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Phytoplankton distribution across the southeast Adriatic continental and shelf slope to the west of Albania (spring aspect)

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Abstract We present the first insight to the oceanography of the southeastern Adriatic Sea, where coastal water influenced by Albanian rivers comes into contact with the inflowing oligotrophic Eastern Adriatic Current (Ionian Surface Water and Levantine Intermediate Water). A distinct plankton distribution was observed on each side of the shelf break hydrographic boundary in May 2009, during gradual warming of the surface waters. The prochlorophytes accumulated along the nutricline above the shelf and continental slope. The phosphorus limited inshore waters were dominated by a small diatom *Chaetoceros circinalis*, dinoflagellates, cryptophytes, autotrophic picoplankton, and heterotrophic nanoplankton. The offshore surface layer was characterized by bigger nanoplankton (coccolithophorids, green flagellates). Low nutrient concentrations influence relatively low productivity not only above the Albanian shelf but also further to the north along the Montenegrine and Croatian coastal Adriatic Sea.

Keywords Phytoplankton · Shelf slope · Front · Albania · Adriatic Sea

Introduction

The Adriatic rivers are the main source of fresh water and nutrients in the northern Mediterranean (Pettine et al. 1998; Meybeck et al. 2006). Although the role of the Po River is relatively well understood, the southeastern Adriatic

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(Albanian) rivers have not been seriously considered to date, neither as a physical force, nor as a nutrient source. Besides studies on phytoplankton size structure (Sabetta et al. 2008), taxonomic composition, and diversity (Saracino and Rubino 2006; Vadrucci et al. 2008) in the southeastern Adriatic, there is no information on fine distribution of plankton across the Albanian shelf and continental slope, where a distinct hydrographic boundary between north westerly inflowing current from the Ionian Sea and the low salinity Albanian coastal waters can be frequently detected by satellite imagery. The discharge of rivers into the Adriatic Sea, the strong northern wind (the bora), and currents participate in the formation of fronts in the northern Adriatic (Lee et al. 2005) and along the Albanian shelf (Le Vourch et al. 1992).

The aim of this study is to present for the first time the influence of Albanian rivers on the southern Adriatic distribution of nutrients and phytoplankton across the hydrographic boundary appearing above the shelf and continental slope, to the southwest of the Albanian mainland, as observed during the spring warming and biological activity in May 2009. The case study in May 2009 gives the first insight into the fine scale oceanography in the area in which Albanian shelf riverine plume waters come to contact with the Eastern Adriatic Current (EAC).

Material and methods

Investigated area

The Adriatic Sea is an isolated northern extension of the Mediterranean Sea, strongly influenced by the European continent. The southern Adriatic is characterized by a deep at its center, the South Adriatic Pit, reaching a depth of 1,200 m (Fig. 1). The bottom rises to a 780-m deep sill in the 75-km wide Strait of Otranto, where the Adriatic is connected to the Ionian Sea and rest of the Mediterranean. The Albanian coastal zone is an example of a narrow shelf smoothly sloping into the Southern Adriatic Pit.

The general circulation of the Adriatic Sea is cyclonic, which is the result of differences in thermohaline conditions (freshwater influx, wind forces, communication with the Mediterranean) (Zore-Armanda 1969; Orlić et al. 1992; Gačić et al. 1999, 2001), as well as basin morphology (Kourafalou 2001).

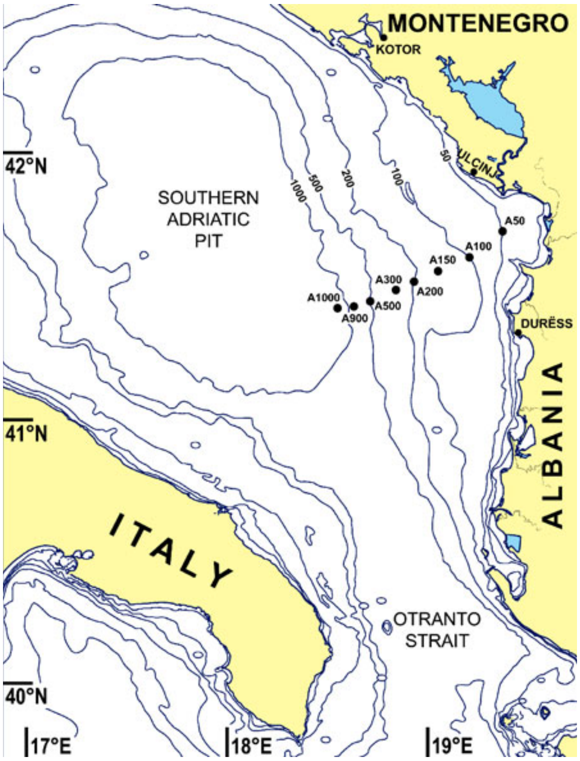


Fig. 1 Position of stations across the shelf break to the southwest of the Albanian mainland

The Albanian coastal zone circulation is greatly influenced by inflowing Ionian waters (upper portion of EAC), strong riverine discharge, and wind action (Gačić 2001). The EAC is oriented to the northwest, because the bathymetry mostly prevents cross-shore variations. Velocity variations (maximum speed is 70 cm s^{-1}) can also be attributed to mesoscale features such as eddies, jets, and filaments formed by baroclinic instabilities of the mean flow (Gačić 2001).

The spring season is characterized by transition from winter to summer conditions. In winter, when southeasterly winds prevail and Adriatic waters are denser than Ionian, the Ionian Surface Waters (ISW) extend well into the central part of the Adriatic basin, keeping the Adriatic Surface Waters (ASW) close to the western shores. The situation reverses in summer, when oceanographic and meteorological conditions favor lateral expansion of the ASW, pushing the ISW closer to the eastern shores. The spring is also characterized by gradual warming of the surface waters, and a change from the winter situation in which waters closer to the shore are colder than those off-shore to a reverse situation in summer, imposed by changes in riverine and Ionian inflows. In remotely sensed sea surface temperature (SST) fields, the Albanian Adriatic shelf is commonly characterized by warm intrusions in winter and cold veins in summer, with considerable interannual variability (see Bohm et al. 2003).

In addition to the Po River, which has a great impact on circulation and productivity in the Adriatic Sea, there is the southeastern Adriatic coastal area greatly influenced by seven Albanian rivers (Buna, Drini, Semani, Vijose, Erzen, Ishem, Mati), with an average discharge of 1,308 $m^3\ s^{-1}$ or 4.1 × 10^4 km^3 $year^{-1}$ (Cullaj et al. 2005). The average Buna river discharge is about 700 $m^3\ s^{-1}$.

