Acta Bot. Croat. 67 (1), 33–43, 2008

CODEN: ABCRA 25
ISSN 0365–0588

The deep chlorophyll maximum in the coastal north eastern Adriatic Sea, July 2007

DAMIR VILIČIĆ[1*], MIRKO ORLIĆ[2], NENAD JASPRICA[3]

[1] University of Zagreb, Faculty of Science, Division of Biology, Rooseveltov trg 6, 10000 Zagreb, Croatia.

[2] University of Zagreb, Faculty of Science, Dept. Geophysics, Horvatovac bb, 10000 Zagreb, Croatia.

[3] University of Dubrovnik, Institute for Marine and Coastal Research, Kneza Damjana Jude 12, 20000 Dubrovnik, Croatia.

Deep chlorophyll *a* maximum (DCM) was found in the 80–110 m deep northeastern coastal Adriatic (Pag and Velebit Channels) in July 2007. Eight times higher concentrations of chlorophyll were determined in the 50 to 60 m DCM layer (0.81 to 0.91 μg L^{-1}) relative to the surface waters. According to thermohaline conditions and phytoplankton biomass distribution, over the greater part of the considered area the water column was separated into three layers (the surface layer approximately 10 m deep, the subsurface layer extending between 10 and 50 m, and the deep layer found below 50 m depth) and three distinctive regimes were detected (in the South Velebit Channel, the Middle Velebit Channel, and the Pag Channel). This is the first evidence of the deep chlorophyll maximum in the eastern coastal Adriatic Sea. Deep chlorophyll maxima were composed of picoplanktonic, rounded cells, probably cyanobacteria (1.2 μm in size, $8 \times 10^3 - 1 \times 10^4$ cells mL^{-1}).

Key words: Phytoplankton, biomass, deep chlorophyll maximum, temperature, salinity, Pag Channel, Velebit Channel, Adriatic Sea

Abbreviations: DCM – deep chlorophyll maximum, SCV – South Velebit Channel, MVC – Middle Velebit Channel, PC – Pag Channel

Introduction

Deep chlorophyll maxima (DCM) are widespread in large parts of the world's oceans, and reflect a compromise of phytoplankton growth exposed to two opposing resource gradients: light supplied from above and nutrients supplied from below (HUISMAN et al. 2006). DCM usually appears in oligotrophic oceans near to the lower euphotic zone boundary. Phytoplankton photosynthetic activity appears there along the nutricline, down to the compensation depth, where minimum light intensity (ca 1% of the surface intensity) equalizes photosynthetic rate and respiration (MANN and LAZIER 1996). In transparent seas such as the eastern Mediterranean, the compensation depth is usually found at depths between 80

---

[*] Corresponding author, e-mail: dvilici@zg.biol.pmf.hr

and 100 m (PARSONS et al. 1979, KIMOR et al. 1987). In warm seas and oceans DCM is formed in the layer between 50 and 150 m (GIESKES and KRAAY 1986, BERMAN et al. 1986, GOULD 1987, FURUYA 1990, CASOTTI et al. 2003). In the offshore Adriatic, DCM has been detected in layers between 50 and 75 m (VILIČIĆ et al. 1995, JASPRICA et al. 2000, NINČEVIĆ et al. 2002).

The DCM in the coastal sea can be found only in places with adequate depth such as Pag Channel in the northeastern coastal area, where, however, vertical profiling has not been carried out to date.

Only a few publications are available on the shallow and relatively closed inner part of the system; in Velebit Channel and Zrmanja Estuary (ORLIĆ et al. 2000; VILIČIĆ et al. 2008; BURIĆ et al. 2004, 2007a, b, 2008).

During the research into the Adriatic Sea with the US RV KNORR in 2003, satellite imagery of temperature indicated strong current inflowing from the open sea through the Kvarnerić Strait and Pag Channel into the Velebit Channel. This resulted in a hypothesis of the existence of a trophic gradient at the contact between open and coastal waters along the transect Pag Channel – Velebit Channel – Zrmanja Estuary. Thus we planned to quantify environmental conditions for phytoplankton growth and overall plankton productivity in the deepest part of the northern Adriatic. There has long been evidence on increased fishing activity there, but without any sufficient scientific evaluation of the ecology in this area.

In this paper we analyze the summer deep chlorophyll maximum formation in the deep north eastern coastal Adriatic.

Investigated area

The Adriatic is a temperate warm sea, with temperatures almost always surpassing 10°C. The northern Adriatic is 8–10 °C colder than its southern part during winter. The Pag and Velebit Channels are oriented northwesterly-southeasterly, the latter between the island of Rab and the Velebit Mountain in the north and between the island of Pag and the same mountain in the south (Fig. 1). The Pag Channel is the deepest part of the northern Adriatic (maximum depth is 110 m). It is connected with the open sea through the Kvarnerić Strait, between the outer islands of Lošinj (Ilovik) and Silba.

