Acta Adriat., 25 (1/2): 119—138 (1984) YU ISSN: 0001—5113
AADRAY

HYDROGRAPHIC AND PRODUCTIVITY CONDITIONS OF THE PALAGRUŽA REGION IN THE MIDDLE ADRIATIC

HIDROGRAFSKE I PRODUKCIONE PRILIKE U PODRUČJU PALAGRUŽE

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An attempt is made to present oceanographic description of the Palagruža region: temperature, salinity, current regime, transparency, oxygen content, nutrient content and productivity.

INTRODUCTION

Palagruža area is known from the old days as a fertile fishing ground. This paper will try to throw some more light to some specific conditions of the area compared to the adjacent zones and will try to explain its fertility. For this reason all the data available were processed (ANDRIJA MOHOROVIČIĆ 1974—1976; Buljan and Marinković, 1956; Buljan and Zore-Armanda, 1966, 1979; CICLOPE 1911—1914; NAJADE 1911—1914, and unpublished data from the file of the Hydrographic Institute of Yugoslav Navy, Split). Data base is large, but the measurements were not always systematically undertaken, thus that some of the series are incomplete. Therefore all phenomena encountered could not be well explained.

The region investigated is located around the isle Palagruža on the Palagruža sill. This sill separates Middle Adriatic with Jabuka Pit from the South Adriatic with deep South Adriatic Pit (basin). Therefore the area investigated is subject to rather intensive exchange and mixing of waters of different origin. This is probably the most important characteristic of the region. Intensive mixing and water exchange influence the turnover of salts which in turn affects the rate of organic production as shall be seen later.

SEA WATER TEMPERATURE

In winter sea surface temperature is under the influence from the South Adriatic and therefore much higher than the temperature in the coastal region of the middle and northern Adriatic (Split, Fano).

Table 1. Monthly mean sea surface and air temperatures (°C). Data for Split after Buljan and Zore-Armanda, 1979 and for Fano after Scaccini-Cicatelli, 1965

	Sea surface temperature			Air temp.	Sea temp. —
	Palagruža (1950—1970)	Split (1951—1970)	Fano (1946—1962)	Palagruža (1951—1974)	Air temp. Palagruža
Jan.	14.5	7.8	6.58	9.6	4.9
Feb.	13.8	8.2	7.14	9.7	4.1
March	14.0	10.7	9.53	11.0	3.0
April	15.1	14.1	13.73	13.7	1.4
May	17.2	18.3	17.89	17.5	—0.3
June	20.9	22.4	22.13	21.6	—0.7
July	23.6	24.9	25.00	24.1	—0.5
Aug.	24.2	24.7	25.13	24.3	—0.1
Sep.	22.3	21.7	22.63	21.4	0.9
Oct.	19.4	17.5	17.95	17.4	2.0
Nov.	16.8	13.5	13.09	14.0	2.8
Dec.	15.3	10.2	8.99	11.3	4.0
Annual	18.1	16.2	15.81	16.3	1.8
Range	10.4	17.1	18.55	14.7	5.6

Annual mean sea surface temperature is higher than air temperature for almost 2°C at Palagruža, whereas at the eastern Adriatic coast (in Split) sea surface temperature is for 1°C higher than air temperature. As already mentioned, sea surface temperature at Palagruža is relatively high in winter. In January sea surface is warmer than the air for almost 5°C. In the warm part of the year, air is warmer than the sea surface, but this difference is much smaller than the opposite difference between the sea surface and air temperature in the cold part of the year. It makes annual fluctuations of the sea surface temperature in the region of Palagruža less important compared to fluctuations closer to the coast and in the northern part of the Adriatic (Split, Fano). Thus Palagruža area has open sea temperature regime compared to the coastal stations under continental influence.

Annual variations of the vertical distribution of temperature are shown in Fig. 2. Data from which this figure was constructed refer to the square: $\varphi = 42°15'$ to $42°30'$; $\lambda = 16°00'$ to $16°20'$ (Fig. 1). Number of data for each

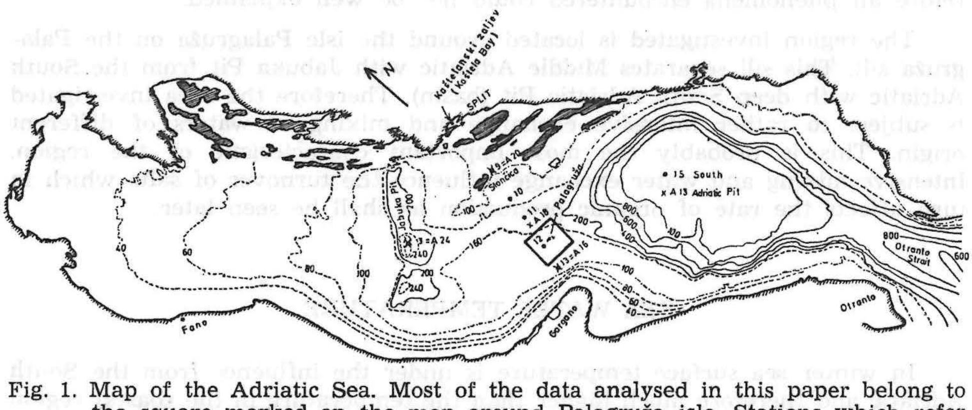

Fig. 1. Map of the Adriatic Sea. Most of the data analysed in this paper belong to the square marked on the map around Palagruža isle. Stations which refer to ANDRIJA MOHOROVIČIĆ expeditions are marked by A.

month differs and there are no data for October. The time interval covered is from the time of expeditions NAJADE and CICLOPE (1911—1914) to 1970 (data obtained from the file of the Hydrographic Institute of the Yugoslav Navy, Split).

Lowest annual temperature range was found in the intermediate layer (50—75 m). Rather significant decrease in March was observed in the bottom layer. It could be understood that it follows water advection from the North Adriatic what proves the fact that salinity decrease coincides (Fig. 10). It is well known that heavy cold water is formed in the North Adriatic in winter which afterwards sinks and progresses towards the south. As expected this water appears in the Middle Adriatic with some time lag, i.e. two months after its formation in the North Adriatic.

