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Review paper

Oceanographic properties of the Adriatic Sea - A point of view

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The development of hydrographic investigation since the end of last century has been presented. The most distinguished characteristics of the Adriatic are strong annual and year-to-year fluctuations of its basic oceanographic properties, giving the sea clearly a continental aspect.

The extremes of the surface temperature embrace a large range, from 6 °C to 29 °C. The salinity ranges are equally important, though minima are difficult to define due to the influences of rivers in the estuary regions.

Currents have generally low speed and variable directions. The fluctuations of different parameters depend, mostly on certain climatic factors over the Mediterranean and therefore on the level of the water exchange between the Adriatic and the eastern Mediterranean.

Strong year-to-year fluctuations of basic oceanographic properties influence the level of secondary production as well as the fish catch.

Key words: General hydrography, Adriatic Sea, climate changes

INTRODUCTION

The purpose of this article is to summarize oceanographic properties of the Adriatic, and especially to describe oceanographic properties relevant to fisheries aspects. Also, an overview of the historical development of the Adriatic oceanography is given.

Classic research, consisting of data collection and hydrographic description, as well as studies of seasonal and multi-year fluctuations of various phenomena, lasted for about hundred years, from the eighteen-eighties to the nineteen-eighties. During that time, phenomenological models have been developed and successfully applied to biological studies.

Recently, the last two decades have seen development of new, sophisticated methods, such as remote sensing and measurements from platforms and buoys, and evolution of computer processing and numerical models. These achievements have helped to develop a new approach, consisting of detailed studies of dynamic phenomena and of small basins. Adriatic oceanography also faces a necessity of dealing with increasingly urgent problems of the sea pollution; however, this article is not addressing the topic.

The Adriatic Sea, especially its northern part is one of the richest fishing grounds in the Mediterranean. The rich river inflows over the shallow shelf of the North Adriatic and in addition, mixing of bottom sediments, enable high productivity of this area. The middle and southern Adriatic are less productive, but their exposure to the influence from the North Adriatic, and to the periodically stronger influence of the Mediterranean waters, enable high productivity in these areas, as well. Open Adriatic waters are, therefore, distinguished as areas for pelagic fisheries.

The interaction between hydrographic parameters: temperature and salinity, and fisheries were recognized long ago. Salinity in the Adriatic is not only a factor that directly influence the fish species, but incoming Mediterranean water caries nutrients in a nutrient poor South Adriatic Basin, therefore salinity is used as an indicator for intensity of the inter-basin exchange. Here, long-term series of hydrographic measurements were compared to the small pelagic fish catch data from the middle Adriatic, which may indirectly influence the stock.

HISTORICAL OVERVIEW OF THE OCEANOGRAPHIC RESEARCH IN THE ADRIATIC SEA

In a context of generally increased scientific interest in the sea, the first oceanographic expeditions took place in the Adriatic during the eighteen-eighties. Oceanographic ships NAUTILUS (1874), DELI (1875, 1876, 1877), and HERTHA (1880) explore the entire Adriatic and parts of the Ionian Sea (sea WOLF and LUKSCH, 1881, 1887).

The increased interest in oceanographic research inspired (in 1865) creation of the Austrian Adriatic Commission (Adria Kommission) in Vienna, which initiates a variety of activities. The Italian Royal Committee for Oceanography (Regio Comitato Talassografico Italiano), established in 1909, measured five transverse profiles across the Adriatic, utilizing the torpedo boat S107, the destroyer MONTBELLO, and the ship CICLOPE.

The Adria Kommission was reorganized in 1903 into a Society for Advancement of Natural Research of the Adriatic. In cooperation with the Regio Committato Talassografico Italiano, it establishes in 1910 the International Commission for Adriatic Research (Permanente Internationale Kommission für Erforschung der Adria). That commission organized well-known cruises with the ships NAJADE (12 cruises) and CICLOPE (10 cruises), during the period between 1911 and 1914. During this campaign the new idea was accepted to repeat the same stations in the same time intervals.

The cruises encompass eight transverse profiles. The gathered data is accurate and in every way comparable in quality to its contemporary counterparts.

After the World War I Austria, having lost the Adriatic, abandons the oceanographic research. Fortunately, previously collected data are published and so preserved.

In 1930 the current Institute of Oceanography and Fisheries was founded in Split. Its small ship BIOS collects hydrographic and plankton data at the permanent stations near Split. It publishes "Acta Adriatica" and "Notes".

The Observatory of Marine Biology was founded in Fano in 1939.

It is apparent that formation of the new states on shores of the Adriatic after World War I had dampened interest in open sea research and expedition work, while it increased research of the coastal waters.

Interest in open waters research increases after the World War II. On both coasts of the Adriatic there is a gradually increasing number of institutes and research stations. Thus improved institutional basis, coupled with the generally accepted interdisciplinary approach to the oceanographic research, gives rise in the subsequent decades to cruises encompassing both the coastal and the various offshore areas of the Adriatic. The Institute of Oceanography and Fisheries organized the first major undertaking during the 1948-1949. Employing the ship HVAR, it gathered data at 176 stations. The first Italian cruise (Crociera Talassografica Italiana) was accomplished by the minesweeper M-306 in 1951. Offshore research was organized during the International Geophysical Year 1957/58 (vessels MINER (*ex* NAJADE), SPASILAC, STAFFETTA).

After fifties started the exploration of the NAJADE and CICLOPE data, and strong year-to-year variation in salinity and temperature data were observed (BULJAN, 1953).

Calculation of geostrophic currents for six situations (ZORE, 1956) showed also variability in the current field. The seasonal variation was rather easily explained by seasonal differences in temperature and salinity between the North, Middle and South Adriatic. The long-term variation was more interesting, and especially applied to the biological problems, became in the Split Institute one of the main research subjects. This was the reason that we wanted to collect good time series. Our plans were to continue the NAJADE and CICLOPE cruises (partially achieved during IGY), but we were able to have at least one cross-section seasonally, and two stations (Stončica, Kaštela Bay) on the monthly basis. Using vessels BIOS and PREDVODNIK, Split Institute has made continuous hydrographic (and other) observations since 1948. Data has been continually collected at eight permanent observation stations along the Split - Gargano line, and at additional stations located in the Jabuka Pit and the South Adriatic Pit (some gaps in data occurred during a recent war in former Yugoslavia). Cruises of BALDO KOSIĆ (ruined in the war in 1991) of the Dubrovnik Laboratory, and VILA VELEBITA of the Rovinj Institute should be mentioned. The Hydrographic Institute in Split was also engaged in a series of oceanographic measurements. Especially important was the 1974-1976 expedition of ANDRIJA MOHOROVIČIĆ.

