 h. Samples for chemical analysis were frozen and stored at −20°C until analysis. The sampling sites for the lake waters and sediments were the following: D1, D2 and D3 for Lake Verde; F1, F2 and F3 for Lake Mergolo della Tonnara; G1, G2 and G3 for Lake Marinello. Samples collected along the coast were numbered from 01 to 19.

2.2. *Environmental parameters*

The main environmental parameters along the water columns (temperature, salinity, conductivity, pH, redox potential (Eh), dissolved oxygen and depth values) were measured using a multi-parametric field probe (Corr-Teck Hydrometria, mod. Datasonde 4a). Sediment pH values were determined using a potentiometric method, following probe calibration with a three point curve using standard reference solutions (Crison, Eh/pH 25 with combined electrode), while the Eh

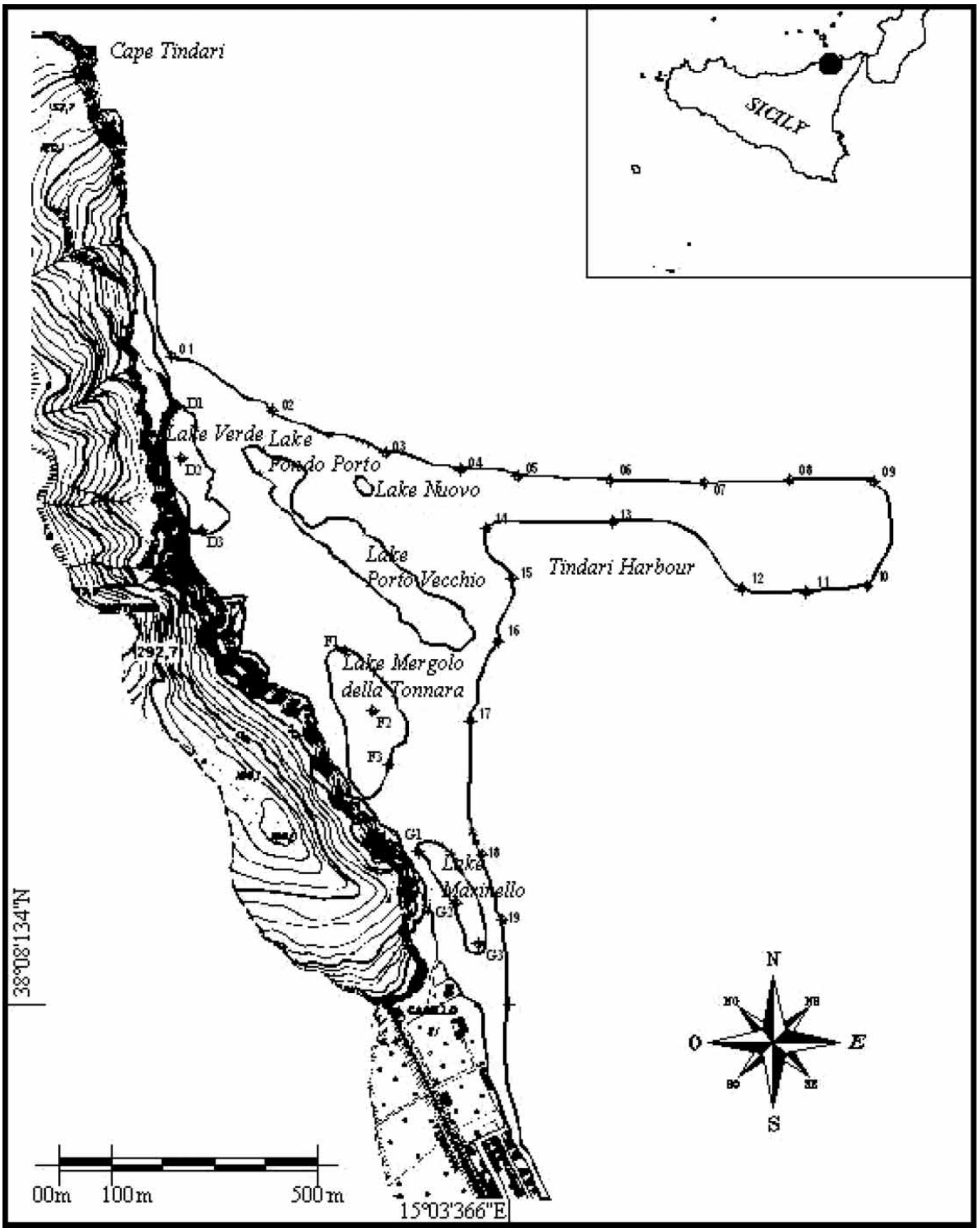

Figure 1. Study area of the Oliveri-Tindari Lagoon and locations of the sampling sites: along the coast (01–19) and in Lake Verde (D1, D2 and D3), Lake Mergolo della Tonnara (F1, F2 and F3) and Lake Marinello (G1, G2 and G3).

values were detected after calibration of the system using a +220 mV calibration solution (Crison, Eh/pH 25 with combined electrode).

2.3. *Nutrients*

Nitrate (NO_3^-), nitrite (NO_2^-), soluble reactive phosphorous (SRP), and total phosphorus (P-tot) were determined in water subsamples filtered through a GF/F filter (Whatman) using colorimetric methods [10]; ammonium (NH_4^+) was determined with the salicylate-hypochlorite method, as described by Bower and Holm-Hansen [11].

2.4. *Chlorophyll-*a

Chlorophyll-*a* (Chl-*a*) was extracted using 90% acetone (in the dark, overnight at 4°C) and determined fluorometrically before and after acidification with 0.1 N HCl [12]. Chlorophyll-a concentrations were converted into carbon content using $40\,\mu gC\,\mu Chl\text{-}a^{-1}$ as a conversion factor [13].