Heating of the upper layer is uniform at the surface only. At depths exceeding 20 m a slight temperature decrease appears in June and another more significant in August (Figs. 2 and 3). Both decreases are connected with simultaneous salinity decrease which indicates the water intrusions from the regions north of the Palagruža Sill. Upwelling was considered as possible mechanism which commonly appears along the eastern coast with typical

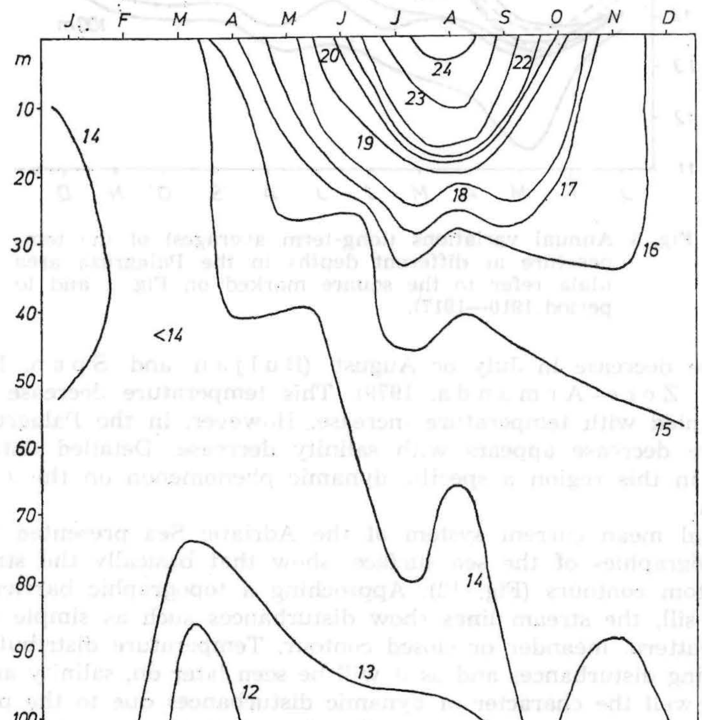

Fig. 2. Annual variations of vertical temperature distribution (°C) in the Palagruža region (data from the square marked on Fig. 1 for the period 1910—1917).

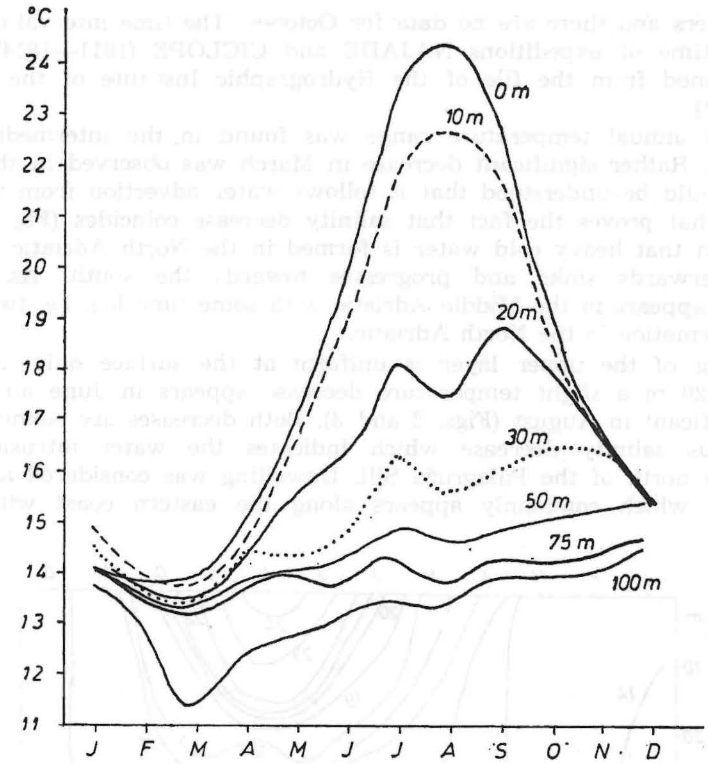

Fig. 3. Annual variations (long-term averages) of the temperature at different depths in the Palagruža area (data refer to the square marked on Fig. 1 and to period 1910—1917).

temperature decrease in July or August (Buljan and Špan, 1976; Buljan and Zore-Armanda, 1979). This temperature decrease as a rule is accompanied with temperature increase. However, in the Palagruža region temperature decrease appears with salinity decrease. Detailed data analysis show that in this region a specific dynamic phenomenon on the sill may be in question.

Seasonal mean current system of the Adriatic Sea presented by geopotential topographies of the sea surface, show that basically the stream lines follow bottom contours (Fig. 12). Approching a topographic barrier, such as submarine sill, the stream lines show disturbances such as simple deflection, wavelike pattern, meander or closed contour. Temperature distribution shows corresponding disturbances and as it will be seen later on, salinity and current data show well the character of dynamic disturbances due to the presence of topographic barrier. At the surface, disturbances in the temperature field are covered by heating due to radiation, but immediately below the depth of the thermocline (cca 20 m) they are very clear (Fig. 3).

Long-term temperature variations are demonstrated by seasonal values of maxima and minima. Data refer to the area and time interval described earlier and seasons are taken in the oceanographic sense.

Table 2. Seasonal values of temperature maxima and minima in the region of Palagruža in °C

Depth (m)		Surf.	10	20	30	50	75	100	Average
Winter	Max.	14.8	14.8	14.7	14.6	14.5	14.4	14.4	14.6
(Jan. Feb.	Min.	12.1	12.5	12.1	12.1	12.2	11.0	10.0	11.7
March)	Range	2.7	2.3	2.6	2.5	2.3	3.4	4.4	2.9
Spring	Max.	22.3	20.8	17.9	15.7	15.0	15.3	14.1	17.3
(Apr. May	Min.	14.4	14.2	13.8	13.1	12.9	12.8	11.9	13.3
June)	Range	7.9	6.6	4.1	2.6	2.1	2.5	2.2	4.0
Summer	Max.	26.1	24.8	23.4	19.0	15.7	15.2	14.7	19.8
(July, Aug.	Min.	20.9	20.0	15.2	13.8	13.1	12.2	12.3	15.4
Sept.)	Range	5.2	4.8	8.2	5.2	2.6	3.0	2.4	4.4
Autumn	Max.	17.8	17.8	17.7	17.6	16.9	16.6	15.6	17.1
(Oct. Nov.	Min.	14.3	14.0	13.9	14.6	13.6	12.6	12.3	13.6
Dec.)	Range	3.5	3.8	3.8	3.0	3.3	4.0	3.3	3.5

Largest long-term temperature ranges are observed in the bottom layer in winter. It could be understood as due to rather variable intensity of the North Adriatic water advection to this region. This advection being strong, bottom layer temperature decreases intensively. Without such dynamic influence, winter cooling from the surface regulates the temperature of the whole layer resulting in vertical homogeneity. Largest ranges in the surface layer which appear in spring are probably due to uneven intensity of heating in different years. Ranges are still larger in the thermocline layer (max at 20 m) in summer. Most probably it is due to variable depth of the thermocline so that depths of 20 and 30 m could be above and bellow the thermocline in different years. Surface ranges in summer are also wider what shows rather uneven heating from year to year.