The EAC is a part of the Levantine Intermediate Water (LIW) and the Eastern Mediterranean Conveyor, with the current vein flowing in the layer below 40 m depth, with salinity greater than 38.75 (Zore-Armanda 1969; Vilibić and Orlić 2001), carrying extremely low concentrations of nutrients (Socal et al. 1999). The velocity of LIW depends upon the atmospheric pressure gradient in the Mediterranean, etesian wind intensities, Adriatic seawater horizontal density gradient, and vertical circulation (Raicich and Crisciani 1999). The strong winter winds in the Aegean Sea usually result in a decrease in southern Adriatic salinity and a weakening of LIW inflow (Samuel et al. 1999). Above the Southern Adriatic Pit, there is the permanent Southern Adriatic Cyclonic Gyre (Malanotte-Rizzoli and Bergamasco 1989). About 75% of water that inflows through the Otranto Strait recirculates in the Southern Adriatic Cyclonic Gyre, and about 25% crosses over the Palagruza Sill on the way to the middle and north Adriatic (Gačić et al. 1999). The northern Adriatic water contributes to only 4% to 5% of the total volume of water being exchanged through the Otranto Strait.

Thermohaline, chemical and microbiological characteristics were determined along the 91-km long cross section through the continental slope of the Southern Adriatic Pit and Albanian shelf, extending to the southwest of the Buna River mouth (Fig. 1).

Water column sampling

The 16-h long sampling and measurements started on May 12, 2009, at 9 A.M. Eight stations were set along the section to measure thermohaline conditions and take samples for nutrient concentrations and phytoplankton abundance above the isobaths of 50, 100, 150, 200, 300, 400, 900, and 1,000 m. At stations A 100 and A 500, only thermohaline conditions were measured. We used Niskin samplers for sampling the water column at depths of 0.5, 5, 20, 50, 75, 100, 200, 300, and 400 m.

Microorganisms, hydrography, and nutrients

Phytoplankton abundance was determined using inverted microscope and flow cytometer. Phytoplankton cells larger than 5 μm were counted using a Zeiss Axiovert 200 inverted microscope (Utermöhl 1958; Hasle 1978a, b; Venrick 1978). Subsamples of 50 cm^3 were analyzed using phase contrast, within 1 month, after 24 h of sedimentation. One transect along the counting chamber bottom was scanned at ×400 and two were scanned at ×200. Recognizable nanoplankton (cells >5 μm) and abundant microphytoplankton (cells >20 μm and chain forming colonies) were counted and identified at ×400. At ×100, a total bottom count was completed for taxa greater than 30 μm. The minimum concentration that can be detected by this method is 20 cells dm^{-3}. The entire phytoplankton community was identified to species or genus after image analysis and processing using the Karl Zeiss AxioVision 3.1 System and AxioCam Camera. The same method was used for counting small ciliates.

The abundance of heterotrophic bacteria and pico- and nano-flagellates was determined using epifluorescent microscope Leitz Laborlux D equipped with a 50-W mercury lamp and filter sets for UV, blue and green excitation. Samples for epifluorescent microscopy were preserved in 2% formaldehyde and stored at −4°C until

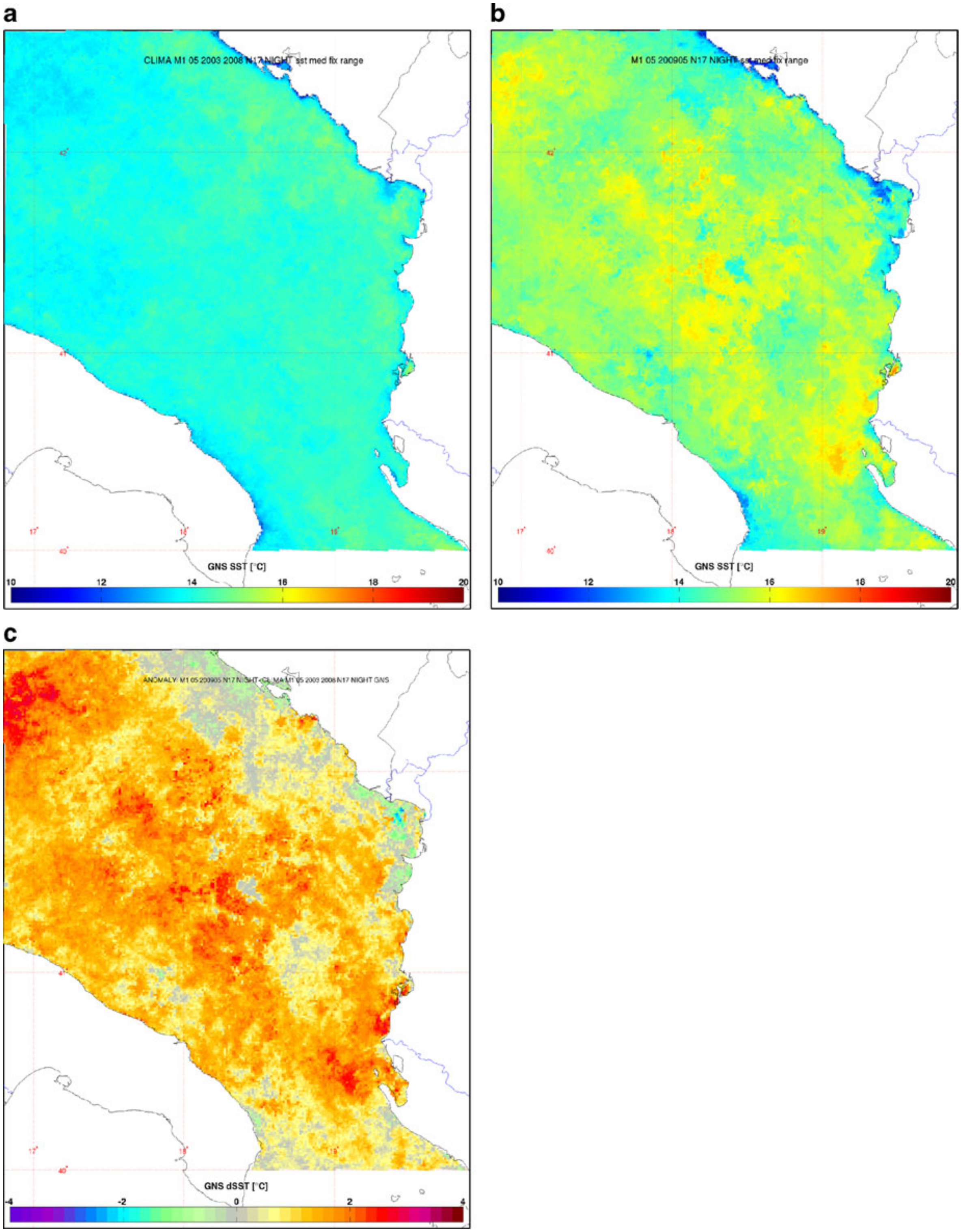


Fig. 2 Satellite-derived sea surface temperature in the southeastern Adriatic; May 2003–2008 average (**a**), May 2009 average (**b**), May 2003–2008 versus May 2009 anomaly (**c**)