2.5. *Sediment characterisation*

The grain size composition of sediments was evaluated according to methods proposed by ICRAM [14]. Texture classifications of sediments were expressed as a function of gravel, sand, silt and clay percentages [15–17]. Data were elaborated according to a statistical formula [18]. The percentages obtained from each sample were analysed using the TriDraw 2.6 software and graphically imaged according to Folk's ternary classification [19].

2.6. *Chemical characterisation*

Total organic carbon (TOC) analysis was carried out according to the IRSA method, following modifications by Gaudette and Flight [20]. Total phosphorous was determined according to Italian Ministerial decree no. 185 of 199 concerning 'Chemical analysis of soil'. Total carbon and total nitrogen analyses were carried out according to ICRAM [21].

2.7. *Trace element determination*

Sediment samples were sieved to obtain the $<250\,\mu m$ fraction and mineralised with 65% nitric acid concentrated in a microwave oven (ETHOS D Microwave Labstation, Milestone), according to the US EPA [22]. Cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), and copper (Cu) determination was carried out by electrothermal atomisation atomic absorption spectrometry (ETA-AAS) (AAnalyst 700, Perkin-Elmer) [23]. Mercury (Hg) was determined by cold vapour atomic absorption spectrometry (CV-AAS) [24]. The percent coefficient of variation (% CV) of three repeated samples was below 5%. Arsenic (As) was determined by hydride generation atomic absorption spectrometry (HG-AAS), according to the US EPA [25]. Zinc (Zn) was determined by atomic absorption spectrometry with flame atomisation (F-AAS) [26]. Accuracy was tested using Standard Reference Material 1646a, from the National Institute of Standards and Technology (NIST) of the US Department of Commerce, Gaithersburg, MD, USA.