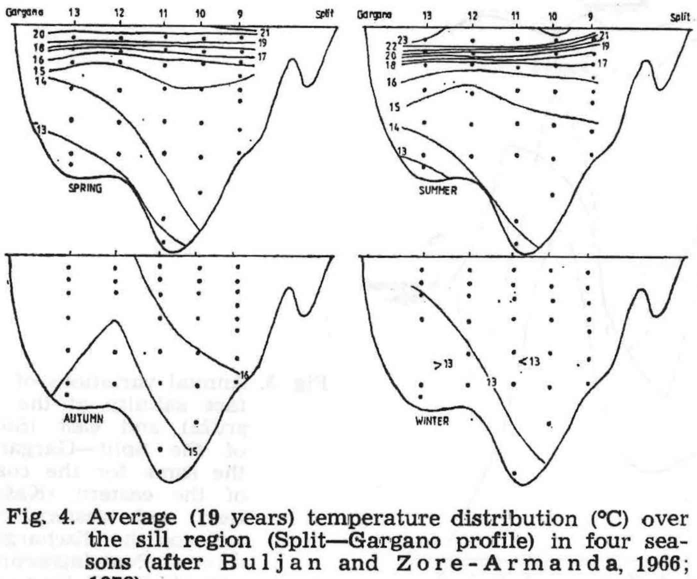

Fig. 4. Average (19 years) temperature distribution (°C) over the sill region (Split—Gargano profile) in four seasons (after Buljan and Zore-Armanda, 1966; 1979).

Annual mean range for the whole layer is 3.7°C which presents maximum temperature difference of the whole layer in different years.

Compared to the areas on the sill located more northward, temperature of the whole layer of the Palagruža region is somewhat lower (Fig. 4) in the warm part of the year.

SALINITY

Since this parameter was not observed daily like temperature on the beach of the Palagruža isle, the data used originate only from the hydrographic stations in the area marked by a square in Fig. 1 and refer to the time interval described earlier.

Annual mean variations of surface salinity in the eastern and western parts of the sill (Stončica and Palagruža) as well as at the eastern and western coast (Kaštelanski zaljev and Fano) are presented in Fig. 5. Annual fluctuations are much smaller on the sill than closer to the coast where fresh water inflows from land and rivers affect salinity. Annual salinity regime at the east part of the sill (Stončica) is similar to that at the eastern coast (Kaštelanski zaljev): minimum in April and maximum in October. Salinity regime is different at Palagruža since only one maximum appears in July. It also differs from that at the western coast (Fano) where salinity maximum appears one month later and is evidently related to Po river discharge minimum. Thus Palagruža maximum in July could not be connected with the impact of Po river discharge.

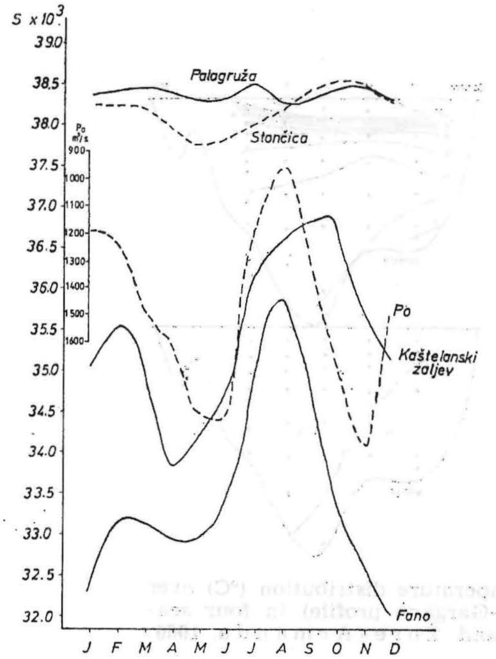

Fig. 5. Annual variations of the sea surface salinity at the west (Palagruža) and east (Stončica) side of the Split—Gargano transect; the same for the coastal station of the eastern (Kaštelanski zaljev) and western coast (Fano) and for the discharge of the Po river at Pontelagoscuro (after Annali idrol.), all long-term series.

It is well known that salinity gradually decreases towards the North Adriatic, since the Adriatic is basically the basin of dilution. For this reason saltier water is advected to the Palagruža sill from the South, and less saline water from the North. Following generally cyclonic circulation in the upper layer of the whole sea, north Adriatic affects Middle and South Adriatic in summer (July) bringing generally water of low salinity, since particularly in this season the outgoing SE current prevails. On the other hand maximum salinity in July coincides with temperature increase (Fig. 6) indicating advection of the saltier and warmer water from the south which conflicts with a general trend of surface current outflow in summer. Salinity increase in July is prominent at all depths (Fig. 7). The only possible explanation is that the sill itself, i.e. its topography affects the currents producing wave like structure and resulting in the South Adriatic impact in June in the region of Palagruža. The north component of surface current at Stončica (Fig. 8) also shows a

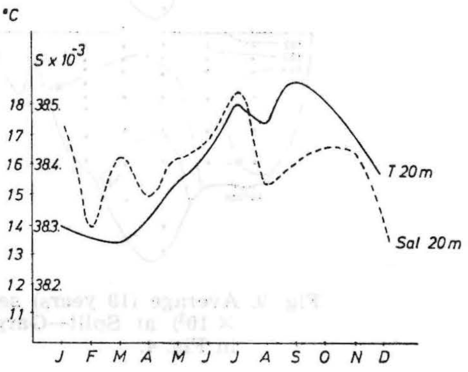

Fig. 6. Annual variations of temperature and salinity at 20 m depth in the Palagruža area (long-term montly means). Data refer to the square around Palagruža isle (Fig. 1).

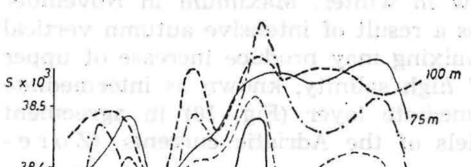

Fig. 7. Annual variations (long-term means) of salinity at different depths of the Palagruža region data from the square around Palagruža).

