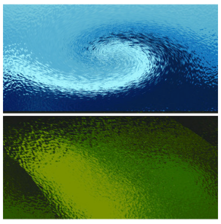
Transitional Waters Bulletin
TWB, Transit. Waters Bull. 2 (2008), n.4, 49-62
ISSN 1825-229X, DOI 10.1285/i1825229Xv2n4p49
http://siba-ese.unisalento.it



RESEARCH ARTICLE

Spatial and temporal variations of nutrients and chlorophyll *a* in a Mediterranean coastal lagoon: Varano lagoon, Italy

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Abstract

1 - The purpose of this paper is to assess the present status of a Mediterranean lagoon (Varano lagoon, Italy), basing on nutrient and chlorophyll *a* data.

2 - A water sampling in Varano lagoon was performed at 7 fixed stations from February 2004 to July 2005, collecting surface water samples to analyse ammonia, nitrite, nitrate, soluble reactive phosphorus (SRP) and soluble reactive silica (SRSi), chlorophyll *a* (chl *a*) and total suspended solids (TSS). Spatial and temporal distributions of chemical and biological parameters in Varano lagoon were examined to accomplish the goal of this study. Statistical tests were used to investigate the correlations between analysed variables and to characterize, from a spatial and temporal point of view, the lagoon in relation to each variable.

3 - Ammonia and nitrate did not showed good correlation ($P<0.05$). SRP was not correlated with any nutrient (only with Chl *a*, $P<0.05$). The seasonal distribution show a random pattern for soluble reactive phosphorus with relatively low mean concentrations (0.16 ± 0.03 µM) and a well-defined seasonal pattern for nitrate, with the highest mean value (34.44 ± 10.18 µM) recorded in the wet season (February 2004) and a high spatial variability. The most homogeneous chl *a* values were observed in both autumn and winter seasons with averages of about 1-1.5 µg . L^{-1}; in contrast, higher mean values (5.50 µg . L^{-1}) were recorded in July 2005. The ratio between the dissolved inorganic nitrogen species and SRP (N/P) in Varano lagoon was constantly high and it varied seasonally from about 300:1 during rainy seasons to 60-90:1 during dry seasons. High values of the N/P ratio in autumn and winter were accompanied by an increase in total N implying an input of nitrogen to the system probably associated with rainfall.

4 - The high fluctuation in the various chemical parameters in the lagoon during the rainy season suggested that this is the period of large variability, in which environmental processes as marine waters, freshwaters and wastewaters represent inputs that determine the spatial behaviour of the system.

Keywords: Coastal ecosystems, Eutrophication, Mediterranean lagoon, Nutrients, Phytoplankton biomass, Varano lagoon

Introduction

Lagoons comprise about 13% of the world's coastline and vary considerably in size, shape, climate, freshwater input, exchange with the sea and human impacts (Carrada, 1990; Nixon, 1982). In Italy, there are about

150,000 ha of coastal lagoons, whose half part is used as nursery areas and for aquaculture and fisheries exploitations (Cataudella *et al*., 1995). Depending on the relationship between freshwater runoff and lagoon geometry, which generally control residence times, lagoons can support high primary productivity, which in turn, often supports valuable fisheries (Mee, 1978; Lasserre, 1981; Phleger, 1981). The assessment of impacts of man-related activities on enclosed systems such as lagoons can be achieved by measuring various chemical markers including nutrients in water column, biota and sediments (Alley, 2000). Lagoons having limited water exchanges with near-shore zones are economically and ecologically important sites (Vazquez *et al*., 1999). Wastewater discharges from various locations are the major sources of organic and inorganic pollutants (including nutrients) in the coastal water ecosystems. Nutrient discharges act as a pressure on algal production, resulting in drastic eutrophication in the coastal waters when physical mixing processes are not sufficient for the dilution of nutrient-enriched wastewaters in the receiving waters. Therefore, measurements of nutrients and phytoplankton biomass in the same environment would lead us to assess both the levels and types of pollution in these ecosystems (Kjerfve, 1994). The present study was carried out within the framework of a Project (ALTAVAR) funded by Apulian Region based on bivalvia farming in Varano lagoon. The purpose of this paper is to assess the present status of the lagoon ecosystem, basing on nutrient and chlorophyll *a* data. For this goal a spatial and seasonal variations of physico-chemical and biological variables in Varano lagoon surface waters were studied.

Material and methods

Study area

Varano lagoon is a shallow body of water (mean depth of 5 m in the central zone) located on the northern coast of the protected area and tourist resort of the Gargano promontory (Gargano National Park, southern Adriatic sea) (Figure 1), with a perimeter of 33 Km. A coastal barrier, with length of 10 Km and width of 1 Km, separates the lagoon from the near sea. It looks a real lake for its both shape and coasts sloped straight down to waters. The lagoon is connected to the sea through two artificial channels, Foce Capoiale (in the weastern side) and Foce Varano (in the eastern side) and exchanges waters and sediments with the Adriatic sea following tidal cycle. Hydrodynamic balance is influenced by tidal levels, freshwater inputs, wind strength and direction and anthropogenic action and water time residence is about 1.3 years. Varano lagoon receives freshwaters input of approximately 87,000 $m3 \cdot d^{-1}$ with an organic content mostly originating from urban and agricultural runoff, fish-farming and zoo-technique activities (Villani *et al*., 2000; Spagnoli *et al*., 2002). The freshwater inputs to the lagoon come from groundwater as springs in the south-western basin of the lagoon, while in the south-eastern zone surrounding urban wastewaters and drainage watercourses (from sourronding agricultural area) discharge into the lagoon through two effluents (Antonino and S. Francesco). Fish-farming and mussels breeding (Mytilus galloprovincialis) were carried out into the lagoon, especially in the northern side of the basin, but the fish production has been greatly reduced over time and in 1995 is estimated less than 1000 quintals against 7-8000 quintals of 60-70 years. The mussels, with a production of a few hundred quintals per year, faces significant difficulties in the summer months for the deficiency of oxygen in the water and consequent reduction in growth of shellfish.