2.8. *Organic contaminant analyses*

A mixture of the seven most common polychlorobiphenyl (PCB) congeners (i.e. PCB-28; PCB-52; PCB-101; PCB-118; PCB-138; PCB-153; and PCB-180), nine organochlorine pesticides (OCPS - hexachlorobenzene (HCB), α-HCH, β-HCH, γ-HCH (lindane), δ-HCH, *pp*′-DDT, *op*′-DDT, *pp*′-DDE, *op*′-DDE), 17 polychlorinated dibenzodioxin and dibenzofurans (PCDD/Fs) and four non-*ortho* polychlorobiphenyl congeners (PCB-77, PCB-81, PCB-126, PCB-169, Wellington Laboratories, Inc.) were extracted from air dried sediment samples with an Accelerated Solvent Extractor (Dionex, mod. ASE 200), according to US EPA [27]. They were then purified on multilayer silica columns (PCB and OCP fractions) and on carbon columns (fraction containing PCDD/Fs and non-*ortho* PCBs) and quantified by gas chromatography with a Ni^{63} ECD (PerkinElmer, Mod. AutoSystem), coupled with a Polaris MS ion trap, according to the US EPA [28]. Polycyclic aromatic hydrocarbons (PAHs) were quantified in another sample aliquot of 10 g according to the US EPA [27]. The extraction procedure was the same as used with PCBs and OCPs. The extracts were purified on multilayer silica columns, concentrated and injected into the high performance liquid chromatography (HPLC) system for analytical quantification. PAHs were identified and their concentrations measured by HPLC. Acenaphthylene was determined using a Waters PDA 996 photodiode array detector. For all the other PAHs, a Waters 474 scanning fluorescence detector was used. Chromatographic separation was performed in a Supelcosil LC-PAH HPLC column (250×4.6 mm i.d., particle size 5 mm, Supelco) with a 60/40 acetonitrile/water gradient, hold 3 min, ramp to 100:0 within 30 min and hold 10 min, and a flow rate of 1.5 ml/min^{-1}. The detection limit (LOD), estimated as 3 σ (three times the background noise, IUPAC criterion), was similar for all compounds analysed.

2.9. *Microbiological characterisation*

Total coliform, faecal coliform, and faecal streptococci were analysed using the Most Probable Number (MPN) method [29], according to APHA [30]. Final numbers were calculated using McCrady tables, according to statistical rules. Spores of the sulphate-reducing bacteria clostridium were detected using the ICRAM method [31]. Total microbiological counts were carried out on plate count agar (PCA) medium (Oxoid, Milan), according to the inclusion method. Colony forming units (CFUs) per millilitre were counted [32] after five days of incubation at 22°C and 48 h at 37°C. Inocula for *Salmonella* detection were prepared in buffered peptone water (1:10) during sampling. Bacteria belonging to the genus *Salmonella* were qualitatively determined according to the ISO 6579:2002 method.

2.10. *Enrichment cultures and isolation of bacterial strains in the presence of arsenic*

Enrichment cultures were prepared in a complex medium containing: 5.0 g of tryptone, 2.5 g of yeast extract, and 1.0 g of D-glucose per litre of distilled water. Different 250 ml flasks were filled with 50 ml of complex medium and each inoculated with 0.5 g of sediment samples, in the presence of 100 $\mu g\, ml^{-1}$ As(III) added as m-$NaAsO_2$. The inoculated flasks were incubated at 28°C for four weeks and growth was detected by microscope analysis throughout incubation. When microbiological growth was detected, an aliquot of 100 μl from each culture was transferred, spread on complex medium in the presence of 1.6% of agar and incubated at 28°C for two weeks. After this period, colonies showing different shapes were selected. Colonies were streak purified at least three times, and isolated strains were stored as liquid culture containing 30% (v/v) sterile glycerol in liquid nitrogen [33].

3. Results

3.1. *Water features*

We investigated the physico-chemical features of water samples collected from three lakes of the Oliveri-Tindari Lagoon: Marinello, Mergolo della Tonnara and Verde. The results are shown in Table 1. In Lake Verde we detected greater primary productivity than in the other two lakes, as well as a high value of chlorophyll-*a* (Chl-*a*), corresponding to 26.89 $\mu g\, l^{-1}$. All three lakes showed

Table 1. Physico-chemical features of the water samples collected from the Oliveri-Tindari Lagoon.