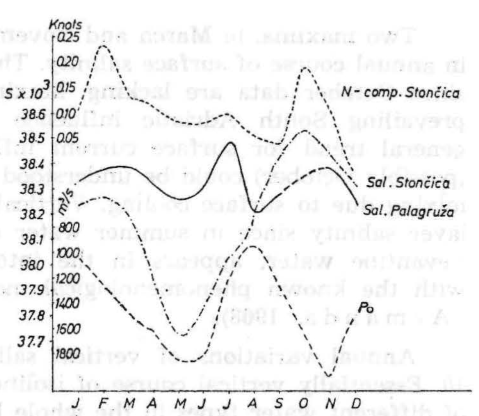

Fig. 8. Annual variations of the N component of the surface current at station Stončica (data from 24-hour measurements undertaken every month during six years and seasonally 15 years more). Annual variations of salinity and Po River discharge as on Fig 5.

small peak in July indicating that advection from the south also occurs there particularly in that month. The wave-like pattern of summer isohalines (Fig. 9) along the Palagruža sill (Split—Gargano transect) also reflects rather complicated dynamic structure on the sill. We shall see some other effects in the chapter dedicated to current regime.

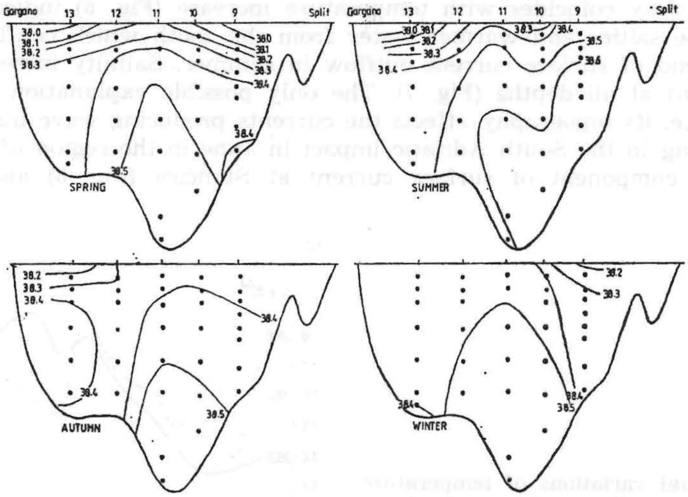

Fig. 9. Average (19 years) seasonal salinity distribution (Sal. $\times 10^3$) at Split—Gargano transect from the data as in Fig. 4.

Two maxima, in March and November, occur in addition to July maximum in annual course of surface salinity. The latter maximum is somewhat doubtful since October data are lacking. Maximum in March could be related to the prevailing South Adriatic influence in that month in agreement with a general trend for surface current inflow in winter. Maximum in November (possibly October) could be understood as a result of intensive autumn vertical mixing due to surface cooling. Vertical mixing may produce increase of upper layer salinity since in summer water of high salinity, known as intermediate Levantine water, appears in the intermediate layer (Fig. 10) in agreement with the known phenomenological models of the Adriatic currents (Zore-Armanda, 1968).

Annual variations of vertical salinity distribution are presented in Fig. 10. Essentially vertical course of isolines points out rather frequent occurrence of different water types in the whole layer. This agrees with earlier expressed opinion of disturbances in the current field on the sill due to its topography and the fact that it is the region where different water types originating in the North, Middle and South Adriatic alternatively appear.

In the whole layer minimum values appear in April and maximum in July. In the latter month high salinity is prominent in the surface layer and has one core in the intermediate layer (50 m).

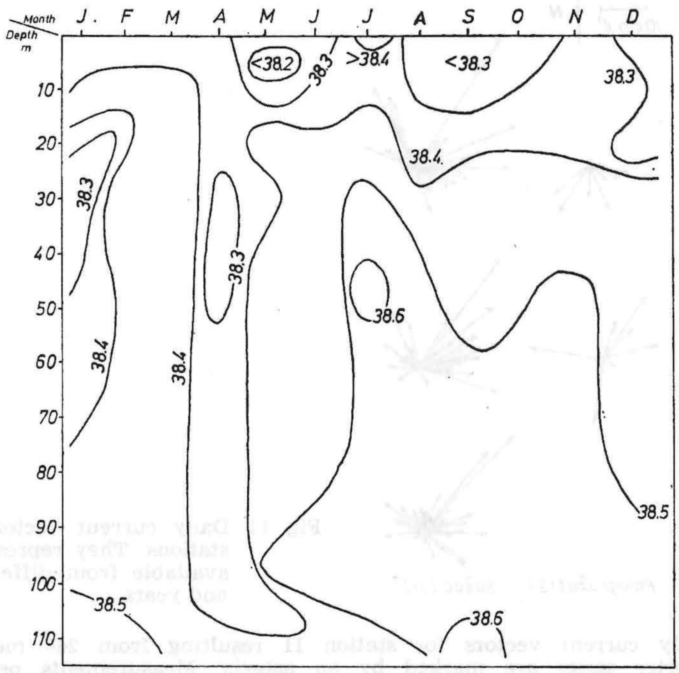

Fig. 10. Annual variations (long-term means) of vertical salinity distribution (Sal. $\times 10^3$) in the Palagruža area (data from the square around Palagruža)

Highest salinity at Split—Gargano transect (stations 9—13) occurs in the middle part, but somewhat closer to the western coast. It seems that most often the influence of different coasts separates stations 11 and 12 (Fig. 9) thus that the line which divides dynamically two coasts is closer to the western coast. This is due to the presence of the Middle Adriatic arhipelago which acts as a barrier to the incoming current of the western coast.

CURRENTS

Current data are rather scarce for the area close to Palagruža isle (Zore-Armanda, 1964; 1968). There are altogether seven 24-hour series for the surface layer, 10 m and 50 m depth (Fig. 11). At the surface southern directions appear and at 10 and 50 m W and NW directions prevail. Average speed at the surface is 15 cm s^{-1}, but the number of data is too small for any definite conclusion. For station closer to the western coast (13) the number of data available is also very small. Somewhat higher number of data is available for station 11 located north of Palagruža where the sill is deepest. Daily current vectors are given in Table 3 and summarized data in Table 4.