Sampling design and laboratory analyses

The study involved 11 surface water sampling from February 2004 to July 2005 at 7 fixed stations, chosen according to the

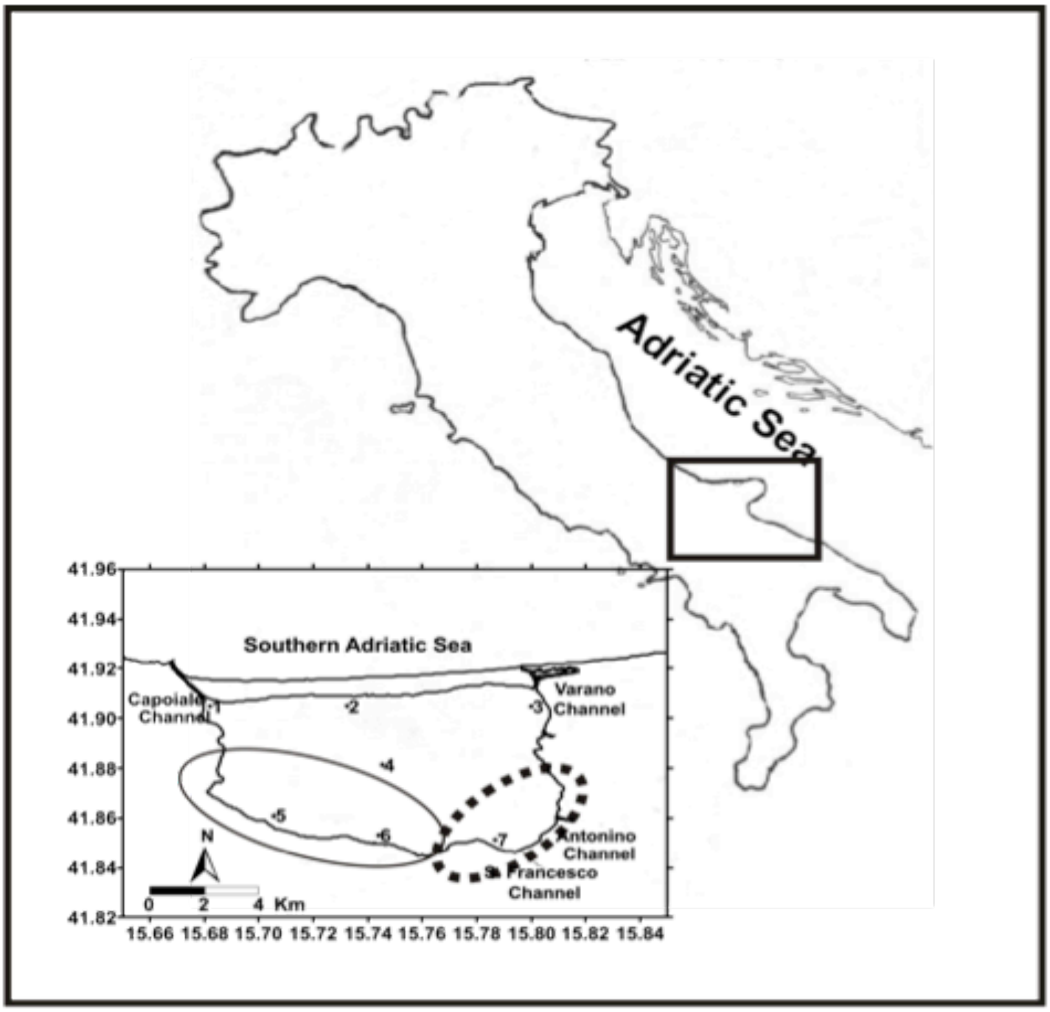

Figure 1. Varano lagoon, Southern Italy and location of sampling sites. Dashed circle indicates urban wastewaters and agricultural drainage watercourses; continuous circle indicates freshwaters input.

marine, groundwater and discharge channels influence (Figure 1). In situ measurements of temperature (°C), salinity (psu) and dissolved oxygen (%) were carried out at each site from October 2004 to July 2005 with an Idromar multiparametric probe. Water samples were collected in pre-cleaned plastic bottles, filtered (0.5-1.0 L) using cellulose acetate fiber filters (Millipore, 0.45 µm), previously heated to 60°C, cooled and weighed. The determination of chemical and biological variables were performed by spectrophotometry, using a Beckman DU-60 spectrophotometer. Dissolved inorganic nutrients (ammonium, NH_4^+; nitrite, NO_2^-; nitrate, NO_3^-; soluble reactive phosphorus, SRP and soluble reactive silica, SRSi) were quantified following Grasshoff (1999) methods. Total suspended solids (TSS) were collected by the filters and determined gravimetrically (drying at 60°C), following the methods reported by Strickland & Parsons (1972). Chlorophyll *a* (chl *a*) was used as an estimate of phytoplankton biomass in the water column and was measured as extractable chl *a* from water samples. One liter of water was filtered through 0.45 Whatman GF/C filters and chl *a* was extracted in 90% acetone, in accordance with Jeffry and Thumphrey (1975) methods. A 6 points reference curve, obtained as linear regression of the absorbances from a scalar dilution of a standard solution (J.T. Baker, Holland), was obtained according to the internal addition procedure. Average percentages of recoveries were within the range of variation 95-100%. Limits of quantification (LOQ) were 0.1μM for all determined nutrients. Dissolved inorganic nitrogen (DIN) was obtained mathematically as sum of ammonium + nitrite + nitrate and used to calculate the ratio DIN/SRP.

Statistical analysis

A Spearman rank order was calculated to evaluate the degree of relationship between the analysed parameters. In a second time, Box-and-Whisker diagrams were used to evaluate significant differences among sites and seasons for all water quality variables. With this objective, a one-way non-parametric ANOVA was performed, using sites and seasons as main factors. StatSoft 5.5 was used on raw data set for this preliminary approach. In order to provide a means of exploring the multivariate nature of the data set, Principal Component Analysis (PCA) was run to identify the key variables with the greatest influence in the physico-chemical and biological system behaviour. In order to confirm differences in variables related to month-season-year factors, the ANOSIM test statistic R (one-way) was performed. Two-way ANOSIM test was performed to highlight the spatial variability and test also for differences related to the "site" factor within the monthly groups and the sites segregation, as a function of water quality, was obtained applying cluster analysis. Multivariate analyses were performed with the software Primer-E (Playmouth Marine Laboratory, UK) according to the methods of Clarke and Warwick (2001).