The main sources of freshwater are the Zrmanja River (represented by the middle reach station N1, Fig. 1) and numerous subsurface springs (»vruljas«, both permanent and temporary) along the northern coast (BENAC et al. 2003). The catchment area is composed of permeable carbonate rocks (BIONDIĆ et al. 1996). Springs along the coast are connected with sink holes (»ponors«) in the hinterland, and are active in the rainy (October-December)

Tab. 1. Range of temperature, salinity, density and chlorophyll biomass values in the surface, middle and deep layers, in the Pag Channel, July 2007.

	Temperature (°C)	Salinity (psu)	Sigma T	Chlorophyll a (μg L^{-1})
0–10 m	23.157–24.485	37.432–38.035	25.550–26.022	0.001–0.206
10–50 m	15.037–23.530	37.865–38.003	26.045–28.260	0.001–0.281
50–75 m	12.506–15.037	37.976–38.264	28.260–29.023	0.265–0.816

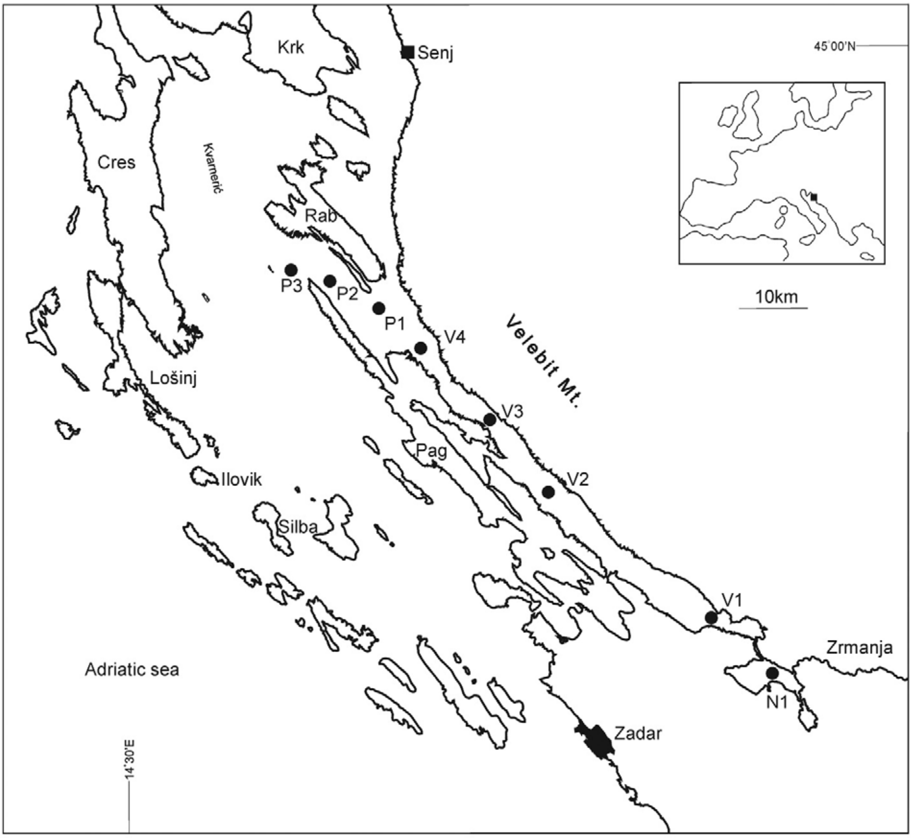

Fig. 1. Position of stations along the Pag Channel (P3, P2, P1), the Velebit Channel (V4, V3, V2, V1) and the Zrmanja estuary (N1).

and snow melting (March-May) periods (Bonacci and Roje-Bonacci 2000). Precipitation in the Velebit Mountain range achieves maximum in November (Penzar et al. 2001). Consequently, the salinity is considerably reduced in the surface layer near the coast during the rainy season (Orlić et al. 2000).

The northeastern Adriatic coastal area is heavily influenced by the catabatic bora wind in winter, with gusts reaching 60 m s^{-1}, which surpasses wind speeds observed elsewhere in the Adriatic (Makjanić 1976, Dorman et al. 2006).

The major part of the Adriatic Sea is influenced by the oligotrophic northwesterly flowing East Adriatic Current, originating in the southern Adriatic and Ionian Seas (Gačić et al. 2001, Totti et al., 2000). The oligotrophic karstic rivers discharging along the eastern coast support the low productivity of the eastern Adriatic Sea (Svensen et al., 2007, Viličić et al. 2008). The exception is the northwestern Adriatic corner, which receives large amounts of freshwater from the Po River (Raicich 1996, Vollenweider et al. 1998), and two isolated spots – the harbours of Split and Šibenik on the eastern coast (Viličić 1989, Marasović et al. 1991), where the trophic state is higher.