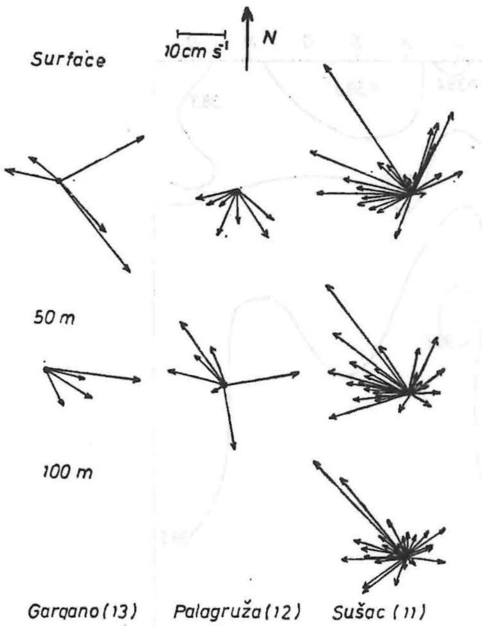

Fig. 11. Daily current vectors for three stations. They represent all data available from different seasons and years.

Table 3. Daily current vectors for station 11 resulting from 24^h measurements. Shorter series are marked by an asterix. Measurements performed by Ekman current meter.

Date	Surface Azimuth°	Surface Speed cm s^{-1}	50 m Azimuth°	50 m Speed cm s^{-1}	100 m Azimuth°	100 m Speed cm s^{-1}
16—17 3 69*	325	36	319	30	318	29
14—15 6 69	64	13	85	6	106	8
6— 7 9 69	275	12	216	5	79	5
13—14 12 69	292	25	283	19	290	12
13 4 70*	62	8	51	3	76	6
8— 9 6 70	23	17	9	3	6	5
4— 5 9 70	338	3	263	8	279	3
12—13 12 70	281	13	263	13	266	7
26—27 3 71	29	20	23	14	60	11
1— 2 6 71	326	4	306	9	315	1
14—15 9 71	7	4	315	1	207	2
14—15 12 71	327	17	319	21	320	23
23—24 3 72*	286	14	280	14	278	14
17—18 6 72	251	9	294	10	309	7
13—14 9 72	313	9	280	11	242	13
24 12 72*	22	11	27	6	315	3
30—31 3 73	281	11	276	9	307	5
27—28 6 73	261	10	324	13	302	10
8— 9 9 73	249	9	24	5	32	5
17 3 74*	24	14	50	9	51	7
8 12 74*	342	2	272	6	323	8
5— 6 3 75	104	25	126	26 (75 m)	127	29 (130 m)
20 9 76*	194	11	262	19	243	11
21 6 77*	322	8	265	6	207	7
29 9 77*	274	20	34	4	135	2
18 12 77*	319	11	301	14	274	8
29 7 78*	210	7	13	12	328	5
19—20 3 79	1	1	117	6	70	6

Table 4. Direction frequencies in percentages calculated from daily current vectors for station 11

Direction		N	NE	E	SE	S	SW	W	NW
All	Surface	18	18	4	—	4	—	34	22
seasons	50 m	4	22	4	7	—	4	33	26
	100 m	4	11	15	7	—	11	22	30
	Average	9	17	7	5	1	5	30	21
Winter	All depths	4	40	10	4		—	23	19
Spring	All depths	11	11	11		1	5	18	44
Summer	All depths	11	14	4	4	4	14	38	11
Autumn	All depths	11	6	—	—		—	44	39

Fig. 11 shows daily current vectors for three stations: Palagruža, area north of Palagruža (station 11) and area south of Palagruža (station 13 — Gargano). From this figure and from Table 4 the prevalence of the W, NW and NE directions is evident at station 11. Southern directions (SE to W) occur at Palagruža in the surface layer. Thus it seems that in the surface layer between the station 11 and Palagruža could be the zone which dynamically divides east from the west part of the sill, or permanent incoming current (NW) of the eastern coast from the outgoing (SE) current of the western coast. Incoming NW current prevails in the intermediate layer at both stations. This is in agreement with the known phenomenological models of the Adriatic currents (Zore-Armanda, 1968). Station closer to the western coast (Gargano) shows different behaviour in this layer.

Seasonal variations are important. On the maps of the seasonal geostrophic currents for the surface layer (Fig. 12) where stations 11, 12 and 13 are marked, we can see that both incoming and outgoing current may appear in the area of station 12, in dependence of the season. Comparison of the Fig. 12 and Table 4 shows that geostrophic current represents well seasonal changes as e.g., in summer, station 11 enters the area of W current and in winter the area of NE current. Thus, in the Palagruža area S direction is prevalent in summer, SW in winter and W in spring and autumn.

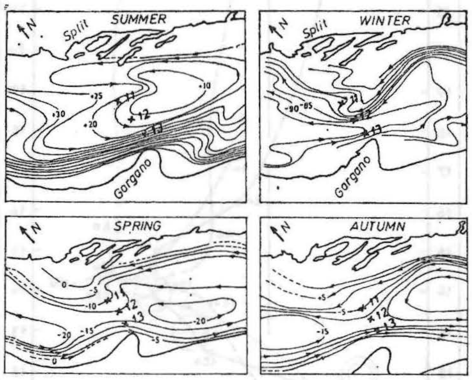

Fig. 12. Geopotential topographies of the sea surface for the middle part of the Adriatic Sea for four seasons (after Zore-Armanda, 1956) referring to 50 or 100 m level. Current field disturbances appear at Split—Gargano transect i.e. in the sill region. They are better developed in summer and winter than in spring and autumn.

It may be of interest to biologists to know how far these seasonal variations extend. After very simple model on the basis of mixing intensity of waters of different salinities, one water renewal would take, on average, two months (B u l j a n and Z o r e - A r m a n d a, 1979). With average speed of 10 cm s^{-1}, water particle can pass 500 km. Therefrom we can see that communication is rather vivid and that sea water originating in the far North or South Adriatic can arrive in one season to Palagruža area.

There is one more point to be discussed, which has already been mentioned in the chapters concerning temperature and salinity.