Italy - either alone or in concert with other countries - organized a succession of expeditions (PICOTTI, 1960; TROTTI, 1969; MOSETTI and LAVENIA, 1969). Scientific teams on MANGO and VERCELLI intensively studied coastal and offshore waters. In the 1959-1960 period the Italian Thalassographic Institute undertook extensive studies of the entire Adriatic and a part of the Ionian Sea, using the Navy units FARFALLA, SCIMITARRA, and GAZELLA. Especially significant was the BANOCK cruise.

The Adriatic was studied by numerous foreign expeditions: American ATLANTIS in 1962 (MILLER *et al.*, 1970), Soviet AKADEMIK VAVILOV, AKADEMIK KOVALEVSKIJ, PROFESOR BOGOROV, PROFESOR VODJANICKIJ (KOSAREV, 1977).

Since 1986, intensive research has been performed under the auspices of the Italian - Croatian program ASCOP (Adriatic Scientific Cooperation Program) and European Community programs POEM (Physical Oceanography of the Eastern Mediterranean) and MATER (Mass Transfer and Ecosystem Response).

Recently, in 1998, the Croatian government established multidisciplinary oceanographic monitoring which comprises measurements in the coastal area (about 55 stations) and in the open sea waters (25 stations), to be performed 7 times per year.

From the beginning of data collection until present, more than 25000 stations are available. After OVCHINNIKOV *et al.* (1976) the Adriatic Sea was one of the best-covered areas by oceanographic stations in the Mediterranean. In addition, even bigger number of BT stations is available from recently.

BASIN MORPHOLOGY AND CURRENT FIELD

Excluding the Black Sea, the Adriatic is the northernmost part of the Mediterranean. This fact influences some important physical properties of even its southernmost areas. The Adriatic is 783 km long and its average width is 243 km.

In the south, the Adriatic Sea is separated from the Ionian Sea, by the 72 km-wide Strait of Otranto, where a submarine sill of 800 m exists. In the Central Adriatic the Palagruža Sill lowers the sea depth to only 170 m. The two sills define the South Adriatic Basin with its steep sides and an abyssal plain as its bottom with the maximal depth of 1233m (Fig.1).

A series of thousand small and large islands lie along the eastern coast, while there are almost no islands along the western shore.

Eastern and western coast have different morphological and topographic properties: eastern coast is composed of limestone, it is steep and narrow shelf deepens fast while western coast has wider shelf because of sediments brought by the river. The largest river input into the Adriatic comes from the Po River, with annual mean inflow of 1700 $m\ s^{-1}$. High variability of this inflow is the major factor, which determines a number of parameters like temper-

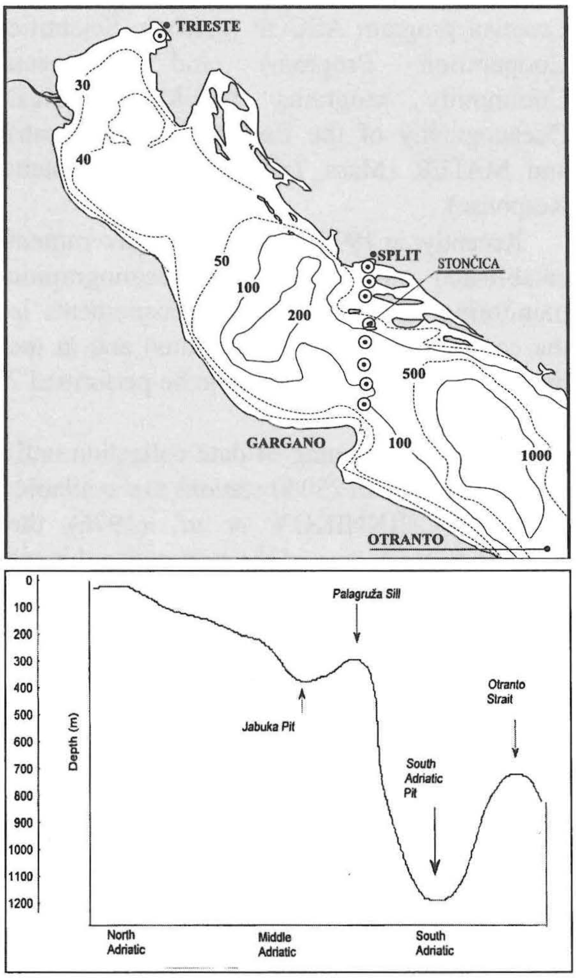

Fig. 1. The map of the Adriatic and depth profile along the Adriatic longer axe. Stations at the Split - Gargano transect are indicated

ature, salinity and transparency in the North Adriatic. River inflow is largest in the season of ice melting in spring, or in seasons of frequent precipitation in autumn. Annual cycle of phytoplankton is influenced by the nutrient salts cycle. Nutrients are brought into the sea by the river inflows and also by resuspension from the sea bottom, caused by mixing. Nutrients carried by rivers are important for the biological productivity, especially in the North Adriatic.

Mean surface current in the Adriatic is cyclonic (ZORE, 1956) which is confirmed from recent drifter observations by POULAIN, *et al.* (1999) whose results has shown more intensive stream toward the coast. The recent currents investigation in the South Adriatic (KOVAČEVIĆ *et al.*, 1999) are also in concordance with previous measurements and in addition found that the most energetic flow fluctuations are those at synoptic time scales (7-10 days).

Water enters in the Adriatic from Mediterranean along its eastern side and exits from the Adriatic on its western side, with seasonally varying intensity. In winter inflow is stronger, which reinforce current along the eastern coast. In summer outflow is stronger along the western coast.

According to the current measurements in the North Adriatic (ZORE-ARMANDA and VUČAK, 1984), inside general cyclonic circulation, there are smaller cyclonic and anticyclonic eddies. The reason for this phenomenon could be the Po River, since bellow its mouth currents often diverges on the cyclonic and anticyclonic eddy. Smaller eddies can be induced by the bora* wind. The difference in the wind stress in the North Adriatic is caused by orography. Stronger bora blows in the bay of Trieste and southern of Istra than against the Istra peninsula, so the currents follow the direction of bora, where it blows stronger and branches of opposite direction are formed where less strong bora blows (ZORE-ARMANDA and GAČIĆ, 1987).