Results

Water characteristics

Mean values and standard deviations (SD) of water quality characteristics in Varano lagoon calculated on yearly and seasonal basis are presented in Table 1. Water temperature behaviour was related to the seasonal pattern. Higher variability was observed in autumn 2004, with the highest mean values (20.39°C) recorded in October and the lowest (12.20°C) during the rainy period (December). A presence of saltier waters was observed in the site (stations 1) close to the main communicating channel with the sea, above all in autumn 2004, when the exchanges of waters lagoon-sea were forced by wind action. Dissolved oxygen values indicated general healthy conditions of waters for most of the study period, with saturation peaks (near to 100%) measured during late spring-summer season. In relation to nutrients, results showed that nitrate was the predominant form of inorganic nitrogen compounds during winter and spring seasons (rainy period), while ammonium reached higher concentrations in late summer and autumn (dry season), coinciding with the period of higher re-mineralization intensity. A seasonal variability of mean ammonia concentrations is shown in Figure 2a, with higher values recorded in the period from late summer 2004 (August, 10 μM) to autumn 2004 (October, 14.5 μM) at the sites located along the southern part of the lagoon (stations 5, 6 and 7). Lower mean values were observed in spring seasons (April 2004, 1.32 μM; May 2005, 4.71 μM) along the northern part of the lagoon from west to east. Higher mean concentrations of nitrite were recorded during the autumn 2004, with the highest values (> 2 μM) observed along the northern side of the lagoon (site 2). In contrast, lower mean concentrations were recorded during the late spring-summer (0.12 ± 0.05 μM in June 2005 and 0.13 ± 0.06 μM in July 2005), with the lowest value (0.06 μM) recorded along the

Table 1 - Mean values and standard deviations (in brackets) of dissolved inorganic nutrients, chlorophyll *a* (chl *a*), total suspended solids (TSS), DIN and DIN/SRP ratio, calculated on yearly and seasonal basis in Varano lagoon. Abbreviations of the variables are given in the text (section 2.2).

	T	Sal	DO	NH4+	NO2-	NO3-	SRP	SRSi	Chl a	TSS	DIN	DIN/SRP
	(°C)	*(psu)*	*(%)*			*mM*			*$\mu g.L^{-1}$*	*$mg.L^{-1}$*		
Winter 2004				4.11	1.53	34.44	0.14	41.29	0.99	14	40.08	314
				(0.9)	(0.3)	(10.2)	(0.04)	(7.5)	(0.2)	(3)	(10.8)	(137)
Spring 2004				1.32	1.50	23.42	0.17	21.42	3.74	13	26.24	195
				(0.3)	(0.5)	(3.6)	(0.009)	(14.9)	(3.5)	(5)	(3.1)	(90)
Summer 2004				6.99	0.38	3.27	0.20	40.67	2.54	12	10.62	58
				(2.5)	(0.1)	(1.8)	(0.0)	(11.7)	(0.4)	(1)	(4.5)	(27)
Autumn 2004	16.30	28.20	78.00	13.36	1.63	15.78	0.14	49.20	1.48	13	30.77	245
	(5.8)	(1.4)	(0.3)	(1.6)	(0.5)	(3.9)	(0.02)	(15.8)	(0.7)	(3)	(3.9)	(60)
Yearly	16.30	28.20	78.00	6.44	1.26	19.22	0.16	38.14	2.19	13	26.93	203
	(5.8)	(1.4)	(0.3)	(5.2)	(0.6)	(13.1)	(0.03)	(11.8)	(1.2)	(1)	(12.3)	(108)
Spring 2005	20.40	24.30	41.00	4.96	0.33	6.70	0.16	11.27	3.95	10	11.99	86
	(3.3)	(0.7)	(50)	(0.3)	(0.1)	(3.2)	(0.03)	(13.7)	(19)	(1)	(3.5)	(21)
Summer 2005	28.50	26.20	92.00	3.56	0.12	1.47	0.15	39.55	4.58	10	5.16	52
	(0.5)	(1.0)	(2.4)	(0.1)	(0.0)	(0.1)	(0.06)	(0.5)	(1.3)	(0.5)	(0.23)	(36)
Yearly	24.40	25.20	67.00	4.26	0.22	4.08	0.15	25.41	4.26	10	8.57	69
	(5.8)	(1.3)	(35)	(1.0)	(0.1)	(3.7)	(0.0)	(20)	(0.4)	(0.2)	(4.8)	(24)

south-western side of the basin (site 5). The temporal pattern of nitrate was characterized by higher mean concentrations during the rainy season (from February to April 2004), with the highest values (40-50 µM) observed along the western part of the lagoon (sites 3 and 7), and lower concentrations in summer seasons (July 2004, <1 µM; July 2005, 1.40 µM) (Figure 2b). Although mean SRP was similar among seasons (Table 1), the highest median SRP concentrations were recorded during hot months (0.20 µM in July 2004 and 0.19 µM in August 2004, April 2005 and July 2005), while values ranged between 0.12 and 0.17 µM were observed during the remaining sampling period (Figure 2c). SRSi exhibited the highest median concentration in autumn (76.6 µM and 67.9 µM at the sites 2 and 7, respectively, in October 2004) and the lowest values in spring (from undetected values to <2 µM in April 2005). A decrease of SRSi concentrations was related to minor freshwater influence during spring 2005. A well-defined temporal trend of concentrations is shown in Figure 2d. The ratio between the dissolved inorganic nitrogen species and SRP (DIN/SRP) in Varano lagoon was constantly higher than Redfield ratio (Table 1) and it varied seasonally from about 300:1 during rainy seasons to 60-90:1 during dry seasons,