Materials and methods

The profiling was performed along a deep-to-shallow water transect in the northeastern coastal Adriatic: the Pag Channel (stations P3, P2, P1), the Velebit Channel (stations V4, V3, V2, V1) and the lower reach of the Zrmanja Estuary (station N1), in the period 4–6 July 2007. Temperature, salinity, density and chlorophyll fluorescence measurements were done with a CTD profiler (Sea Bird Electronics Inc., USA). Chlorophyll fluorescence was calibrated in units of μg L^{-1}. A white Secchi disc (30-cm diameter) was used to estimate transparency.

Results

In July 2007, over the greater part of the considered area the water column was separated into three layers, distinguished according to salinity, temperature and phytoplankton biomass (Figs. 2, 3). The surface layer was approximately 10 m deep, the subsurface layer extended between 10 and 50 m, and the deep layer occupied depths larger than 50 m. Horizontally, the data revealed three distinctive regimes, the first one in the South Velebit Channel (SVC, stations V1–V2), the second one in the Middle Velebit Channel (MVC, stations V2–P1), and the last one in the Pag Channel (PC, stations P1–P3). The SVC behaved as the outer part of a partially mixed estuary, with the surface low-salinity layer of a 10 m depth obviously related to the Zrmanja River inflow, the subsurface high-salinity layer being in-

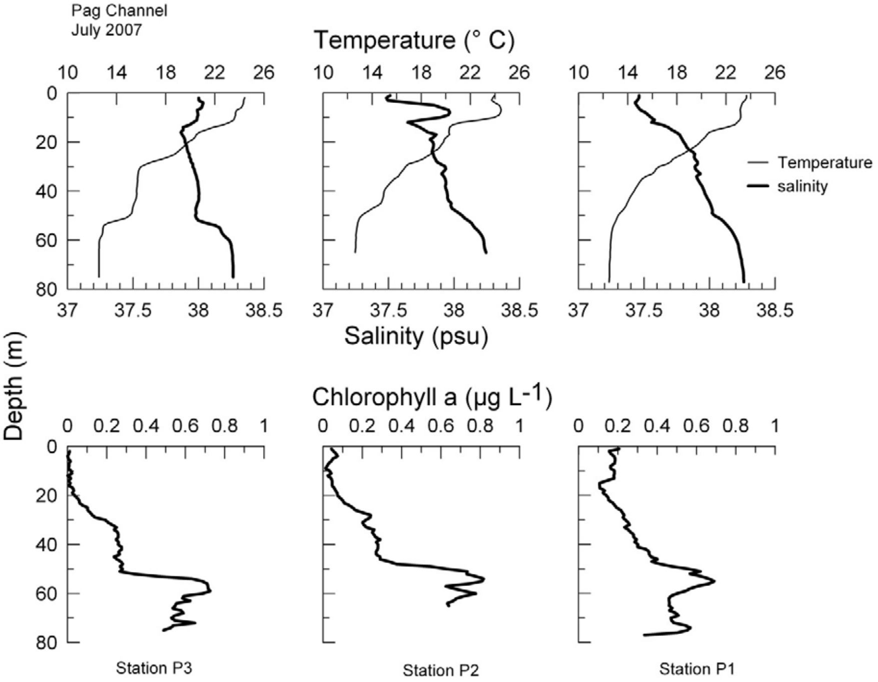

Fig. 2. Vertical profiles of salinity, temperature and chlorophyll-a concentration in the Pag Channel, during 4–6 July 2007. For station positions see Fig. 1.

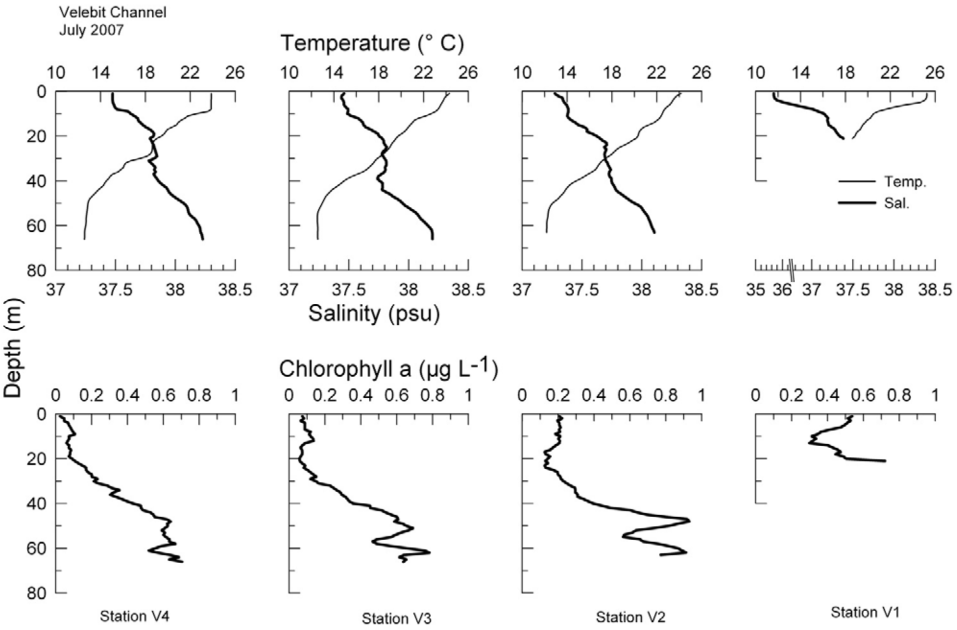

Fig. 3. Vertical profiles of salinity, temperature and chlorophyll-a concentration in the Velebit Channel, during 4–6 July 2007. For station positions see Fig. 1.