Variability of weather conditions in the North Adriatic comes from frequent synoptic disturbances. Winter is characterized by cyclonic disturbances followed by anticyclonic periods, with wind regime from SE direction (sirocco) and from the NE direction (bora). North Adriatic is especially exposed to the bora wind. In summer at the open sea ethesian (NW direction) winds prevail.

Generally, calculated geostrophic currents show the influence of topography on the current field, where streamlines follow the isobatic lines (Fig. 2). The sill in the middle Adriatic (Palagruža Sill) affects the shape of streamlines, forming a wavelike patterns or meanders in otherwise simple cyclonic current regime. Such disturbances in current field at the sill are more pronounced, while characteristics of the water north and south of the sill differ significantly. A simple analytical model attempted to describe

*Bora is a very strong and dry NE wind, of cathabatic origin, with gusts up to 200ms^{-1}, especially characteristic for the eastern Adriatic coast.

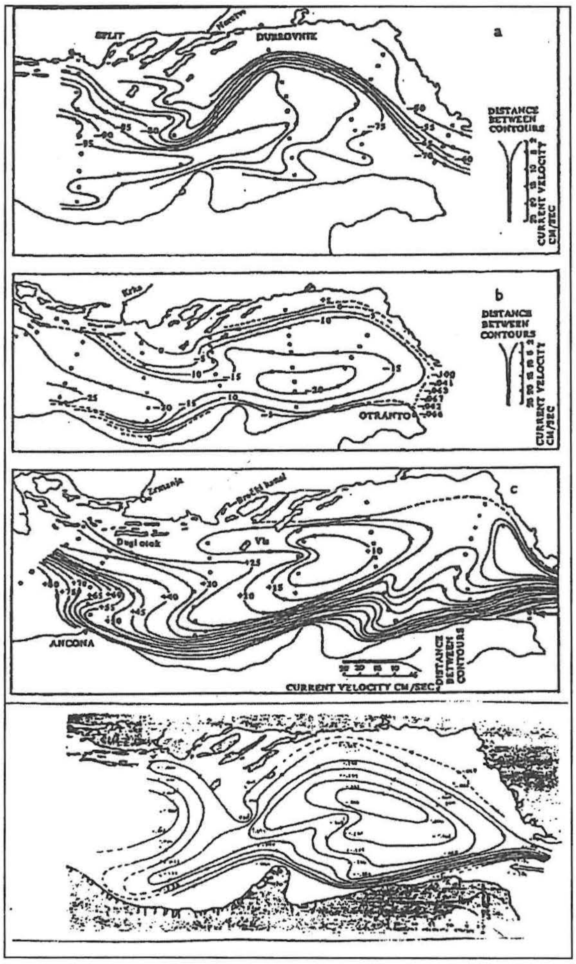

Fig. 2. Geopotential topographies for the year 1911, according to NAJADE-CICLOPE expedition for winter (a), spring (b) and summer (c) and for sum mer 1913 (d) relative to 50 or 100 m levels (after ZORE, 1956)

the mechanism of the topographic effects on a current field (ZORE-ARMANDA and BONE, 1987).

Streamlines affect the salinity distribution on the sill, which also shows the wavelike form. This observation opened the question of the mutual influence of dynamics and salinity distribution.

The main flow follows bottom contours at some distance from the coast, i.e. over the steep, towards the pits. Temperature and salinity distribution at the same distance from the coast indicates the coastal front, clearly confirmed by satellite observations of surface temperature (LE VOURCH *et al.*, 1992; BORZELLI *et al.*, 1999). The coastal front changes its position depending on the season and dynamic circumstances. In the North Adriatic in 1982/83 the study of the coastal front has been organized during the Alpex-Medalpex experiment. The position of a coastal front changes its position rather significantly. Is seems that bora (NE wind) have strong impact on the dynamics of the area.

SEASONAL THERMOHALINE FLUCTUATION

The thermohaline properties of the Adriatic Sea are determined mainly by the air-sea interaction, water exchange through the Otranto Strait, river discharge, mixing, currents, and topography of the basin. Vertical structure of the open water column has three characteristic layers. In the upper layer processes are balances between incoming heat, heat losses through short-wave and long-wave radiation, evaporation and turbulent convection (Fig. 3). Temperature of the surface layer lags one month behind the heat flux. The annual amplitude of the sea surface temperature is as a consequence of continental characteristics. The annual temperature range at the surface is 18°C in the South and 25°C in the North Adriatic.

In the Middle Adriatic, temperature in the deeper layers lag four months behind heat flux having two maxima: in May and in November. Maximal values in May are the consequence of the fast transport of heat in deep layers as the thermocline layer is not yet formed to prevent

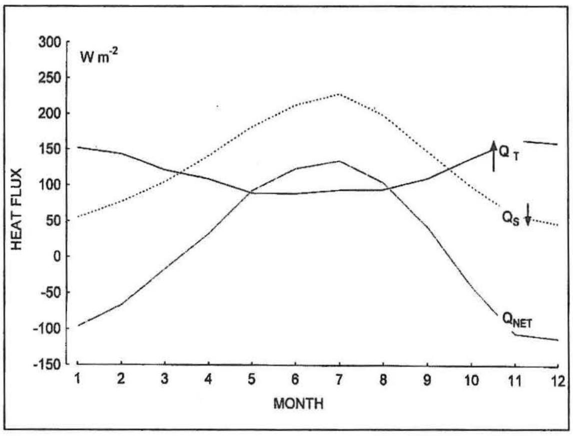

Fig. 3. Annual cycles of the heat fluxes: solar radiation (QS), total outgoing (QT) radiation and net heat flux (QNET). Total heat loss is the sum of heat loss due to the longwave radiation and latent and sensible heat conduction (after GRBEC, 1997)

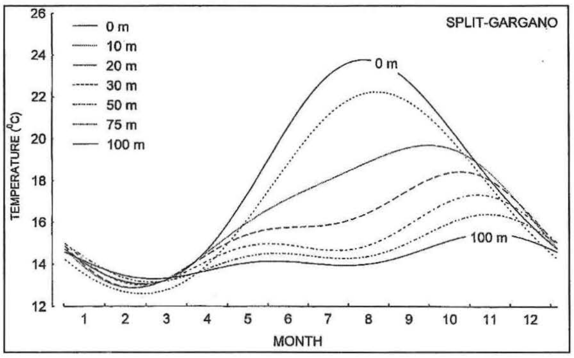

Fig. 4. Mean annual temperature cycles at the standard oceanographic depths for the Split- Gargano tran sect (after GRBEC, 1997)