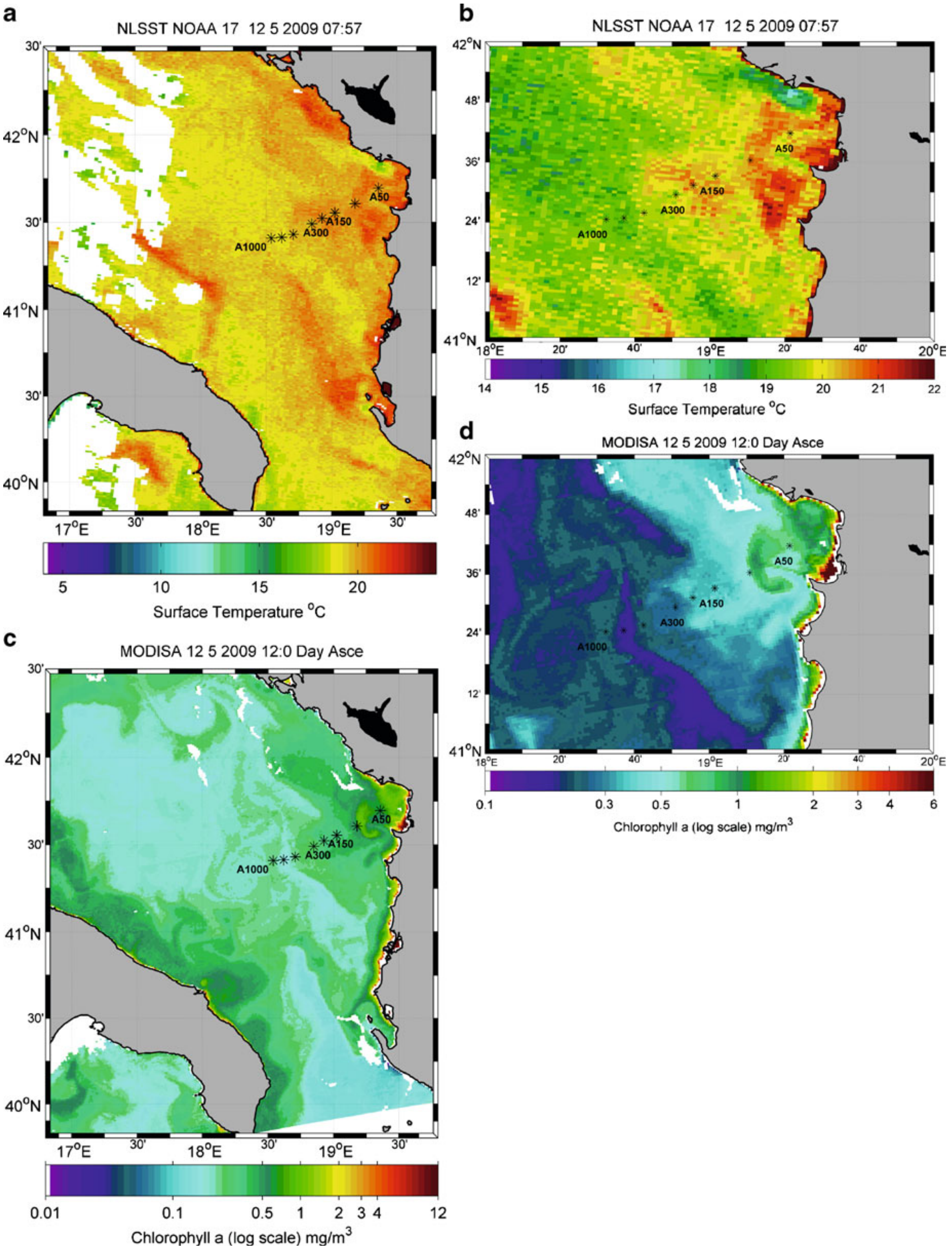


Fig. 3 Satellite-derived sea surface temperature (**a**, **b**) and chlorophyll (**c**, **d**) distribution in the southeastern Adriatic, May 12, 2009

analysis in the laboratory. For determination of heterotrophic bacteria, 2 cm^3 of samples were filtered through black polycarbonate membrane filters (0.2 μm pore size), stained with DAPI, and counted under UV light excitation. For pico- and nanoheterotrophic flagellates, 15 cm^3 of samples were filtered through the same type of filters, stained with Primulin (250 μg cm^{-1} in 0.1 M Trizma HCl, pH = 4.0), and counted under blue excitation (Caron 1983).

A flow cytometer was used to count autotrophic pico- and nanoplankton. Samples were treated with 0.5% glutaraldehyde for 10 min, frozen in liquid nitrogen, and stored at −80°C until analysis with a Partec PAS flow cytometer (Germany) equipped with an Argon-ion laser (488 nm). The different subpopulations of phytoplankton were distinguished by their autofluorescence of chlorophyll and phycoerythrin content as well as by the cells' side-angle light scatter as a proxy of their size. The data were collected in listmode files using autofluorescence of chlorophyll as a trigger parameter and were processed with FloMax software (Partec, Germany).

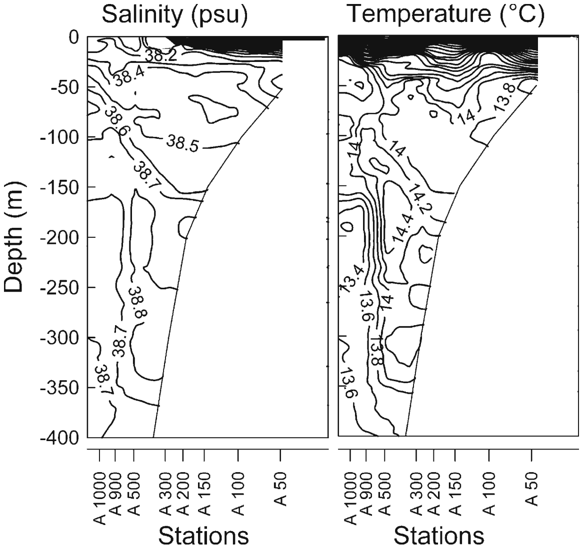


Fig. 5 Distribution of temperature and salinity in the 0–400-m layer, along the profile. For station positions, see Figs. 1 and 3

