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BIOLOGICAL EFFECTS OF THE HYDROCLIMATIC CHANGES IN THE MIDDLE ADRATIC

BIOLOŠKI EFEKTI HIDROKLIMATSKIH PROMJENA U SREDNJEM JADRANU

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The paper is an attempt to establish the effects of the hydroclimatic changes in the middle Adriatic (Jabuka Pit) on the fluctuations in sardine (*Sardina pilchardus* Walb.) catches along the eastern Adriatic coast.

INTRODUCTION

The cold winter of 1962/63 was the coldest for the preceding 223 years (Scherhag, 1963). Studying the hydroclimatic peculiarities in the northern Atlantic and Euroasian region of the north Polar Sea in the decade 1961—1970, Rodewald (1972) recorded very low sea temperatures. Different aspects of hydroclimatic development are, according to this author, an indication of the end of the »secular warming« which possibly announces the beginning of a new »Little Ice Age«.

It was also cold throughout the whole of the northern hemisphere during the previous summer, that is from April 1962 to March 1963 (Cushing, 1982). Besides the cold winter 1962/63, the winters of 1928/29, 1946/47 and 1978/79 of this century were, according to the same author, also very cold. The cold winters are usually associated with a persistent anticyclone over Scandinavia bringing cold easterly winds flowing accross the North Sea and the British Isles. During the onset of this cold arctic air, there occurred considerable mortality among adult fish and shellfish, and a considerable increase of recruitment of individual commercially important fish species. These phenomena were recorded during »ice winters« of 1928/29, 1946/47 and particularly 1962/63 in the North Sea (Lumby and Atkinson, 1929; Schnoor, 1929; Dannevig, 1930; Orton, 1930; Simpson, 1953; Boddeke, 1963; Crisp 1964; Hancock, 1964; Waugh, 1964; Ziegelmayer, 1964; Woodhead, 1964a and b).

In addition to the mortality of fish and shellfish in the North Sea, a rapid increase of catch of both demersal and pelagic species was also recorded as a consequence of very severe and cold winter of 1962/63. Maximum catch was attained in 1968 (Holden, 1978; Hempel, 1978).

This drastic increase of the North Sea catch after 1961 aroused much interest among fishery scientists who studied the causes of those recent changes of fish stock. For that purpose two ICES North Sea Symposia were organized the reports of which were published in Volumes 172 and 173 of the Rapports and Procès-Verbaux series.

Dickson and Lee (1972) found that the correlation between the year class strength of cod in the North Sea and cold winters was particularly significant in the 1963—1966 period. This correlation was possibly associated with the extraordinary cold winters of 1963 and 1966 (Hill and Dickson, 1978).

Biological effects of hydroclimatic changes after very severe winter of 1962/63 were recorded also along the eastern Adriatic coast. They were reflected as the changes in the small pelagic fish stock, particularly that of sardine, resulting in a continuous catch increase (Mužinić, 1974).

Phenomena of death of individual fish and shellfish species during the cold winters of 1928/29 and 1946/47 developed along the eastern Adriatic coast in the manner similar to that in the northwestern Europe. The same probably occurred after very severe and cold winter of 1962/63 even though there is no sufficient data supporting this statement for the eastern Adriatic.

Schreiber (1931, 1940) reported for the eastern Adriatic coast that in February and March 1929 »... the sea water and air temperature dropped so that fish and molluscs froze and dead floated on the sea surface. These victims of an abnormal winter floated in the channels and were driven to the coast by waves. This terrible phenomenon took place between 10 and 22 February and from 28 February to 3 March of the mentioned year.« ... »It should be added, however, that this climatic phenomenon was immediately followed by very mild and more steady climate.« ... «Inasmuch this very severe winter caused the death of so many local fish forms it affected however, another reaction, to say so, an antiphenomenon, an *extraordinary early* and intensive occurrence of pelagic fish particularly *sardine* and *mackerel* ...«

The cold winter of 1946/47 caused mass mortality of Noah's arche *(Arca noae)* and white mussels *(Modiolus barbatus)* in Pašman channel, the Bay of Pirovac, particularly in the Markirina cove in 1948 (Plančić, 1956; Županović, 1976).

Markedly low temperatures at the bottom of the Jabuka Pit during the cold winter of 1962/63 were accompanied with the rapid reduction of *Nephrops norvegicus* catch (Županović, 1968, 1969, 1976).