fluenced by conditions in the sea further north (Figs. 3, 4). The surface layer was slightly warmer and the layer below it slightly colder than the corresponding layers in the MVC, due to the sharp halocline, which reduces downward transport of heat. The density stratification appeared to be controlled mostly by the salinity variations. In the MVC the existence of three layers was obvious, with salinity and temperature being rather uniform in the surface layer, extending to a depth of 10 m. Salinity was somewhat higher and temperature decreased with depth in the subsurface layer, which extended from about 10 to 50 m, salinity stabilizing at about 38.2 and temperature at about 12 °C in the deep layer occupying depths greater than ca 50 m (Figs. 3 and 4). The density stratification was here primarily controlled by the temperature variations, with the sigma-t value in the deep layer surpassing 29.0. In the PC the three layers were again visible, the two lower ones corresponding to those in the MVC, the surface one being under the influence of an intrusion of high-salinity, high-temperature water (Figs. 2, 4). The intrusion was not visible in the density field, due to its compensating nature, and therefore was probably not of a particular dynamical importance.

Vertical distribution of chlorophyll was characterized by values eight times smaller close to the sea surface than in the layer below 50 m, where deep chlorophyll maxima were detected, attaining 0.81 to 0.91 µg L^{-1} in the Pag and Velebit Channels (Figs. 2, 3, 5). The preliminary survey of the phytoplankton composition provided information that deep chlorophyll maxima were composed of rounded picoplanktonic cells, probably cyanobacteria (1.2 µm in size, $8\times10^3 - 1\times10^4$ cells mL^{-1}, Fig. 6).

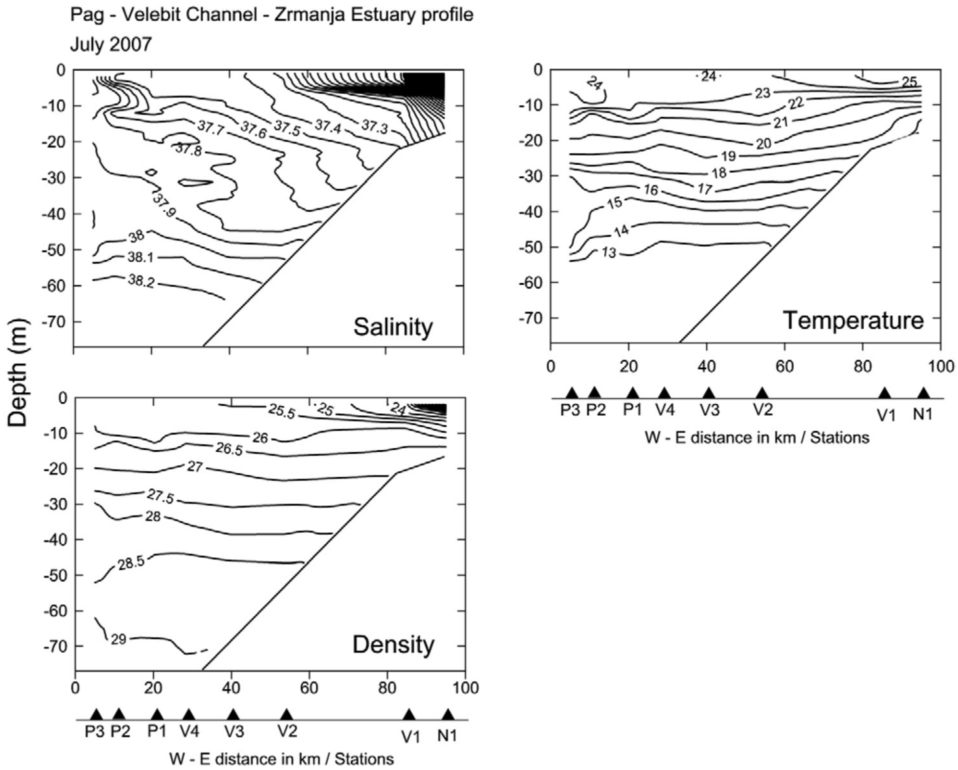

Fig. 4. Along-basin vertical profiles of salinity, temperature and density. For station positions see Fig. 1.