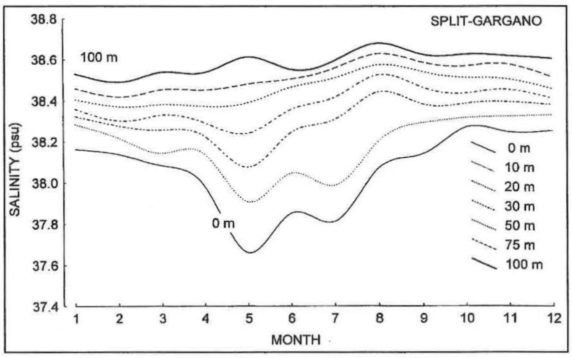

Fig. 5. Mean annual salinity cycles at the standard oceanographic depths for the Split-Gargano tran sect (after GRBEC, 1997)

vertical mixing process (Fig. 4). In the summer, when the thermocline is formed, deeper layer does not receive heat, and lower temperature was present. The temperature drop, below the thermocline, when the thermocline is fully developed, is attributed to the upwelling on the topographic barrier in the middle Adriatic.

As a whole, the Adriatic is a temperate warm sea. Temperatures of even the deepest layers are almost above 10°C. The South Adriatic is 8 -10°C warmer than its central and northern parts during winter. In other seasons the horizontal temperature distribution is more uniform. Generally, the open sea is warmer than the coastal waters. At the Split-Gargano transect the highest temperature occurs in the central part, the lowest surface temperatures are near the eastern coast, and the lowest bottom temperatures are found towards the western coast.

Adriatic belongs to those parts of the Mediterranean that have a positive difference between precipitation (including the run-off) and evaporation. The influx of the saline Mediterranean water through the Strait of Otranto increases, while precipitation and the run-off (the latter mostly in the north), decreases salinity of the Adriatic water.

Salinity of the Adriatic is relatively high. The largest part of its volume, i.e. its open southern part, has salinity between 38.4 to 38.9 psu. Salinity is lower, and also more variable, in the northern part and in the coastal zones. The lowest salinity is found close to the Po River mouth. Out of the three clearly distinguished layers in the South Adriatic Pit, the intermediate layer has the highest salinity.

Outside the coastal zone there are two salinity minima and maxima per year (BULJAN and ZORE-ARMANDA, 1976; ZORE-ARMANDA *et al.*, 1991; MOROVIĆ *et al.*, 1996). In the coastal zone of the North Adriatic (in Fano and Rovinj) mostly one salinity maximum per year occur (SCACCINI, 1951; SCACCINI and CICCATELLI, 1957, 1965, 1970, 1975; ORLIĆ, 1989).

The salinity minima, generally, occur in April-May and the September-January periods. The first maximum occurs during February and March, while the second (and higher) one occurs during July and August along the western coast and during September and October along the eastern coast. The annual salinity distribution at the Split - Gargano transect (Fig.5) depends on the annual variations in the current system. The salinity maxima are most distant from the eastern coast in winter, and approach the coast gradually from spring to autumn (ZORE-ARMANDA *et al.*,1991).

Thermohaline fluctuations in the Adriatic, depending on the layer, are the consequence of the vertical and horizontal processes. Throughout the whole year, surface layer being the atmospheric influences. In the summer season surface layer is also under horizontal advective control. Horizontal contribution of warmer and less saline water from the North Adriatic is evident in the Middle Adriatic. Vertical fluxes of heat and salt, compared to the rate of change of heat and salt content point to the important advection in the warm season (GRBEC and MOROVIĆ, 1997), while vertical exchange prevails in the cold period.

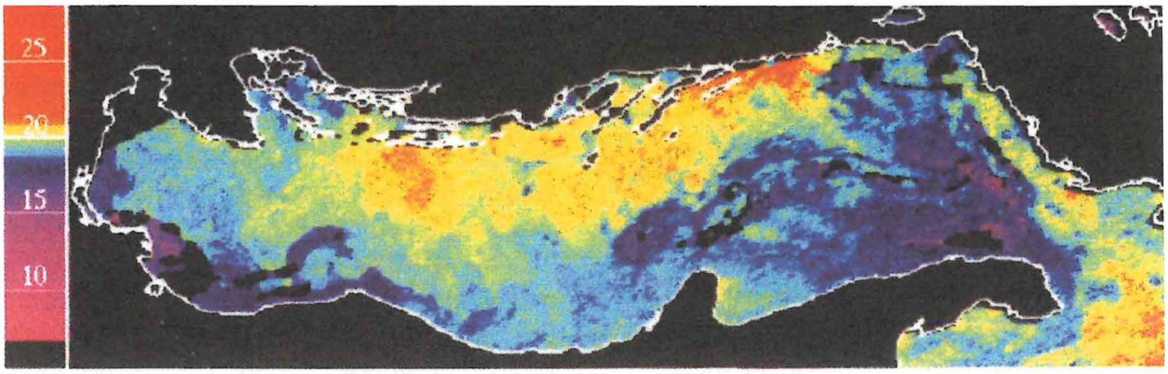

Fig. 6. Surface temperature structure for one situation at the end of September 1995. Image was taken from the set of SST images (after POULAIN et al., *1995)*