	Mean	*Min*	*Max*
Lake Verde			
Temperature (°C)	21.33	20.32	23.12
pH	8.59	8.31	8.71
Eh (mV)	144.75	82.00	203.00
Salinity (‰)	25.61	25.45	26.03
Conductivity ($\mu S\,cm^{-1}$)	40530.50	40079.00	41360.00
D.O. (mg^{-1})	8.63	7.69	9.61
D.O. (%)	113.73	97.50	127.50
Depth (cm)	60.00	10.00	190.00
Chl-*a* ($\mu g\,l^{-1}$)	26.89	23.63	28.52
$[NH_4^+]$ (μM)	0.31	0.13	0.50
$[NO_2^-]$ (μM)	0.18	0.18	0.18
$[NO_3^-]$ (μM)	0.19	0.18	0.20
P-tot (μM)	0.03	0.03	0.03
SRP (μM)	0.03	0.03	0.03
Lake Mergolo della Tonnara			
Temperature (°C)	21.68	20.91	22.71
pH	7.89	7.87	7.91
Eh (mV)	152.75	123.00	198.00
Salinity (‰)	31.07	31.02	31.13
Conductivity ($\mu S\,cm^{-1}$)	48098.50	47977.00	48263.00
D.O. (mg^{-1})	6.79	6.53	7.24
D.O. (%)	93.35	89.00	99.40
Depth (cm)	80.0	10.0	280.0
Chl-*a* ($\mu g\,l^{-1}$)	0.90	0.20	1.49
$[NH_4^+]$ (μM)	0.29	0.13	0.49
$[NO_2^-]$ (μM)	0.18	0.18	0.18
$[NO_3^-]$ (μM)	0.19	0.16	0.23
P-tot (μM)	0.03	0.03	0.03
SRP (μM)	0.03	0.03	0.03
Lake Marinello			
Temperature (°C)	21.39	20.99	21.83
pH	7.97	7.88	8.02
Eh (mV)	164.50	148.00	180.00
Salinity (‰)	31.22	31.13	31.27
Conductivity ($\mu S\,cm^{-1}$)	48370.25	48278.00	48440.00
D.O. (mg^{-1})	7.29	6.83	7.86
D.O. (%)	100.08	93.10	106.50
Depth (cm)	80.00	10.00	280.00
Chl-*a* ($\mu g\,l^{-1}$)	0.06	0.00	0.20
$[NH_4^+]$ (μM)	0.24	0.18	0.29
$[NO_2^-]$ (μM)	0.18	0.18	0.18
$[NO_3^-]$ (μM)	0.17	0.16	0.17
P-tot (μM)	0.03	0.03	0.03
SRP (μM)	0.03	0.03	0.03

brackish characteristics, with Lake Marinello reaching the highest mean salinity of 31.22‰. Generally low concentrations of nutrients were detected (Table 1).

Microbiological analyses were carried out to detect faecal contamination in the waters, and showed normal results for this kind of lagoon. Specifically, analyses were performed to detect recent (i.e. *Salmonella* spp.; total coliforms; faecal coliforms), old (i.e. faecal streptococci), and remote (i.e. sulphate reducing clostridia spores) contamination (Table 2). A low level of old faecal contamination was present in one site only, located in the deep water 'D2 Bottom' of Lake Verde (Table 2). The other faecal bioindicators, except *Salmonella* spp., were also detected at the same site (Table 2).

Table 2. Microbiological analyses in water samples collected from the three lakes tested in the Oliveri-Tindari Lagoon.