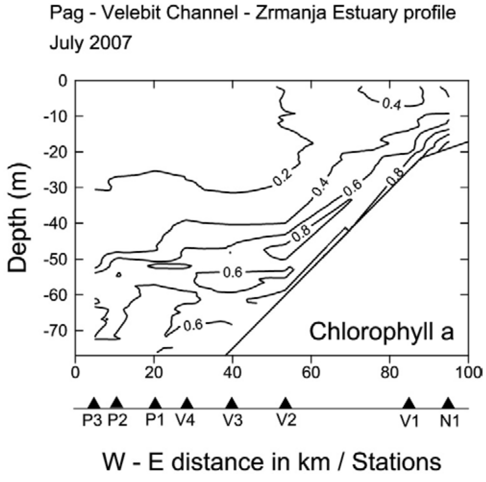

Fig. 5. Along-basin vertical profile of chlorophyll-a concentration. For station positions see Fig. 1.

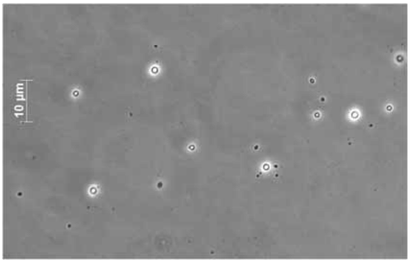

Fig. 6. Picoplankton in the Pag Channel deep chlorophyll maximum as seen while counting cells.

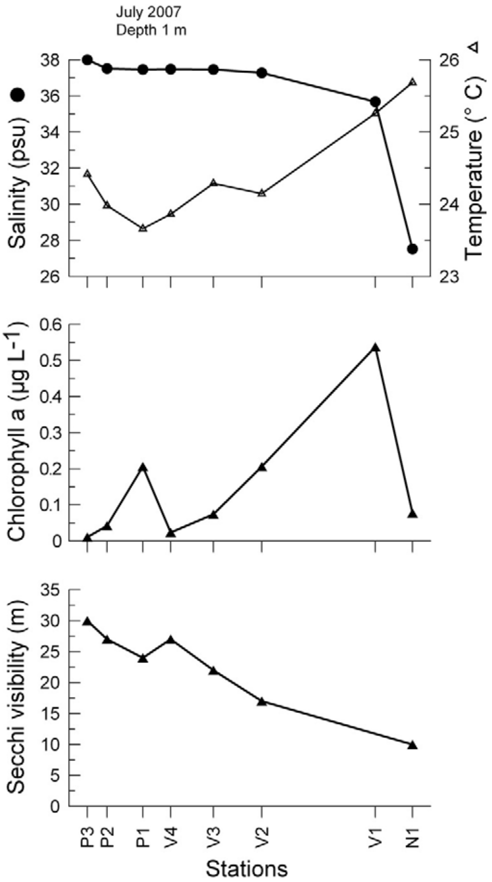

Fig. 7. Longitudinal distribution of surface salinity, temperature, chlorophyll *a* biomass and Secchi visibility, along the profile Pag Channel – Velebit Channel – Zrmanja Estuary during 4–6 July 2007. For station positions see Fig. 1.

The July 2007 was characterized by less than average rainfall (< 40 mm) in the drainage area (www.dhmz.htnet.hr), resulting in probably low discharge through submarine springs, and high Secchi disc visibility in the channel area (30 m) but also in the innermost middle Zrmanja Estuary (10 m, Fig. 7). In such conditions low surface phytoplankton biomass was found at all Velebit Channel stations. An exception is station V1 where water dynamics and nutrient concentrations were probably more favourable, resulting in the surface chlorophyll biomass increase to 0.5 μg L^{-1}. In the middle Zrmanja Estuary (at station N1) the surface chlorophyll concentration was low again.

Discussion

The CTD data may be interpreted in terms of (1) dense water occupying the deep layer found in the deeper part of the basin only, (2) estuarine circulation developing in the surface and subsurface layers, above the dense water or above the bottom, and (3) surface-layer intrusion influencing the outer stations. During winter, dense water is formed in the area (ORLIĆ et al. 1994, CUSHMAN-ROISIN et al. 2001). In spring, heating reaches a depth of about 50 m and estuarine circulation develops in the surface and subsurface layers with the dense water persisting close to the bottom in the deeper part of the basin. The circulation is primarily driven by the Zrmanja freshwater input and by the open sea, but uniform salinity found in the MVC surface layer suggests that some lateral freshwater input may be at work in the area. The origin of high-salinity, high-temperature intrusion at the outer stations is not clear.

The present interpretation suggests that there may be an outflow in the surface layer in the greater part of the Velebit and Pag Channels, and an inflow in the subsurface layer, with the deep layer being probably stagnant. As for mixing, it appears to be mostly related to internally generated turbulence at the interfaces between the surface and subsurface layers and between the subsurface and deep layers. Boundary-generated turbulence, which in the Velebit and Pag Channels should be mostly related to the wind, seems not to have been particularly active in the time interval before the cruise. At the interface between the subsurface and deep layers, entrainment may be suspected of being more important than turbulence, but without some dedicated measurements it is difficult to decide on the issue.