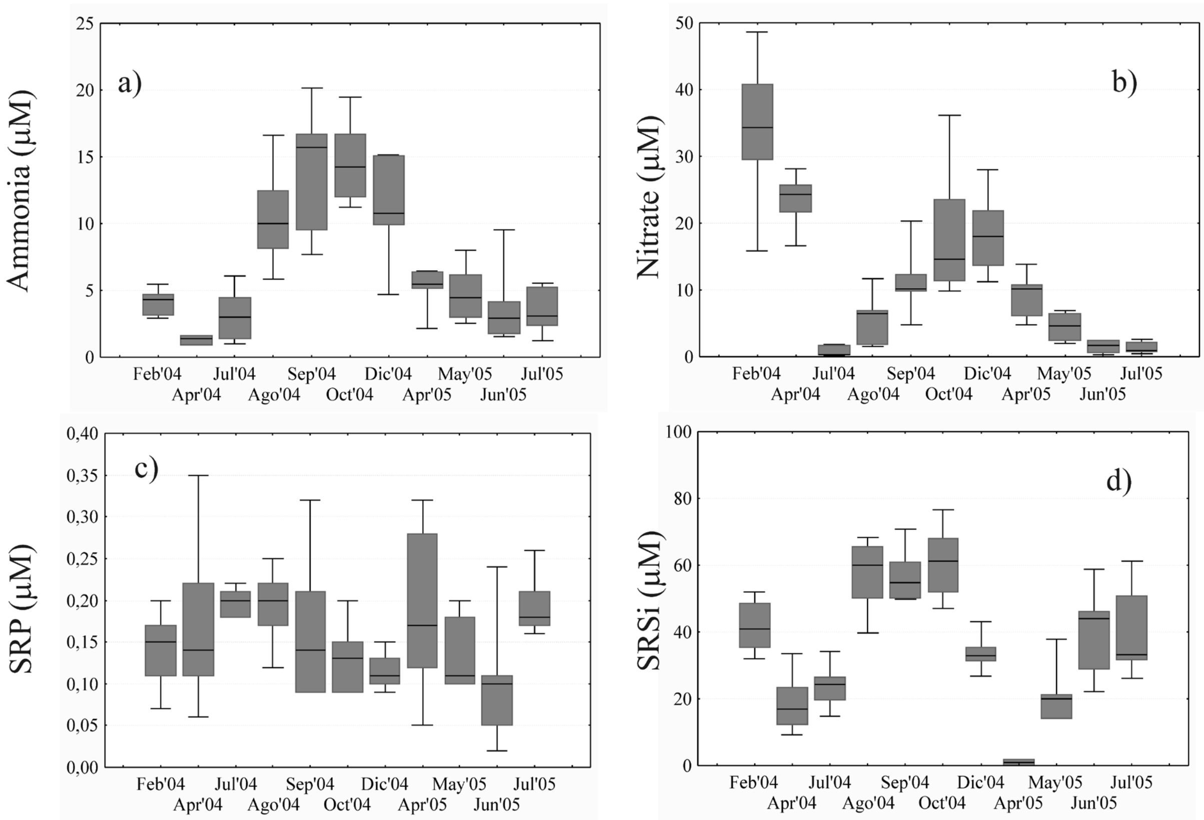

Figure 2. Seasonal and temporal variation in Varano lagoon of median ammonia (a), nitrate (b), soluble reactive phosphorus (c) and soluble reactive silica (d), during the study period. The box is characterised by a median line and percentiles values with coefficients of 25th and 75th, on the bottom and the top respectively; the whisker is characterized by percentiles values with coefficients of 5th and 95th, located on the tips.

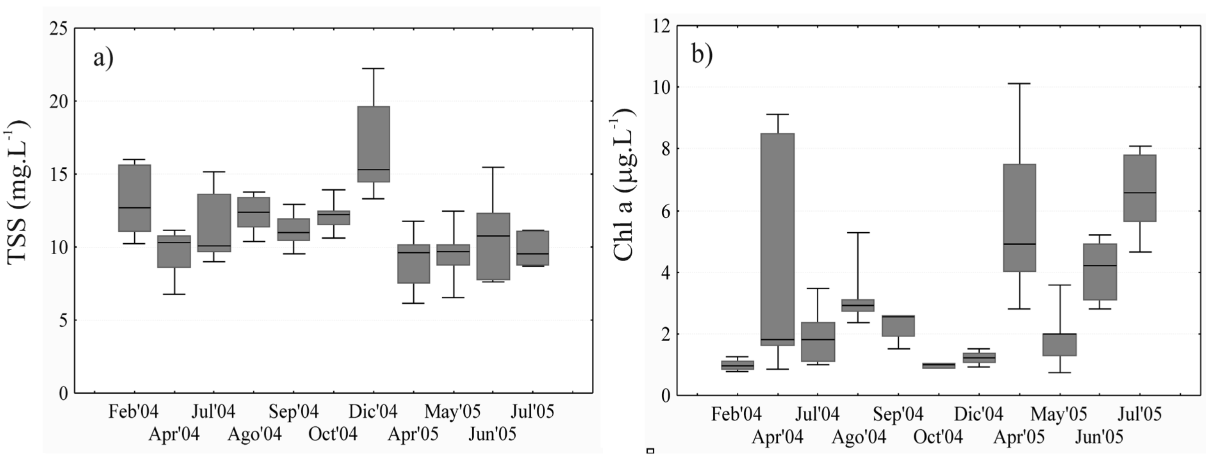

Figure 3. Seasonal and temporal variation in Varano lagoon of median total suspended solids (a) and chlorophyll *a* (b), during the study period.

suggesting SRP as the limiting nutrient. The highest mean value of TSS was observed in December 2004 (16.5 ± 3.20 $mg.L^{-1}$) with a high spatial variability indicated by standard deviation, while mean concentrations ranging between 10 and 14 $mg.L^{-1}$ were measured during the study period (Figure 3a). Chl a showed higher concentrations in both spring seasons, with the highest means registered at site 7 (9.12 $\mu g.L^{-1}$, April 2004; 10.13 $\mu g.L^{-1}$, April 2005) and lower values observed during winter 2004 (0.78 $\mu g.L^{-1}$ at site 7, February 2004) (Figure 3b).