Samples	Total Coliform MPN ml^{-1}	Faecal Coliform MPN ml^{-1}	*Escherichia coli* MPN ml^{-1}	Faecal Streptococci MPN ml^{-1}	Total Microbiological CFU Count ml^{-1} 36°C	Total Microbiological CFU Count ml^{-1} 22°C	*Salmonella* spp.
D1	4	4	4	0.9	2.3×10	6.6×10	A
D2 top	0	0	0	0	1.7×10	8.2×10	A
D2 bottom	2	1.7	1.7	2.5×10	1.8×10	1.1×10	A
F1	0	0	0	0	6.5	1.1×10^2	A
F2 top	0	0	0	0	4.5	2.5×10^2	A
F2 bottom	0	0	0	0.4–0.6	3.5	3.0×10^2	A
F3	0	0	0	0	2.5	1.1×10^2	A
G1	0	0	0	0	2.5	4.3×10	A
G2 top	0	0	0	0	3.1×10	3.5×10^2	A
G2 bottom	0	0	0	0	5.5	1.5×10^3	A
G3	0	0	0	0.6–0.8	1.1×10^2	1.6×10^3	A

Note: A = absent.

3.2. *Sediment features*

The sediment samples analysed in this study originated from two areas: along the coast and from the three lakes of the Oliveri-Tindari Lagoon. Grain size characterisation showed that sediment samples collected along the coast were included in the class of fine gravel and coarse sand (Figure 2a), whereas sediment samples collected from Lake Verde (Figure 2b), Lake Mergolo della Tonnara (Figure 2c) and Lake Marinello (Figure 2d) were assigned to the class of very coarse sand and fine silt. These results showed that sediments from the Oliveri-Tindari Lagoon can be allocated to two main grain size classes: ruditic-arenitic and arenitic-lutitic.

The mean values of pH and Eh in sediment samples collected along the coast were 8.04 and 191.51 mV, respectively. The mean values of pH and Eh measured in lagoon sediments were 7.84 and −282.5 mV for Lake Verde; 7.12 and −195.22 mV for Lake Marinello; 7.30 and −62.45 mV for Lake Mergolo della Tonnara, showing high levels of reduction in the sediments of the two first lakes, and lower reduction in the latter.

Concerning macronutrients, a high value of total carbon (17.08%) was observed in the sediments from Lake Mergolo della Tonnara, while the other two lakes showed lower percentage values. All the other macronutrients were detected at equally low concentrations in all lakes (Figure 3).

Organic contaminants showed concentrations below the limits of detection in all the sites analysed, with only the pesticide *pp*′-DDE resulting measurable, although at a concentration of below 2.5 ng g^{-1} (d.w.) (Table 3). The Σ PAH concentrations indicate that these contaminants were below the limits of detection in the Oliveri-Tindari Lagoon sediments, in all sampling sites.

The heavy metals and metalloids tested in sediment samples collected along the coast and from the three lakes showed values in accordance with the quality standards of Italian Ministerial Decree no. 367/2003, except for As, which had a mean upper value of 17.25 mg kg^{-1} (d.w.). Trace element concentrations showed homogeneous distribution among the three lakes, although Lake Verde had higher concentrations than the other two lakes and the costal area. In total, Zn was the trace element with highest values in all the sediments tested, with a maximum of 62.99 mg kg^{-1} (d.w.), and a high concentration of Cu, corresponding to a value of 58.38 mg kg^{-1} (d.w.), was detected in Lake Marinello (Figure 4).

Faecal contamination tested in the sediments showed normal results for this kind of lagoon, with low concentrations of the bioindicators, as shown in Table 4. As limited samplings were