Source regions of different water types are north and south from Palagruža sill (northwest and southeast strictly speaking, but expressions like North and South Adriatic are in common use). Source region of the North and Middle Adriatic waters is north from the sill. These waters have lower salinity and temperature compared to the South Adriatic water with source region south of the sill. Such arrangement defines the average current field presented by seasonal geopotential topographies of the sea surface. Basically the stream lines follow bottom contours forming cyclonic circulation. Pronounced seasonal variation of characteristics of the whole Adriatic resulting from the wide annual temperature and salinity ranges and rather different meteorological conditions in the warm and cold part of the year result in a corresponding seasonal rhythm in the current system (Fig. 12). The most important feature of the whole system is the outgoing current in the summer and incoming in winter: the former is compensated by the water advection from the Mediterranean (Levantine intermediate water) and the latter by the outflow of water in the bottom layer (Z o r e - A r m a n d a, 1963). Morphology of the sill affects the shape of the stream lines forming deflection and wavelike patterns in otherwise simple cyclonic regime. Such disturbances in the

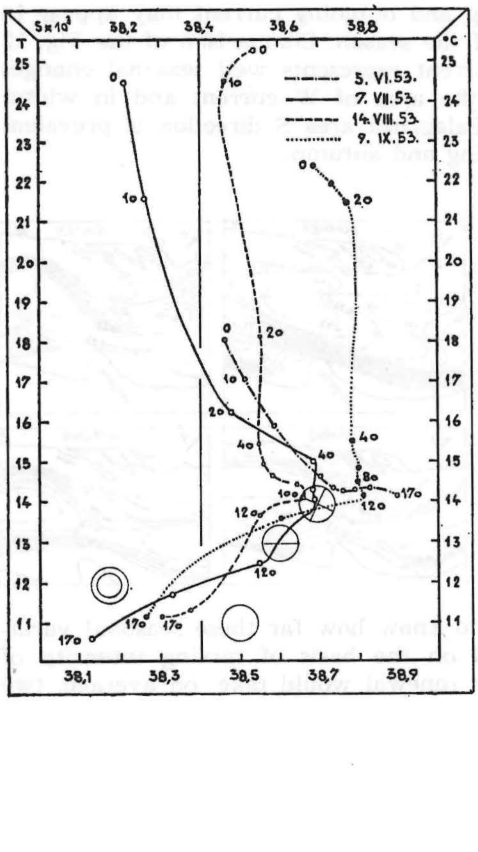

Fig. 13. T-S diagram for the central part of the Palagruža sill region (station 11). Four Adriatic water types are marked by different circles: sample circle refers to North Adriatic water, double circle to Middle Adriatic water, simply crossed circle to South Adriatic water and double crossed circle to Mediterranean intermediate water.

current field at the sill are more pronounced while the characteristics of the water north and south of the sill differ significantly. Since the horizontal temperature and salinity gradients are best marked in summer and winter, disturbances in the current field are prominent in these two seasons (Fig. 12). The advection from the south appearing close to western coast in summer conflicts with a general trend of surface current outflow particularly developed along the western coast. Due to such disturbances at the sill, this region is under alternative impact of waters originating south and north from the sill. T-S diagram for four successive months (Fig. 13) shows well such developement. Four water types defined for the open Adriatic (Zore-Armanda, 1963) are marked. In June influence of the Mediterranean water comming from the south is felt in the whole intermediate and bottom layers. In July and August this influence reduces and North and Middle Adriatic waters begin to appear. In September salinity again increases due to the influence of the South Adriatic water at all levels. In the area of Palagruža, i.e. somewhat more south on the sill, maximum salinity appears somewhat later, i.e. in July. The fact that this salinity increase, i.e. irregularity of the annual salinity variations at Split—Gargano transect which appear in the long-term data series prove the assumption of a topographic effect. The annual variation could be connnected to the seasonal changes in current regime. The summer outgoing and the winter incoming current both »feel« the sill, but for the incoming current the barrier is more steep thus that different effect appear in different seasons.

Such dynamic circumstances at Split—Gargano transect influence distribution of mean seasonal temperatures and salinities (Figs. 4 and 9). Wave shape of isohalines in summer results from alternative influence of the North and South Adriatic. Thermocline appears at different depths along the transect and is most distinctive in the Palagruža area.

TRANSPARENCY

Map of the average transparency of the Adriatic Sea (Tešić and Vučak, 1976) shows that the sea water is most transparent in the central part of the South Adriatic, somewhat less in the region of Jabuka Pit and still less at the transect Split—Gargano. Along that transect the transparency is maximum at the central station (11), where the sea is deepest. In the area of Palagruža transparency is only slightly lower. Long-term Secchi disk mean obtained for this station is 26.6 m (Buljan and Zore-Armanda, 1979). The fact that along the transect Split—Gargano i. e. in the region of the sill, the transparency is permanently lower than south and north from the sill points to the higher productivity in the region of the sill. We have seen that this zone could be also understood as a zone where different water masses meet, i.e. a frontal zone, which, as a rule is a zone of high productivity.

Seasonal mean values for station 12 (Palagruža) are given in Table 5.

Table 5. Seasonal mean values of transparency in m obtained by Secchi disk at Station 12 for the 1952—1969 period.

Season	Winter	Spring	Summer	Autumn
Transparency (m)	26	27	30	22

Transparency reaches highest values in summer and lowest in autumn as everywhere in the Adriatic. On the contrary primary production is highest in spring and lowest in autumn (Pucher-Petković, 1979). It is therefore evident that some other factors also affect annual variations of transparency like fresh water river discharge with maximum in autumn and vertical mixing with maximum in winter. Reduction of transparency by these factors could also be a limiting factor of production since reduced transparency diminishes the penetration of light into deeper layers.

OXYGEN CONTENT

Oxygen content data were available for station 12 (Palagruža) for the period from 1948 to 1958, however of different extent and regularity of sampling for different seasons and years. On the basis of these data annual ranges have been calculated which could be useful for estimation of production level.

Table 6. Annual maximum and minimum values of oxygen content (ml/1) and their differences for station 12

Year	Maximum	Minimum	Range
1948	6.44	4.79	1.65
1952	6.07	4.60	1.47
1953	7.38	4.84	2.54
1957	7.64	4.80	2.84
1958	6.62	5.30	1.32
Average	6.83	4.87	1.96

Table 7. Long-term maxima, minima and their differences of oxygen content (ml/1) for five stations for the period 1962—1970 and for station 12 for period 1948—1958 after Buljan and Zore-Armanda, 1979.

Station	Maximum	Minimum	Range
Kaštelanski zaljev (25)	6.61	4.72	1.89
Stončica (9)	6.57	4.66	1.93
Palagruža (12)	6.83	4.87	1.96
Gargano (13)	6.32	4.60	1.72
Jabuka Pit (3)	6.21	4.85	1.35
South Adriatic Pit (15)	6.26	4.56	1.69

Compared to some other stations of the Middle and South Adriatic (Table 7) maximum is somewhat higher at Palagruža than at rather nearby station 13 and in the Jabuka and South Adriatic Pits. Compared values do not cover the same period, but they still could be representative since all of them are long-term averages. If annual ranges are taken as indicators of the production level, Palagruža area is even more productive than coastal basin (bay Kaštelanski zaljev) and even more productive than open waters of the Middle and South Adriatic.