Correlation factors and multivariate assessment

Spearman rank order correlations between observed variables for surface water of Varano lagoon from 2004 to 2005 period are presented in Table 2. Dissolved nitrogen species exhibited significant positive correlations amongst themselves. SRP did not correlate with any nutrient, but only with chl *a* ($P<0.05$). SRSi showed a significant positive correlation with ammonia ($P<0.001$), also highlighted by the same seasonal pattern shown in Figure 2a,d, while TSS presented good correlations with dissolved nitrogen species. Chl *a* was negatively correlated with nitrite and nitrate, but positively with SRP, indicating an influence of phosphorus over the phytoplankton growth. Temperature water showed negative correlations with nitrogen salts and TSS and a slight positive correlations with chl *a*. Good correlations were also found between salinity and SRSi (positive) and chl *a* (negative), indicating a loading of freshwater for phytoplankton biomass, but not for silicate. DO exhibited good positive relationships with T and negative with dissolved nitrogen species. With the objective of evaluating significant differences among months and sites, for all water quality variables, data were analyzed using a one-way non-parametric ANOVA (Table 3). Highly significant differences ($p<0.001$) were observed for all data in relation to the factor "month", except for SRP and DO ($p<0.05$). Although from Figures 2 and 3 it is noteworthy that some parameters

Table 2 - Spearman rank order correlations among all the variables for surface water of Varano lagoon during the study period.

	Ammonia	Nitrite	Nitrate	SRP	SRSi	TSS	Chla	Temperature	Salinity	DO
Ammonia	1	0.42***	0.23*	-0.11	0.50***	0.27*	-0.19	0.61***	0.34*	-0.56***
Nitrite		1	0.73***	-0.2	0.15	0.54***	-0.44***	-0.71***	0.30*	-0.5***
Nitrate			1	-0.14	0.1	0.40***	-0.4***	-0.85***	0.14	-0.69***
SRP				1	0.04	-0.13	0.25*	0.1	-0.05	-0.002
SRSi					1	0.12	-0.1	0.03	0.38**	-0.04
TSS						1	-0.13	-0.41**	0.26	-0.27
Chla							1	0.33*	-0.44**	0.17
Temperature								1	0.11	0.72***
Salinity									1	0.02
DO										1

Table 3 - One-way ANOVA on all water quality variables of Varano lagoon, considering sites and months as main factor to test significant differences.

	Months		Sites	
	F	p	F	p
NH_4^+	23.79	0.0000	0.4797	0.8213
NO_2^-	0.92	0.5206	0.9972	0.4342
NO_3^-	315.576	0.0000	0.1937	0.9776
SRP	22.775	0.023	1.3049	0.2665
SRSi	4.4783	0.00008	0.1597	0.9864
Chl a	12.0131	0.0000	0.8498	0.5361
TSS	8.3801	0.0000	0.5157	0.7945
DIN	33.3481	0.0000	0.2355	0.9635
DIN/SRP	16.2966	0.0000	0.1896	0.9788
T	248.8136	0.0000	0.0254	0.9999
S	4.6943	0.0004	0.758	0.6076
DO	2.8214	0.0130	0.9115	0.4982

presented a high spatial variation, ANOVA analysis showed no significant difference considering sites as the main factor (Table 3). Several multivariate classifications were used to reveal structures and differences that otherwise could not be highlighted. An ordination analysis was performed with all water quality variables measured, except for temperature, salinity and dissolved oxygen, due to a shorter observation period with respect to these variables. From PCA analysis, five principal components were obtained and the majority of the existing variability in the original variables (92.1%) was explained by the first component (PC1, 48.4%) while the second (PC2) and the third (PC3) components accounted for 13.9% and 12.4%, respectively (Figure 4). PC1 was mainly defined by nitrite (-0.433), nitrate (-0.420), DIN (-0.453) and DIN/SRP ratio (-0.452) which are related to rainy seasons, as indicated by segregation on the left side of the diagram of autumn and winter months. PC2 was positively associated with SRSi and ammonia, indicating a relationship with possible polluted water discharges, and negatively with chl *a*, related to phytoplankton blooms occurring during spring season. Dissimilarities related to month-season-year factors, well highlighted by PCA, were also confirmed by the application of the ANOSIM test (Analysis of similarities performed on 9999 permutations on “month-season-year” factors), which produced significant results (P=0.01%) for month (R=0.724), season (R=0.53) and year (R=0.43) factors. Two-way ANOSIM test was

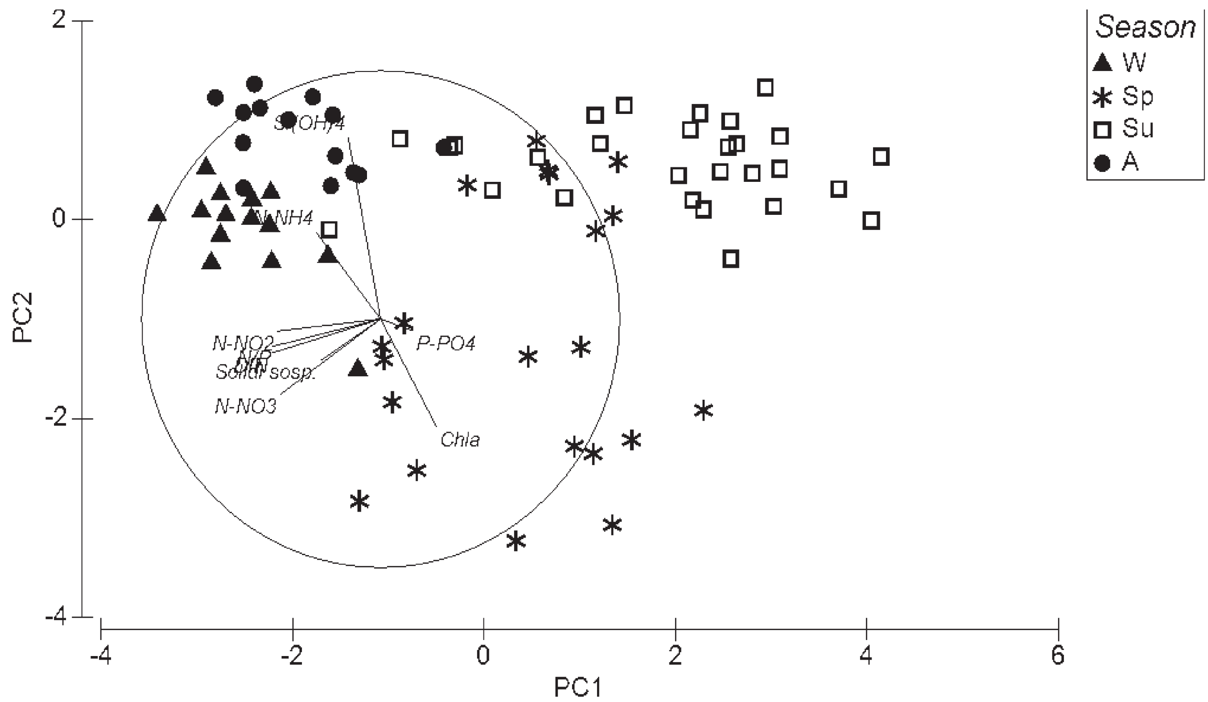

Figure 4. Two-dimensional plot of water variables from the two Principal Component of the PCA in Varano lagoon.