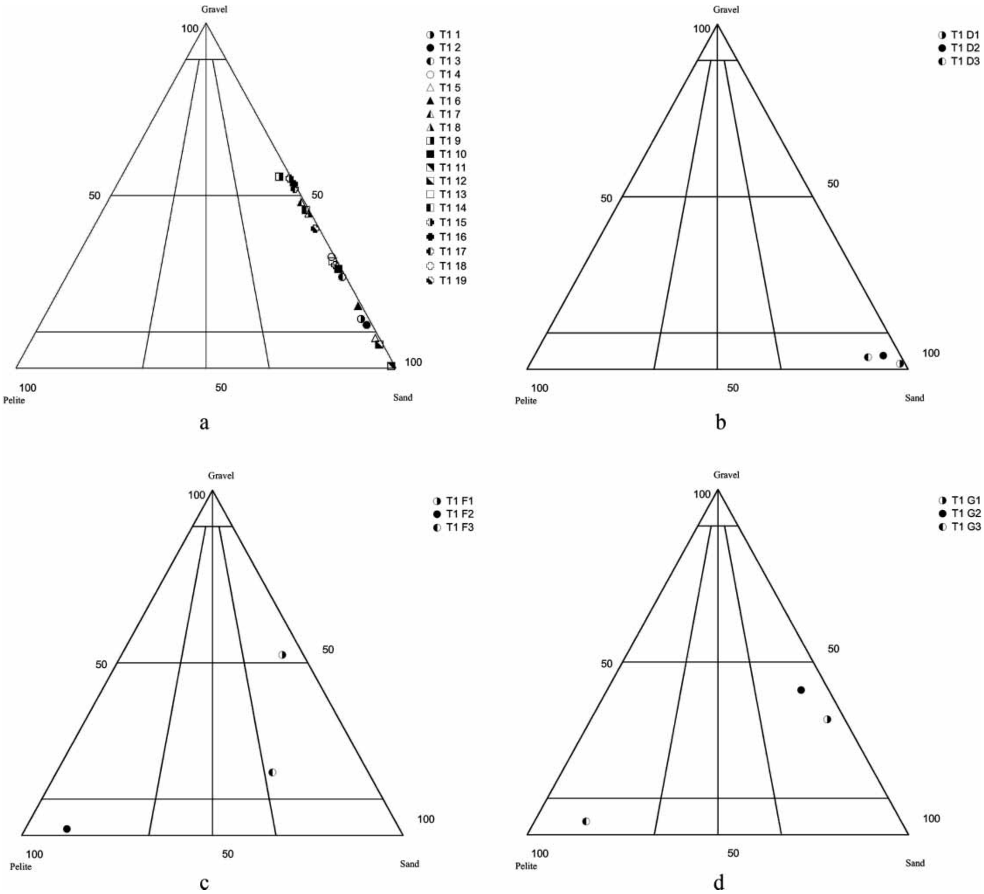

Figure 2. Folk and Ward diagrams and sediment texture classification along the coast (a), and in Lake Verde (b), Lake Mergolo della Tonnara (c) and Lake Marinello (d).

carried out in this study and the area is subject to such high seasonal variability, the results can only provide partial information. Several bacterial strains capable of growing in the presence of As(III) were isolated from sediments collected from the three lakes tested, showing probable bio-availability of this metalloid in these sediments (Table 5).

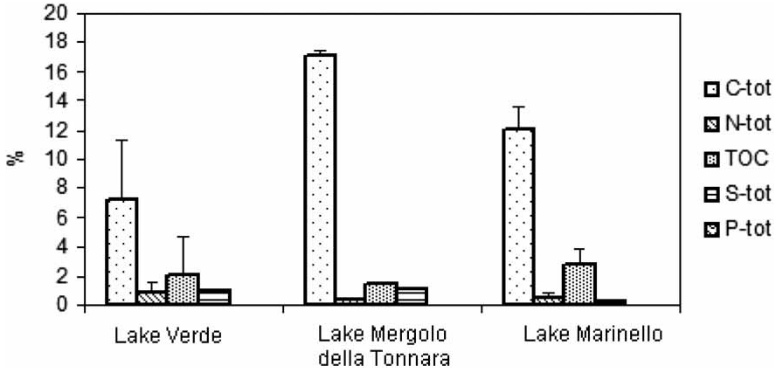

Figure 3. Nutrient concentrations in sediment samples collected from the three Oliveri-Tindari lakes analysed in this study: Lake Verde; Lake Mergolo della Tonnara and Lake Marinello.

Table 3. Organic contaminants in sediment samples collected from the three lakes analysed in the Oliveri-Tindari Lagoon.

	Organochlorinated Pesticides 4,4′ – DDE	Aroclor PCBs	PAHs	PCDD/FS
Lake Verde	0.435	n.d.	n.d.	n.d.
Lake Mergolo della Tonnara	1.4673	n.d.	n.d.	n.d.
Lake Marinello	2.2258	n.d.	n.d.	n.d.