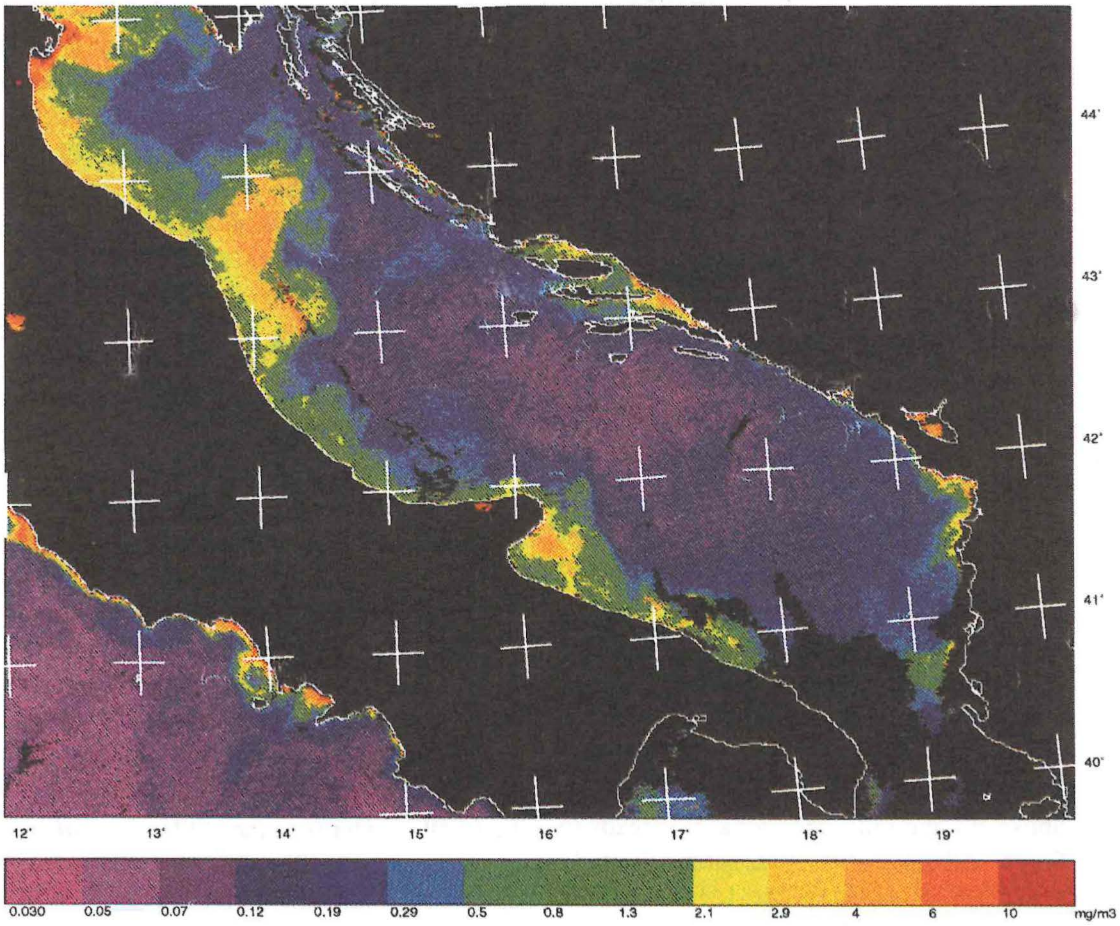

Fig. 7. Pigment concentration distribution (mg m^{-3}) for the 18th July, 1979 according to CZCS satellite data. The satellite data were processed for pigment concentration with the software developed by JRC-IRSA and ESA, in Ispra within the frame of the OCEAN project

In order to illustrate the connection between the richest fishing grounds and hydrographic parameters, the surface thermal structure of the Adriatic Sea is presented in the Fig 6. Typical thermal structure at the end of summer, shows spreading of river waters along the Italian coast. In the southern region, and in the Palagruža Sill, cooling is evident as a consequence of rising up of colder water from deeper layers. The regions across Ancona and around Palagruža Sill both are known as rich fishing grounds, especially for pelagic fisheries. The satellite image (Fig.7) for the 18th July, 1979 shows high pigment concentration near the Italian coast, also suggesting spreading of nutrient rich river waters. Nutrients enhance phytoplankton production, which reflects on fisheries grounds. In this image, the areas for pelagic and trawling fisheries have very high pigment content.

WATER MASS PROPERTIES

The Adriatic is a site of the deep water formation for the entire eastern Mediterranean (POLLAK, 1951; ZORE-ARMANDA, 1963; OVCHINNIKOV *et al.*, 1985), although some evidences are demonstrated that eastern Mediterranean water provides from Aegean Sea (LACOMBE *et al.*, 1958; ROETHER *et al.* 1996). Meteorological conditions favorable for the water mass formation are outbreaks of cold and dry winter weather, when the bora is blowing.

Three water types of the Adriatic origin are identified (ZORE-ARMANDA, 1963) and characterized with respect to the temperature T (^{0}C), salinity S (psu), and σ_t units. The North Adriatic Deep Water (NAdDW): T=11, S=38.5, t=29.52; the Middle Adriatic Deep Water (MAdDW): T=12, S=38.2, σ_t=29.09; and the South Adriatic Deep Water (SAdDW): T=13, S=38.6, σ_t=29.20. Recently, the last salinity value could be somewhat higher due to the salinity increase in the Middle and South Adriatic. Recently, ARTEGIANI *et al.* (1997) have redefined the same water masses, attributing some of them new values.

Due to its high density, the NAdDW fills up the Jabuka Pit and only occasionally spreads to the South Adriatic Pit. A theoretical study (HENDERSHOT and RIZZOLI, 1976) shows a development of a cyclone gyre in the North Adriatic during winter. It is driven by a horizontal density gradient between the dense water in the central part of the basin, and the fresh-water coastal runoff.

Other hypothesis points to the frontal zone in the North Adriatic, as an area of convergence and the sinking of water, and so may be functioning as a site for the dense NAdDW formation (ZORE-ARMANDA and GAČIĆ, 1987). ARTEGIANI and SALUSTI (1987) proposed that the core of this water forms a vain flowing along the isobats near the western coast and split into two branches, one descending into the Jabuka Pit and the other overflowing the Palagruža Sill.

The MAdDW is formed in the Jabuka Pit area, when there is no intensive northwestward flow, i.e., during the period of a low Mediterranean water inflow. The SAdDW originates in the South Adriatic Pit under the equivalent conditions. Due to its high density, this water spreads into the bottom layer of the eastern Mediterranean. According to OVCHINNIKOV *et al.* (1985), the SAdDW is formed in the center of the cyclonic gyre during the period of the strongest cooling. This particular water formation process occurs over the time scale of several days, and the distance scale of a few tenths of nautical miles. Another possibility for the SAdDW formation is the convection on the slope regions like in the Otranto Strait, where the denser Adriatic water is forced to sink and mix with the intermediate Mediterranean water (ZORE-ARMANDA, 1974), or by convective overturning closer to the coastal area under the particular meteorological conditions.

The forth water type is not of Adriatic origin. The Levantine Intermediate Water (LIW) is formed in the Levantine Basin. This water experiences a salinity decrease on its way to the Adriatic, and eventually enters the Adriatic through the Strait of Otranto. This water type can be recognized in the intermediate layer of the South and Middle Adriatic as mLIW (modified LIW) water type (see ORLIĆ, *et al.*, 1992).