performed to highlight the spatial variability and test also for differences related to the "site" factor within the monthly groups. The results produced a significant global R value of 0.633 (P=0.5%). In addition, to evaluate relative distances among site groups, the Pairwise Test was reported (Table 4), showing greater differences between marine and freshwater inputs (Ch-S) and wastewater treatment plants and springs (WWTP-S). The dendrogram obtained by cluster analysis (Figure 5) shows the difference between the site 1 (near the channel) and the sites 5 and 6 (spring influence) and between the site 3

Table 4 - Pairwise Test results obtained to evaluate relative distances among sites

	R	significance	Possible	Actual	Number ≥ observed
Pair of sites	Statistic	Level %	Permutations	permutations	
Ch, S	0.667	**3.8**	729	729	28
MF, S	0.5	10.7	729	729	78
WWTP, S	0.833	**1**	729	729	7
I, S	0.333	23	729	729	168
S, UAD	0.167	40.3	729	729	294

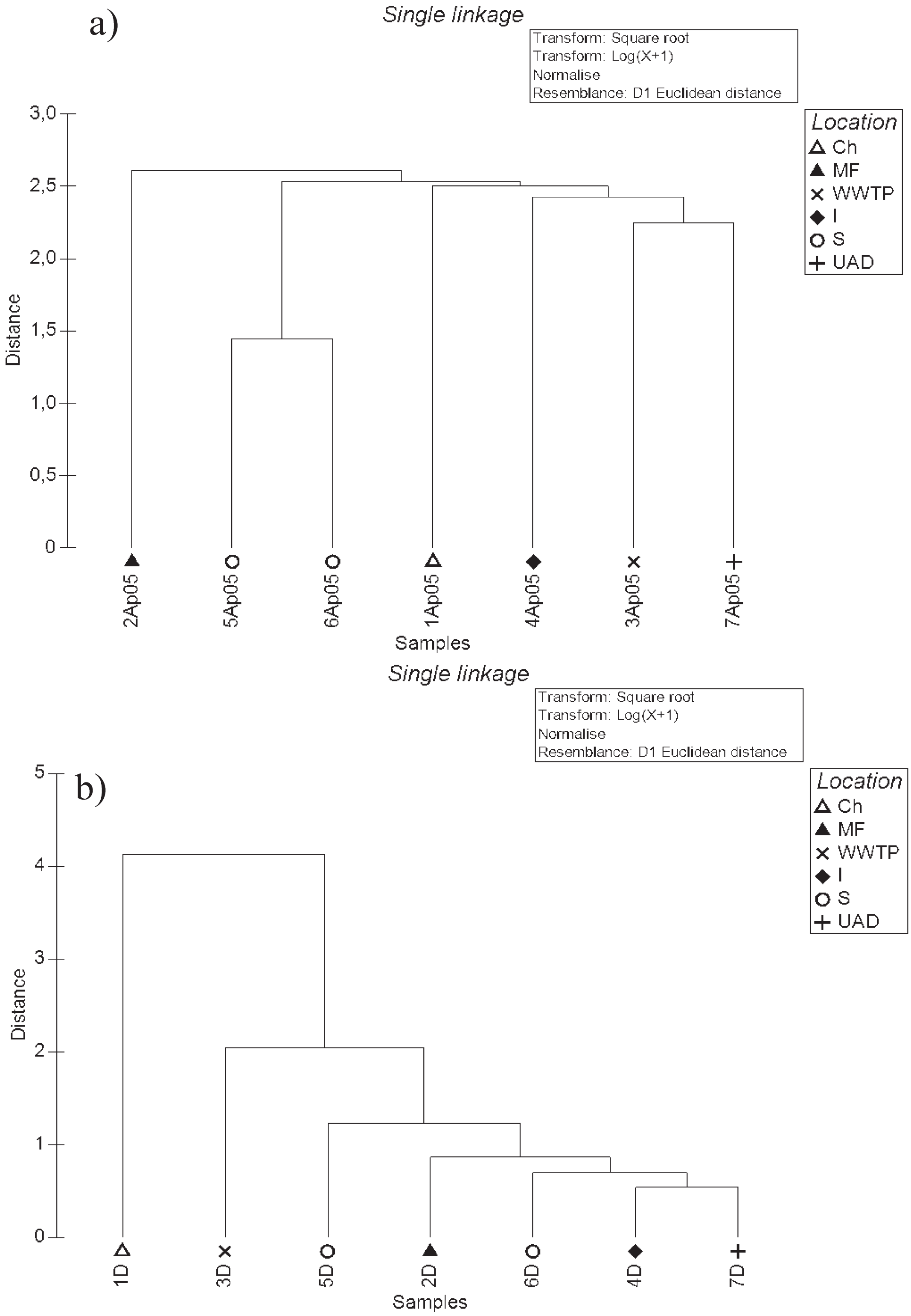

Figure 5. Similarity dendrograms for the seven sampling sites, obtained by cluster analysis in April 2005 (a) and December 2004 (b). Lower linkage distances mean higher similarities. The symbols used in the legend are explained by footnotes in Table 4.

(close to the wastewater treatment plants) and the sites 5 and 6 (freshwater inputs) well defined in April 2005 (Figure 5a) and December (Figure 5b).
The different behaviour of these sites was mainly due to DIN, chl a and TSS, which were the variables strongly related to the first two component of PCA analysis, representing the most variability of the system. The different evolution of these parameters in the sites representative of different influences is shown in Figure 6.