Note: Values are expressed as ng g^{-1} dry weight. n.d. = not detected.

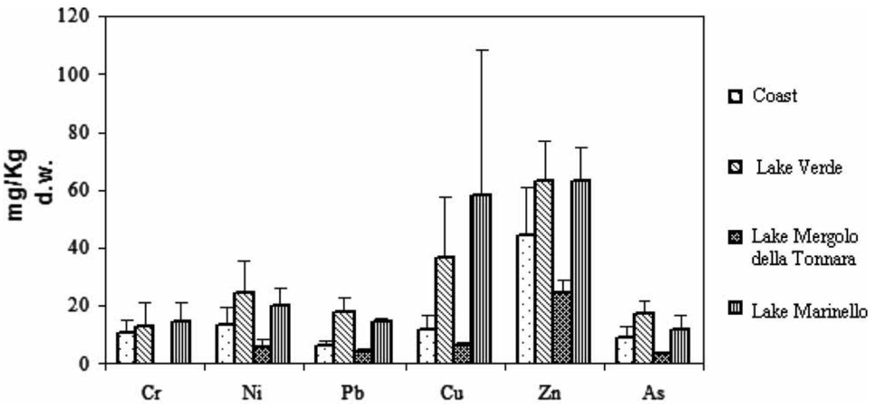

Figure 4. Trace element concentrations in sediment samples collected both along the coast and from the three lakes of the Oliveri-Tindari Lagoon: Lake Verde; Lake Mergolo della Tonnara and Lake Marinello.

Table 4. Microbiological analyses in sediment samples collected from the three lakes tested in the Oliveri-Tindari Lagoon.

Samples	Total Coliform MPN g^{-1}(d.w.)	Faecal Coliform MPN g^{-1}(d.w.)	*Escherichia coli* MPN g^{-1}(d.w.)	Faecal Streptococci MPN g^{-1}(d.w.)	Sulfate-reducing clostridium spores CFU g^{-1} (d.w.)	*Salmonella* spp.
D1	0.0–0.2	0.0–0.2	0.0–0.2	0.0–0.2	2.5×10	A
D2	0.0–0.2	0.0–0.2	0.0–0.2	0.0–0.2	0	A
D3	0.0–0.2	0.0–0.2	0.0–0.2	0.2–0.4	2.0×10^2	A
F1	0.0–0.2	0.0–0.2	0.0–0.2	0.5–0.7	0	A
F2	0.0–0.2	0.0–0.2	0.0–0.2	0.0–0.2	0	A
F3	0.0–0.2	0.0–0.2	0.0–0.2	0.0–0.2	0	A
G1	0.4–0.6	0.0–0.2	0.0–0.2	0.0–0.2	0	A
G2	0.8	0.0–0.2	0.0–0.2	0.0–0.2	1.1×10^3	A
G3	0.2–0.4	0.0–0.2	0.0–0.2	0.0–0.2	2.2×10^2	A

Note: A = absent.

4. Discussion

4.1. *Water characterisation*

A study of the Oliveri-Tindari Lagoon was carried out in order to clarify the status of this delicate system. The waters of Lakes Verde, Mergolo della Tonnara and Marinello were found not to be contaminated, confirming previous studies performed on the waters of these lakes that suggested the feasibility of aquaculture plants in this area due to the high quality of the waters [8]. Analyses

Table 5. Heterotrophic bacterial strains isolated in the presence of As(III) from sediment samples collected from the three lakes of the Oliveri-Tindari Lagoon.