Seasonal distributions of water masses are closely related to the current fields (Fig. 8). The three levels in the vertical distribution of currents could be clearly distinguished (ZORE-ARMANDA, 1963). In the Middle and South Adriatic, the intermediate layer is separated by 20 to 40 m from the surface, and descends to 200 to 400 m. A northwesterly flow prevails in this layer throughout the year. In summer this flow is compensatory to the surface flow. In winter, the flow has the same direction, both the

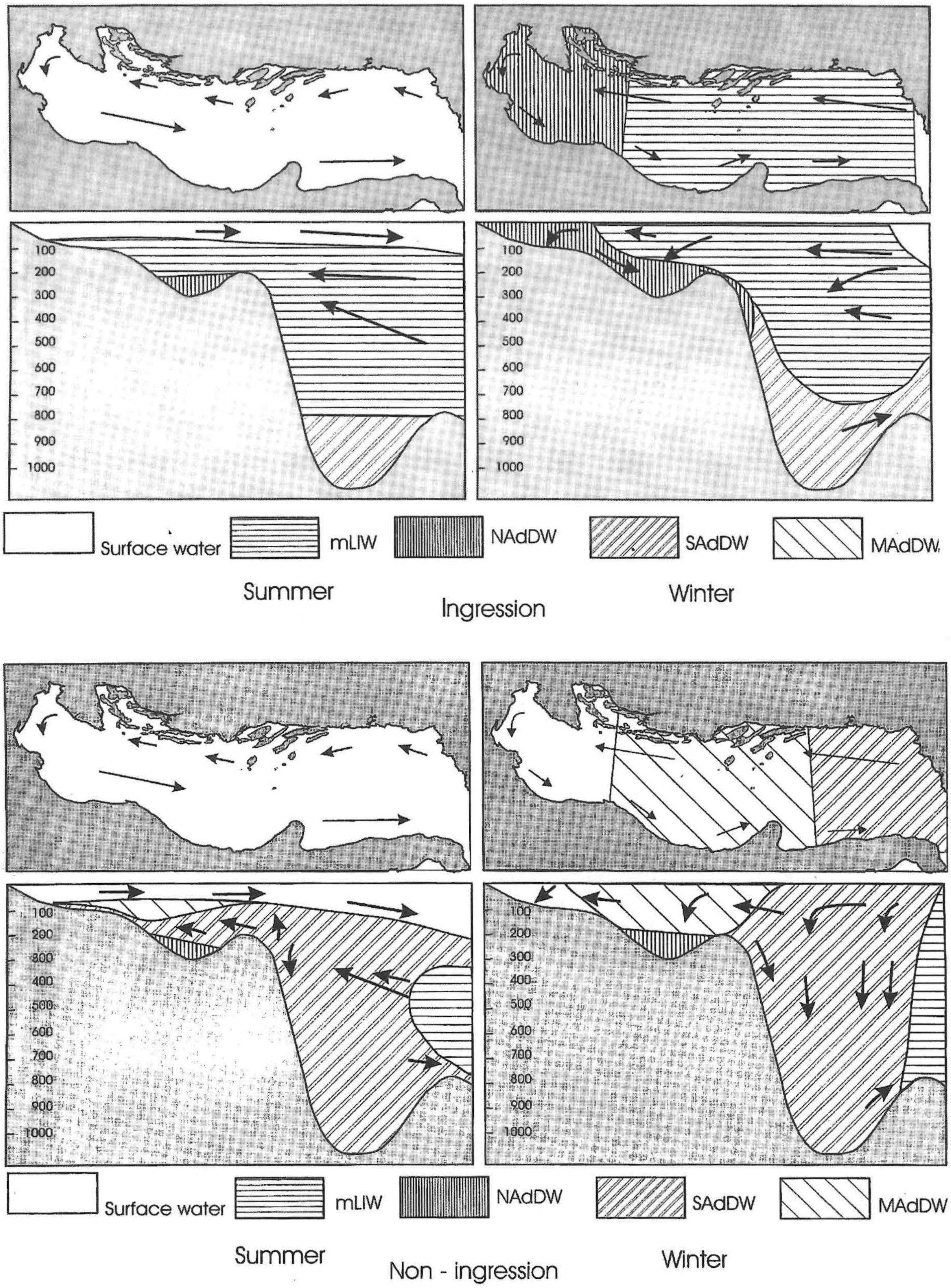

Fig. 8. Seasonal distribution of water masses in the Adriatic Sea with principal direction of currents (after ZORE-ARMANDA, 1963) in ingressional and noningressional period

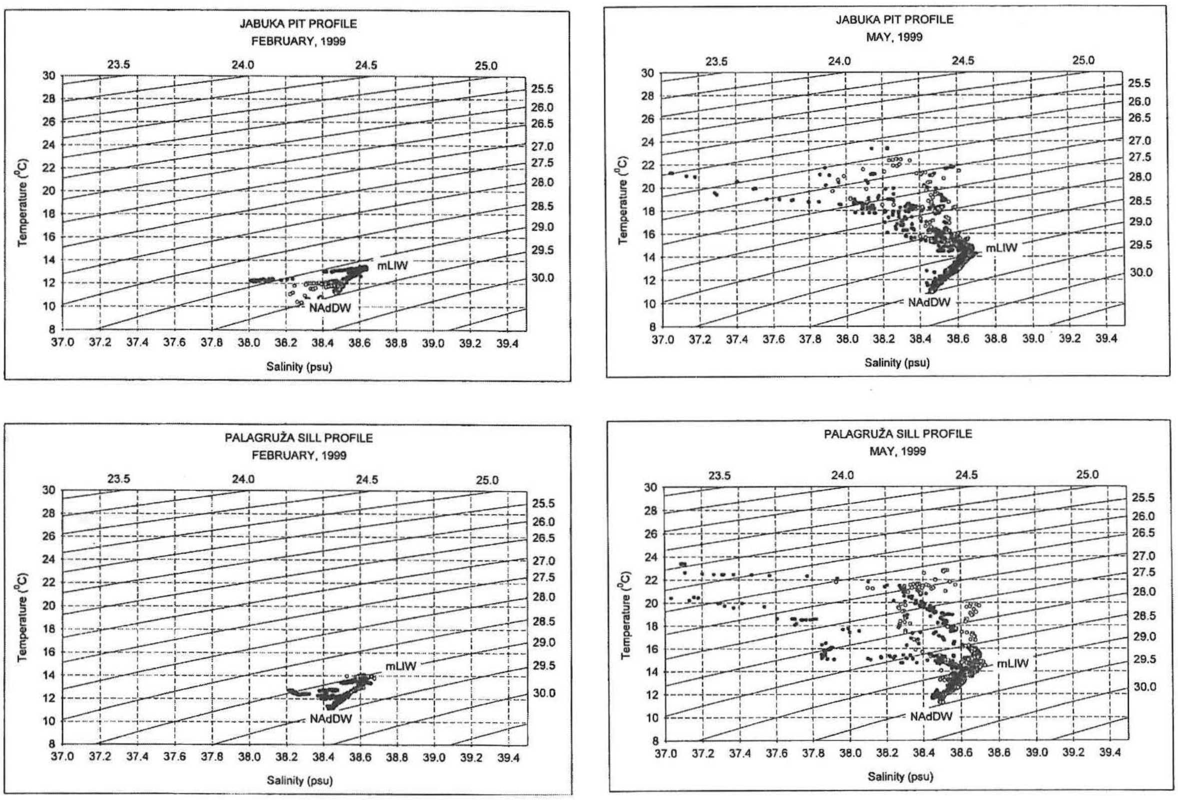

Fig. 9. T-S diagram constructed from CTD profiles measured within the frame of the new Adriatic monitoring project. Data were from Jabuka Pit profile and Palagruža Sill profile in February and May 1999, with principal water types indicated. Different symbols in the figure indicate different stations