Discussion
The findings obtained in this study were well below those reported in literature for

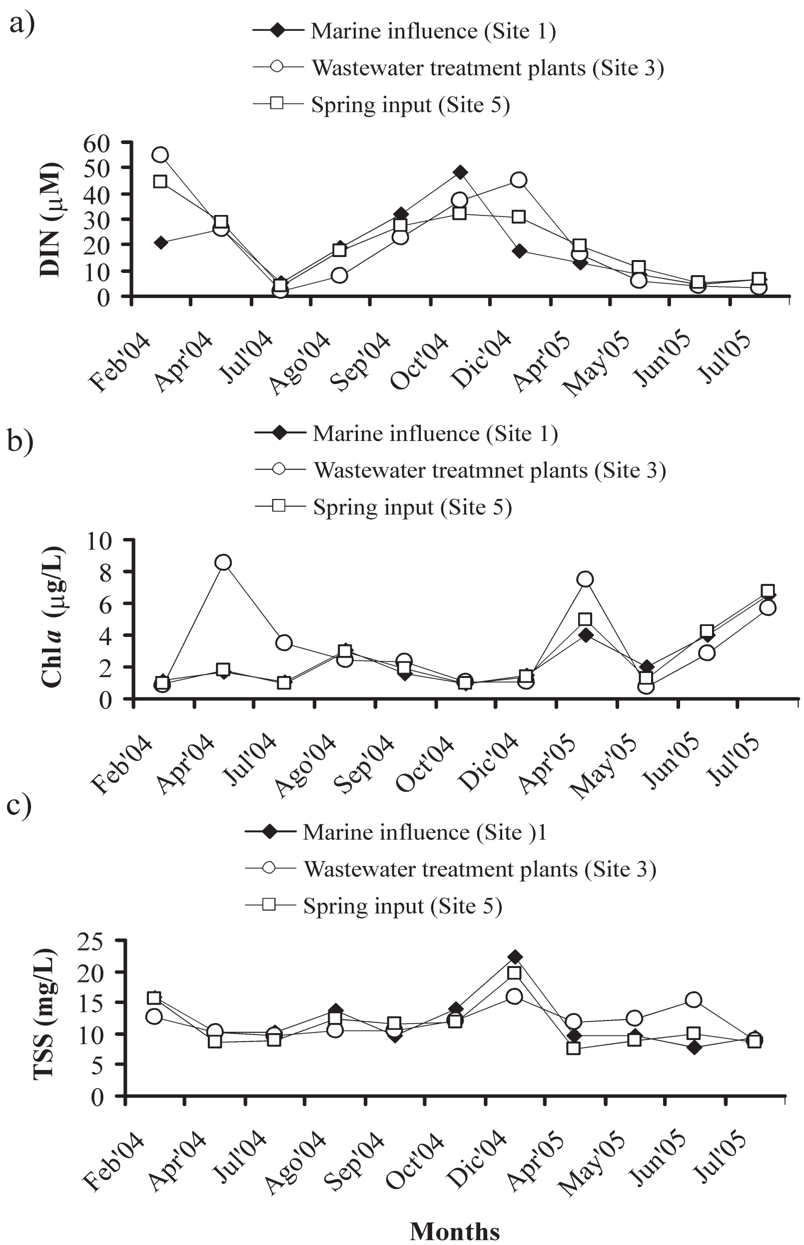

Figure 6. Different evolution of DIN (a), chl *a* (b) and TSS (c) in the sites representative of areas with different influences, as obtained by cluster analysis.

a number of Mediterranean areas such as NE Iberian Peninsula (Badosa *et al*., 2006), coastal lagoons of Viladecans (NE Spain) (Lucena *et al*., 2002), Mar Menor lagoon (SE Spain) (Velasco *et al*., 2006) and Vistonis lagoon (Northern Greece) (Gikas *et al*., 2006). Also, higher concentrations of inorganic nitrogen species than results recorded in previous sampling programme (Caroppo, 2001) were obtained. The sites chosen in this study were representative of areas influenced by different inputs and the nutrient surplus from urban and agricultural lands seem to be the main cause of nitrogen (nitrate as predominant form) inputs into the lagoon, above all in the rainy season. In fact, the high maximal DIN concentrations were limited in autumn and winter 2004, depending on wet period, while SRP concentrations were particularly low. Moreover, DIN levels seems to remain constantly high in Varano lagoon, indicating that nitrogen excess, more noticed in rainy period, is most likely occur. Furthermore, DIN/SRP was also high in all the sites of the lagoon during the entire period of observation, except for summer months (July 2004 and 2005), when values lower than Redfield ratio (DIN/SRP=16) were observed in the central site of the lagoon, supporting the hypothesis of SRP release through sedimentary biogeochemical processes, enhanced by higher temperatures.
Phytoplankton biomass occurred during the spring months and the inverse relationship between chl *a* and salinity suggests that freshwater inputs are an important forcing function stimulating phytoplankton growth. The most homogeneous chl *a* condition was observed during both the autumn and winter seasons. In addition, the high values of DIN/SRP ratios suggest that the phytoplankton biomass is restricted by phosphorus availability.
The significant inverse correlation between nitrate and temperature confirmed the great influence of the rainy period (winter) on nitrate dynamics, while the strong positive correlation between temperature and ammonia (peaks of ammonia observed in late August and September 2004) indicated that the main source of ammonia comes from exchanges at the water-sediment interfaces where strong organic matter mineralisation occurs (Caffrey, 1995).
The differences observed in water quality of Varano lagoon during the study period indicate that the nutrient availability to water was influenced by many factors, including local input (marine and fresh waters), human activities (urban and agricultural discharges) and season. All these forcing functions, in addition to the peculiar geomorphology of the lagoon (the low water flow and the restriction of water exchange) play an important role in promoting changes in the trophic state of the system and, in turn, determine the space-time fluctuations of almost all variables.
The intense fluctuation observed in the physico-chemical and biological variables of the lagoon during late autumn and winter, suggests that the rainy season is a period of large spatial variability, when discharges coming from the surrounding land represent inputs that strongly determine the spatial behaviour of the system. PCA analysis showed that the system variability was mainly determined by "season" factor. The effects of the rainy season was easily seen along the first component (strongly related to nitrate values), while the prevalent conditions during the dry season (high temperatures, as well increasing of phytoplankton biomass and ammonia) were highlighted along the second component. Spatially, the gradients observed in Varano lagoon were mainly related to the balance between marine-fresh water inputs and wastewater-spring inputs. These gradients resulted from a different clustering of sites located near the main communicating channel, close to the springs and near the wastewater treatment plants, due to different behaviour of DIN, chl *a* and

TSS during the extreme seasons (spring and late autumn-winter).