Very cold winters both in the past and more recently affected the appearance and catches of sardine along the eastern Adriatic coast (Županović, 1968). Very poor catches in 1955, the poorest catches realized from the eastern Adriatic coast in the post-war period, aroused interest in the relationship between the hydroclimatic changes and sardine catch fluctuations (Županović, 1956). Similar was recorded for sardine in 1855! Due to very poor catches in 1855 an unknown author asked the authorities in charge whether the sardine from the northern Adriatic had been liable to the same intervals as sardine from the Vis, Hvar and Makarska areas during the previous 30 years (1825—1855).

The answer to the unknown author was that the catch differences had been noted in the northern Adriatic as well as in Dalmatia and that they had been, in the first place, dependent on the conditions in the sea at the time of spawning, sea state and insufficiently high temperatures recorded. The catch would be, accordingly, it was written in the reply, now more marked and then less marked dependently on the »stronger or poorer effects of the circumstances which caused the given conditions« (Anon, 1960).

On the basis of fishermen reports from 1855, Županović (1968) forecasted rich catches of sardine along the eastern Adriatic coast between 1965 and 1970, analysing the relationship between hydroclimatic changes and long-term fluctuations of sardine catches for the period from 1835 to 1960.

The most recent detailed studies (Buljan, 1969; Pucher-Petković et al., 1971a and b; Zore-Armanda and Pucher-Petković, 1972; Zore-Armanda et al., 1973; Pucher-Petković and Zore-Armanda, 1973; Karlovac, J. et al., 1974; Mužinić, 1974; Regner and Gačić, 1974, 1977; Alegría Hernández, 1983) as well as fulfilled forecasts of abundant catches are another proof of the interrelations of hydroclimatic changes and sardine catch in the Adriatic.

The continuous fluctuations of temperature and salinity of the Adriatic sea water were taken (Županović, 1968) as a very good indicator of prevalent and changeable *ecological conditions* characteristic for the occurrence of sardine in the Adriatic. On this basis the author suggested that during the ingressions the adult sardine catches were better as well as the survival of younger fish stages and their catch at recruitment due to the *better biological conditions*. This extraordinary phenomenon, being periodically repeated, is indicative of an aspect of climatic changes in the sea water and the possibility of forecasting the phenomenon itself, provided that the observations in the respective area are carried out systematically at regular intervals.

Since the Adriatic sardine require optimum conditions for their spawning (relatively high salinity, temperature between 10 and 15°C, homothermic and homohaline conditions, etc.) it may be supposed that the favourable biological conditions occur at the time of rather strong confrontation of water masses in the Adriatic (Škrivanić and Zavodnik, 1973). At that time also the cold water core is formed in the Jabuka Pit, originating from the northern Adriatic, and the layer formed in March is markedly homothermal and homohaline. The same phenomenon is found in the »equilibrium zone« between the outer margin of the Bay of Kvarner in the north and Monte Gargano and Palagruža Sill in the south. This phenomenon is not accidental and may be a part of the cause-effect system.

Studies of the intensity of confrontation of water masses in the Adriatic which become particularly pronounced by the occurrence of ingressions (Buljan, 1953) is, according to the author, of great significance for the appearance and catch of sardine along the eastern Adriatic coast. Since the Jabuka