surface and the intermediate layer, and is compensated for by an outgoing southeasterly flow in the bottom layer. As already mentioned, the intensity, and the quantity of the intermediate eastern Mediterranean flow of water entering the Adriatic, vary considerably from year to year. Otherwise, the northwesterly flow in the intermediate layer is very consistent. Its frequency in the Palagruža Sill area amounts to 30 - 50% (BULJAN and ZORE-ARMANDA, 1976).

The outflow prevails in the bottom layer. Part of the winter, dense water from the North Adriatic flows towards the bottom layer of the Jabuka Pit, and after filling it, proceeds further to the deep layer of the South Adriatic and, exiting through the Otranto Strait, to the bottom layer of the entire eastern Mediterranean.

Following T-S diagram analysis, obtained from the data collected during winter-spring 1999 period at the Jabuka Pit and Palagruža Sill, the presence of distinct water masses is clearly observed. In the Jabuka Pit region (Fig. 9), NAdDW with a temperature of about 10.5°C, and salinity of about 38.4 psu is present. Second water type located slightly above NadDW is a modified LIW. It occurs with salinity about 38.4 psu and temperature above 13°C. The chosen year is a year with increased exchange of water between the Mediterranean and the Adriatic Sea (called ingressional year), so MAdDW is not formed. Cluster of points located in the T-S diagram around the point (38.1 ; 12.0) is the surface water.

CLIMATIC CHANGES

The Adriatic shows considerable year-to-year variations in the oceanographic parameters, as evidenced by the amount of the LIW present in it. Changes in the air pressure field over the North Atlantic, Europe, and the Mediterranean dictate the activity of small moving cyclones

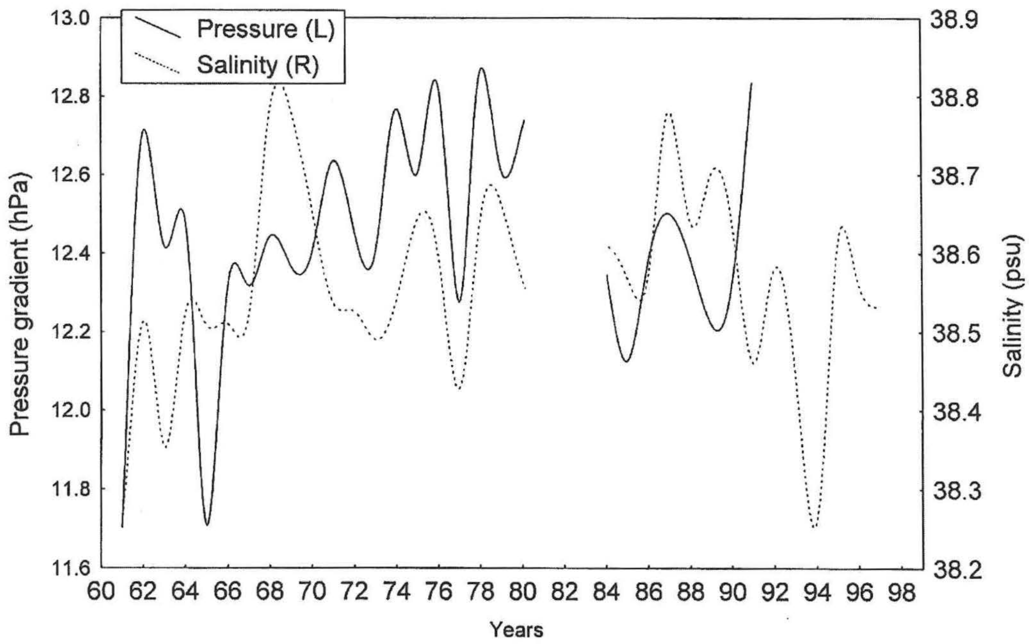

Fig. 10. Mean annual air pressure differences between Trieste and Dubrovnik and mean annual salinity for Stončica station (MEDAS data bank of Institute of Oceanography and Fisheries)

over the Adriatic, and influence the amount of the bottom water formed in the region. This leads to the variable exchange rates between the Adriatic and the eastern Mediterranean. The variable air pressure field also influences the magnitude of the air pressure gradient, which, in turn, directly acts on the intensity of water exchange between the Adriatic and the Ionian Sea. Advection mechanism appears to be related to the distribution of the large-scale (from Atlantic to Europe) low and high-pressure centers. It seemed that more northeastward location of cyclones increase zonal pressure gradient, which enhance saltier water advection from the Mediterranean into the Adriatic (GRBEC, *et al.*, 1998). The variability of local atmospheric parameters can be related to much larger scale atmospheric variability (ZORE-ARMANDA, 1972) and probably with North Atlantic Oscillation Index (ROGERS, 1984; 1990). Salinity change in the intermediate layer is highly correlated to horizontal pressure gradient between northern and southern Adriatic (Fig.10). In the period 1973-1980 correlation coefficient between the horizontal pressure gradient and salinity was 0.55 (GRBEC, 1997). Since the wind is directly connected to the horizontal pressure gradient between northern and southern Adriatic, the salinity changes in the intermediary layer is a consequence of wind induced advection.

Uneven impact of the LIW influences also primary and secondary production (BULJAN, 1953; PUCHER-PETKOVIĆ and ZORE-ARMANDA, 1973; MARASOVIĆ, *et al.*,1996). So, it is clearly that significant correlation (0.35 : significant at 0.05) exists between interannual salinity variation in the intermediate layer in the middle Adriatic and small pelagic fish catch of (Fig. 11), although this relation does not mean a direct relation between these two parameters.