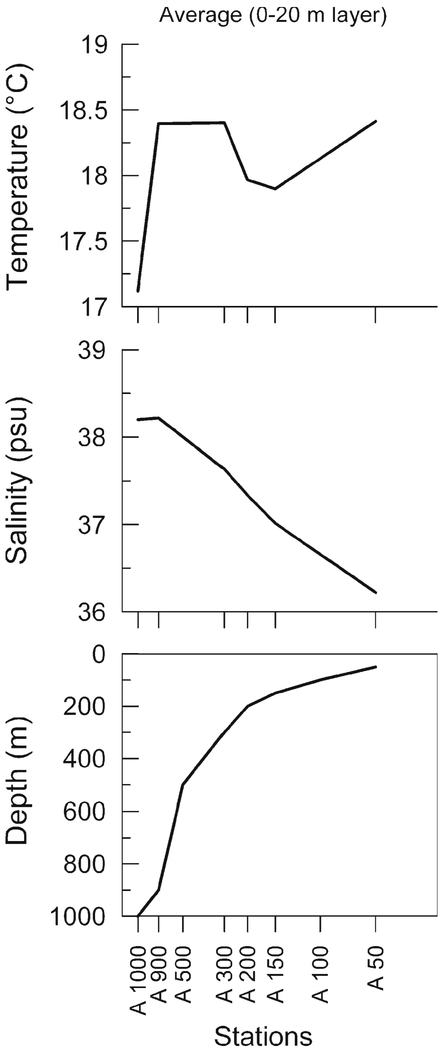


Fig. 4 Distribution of temperature and salinity (0–20-m layer averages) along the profile and bottom morphology

Temperature, salinity, and density were measured with a CTD profiler (Sea Bird Electronics Inc., USA).

The NOAA 15 Advanced Very High Resolution Radiometer (AVHRR) data used in this study were received at a locally operated HRPT station (Rudjer Bošković Institute, Zagreb). The HRPT data were processed to Level 1B format using the AAPP package supplied by EUMETSAT and the Automatic Navigation Adjustment (ANA 3.1) application provided by Meteo France, CMS. Processing to Level 2 was done with an "in-house" software package (Tomažić 2006). Only the SST/nonlinear sea surface temperature product is used in this study.

Samples for nutrient analysis were deep frozen on-board. Nutrient concentrations were determined by means of a standard colorimetric method (Parsons et al. 1984; Degobbis et al. 1986) using a Shimadzu spectrophotometer UV-1800. The total inorganic nitrogen/ortophosphate ratio (TIN/PO_4^-) was calculated according to Redfield et al. (1963). The limiting nutrients for phytoplankton growth at any salinity were determined using the graphic method according to Neill (2005). Graphs are prepared for TIN vs. salinity and for *o*-phosphate vs. salinity with the vertical axes set at a ratio of $N/P = 16:1$ (i.e., the scales for N and P in the graphs are set so that they are proportional to the average rate at which these nutrients are absorbed by phytoplankton during growth). When these graphs are superimposed, the lowermost trendline indicates the limiting nutrient for phytoplankton growth at any salinity.

Results

Surface temperature from a broader measurement area in May is derived from night NOAA 17 AVHRR sensor data (to avoid addressing the issue of diurnal warming) and a nonlinear algorithm used to derive these averaged SST fields (Fig. 2). One notes relatively uniform low temperature over the Southern Adriatic (Fig. 2a) with a somewhat warmer eastern part and the clearly cooler signal of the Buna River. The average May 2009 SST field (Fig. 2b) appears generally warmer than the average of six previous years (Fig. 2c) in the middle of the southern Adriatic basin in particular. The surface temperature in the discharge area of the Buna River exhibits a small anomaly, suggesting minimal interannual differences in the volume and temperature of its runoff. Generally, the interannual temperature anomaly is less pronounced on the north-eastern side of the basin.

The surface temperature is retrieved by the NOAA 17 AVHRR sensor during a daytime pass. As the scene exhibits somewhat higher temperatures; we used nighttime scenes to compose the Fig. 2 images. The spring time is generally characterized by gradual warming of the surface waters and a change from spatially heterogeneous winter conditions to spatially more homogeneous summer conditions, controlled by exchanges at the air–sea interface, as well as by changes in riverine and Ionian inflows. Against the backdrop of increasing average temperature, warm patches develop in response to calm and sunny weather, when vertical mixing is reduced and solar heating sporadically increased (Fig. 3a). Fine spatial details around the measurement stations are further resolved with a zoom depicted in Fig. 3b. For the same day, the chlorophyll-a distribution based on the data retrieved from the MODIS sensor on the Aqua platform is given in Fig. 3c, d.

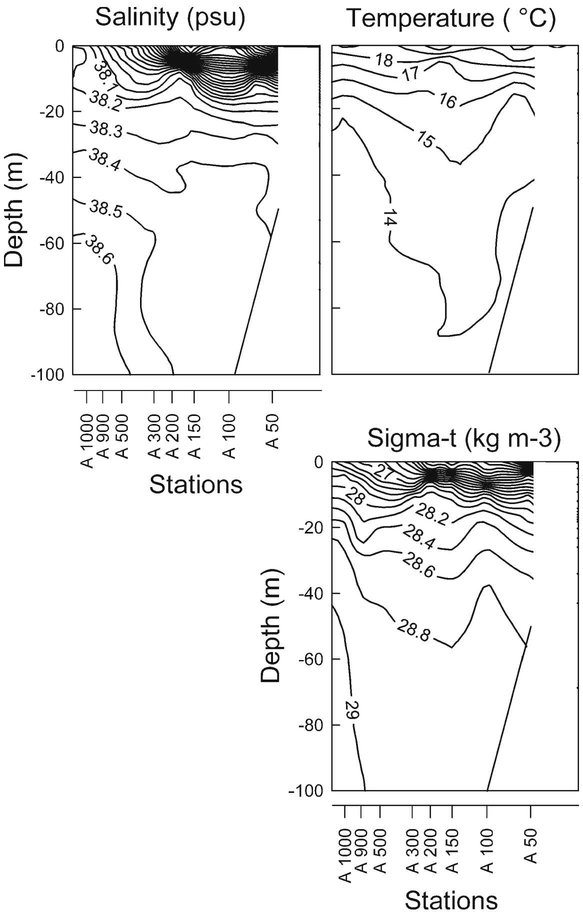


Fig. 6 Distribution of temperature and salinity in the 0–100-m layer, along the profile. For station positions, see Figs. 1 and 3