NUTRIENTS

Data basis for nutrients for the Palagruža area is rather poor. Expedition ANDRIJA MOHOROVIČIĆ (1974—1976) covered 5 times (all seasons) the whole Adriatic, but not the area close to Palagruža isle. Five stations were selected for discussion, three of them from the Palagruža sill region, one from the Jabuka Pit and one from the South Adriatic Pit (Fig. 1). Mean values for the layer of upper 100 m calculated from data for surface, 50 and 100 m are presented in Fig. 14. It seems that the layer of upper 100 m shows a general trend for all nutrients, that their content decreases going from the South Adriatic (station 13) towards Middle Adriatic (station 24). Some of them (tot P, NH_4, NO_2) reach maxima over the sill area. At station 18, which is closest to Palagruža, no one nutrient reaches minimum value, and tot P achieves maximum value. Fig. 15 shows distribution of P tot and SiO_4Si longitudinally through the Adriatic in summer 1976. Both show some kind of

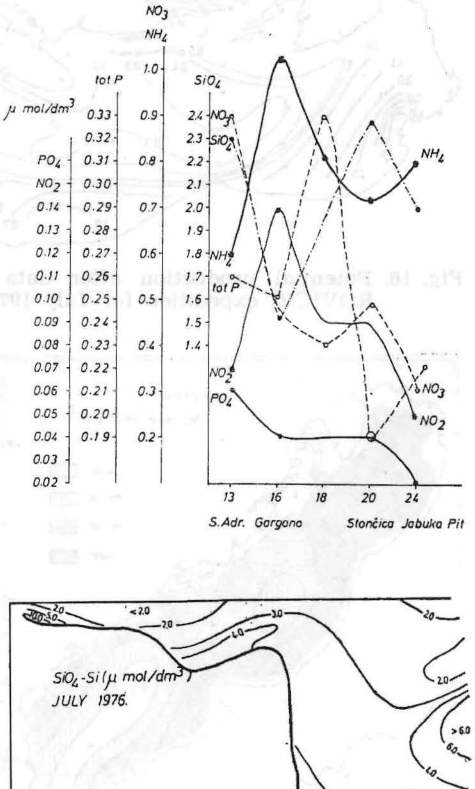

Fig. 14. Mean values of nutrients for upper 100 m calculated from the data of five cruises of ANDRIJA MOHOROVIČIĆ expedition (1974—76).

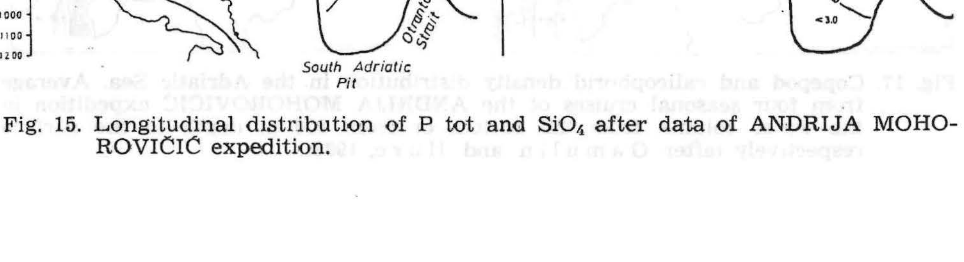

Fig. 15. Longitudinal distribution of P tot and SiO_4 after data of ANDRIJA MOHOROVIČIĆ expedition.

enrichment over the sill compared to Jabuka and South Adriatic Pits. Therefore it could be stated that in the Palagruža region the level of nutrients is higher than at the corresponding layer of the open Middle and South Adriatic most probably due to peculiar dynamic characteristics over the sill.

PRODUCTION

Data collected by ANDRIJA MOHOROVIČIĆ (1974—1976) expedition will be used to show relatively convenient life conditions in the Palagruža zone. First, the primary production measured as potential production will be discussed. Samples were incubated at constant light and at sea surface temperature for three hours (after Smodlaka in ANDRIJA MOHORO-

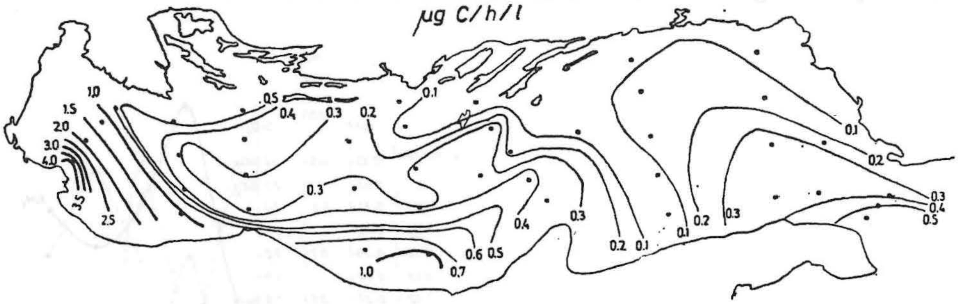

Fig. 16. Potential production after data by Smodlaka in ANDRIJA MOHOROVIČIĆ expedition for July 1976 (means from surface and 30 m).

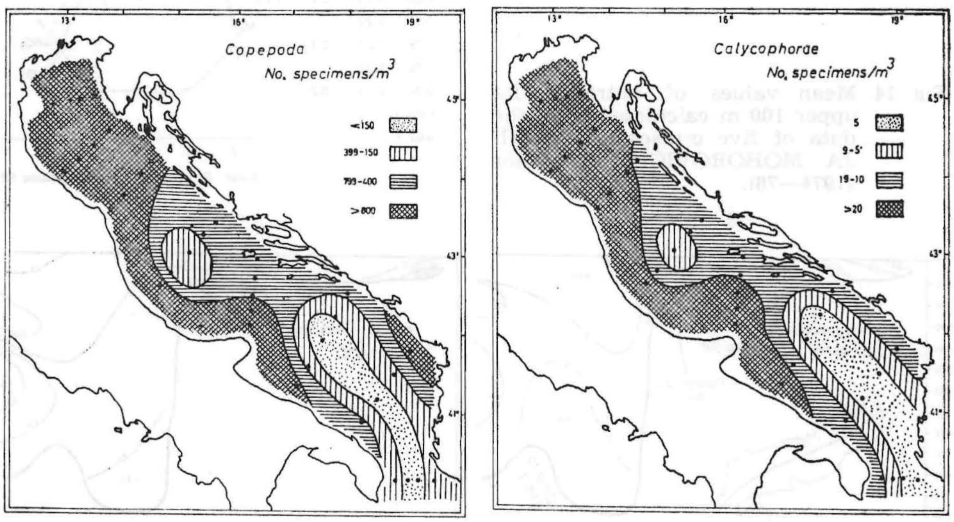

Fig. 17. Copepod and calicophorid density distribution in the Adriatic Sea. Average from four seasonal cruises of the ANDRIJA MOHOROVIČIĆ expedition in the water column from the bottom or from 100 m depth to the surface respectively (after Gamulin and Hure, 1983).