DCM formation may be the result of two dominant processes: growth in the nutricline and chromatic adaptation. In the oligotrophic ocean, prochlorophytes uptake and reduce nitrogen and assimilate a significant fraction of NO_3, contributing to new production in the DCM (Casey et al. 2007). Growth of cyanobacteria at the boundary between the subsurface and deep layers (in the nutricline) may be due to the entrainment of a deep layer richer in nutrients. In fronts and thermoclines the necessary conditions for phytoplankton accumulation are met as the environment is stable for a longer time. If there is no pronounced current shear, turbulent diffusion is reduced by the sharp density gradient, with nutrients possibly being available from the entrainment of deeper, nutrient rich water (FRENCH et al. 1983). It is often argued that DCMs are stable features. However, reduced vertical mixing in the ocean can generate oscillations and chaos in phytoplankton biomass and species composition of DCMs (HUISMAN et al. 2006). These fluctuations are caused by a difference in the time scales of two processes: (1) rapid export of sinking plankton, withdrawing nutrients from the euphotic zone, and (2) a slow upward flux of nutrients fuelling new phytoplankton production. These processes were probably not evident in the Pag and Velebit Channels in July 2007. DCM may be formed in layers deeper than compensation depth (KIMOR et al. 1987, VELDHUIS and KRAAY 1993, CASOTTI et al. 2003). However, in our case study the euphotic layer boundary was probably located between 75 and 90 m depth, due to the Secchi visibility range between 25 to 30 m in the Pag Channel.

DCM may be formed due to different specific chlorophyll content in deep layers. As a response to the exponential decrease of light during summer stratification, the phytoplankton usually exhibits photoacclimation, evident as a marked increase in cellular chlorophyll with increasing depth (STAMBLER 2006).

In tropical seas phytoplankton in DCM is usually composed of picoplanktonic cyanobacteria, prochlorophytes and coccoid prasinophyceae (MCMANUS and DAWSON 1994, MURPHY and HAUGEN 1985, TAGUCHI et al. 1988). Based on the analysis of plastid 16S ribosomal DNA (rDNA) sequences, photosynthetic picoeukaryotes (< 3 µm) DCM in the Arabian Sea is found to be composed of Chlorarachniophyceae, Chrysophyceae, Cryptophyceae, Eustigmatophyceae, Pavlovophyceae, Pelagophyceae, Pinguiophyceae, Prasinophyceae, Prymnesiophyceae, and Trebouxiophyceae, with abundances from 1.0×10^3 to 3×10^4 cells mL^{-1} (FULLER et al. 2006). DCM is also composed of low nucleic acid content bacteria (SCHAREK and LATASA 2007). In the oligotrophic eastern Mediterranean, subsurface chlorophyll maxima are composed mostly of nanoplanktonic coccolithophorids, pennatae diatoms, small dinoflagellates (KIMOR et al. 1987) and picophytoplankton (BERMAN et al. 1986). In the southern Adriatic we found accumulations of diatoms in the deep chlorophyll maximum, possibly due to downward transport of cells (VILIČIĆ et al. 1995, JASPRICA et al. 2000).

In the marine realm picoplanktonic cyanobacteria show a broad distribution from the open ocean to the offshore and coastal waters of semi-enclosed seas and, because of their photoheterotrophy, they are responsible for a substantial fraction of both primary production and organic matter degradation/utilization (PAOLI et al. 2007). Forthcoming research will evaluate community structure (including biomarker pigments and electron microscopy) and ecological characteristics in different seasons in this area.

Acknowledgements

This research was supported by the Ministry of Science of Croatia (projects no. 119-1191189-1228, 119-1193086-3085 and 275-0000000-3186). Thanks to the staff of the trawler *Eufemia* for help during sampling and measurements.

References

BENAC, Č., RUBINIĆ, J., OŽANIĆ, N., 2003: The origin and evolution of coastal and submarine springs in Bakar Bay. Acta Carsologica 32, 157–171.

BERMAN, T., AZOV, Y., SCHNELLER, A., WALLINE, P., TOWNSEND, D.W., 1986: Extent, transparency and phytoplankton distribution of the neritic waters overlying the Israeli coastal shelf. Oceanol. Acta 9, 439–448.

BIONDIĆ, B., ŠARIN, A., FRITZ, F., 1996: Hydrogeological map of the Adriatic catchment area. Institut for Geological Research, Zagreb.

BONACCI, O., ROJE-BONACCI, T., 2000: Interpretation of groundwater level monitoring results in karst aquifers: examples from the Dinaric karst. Hydrol. Process. 14, 2423–2438.

BURIĆ, Z., CAPUT, K., VILIČIĆ, D., 2004: Distribution of the diatom *Cocconeis scutellum* in the karstic estuary (Zrmanja, eastern Adriatic Sea). Biologia 59, 1–8.