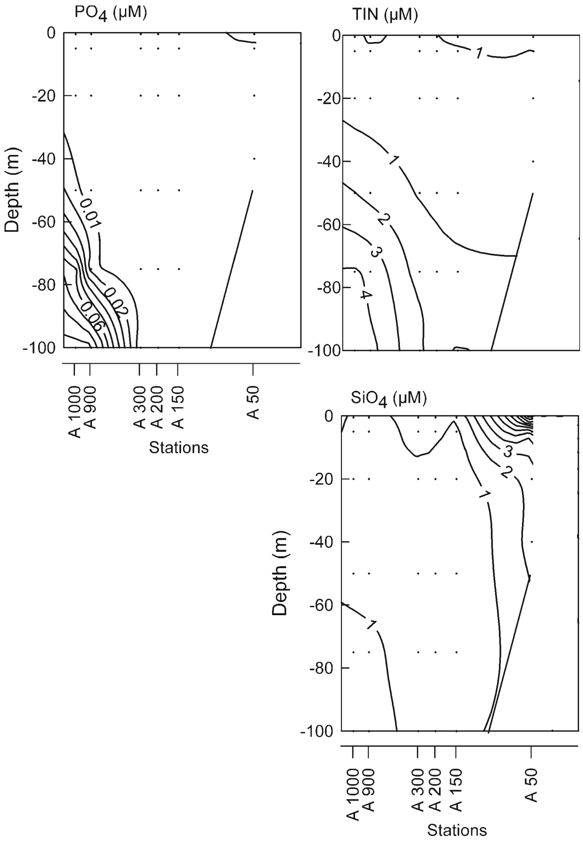


Fig. 7 Distribution of ortophosphates (PO4), total inorganic nitrogen (TIN), and orthosilicates (SiO4) in the 0–100-m layer, along the profile. For station positions, see Figs. 1 and 3

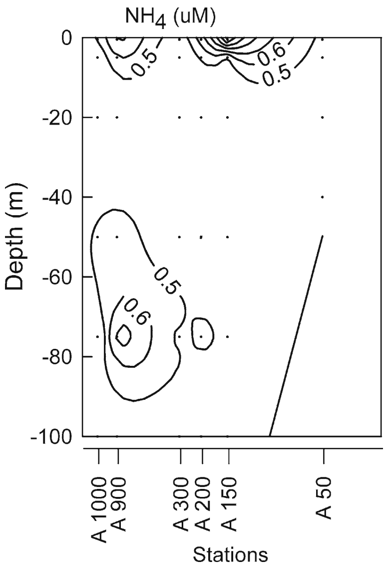


Fig. 8 Distribution of ammonium (NH_4) in the 0–100-m layer, along the profile. For station positions, see Figs. 1 and 3

The surface temperature was measured during the along-transect CTD casts (12 May 2009; Fig. 4). The average 0–20-m layer temperature increased from 17.2°C to 18.4°C in the coastward direction, showing two minima: one offshore above the isobath of 900 m and a second above the shelf between isobaths 150 and 200 m (17.8°C). The average salinity in the 0–20-m layer gradually decreased from 38.1 to 36.2 in the transect from station A 900 to the coast, indicating the plume of Albanian rivers.

Considering the 0- to 400-m water column, the isohalines between 38.5 and 38.6, as well as isotherms between 13.6°C and 13.8°C, indicated the boundary layer between the coastal sea and the northwesterly inflowing Levantine Intermediate Current (Eastern Adriatic Current; Fig. 5). The maximum vertical salinity gradient of 0.3 was found in the layer between 96 to 150 m, in the area around the isobath of 500 m. The maximum thermic gradient between 13.4 to 14.4 was

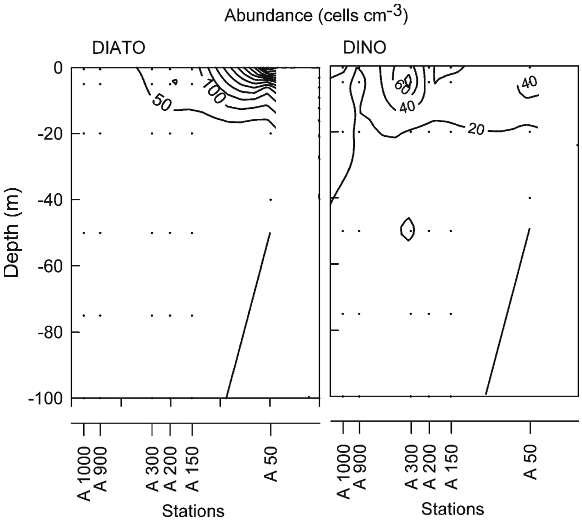


Fig. 9 Distribution of abundances (cells cm^{-3}) of diatoms (DIATO) and dinoflagellates (DINO) in the 0–100-m layer, along the profile. For station positions, see Figs. 1 and 3

Table 1 Dominant phytoplankton taxa in the southeastern Adriatic Sea to the west of Albania, with maximum abundance (MAX) greater than 10^4 cells dm^{-3}, and frequency of appearance (Fr) greater than 10%

Taxa	Syst. group	10^3 cells dm^{-3}			Fr%
		MAX	AVG	STD	
Rhabdosphaera tignifer Schiller	COC	17	3.2	4.5	64.7
Chaetoceros affinis Laud.	DIA	24	1.4	8.2	26.5
Chaetoceros circinalis (Meunier) K.G. Jensen et Moestrup	DIA	150	7.4	44.4	35.3
Chaetoceros curvisetus Cleve	DIA	22	1.9	6.6	44.1
Chaetoceros decipiens Cleve	DIA	10	1.1	3.5	32.4
Chaetoceros diversus Cleve	DIA	272	9.7	84.3	29.4
Chaetoceros sp.	DIA	150	6.0	64.5	14.7
Chaetoceros throndsenii (Marino, Montresor, Zingone)	DIA	17	1.1	5.6	20.6
Cyclotella sp.	DIA	76	4.0	28.1	14.7
Leptocylindrus danicus Cleve	DIA	10	0.5	4.1	17.6
Pseudo-nitzschia spp.	DIA	19	0.7	5.7	32.4
Oxytoxum variabile Schiller	DINO	11	1.3	2.9	47.1

Analysis was performed on the basis of 34 Niskin samples, in the 0–50-m layer, on May 12 2009

AVG average abundance, *STD* standard deviation, *COC* coccolithophorids, *DIA* diatoms, *DINO* dinoflagellates

4.98 km thick, extending horizontally in the 150- to 250-m layer, in the area between isobaths of 900 and 500 m. Salinities higher than 38.8 and temperatures 14.2°C to 14.4°C indicated the core of the EAC in the 150- to 350-m layer, above the shelf slope, between isobaths of 500 and 300 m (ca. 80 km to the southwest of the Albanian mainland).