Samples*	Isolated strains	Colony features
D1	D1a	Ø1 mm, white, oval, flat, matt, entire margins
D1	D1 b	Ø 2.5 mm, cream, irregular form, flat, moist, irregular margins
D3	D3	Ø 2 mm, cream, irregular form, flat, matt, irregular margins
F1	F1	Ø1 mm, cream, oval, flat, matt, entire margins
F2	F2 a	Ø1.5 mm, white, oval, flat, matt, entire margins
F2	F2 b	Ø 2 mm, cream, irregular form, flat, moist, irregular margins
F3	F3	Ø 2.5 mm, white, irregular form, flat, moist, irregular margins
G1	G1 a	Ø1 mm, cream, oval, flat, matt, entire margins
G1	G1 b	Ø 2 mm, cream, irregular form, flat, matt, irregular margins
G2	G2	Ø 2 mm, cream, irregular form, flat, matt, irregular margins
G3	G3 a	Ø1.5 mm, white, oval, flat, matt, entire margins
G3	G3 b	Ø 2.5 mm, cream, irregular form, flat, moist, irregular margins

Note: *Lake Verde (D1, D2 and D3), Lake Mergolo della Tonnara (F1, F2 and F3) and Lake Marinello (G1, G2 and G3).

carried out in this study confirmed the brackish nature of the system, with the exception of Lake Verde, which showed lower values than previously reported [3,4].

The water quality was also assessed by microbiological analyses and low level faecal contamination was observed in deep water. In one sample from Lake Verde the values were quite high, probably due to input originating from animal contamination, indicated by the presence of faecal bioindicators [34].

4.2. *Sediment characterisation*

Sediments were characterised by reduced oxidation conditions and texture classification gave the results expected considering the area. The high total carbon levels measured in the sediments of the three lakes, and in particular Lake Mergolo della Tonnara, were probably due to a high concentration of inorganic carbon, rather than organic matter accumulation. These features were probably due to the presence of inorganic carbon in the whole shells and mollusc fragments that accumulate in sediments, as was also shown by grain size analysis. All the other parameters tested in the Oliveri-Tindari Lagoon were within expected ranges, in accordance with the natural reserve status of this area. Moreover, the results reported here represent the first quantitative investigation of PAHs in sediments from the Oliveri-Tindari Lagoon. A comparison with other studies of total PAHs showed that the levels were below the concentration ranges reported by other authors in coastal lagoon sediments from Sicily [35,36].

P-tot levels in sediments were within the expected range [37]. The presence of pp'-DDE could be due to the global distribution of this DDT derivative, rather than the presence of a local source of contamination [38].

In general, concentrations of heavy metals tend to increase as the size fractions get finer [39]. In this study the relationship between grain size characteristics and toxic element distribution was normalised before sediment extraction by sieving them, and determining element contents in the fraction $<250\,\mu m$. We found relatively high concentrations of zinc in all the sediment samples tested and of copper in sediments from Lake Marinello. This is probably related to the fact these two elements have been present in the rocks of this area since their geological origin [40]. The results obtained highlighted the absence of toxic elements, except for arsenic. The latter was present in all the sediments tested, suggesting a probable interaction with agricultural activities, as was also found with the sediments of the Lesina Lagoon, another lagoon system located in Apulia, Italy, showing the presence of heavy metals due to agricultural practices and soil leaching nearby [41].

Moreover, the presence of bacteria capable of growing in the presence of arsenic highlighted the bio-availability of this metalloid. Bacteria that grow in the presence of arsenic are also present in non-contaminated areas, suggesting a broad distribution of these microorganisms, which are probably involved in the biogeochemical cycle of the metalloid [42].

5. Conclusion

The preliminary results of this study, conducted using a multidisciplinary approach, demonstrated that contamination was not present in the waters or sediments of the three lakes of the Oliveri-Tindari Lagoon. Although some of the parameters considered may vary according to seasonal and global changes, this sample provides useful, albeit incomplete, information. The results obtained showed the absence of heavy metal contamination, except for arsenic. However, we cannot at present speculate on the origin of this contamination, as geological, minor anthropogenic activities, or activities related to the presence of animals could have been involved.

Further appropriate studies are required to provide a comprehensive picture of this particular area and, as our results are from a single sampling, we cannot yet make any definite conclusions. Nonetheless, this study represents the first general investigation of this particular area, which is subject to continuous change, and could constitute a starting point for future research.

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