VIČIĆ expedition). Data from the surface and 30 m depth were averaged and results presented in Fig 16. Very high potential production was recorded in the North Adriatic in the zone under impact of Po fresh water discharge. In general, much lower production was recorded along the eastern coast than along the western coast. Since the scope of this paper is not to analyse the whole Adriatic it could be emphasized that in the Palagruža area potential production is higher than anywhere else over the sill and especially than in Jabuka and South Adriatic Pits. Zooplankton community is adapted to such circumstances. Distribution of Copepoda and Calycophora (Fig. 17) shows well peculiar position of the Palagruža area compared to the regions North and South of the sill. The same could be said for some other groups like Doliolida (Katavić, 1977) and Appendicularia (Skaramuca, 1983). Echo-grams from the region of Palagruža show also large concentrations of pelagic fish (Pucher-Petković et al., 1971). It is evident therefrom that Palagruža zone is relatively abundant in phyto- and zooplankton biomass compared to the central part of the sill region and especially compared to open waters of the Middle and South Adriatic. Consequently, such region is also rich fishing ground.

CONCLUSIONS

Annual variations of the sea surface temperature in the Palagruža region is rather small compared to the zones closer to the coast and to the northern Adriatic. Lowest annual range of temperature fluctuations vas found in the intermediate layer (50—75 m). In the bottom layer minimum temperature appears in March due to water advection from the North Adriatic. Summer heating of the upper layer is only uniform at surface. At depths exceeding 20 m a slight temperature decrease appears in June and one more significant in August. They are connected to some specific dynamic conditions over the sill.

Very particular characteristic of the Palagruža area is salinity maximum in July appearing at all depths and indicating water advection from the South Adriatic which conflicts with a general trend of surface outflow in summer. It is connected with dynamic disturbances over the sill due to topographic effects. Annual variations of vertical salinity distribution points to a rather frequent occurrence of different water types indicating as well the disturbances in the current field.

Southern directions prevail in the surface current regime of the Palagruža region. Average speed is 15 cm s^{-1}. Disturbances in the current field are typical for the whole region over the sill due to the topographic effects resulting in rather vivid communication of waters of different origin. Characteristics of the mean flow pattern appearing in that region could be connected to some particular properties like specific annual variation of salinity and temperature and some other conditions.

Transparency in the Palagruža area is lower than in the open waters over the sill and in the Middle and South Adriatic indicating higher level of production. Annual range of oxygen content is rather high indicating as well higher rate of production. Level of nutrients is higher than in the corresponding layer (upper 100 m) of the open Middle and South Adriatic. Potential production is higher than at other locations over the sill and particularly much higher than in Jabuka and South Adriatic Pit. Distribution of some zooplankton groups show well such particular position of the Palagruža area.

In general, it may be concluded for the Palagruža area that specific dynamic conditions over the sill and particularly in the vicinity of the isle Palagruža cause strong mixing of waters of different origin which results in high production. Consequently, such region is also rich fishing ground.

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Received: May 17, 1984

HIDROGRAFSKE I PRODUKCIONE PRILIKE U PODRUČJU PALAGRUŽE

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KRATKI SADRŽAJ

Opisana su neka osnovna svojstva područja Palagruže i uspoređena s lokalitetima na palagruškom pragu, te sjeverno i južno od praga. Upotrebljeni su svi raspoloživi podaci prikupljani od razdoblja ekspedicija NAJADE i CICLOPE do 1970, te materijal ekspedicije ANDRIJA MOHOROVIČIĆ (1974—1976).

Godišnje promjene temperature površine mora su manje nego u zonama bliže obali i sjevernije. Najmanje godišnje fluktuacije temperature se javljaju u međusloju (50—75 m). U pridnenom sloju minimalna temperatura je u martu kao posljedica advekcije sjevernojadranske zimske vode. Ljetno zagrijavanje je jednoliko samo na površini. U sloju ispod 20 m temperatura se lagano snizuje u junu i izrazitije u augustu. Takav godišnji hod temperature je povezan s posebnim dinamičkim prilikama na pragu.

Specifičnost palagruškog područja je i maksimum slanosti u julu, koji se javlja na svim dubinama, a indicira advekciju vode iz područja južno od praga. Međutim to je u raskoraku s općenito izraženom izlaznom strujom iz Jadrana u ljetnim mjesecima. Julski maksimum saliniteta je također povezan s posebnim dinamičkim prilikama na pragu zbog topografskog efekta. Godišnje promjene vertikalnog rasporeda saliniteta ukazuju na česte izmjene različitih tipova vode pa prema tome također indiciraju poremećaje u srednjem polju struja.

Prevladavaju južni smjerovi strujanja sa srednjom brzinom od 15 cm s^{-1}. Na pragu je tipičan poremećaj u srednjem strujnom polju u inače ciklonalnoj cirkulaciji. Poremećaj je pripisan utjecaju nagle promjene dubine zbog čega strujnice prime valni ili drugačije zakrivljeni oblik. Zbog toga se u području praga češće izmjenjuju vode različitog porijekla. U kombinaciji sa sezonskim promjenama u strujnom polju, poremećaji na pragu uvjetuju specifičan godišnji hod temperature i slanosti kao i neka druga svojstva.

Prozirnost voda oko Palagruže niža je nego u otvorenim vodama srednjeg i južnog Jadrana, što indicira viši nivo produkcije. Višu produkciju indicira također veliki godišnji raspon sadržaja kisika. Sadržaj hranjivih soli u gornjih

100 m je viši nego u odgovarajućem sloju srednjeg i južnog otvorenog Jadrana. Potencijalna produkcija je upravo u području Palagruže viša nego na ijednom drugom mjestu iznad praga, ali i u usporedbi s otvorenim srednjim i južnim Jadranom. Raspodjela nekih zooplanktonskih grupa također slijedi takve produkcione prilike.

Općenito se može zaključiti da se u području Palagruže zbog specifičnih dinamičkih prilika uzrokovanih utjecajem praga na strujno polje stvaraju uvjeti za živo miješanje voda različitog porijekla, te da to povoljno utječe na produkciju. Zbog toga je to područje od davnine poznato kao dobro ribolovno područje.