In the upper 100-m water column, the thermohaline boundary between the Ionian Surface Water and the shelf water was indicated by the 38.5 isohaline and 14°C isotherm, sloping upward and offshore from the 200-m isobath (Fig. 6). At the same time, bell-shaped isotherms and isohalines across the transect gave information about nonhomogeneity in the water column above the shelf.

The orthophosphate isopleth of 0.01 μM deepened from 30 m at A 1000 to 100 m at A 300 (Fig. 7). The TIN gradient between 1 0 and 2.0 μM nearly followed the isohaline of 38.5. The deep ammonium accumulation coincided with the nutricline above the continental slope (Fig. 8).

Surface phytoplankton chlorophyll *a* biomass distribution coincided with hydrographical discontinuity, providing a maximum horizontal gradient in the area between the 200- and 300-m isobaths (Fig. 3c, d). Maximum abundances of diatoms (>50 cells cm^{-3}) and dinoflagellates (>20 cells cm^{-3}) were found in the upper 20-m layer within salinities lower than 38 (Fig. 9). The chlorophyll accumulation in the area between A50 and A 150 (Fig. 3d) could not be constructed because on board sampling was not performed there. Diatom abundances increased coastward, while maximum dinoflagellate abundances were found at A 300. We found the specific taxonomic composition of phytoplankton in the Albanian coastal waters, with dominant diatoms such as *Chaetoceros* species (*Chaetoceros circinalis*, *Chaetoceros diversus*; Table 1).

The larger nanoplankton abundances (counted by inverted microscopy) revealed patchy accumulations (Fig. 10). Coccolithophorides and green flagellates accumulated at A 900 and A 1000 (maximum 48 cells cm^{-3}, at 50 m depth). Green flagellates accumulated in the same area at the surface (39 cells cm^{-3}). An inshore accumulation of cryptophytes was detected at A 150 (99 cells cm^{-3}, at 20 m depth). Small nanoplankton (counted by flow-cytometry) revealed maximum inshore accumulations of 4×10^3 cells cm^{-3} (Fig. 11).

Picoplankton dominated in the offshore phytoplankton community (Fig. 11); picoautotrophic eukaryotes accumulated at A 900 (3.8×10^3) and A 1000 (4.5×10^3 cells cm^{-3}), at 50 m depth. Cyanobacteria accumulated at A 200 at

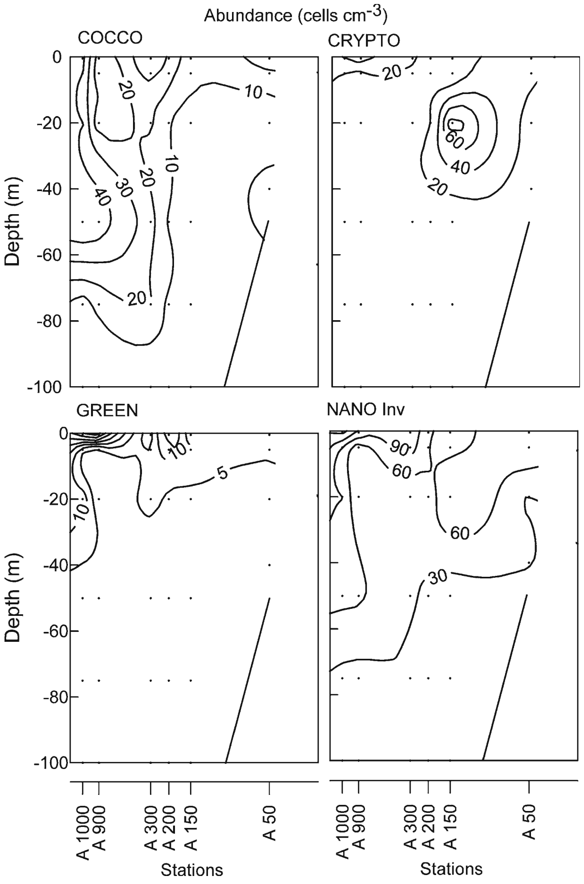


Fig. 10 Distribution of abundances (cells cm^{-3}) of coccolithophorids (COCCO), cryptophytes (CRYPTO), green flagellates (GREEN), and total nanoplankton counted by inverted microscope (NANO Inv) in the 0–100-m layer, along the profile. For station positions, see Figs. 1 and 3

50 m depth (9×10^4 cells cm^{-3}). The maximum of prochlorophytes (10^4 cells cm^{-3}) was also detected at station A 200, below the maximum of cyanobacteria (at 75 m depth).

Heterotrophic nanoplankton accumulated at the surface 40-m layer at the nearshore stations (Fig. 12). The maximum abundance of 981 cells cm^{-3} was recorded at the surface at A50. Like nanoheterotrophs, abundant picoheterotrophs were found in the upper 20-m layer (maximum 891 cells cm^{-3}, at station A 300), with exceptions for A 200, where increased picoplankton were found in the 50- to 75-m layer. Bacteria did not provide marked accumulations.

Spatial patchy distribution is summarized by the presentation of the relative contribution of particulate size and taxonomic categories of phytoplankton (Fig. 13). The deep accumulation of cyanobacteria and prochlorophytes and surface accumulation of dinoflagellates and ciliates were detected in the area between the isobaths of 200 and 300 m. Offshore from this area, we detected deep accumulations of eukaryotic picoplankton and surface accumulations of bigger nanoplankton (coccolithophorids, green flagellates), while inshore accumulations were characterized by diatoms, cryptophytes, as well as smaller autotrophic and heterotrophic nanoplankton.

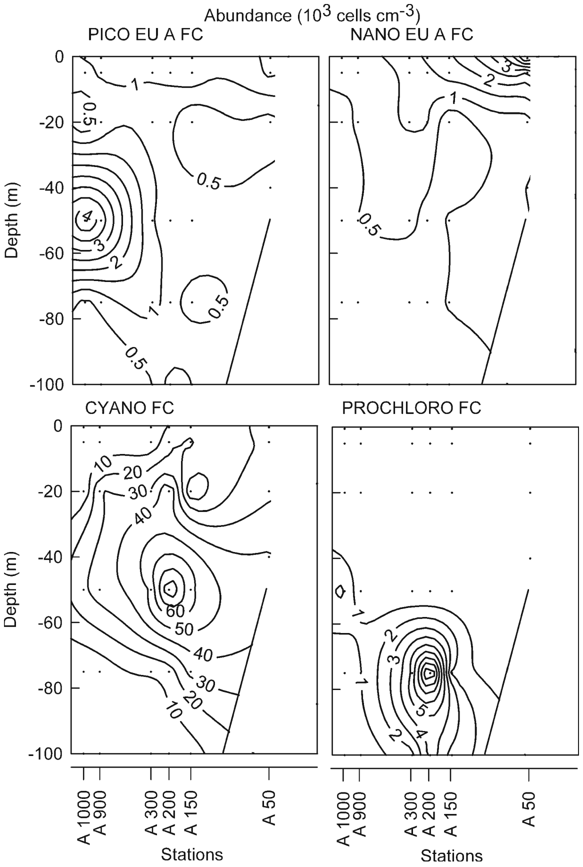


Fig. 11 Distribution of abundances (10^3 cells cm^{-3}) of picoplankton counted by flowcytometer; eukaryotic autotrophs (PICO EU A FC), nanoplanktonic autotrophic eukaryotes (NANO EU A FC), cyanobacteria (CYANO FC), and prochlorophytes (PROCHLORO FC) in the 0–100-m layer, along the profile. For station positions, see Figs. 1 and 3