Year-to-year temperature variations are also high. Spectral analysis performed on the monthly mean surface temperature series measured at the Split's Marian Cape shows a periodicity of 33.3 months (2.8 years). An approximately 3-year period is also visible in the surface temperature data at the Split - Gargano transect (ZORE-ARMANDA, 1969).

Measurements in the coastal and open waters of the middle and southern Adriatic have

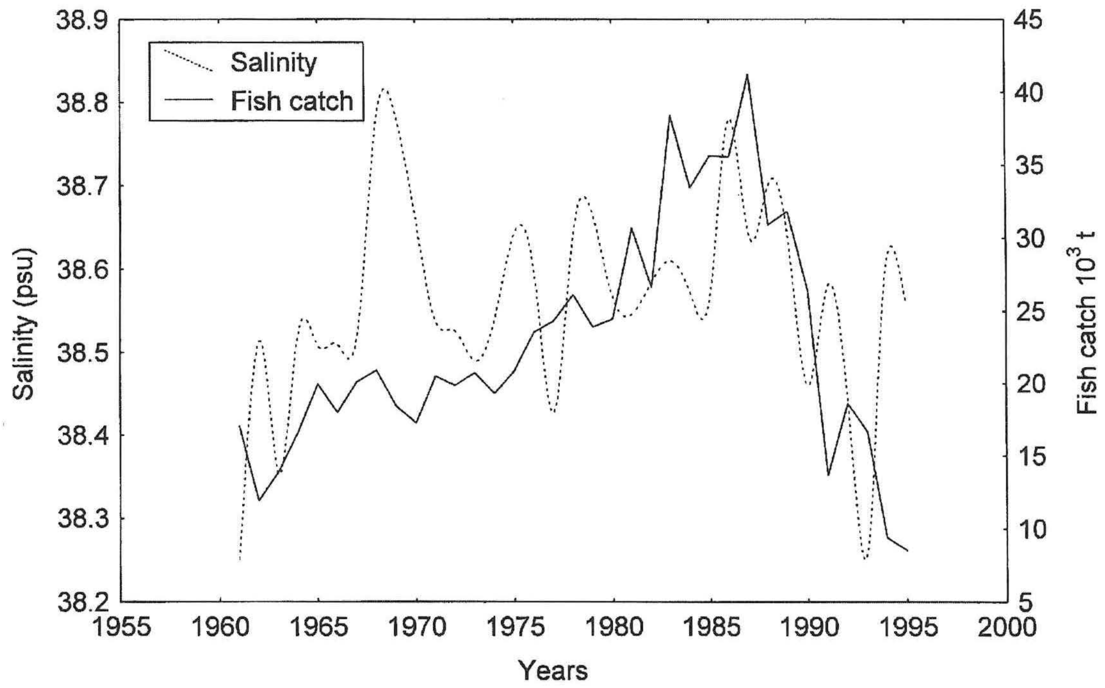

Fig. 11. Mean annual salinity for the deep layers (bellow 50m) of the Stončica station (psu) and pelagic fish catch (tons) for the whole Adriatic in the period 1960-1995

shown a constant salinity increase in the period from 1961 up to 1987. It has been suggested (ZORE-ARMANDA *et al.*, 1991) that a reduction in the fresh water supply to the eastern Mediterranean caused by the Assuan Dam, increases the salinity of these waters (ROHLING and BRYDEN, 1992. and references therein), and, indirectly, the salinity of the Adriatic. Certain climatic factors, such as a reduction in the precipitation, or an increase in the evaporation, may also be responsible for the gradual salinity increase.

CONCLUSIONS

The Adriatic was systematically investigated since the end of the last century and broad literature exists describing its oceanographic properties. Classic research consisted of data collection and hydrographic description, as well as studies of seasonal and multi-year fluctuations of various phenomena, lasted for about hundred years. During that time, phenomenological models have been developed and successfully applied to biological studies. More recently, the last two decades have seen development of new, sophisticated methods, such as remote sensing and measurements from platforms and buoys, and evolution of computer processing and numerical models. These achievements have helped to develop a new approach to the studies of dynamic phenomena.

The most distinguished characteristics of the Adriatic are large annual and year-to-year fluctuations of its basic oceanographic properties, giving the sea clearly a continental aspect. The extremes of the surface temperature embrace a large range, from 6°C to 29°C. Temperatures of even the deepest layers are almost always above 10°C.

Salinity of the Adriatic is relatively high and its ranges are important, as well. The southern part has salinity between 38.4 to 38.9 psu, and is especially high in the intermediate layer. In the northern part and in the coastal zones salinity is lower, and also more variable. The lowest salinity is found close to the Po River mouth.

Currents have generally low speed and variable directions. The current field shows simple cyclonic circulation regime. Generally, streamlines follow the isobath lines along both coasts, but wavelike patterns or meanders appear, influenced by topography in the Middle Adriatic (Palagruža Sill).

Long-term measurements in the coastal and open waters of the middle and southern Adriatic have shown a salinity-increased trend up to 1993/94.

The horizontal pressure difference varies between the northern and the southern Adriatic, which influence the intensity of water exchange between the Adriatic and the eastern Mediterranean as a consequence of distribution of large pressure center over the wider Mediterranean region. Year to year fluctuations of water exchange between these basins influenced long-term fluctuations of a variety of parameters like salinity, temperature, transparency and nutrient salts, the latest having a consequence in chlorophyll concentration fluctuations.

In addition, the man-made impact on at least some of the oceanographic properties has become clear over the past three decades. Nowadays, Adriatic oceanography, especially in the North Adriatic area, faces a necessity of dealing with increasingly urgent problems of the sea pollution, which might influence toxic phytoplankton blooms as well as biodegradation of the environment having consequences to biodiversity, as well.

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SAŽETAK

Jadransko more je sustavno istraživano od konca prošlog stoljeća te postoji ospežna literatura u kojoj su opisana njegova oceanografska svojstva. Klasična istraživanja su trajala čitavo stoljeće a sastojala su se od prikupljanja podataka, opisivanja hidrografskih procesa i studiranja sezonskih i višegodišnjih fluktuacija različitih parametara. U tom vremenu razvijeni su fenomenološki modeli koji su uspješno primijenjeni na biološke studije.

U novije vrijeme, posebno u zadnja dva desetljeća, razvijene su nove sofisticirane metode, kao što su daljinska istraživanja, mjerenja sa platforma i plutača a razvijali su se i programi za kompjutersko procesiranje te numerički modeli. Ova su dostignuća pomogla razvoju novih pristupa u proučavanju dinamičkih fenomena.