Conclusions

Nutrient variability in the waters of Varano lagoon was found to be highly influenced by external inputs which represent the major source of nutrients, especially of nitrate during the wet period. The high fluctuation in the various chemical parameters in the lagoon during the rainy season suggested that this is the period of large variability, in which environmental processes as marine waters, freshwaters and wastewaters represent inputs that determine the spatial behaviour of the system.

A pronounced seasonal pattern was a characteristic of this lagoon. This pattern had a direct effect on water nitrate and phytoplankton biomass. Nitrate and nitrite were mostly predominant during rainy season, while ammonia was the most important nitrogen species in summer, indicating a release of this component from sediments, enhanced by high temperatures. The most homogeneous chl *a* condition was observed in both autumn and winter seasons, when water dilution is caused by rainfalls and the mixing of water column occurred for wind action.

Acknowledgements

Financial support for this research was provided by Apulia Region (P.O.R. Apulia 2000-2006/Asse IV/4.13.E) within a project aimed to bivalvia farming in Varano lagoon.

References

Alley ER, 2000. *Water Quality Control Handbook*. MCGraw-Hill Inc., New York, p.12.

Badosa A, Boix D, Brucet S, Lòpez-Flores R, Quintana XD, 2006. Nutrients and zooplankton composition and dynamics in relation to the hydrological pattern in a confined Mediterranean salt marsh (NE Iberian Peninsula). *Estuarine Coastal and Shelf Science* **66**: 513-522. DOI:10.1016/j.ecss.2005.10.006.

Caffrey JM, 1995. Spatial and seasonal patterns in sediment nitrogen remineralization and ammonium concentrations in San Francisco Bay, California. *Estuaries* **18**: 219-233.

Caroppo C, 2001. Autoecology and morphological variability of *Dinophysis sacculus* (Dinophyceae: Dinophysiaceae) in a Mediterranean lagoon. *Journal of the Marine Biological Association of the United Kingdom* **81**: 11-21.

Carrada G, 1990. Le lagune costiere. *Le Scienze* **264**: 32-39.

Cataudella S, Rossi R, Cognetti G, 1995. Schede informative sulle lagune e sugli stagni costieri italiani. *Consorzio Venezia Nuova*, 1-57.

Clarke KR, Warwick RM, 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd Edition. Primer-E: Plymouth.

Gikas GD, Trisevgeni Y, Tsihrintzis A, 2006. Water quality trends in a coastal lagoon impacted by non-point source pollution after implementation of protective measures. *Hydrobiologia* **563**: 385-406. DOI: 10.1007/s10750-006-0034-2.

Grasshoff K, Ehrhardt M, Kremling K, 1999. *Methods of Seawater Analysis*, Verlag Chemie, Weinheim, 1-419.

Jeffry SW, Humphrey GF, 1975. New spectrophotometric equation for determining chlorophyll a, b, c1 and c2 in higher plants, algae and natural phytoploankton. *Biochemie, Physiologie Pflantzen* **167**: 191-194.

Kjerfve B, 1994. *Coastal Lagoon Process*.

Elsevier Science Publishers, Amsterdam, The Netherlands.

Lassere P, 1981. *Biological approach to coastal lagoons: metabolism and physiological ecology.* In: Coastal Lagoon Research, Present and Future. *Unesco Technical Papers in Marine Science* **33**: 351-324.

Lucena JR, Hurtado J, Comìn FA, 2002. Nutrients related to the hydrologic regime in the coastal lagoons of Viladecans (NE Spain). *Hydrobiologia* **475/476**: 413-422.

Mee LD, 1978. *Coastal Lagoons*. In: Chemical Oceanography (Riley, J. P. & Chester, R. eds), Vol. 7, 2nd Edition, 441-490.

Nixon SW, 1982. Nutrient dynamics, primary production and fisheries yields of lagoons. *Oceanologica Acta*. Proceedings International Symposium on Coastal Lagoons. SCOR/IABO/ UNESCO, Bordeaux, 8-14 September, 357-371.

Phleger FB, 1981. *A review of some general features of coastal lagoons*. In: Coastal Lagoon Research, Present and Future. *UNESCO Technical Papers in Marine Science* **33**: 7-14.

Spagnoli F, Specchiulli A, Scirocco T, Carapella G, Villani P, Casolino G, Schiavone P, Franchi M, 2002. The lago di Varano: Hydrologic characteristics and sediment composition. *Marine Ecology* **23** (I), 384-394.

Strickland JDH, Parson TR, 1972. *A pratical handbook of sea analysis*, Fisheries research board of Canada, Ottawa. II. 14.II, 5, 137.

Vazquez GF, Virender KS, Magallanes VR, Marmolejo AJ, 1999. Heavy metals in coastal lagoon of Gulf of Mexico. *Marine Pollution Bulletin* **38**: 479-485.

Velasco J, LLoret J, Millan A, Marin A, Barahona J, Abellan P, Sanchez-Fernandez D, 2006. Nutrient and particulate inputs into the Mar Menor lagoon (SE Spain) from an intensive agricultural watershed. W*ater, Air and Soil Pollution* **176**: 37-56. DOI: 10.1007/s11270-006-2859-8.

Villani P, Carapella G, Scirocco T, Specchiulli A, Maselli M, Schiavone R, Spagnoli F, Marolla V, Casolino G, Franchi M, Schiavone P, Deolo A, 2000. *Progetto Integrato di Recupero e Riqualificazione della Zona Umida della Laguna di Varano*. Technical Report Consorzio ELTCON, Roma, Italy.