BURIĆ, Z., KISS, K.T., ÁCS, E. VILIČIĆ, D. CAPUT-MIHALIĆ, K., CARIĆ, M., 2007a: The occurrence and ecology of the centric diatom *Cyclotella choctawhatcheeana* Prasad in a Croatian estuary. Nova Hedw. 84, 135–153.

BURIĆ, Z., CETINIĆ, I., VILIČIĆ, D., CAPUT-MIHALIĆ, K., CARIĆ, M., OLUJIĆ, G., 2007b: Spatial and temporal distribution of phytoplankton in a highly stratified estuary (Zrmanja, Adriatic Sea). Mar. Ecol. 28 (Suppl. 1), 169–177.

BURIĆ, Z., VILIČIĆ, D., CAPUT-MIHALIĆ, K., CARIĆ, M., KRALJ, K., LJUBEŠIĆ, N., 2008: *Pseudo-nitzschia* blooms in the Zrmanja River Estuary (eastern Adriatic Sea). Diatom Res. (In press)

CASEY, J.R., LOMAS, M.W., MANDECKI, J., WALKER, D.E., 2007: *Prochlorococcus* contributes to new production in the Sargasso Sea deep chlorophyll maximum. Geophys. Res. Lett. 34, art. no.10604.

CASOTTI, R., LANDOLFI, A., BRUNET, C., D'ORTENZIO, F., MANGONI, O., RIBERA D'ALCALA, M., DENIS, M., 2003: Composition and dynamics of the phytoplankton of the Ionian Sea (eastern Mediterranean). J. Geophys. Res. 108, 1–19.

CUSHMAN-ROISIN, B., GAČIĆ, M., POULAIN, P.M., ARTEGIANI, A., 2001: Physical oceanography of the Adriatic Sea. Kluwer Academic Publishers, Dordrecht.

DORMAN, C.E., CARNIEL, S., CAVALERI, L., SCLAVO, M., CHIGGIATO, J., DOYLE, J., HAACK, T., PULLEN, J., GRBEC, B., VILIBIĆ, I., JANEKOVIĆ, I., LEE, C., MALAČIĆ, V., ORLIĆ, M., PASCHINI, E., RUSSO, A., SIGNELL, R.P., 2006: February 2003 marine atmospheric conditions and the bora over the northern Adriatic. J. Geophys. Res. 111, art. no C03S03.

FRENCH, D.P., FURNAS, M.J., SMAYDA, T.J., 1983: Diel changes in nitrite concentration in the chlorophyll maximum in the Gulf of Mexico. Deep Sea Res. 30, 707–722.

FULLER, N.J., TARRAN, G.A., CUMMINGS, D.G., WOODWARD, E.M.S., ORCUTT, K.M., YALLOP, M., LE GALL, F., SCANLAN, D.J., 2006: Molecular analysis of photosynthetic picoeukaryote community structure along an Arabian Sea transect. Limnol. Oceanogr. 51, 2502–2514.

FURUYA, K., 1990: Subsurface chlorophyll maximum in the tropical and subtropical western Pacific Ocean: vertical profiles of phytoplankton biomass and its relationship with chlorophyll a and particulate organic carbon. Mar. Biol. 107, 529–539.

GAČIĆ, M., POULAIN, P.M. ZORE-ARMANDA, M., BARALE, V., 2001: Overwiew to the Adriatic Sea. In CUSHMAN-ROISIN, B., GAČIĆ, M., POULAIN, P-M., ARTEGIANI, A. (eds.), Physical oceanography of the Adriatic Sea, 1–44. Kluwer, Dordrecht.

GIESKES, W. W., KRAAY, G. W., 1986: Floristic and physiological differences between the shallow and the deep nanophytoplankton community in the euphotic zone of the open tropical Atlantic revealed by HPLC analysis of pigments. Mar. Biol. 91, 567–576.

GOULD, R. W. JR., 1987: The deep chlorophyll maximum in the world ocean: A review. The Biologist 66, 4–13.

HUISMAN, J., THI, N. N. P., KARL, D. M., SOMMEIJER, B., 2006: Reduced mixing generates oscillations and chaos in the oceanic deep chlorophyll maximum. Nature 439, 322–325.

JASPRICA, N., CARIĆ, M., VILIČIĆ, N., 2000: Relationships of subsurface chlorophyll maximum to diatoms and other microphytoplankton in the southern Adriatic Sea. Proc. 16 Int. Diatom Symp. Athens, 365–379.

KIMOR, B., BERMAN, T., SCHNELLER, A., 1987: Phytoplankton assemblages in the deep chlorophyll maximum layers off the Mediterranean coast of Israel. J. Plankton Res. 9, 433–443.

MAKJANIĆ, B., 1976: A short account of the climate of the town of Senj. In Yoshino, M.M (ed.), Local wind bora, 145–152. University of Tokyo Press, Tokyo.