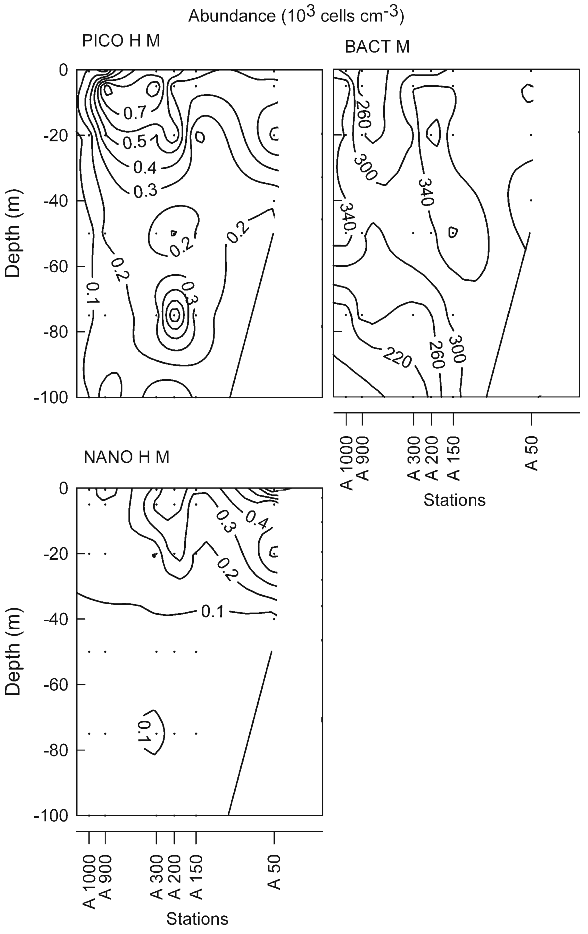
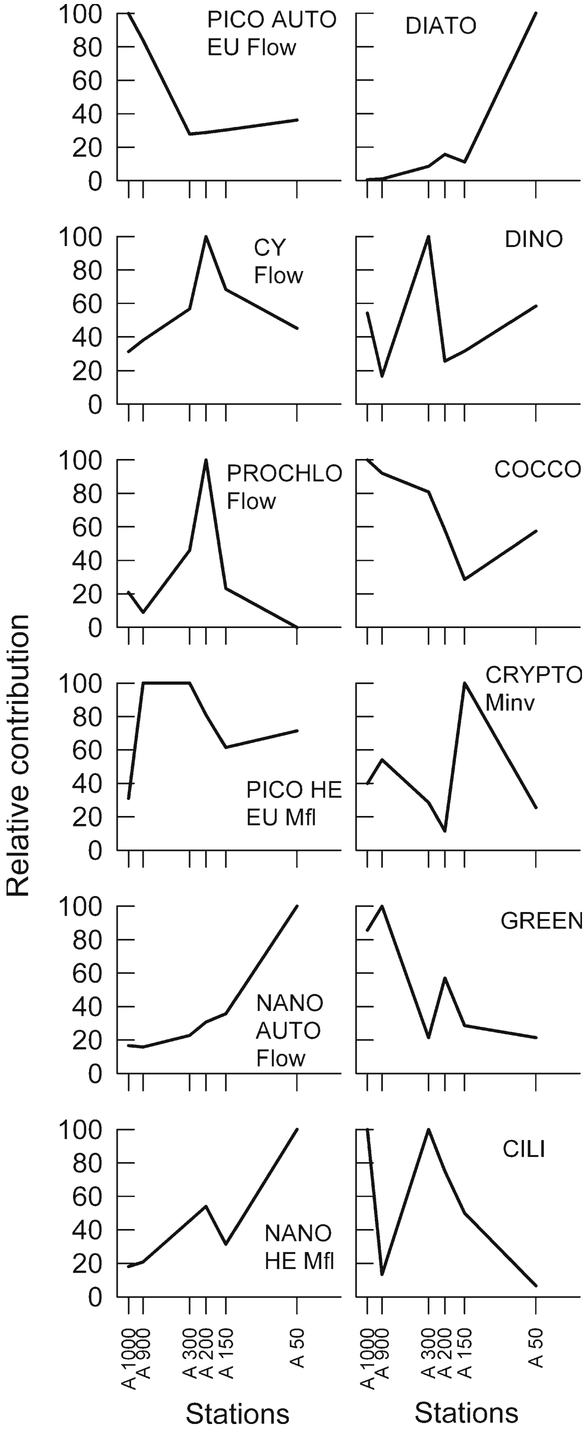


Fig. 12 Distribution of abundances (10^3 cells cm^{-3}) of picoplankton and nanoplankton counted by fluorescence microscopy; heterotrophic picoplankton (PICO H M), bacteria (BACT M), and heterotrophic nanoplankton (NANO H M) in the 0–100-m layer, along the profile. For station positions, see Figs. 1 and 3

Fig. 13 Relative contribution of different phytoplankton ▶ taxonomic and size fractions along the profile across the shelf break to the southwest of the Albanian mainland. Data are maximum concentrations in the 0–10-m layer (325 data). For station positions, see Figs. 1 and 3. *PICO AUTO EU* eukaryotic pico autotrophs, *CY* cyanobacteria, *PROCHLO* prochlorophytes, *PICO HE EU* pico eukaryotic heterotrophs, *NANO AUTO* autotrophic nanoplankton, *NANO HE* heterotrophic nanoplankton, *DIATO* diatoms, *DINO* dinoflagellates, *COCCO* coccolithophorides, *CRYPTO* cryptophytes, *GREEN* green flagellates, *CILI* small ciliates, *Minv* counted by inverted microscopy, *MFL* counted by fluorescence microscopy, *FLOW* counted by flowcytometer



Discussion

The spring hydrological conditions in the south-eastern Adriatic are characterized by a reduction in the north-westerly inflowing EAC (Poulain 1999). In May 2009 scenes, we can see the transient nature of the spring SST fields. Against the backdrop of increasing average temperature, warm patches develop in response to calm and sunny weather, when vertical mixing is reduced and solar heating sporadically increases.

In the May 2009 IR imagery, meandering currents may be traced, as has been previously indicated in May during the reduced surface water transport (Bergamasco and Gačić 1996). The northwesterly inflowing EAC that forms the hydrographic boundary hints that advection may play a role in establishing the thermohaline structure.

We observed distinct plankton distribution patterns on each side of the hydrographic boundary. The hydrographic boundary could be determined by thermohaline and density characteristics and nutrient concentrations. The 38.5 isohaline, 14°C isotherm, 28.8 isopleth of density and the 2 μM orthosilicate isopleth revealed a hydrographic boundary zone between the coastal sea, mostly affected by Albanian rivers, and the EAC, sloping upwards in the sector from the isobath of 300 to isobath 500 m (12 km apart, 67 to 79 km offshore). Variability in temperature, salinity, and density distribution across the profile was the result of non homogeneity in the current field above the shelf. North-westerly from the Otranto Strait, eddies could be generated, as has been observed previously (Ferentinos and Kastanos 1988; Borzelli et al. 1999). Eddies reaching this region might contribute to the location of the hydrographic boundary. The surface thermal conditions on May 12 could also be regulated by river water temperature. According to satellite data, the position of the surface thermal gradient on 5th and 12th May was similar.

The main sources of nutrients are Albanian rivers, and their transfer through the food web in the vertical and horizontal direction, in the period 5th–12th May, 2009. Wind stress and along-coast currents regulate offshore cross-shelf transport of phytoplankton-rich waters (Martinez-Lopez and Zavala-Hidalgo 2009).

We recorded relatively low concentrations of nutrients, similar to those recorded in October 2000 and April 2001 (Saracino and Rubino 2006) and in the Otranto Strait (Viličić et al. 1995; Socal et al. 1999). TIN/PO_4 molar ratio ranged from 39 to 1,389, with an average of 330, indicating phytoplankton growth limited by phosphorus at all stations (much more at offshore stations; Fig. 14). Phytoplankton such as diatoms, dinoflagellates, cryptophytes, and small autotrophic and heterotrophic nanoplankton develop successfully in coastal waters due to greater availability of inorganic nutrients and their mixotrophic potential (Lewitus 2005). Small cells usually predominate in the phytoplankton community in phosphorus-limited conditions (Guillaud et al. 2008). Extremely low phosphorus concentrations in the coastal sea (<0.01 μM) is probably due to mineralogical composition of sediments characterized by silicates, which is different than those in the middle and northern Adriatic (Sondi, personal communication). This could probably result in the specific taxonomic composition of phytoplankton, with dominant diatoms such as *Chaetoceros* species (*Ch. circinalis*, *Ch. diversus*).

The increased biological activity is usually associated with shelf-sea (tidal) fronts (Pingree et al. 1975; Mann and Lazier 2006; Guillaud et al. 2008), which could be attributed to the hydrographic boundary recorded in this study. Subsurface

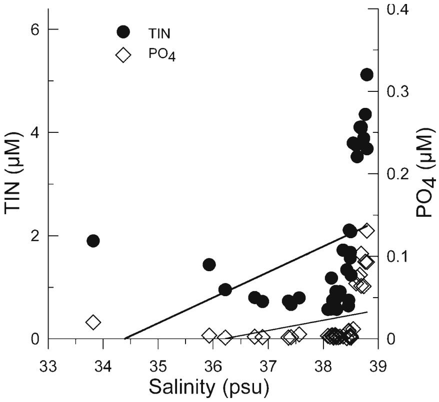


Fig. 14 Demonstration on nutrient limitation at any salinity in the Albanian shelf profile salinity gradient. The lowermost trendline denotes the limiting nutrient

accumulations of picoplankton were found along the thermohaline gradient and nutricline sloping upward in the offshore direction from the isobath of 200 m to isobath of 900 m (Figs. 4–6), and traced by the isohaline of 38.5, the isotherm of 14°C, the orthophosphate isopleth of 0.01 μM, and the TIN isopleth of 2 μM. The increased ammonium accumulation along the nutricline, above the continental slope (Fig. 8), could be the result of ciliate activity, but not microzooplankton, which dominated in the surface layer (Njire, unpublished results). Some phytoplanktons may obtain a major nitrogen requirement from ammonium in frontal regions (Holligan et al. 1984). The increased ammonium concentration in the surface offshore station A 300 was probably a result of zooplankton grazing. Such a source of nitrogen and a thermal gradient could explain why some dinoflagellates accumulated there.

In contrast to this research, the deep phytoplankton maximum composed of diatoms has been found in the 50- to 75-m layer, in the offshore middle Adriatic, in spring (Ninčević et al. 2002). There is also evidence about distinct accumulation of coccolithophores in frontal zones and along nutricline of the ocean (Boeckel and Baumann 2008). In a comparison of the nanoplankton and bacteria abundances presented in this paper with those from worldwide planktonic ecosystems (Sanders et al. 1992), the Albanian samples can be seen to have provided low abundances, indicating an oligotrophic marine environment, similar to that in the middle Adriatic (Krstulović et al. 1997). The distribution of bacteria did not coincide with either phytoplankton or temperature and salinity, as has been found elsewhere (Zubkov et al. 2002).

Due to scarcity of data from the southeastern Adriatic, this research would benefit further insight into physical–chemical and biological processes across the most remarkable frontal zone in the southern Adriatic Sea, off the Albanian mainland. Future research should assess how Albanian rivers participate in the regulation of the circulation, chemistry and biology of the Adriatic Sea in different seasons. A role of inland hydrostructures in terms of potential blockage of nutrients such as silica and orto-phosphate is important for coastal sea productivity and should be a scope of recent and future monitoring activities.

The case study in May 2009 gives the insight into the oceanography in the area in which Albanian shelf riverine plume waters come into contact with the Southern Adriatic Pit environment. We would particularly welcome further research during the winter hydrological regime, when the intensity of IAC along the Albanian shelf should be maximum, or in late spring during the southward reversal currents (Poulain 1999), to show contrasting plankton community composition and dynamics between offshore and coastal shelf region.

This research provides effort to improve coastal area management, which has been hard to organize in the Albanian coastal sea over last decades. Possible application should be in marine fisheries and mariculture which tend to increase capabilities (Sherman and Hempel 2008). In addition, biological monitoring should be continued, since the Adriatic is starting to show impacts from toxic (invasive) marine organisms well documented in other parts of the Mediterranean (AlgaeAdria network 2006).

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