MANN, K. H., LAZIER, J. R. N., 1996: Dynamics of marine ecosystems. Biological –physical interactions in the oceans. Blackwell Science Inc., Malden.

MARASOVIĆ, I., GAČIĆ, M., KOVAČEVIĆ, V., KRSTULOVIĆ, N., KUŠPILIĆ, G., PUCHER-PETKOVIĆ, T., ODŽAK, N., ŠOLIĆ, M., 1991: Development of the red tide in the Kastela Bay (Adriatic Sea). Mar. Chem. 32, 375–385.

MCMANUS, G. B., DAWSON, R., 1994: Phytoplankton pigment in the deep chlorophyll maximum of the Caribbean Sea and the western tropical Atlantic Ocean. Mar. Ecol. Prog. Ser. 113, 199–206.

MURPHY, L. S., HAUGEN, E. M., 1985: The distribution and abundance of phototrophic ultraplankton in the North Atlantic. Limnol. Oceanogr. 30, 47–58.

NINČEVIĆ, Ž., MARASOVIĆ, I., KUŠPILIĆ, G., 2002: Deep chlorophyll a maximum at one station in the middle Adriatic Sea. J. Mar. Biol. Ass. U. K. 82, 9–19.

ORLIĆ, M., KUZMIĆ, M., PASARIĆ, Z., 1994: Response of the Adriatic Sea to bora and sirocco forcing. Cont. Shelf Res. 14, 91–116.

ORLIĆ, M., LEDER, N., PASARIĆ, M., SMIRČIĆ, A., 2000: Physical properties and currents recorded during September and October 1998 in the Velebit Channel (east Adriatic). Period. Biol. 102, 31–37.

PAOLI, A., CELUSSI, M., VALERI, A., LARATO, C., BUSSANI, A., UMANI, S. F., VADRUCCI, M. R., MAZZIOTTI, C., DEL NEGRO, P., 2007: Picocyanobacteria in Adriatic transitional environments. Estuar. Coast. Shelf Sci. 75, 13–20.

PARSONS, T. R., TAKAHASCHI, M., HARGRAVE, B., 1979: Biological oceanographic processes. Pergamon Press, Oxford.

PENZAR, B., PENZAR, I., ORLIĆ, M., 2001: Weather and climate of the Croatian Adriatic (in Croatian). Dr. Feletar, Zagreb.

RAICICH, F., 1996: On the fresh water balance of the Adriatic Sea. J. Mar. Syst. 9, 305–319.

SCHAREK, R. LATASA, M., 2007: Growth, grazing and carbon flux of high and low nucleic acid bacteria differ in surface and deep chlorophyll maximum layers in the NW Mediterranean Sea. Aquat. Microb. Ecol. 46, 153–161.

STAMBLER, N., 2006: Light and picophytoplankton in the Gulf of Eilat (Aqaba). J. Geophys. Res.-Oceans 111, art. no. C11009.

SVENSEN, C., VILIČIĆ, D., WASSMANN, P., ARASHKEVICH, E., RATKOVA, T., 2007: Plankton distribution and vertical flux of biogenic matter during high summer stratification in the Krka estuary (Eastern Adriatic). Estuar. Coast. Shelf Sci. 71, 381–390.

TAGUCHI, S., DITULLIO, G.R., LAWS, E. A., 1988: Physiological characteristics and production of mixed layer and chlorophyll maximum phytoplankton populations in the Caribbean Sea and western Atlantic Ocean. Deep – Sea Res. 35, 1363–1378.

TOTTI, C., CIVITARESE, G., ACRI, F., BARLETTA, D., CANDELARI, G., PASCHINI, E., SOLAZZI, A., 2000. Seasonal variability of phytoplankton populations in the middle Adriatic sub-basin. J. Plankton Res. 22, 1735–1756.

VELDHUIS, M. J. W., KRAAY, G. W., 1993: Cell abundance and fluorescence of picoplankton in relation to growth irradiance and nitrogen availability in the Red Sea. Neth. J. Sea Res. 31, 135–145.

VILIČIĆ, D., 1989: Phytoplankton population density and volume as indicators of eutrophication in the eastern part of the Adriatic Sea. Hydrobiologia 174, 117–132.

VILIČIĆ, D., LEDER, N., GRŽETIĆ, Z., JASPRICA, N., 1995: Microphytoplankton in the Strait of Otranto (eastern Mediterranean). Mar. Biol. 123, 619–630.

VILIČIĆ, D., TERZIĆ, S., AHEL, M., BURIĆ, Z., JASPRICA, N., CARIĆ, M., CAPUT-MIHALIĆ, K., OLUJIĆ, G., 2008: Phytoplankton abundance and pigment biomarkers in the oligotrophic, eastern Adriatic estuary. Environ. Monit. Assess, in press.

VOLLENWEIDER, R.A., F. GIOVANARDI, G. MONTANARI & A. RINALDI, 1998. Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index. Environmentrics 9, 329–357.