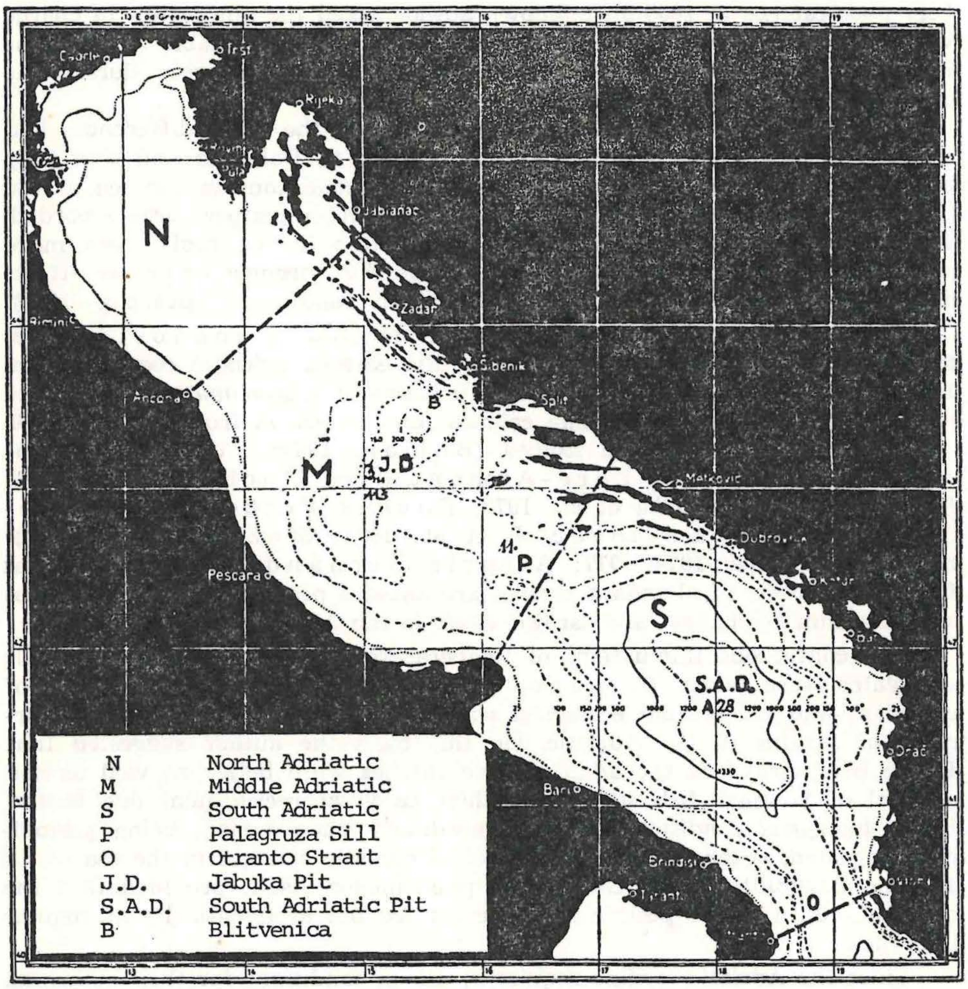

Fig. 1. Bathymetric map of the Adriatic.

Pit (Fig. 1) occupies the position between the southerly and northerly water types, it is held that the fluctuations of the Adriatic oceanographic properties may be best studied right there.

RESULTS AND DISCUSSION

Hydroclimatic changes in the Jabuka Pit

During the studies of Adriatic thermal structure by thermometric method in the spring-summer of 1962 (Županović, 1964) the lowest temperatures were recorded from the Jabuka Pit (10.5 and 10.7°C). The thermocline at the bottom seems to preserve the cold winter water originating from the northern Adriatic. Even though present all year round and for several years in succession this core of cold water shows certain fluctuations disappearing in some years. This is in fact applicable to the years of ingressions when it fully disappears in March. It is just this disapperance of cold winter water from the Jabuka Pit which, as it will be seen later, plays a very significant part in the formation of the Adriatic water structure. However, to observe properly these occurrences it is necessary to know the following:

1. positions of the cores of cold winter water,
2. temperature of the cores,
3. structure of thermocline.

The position of the cores of cold water is to a certain extent affected by the current system which is changed with wind conditions (Dietrich et al., 1968). The temperature of cold water cores is also determined by the cold of previous winters. Very cold winters which frequent the Adriatic affect to a considerable extent those intensified activations of the cold water cores.

Prahm (1958) found that bottom ingression of cold Icelandic water into the central part of the Nort Sea showed considerable fluctuations in summer from one year to another. This author tried to bring these fluctuations into connexion with the temperature conditions of the previous year. Namely the colder the winter the water at the bottom was colder and vice versa.

Some analogous phenomena were recorded from the Adriatic.

Pollak (1951), analysing the temperature data from station A 28 of the NAJADE Expedition in the South Adriatic Pit (see Fig. 1), found a homogeneous water layer from bottom to surface on March 3, 1911. Temperature varied between 12.78° and 13.21°C. Of all the NAJADE and CICLOPE stations the station A 28 showed this homogeneity on only one occasion. On all the other stations water was well mixed even though never from bottom to surface. The fact that this phenomenon was recorded on only one occasion in the course of 12 NAJADE Expedition cruises (1911—1914), is indicative of its irregular occurrence as well as the possibility of its being repeated. The Adriatic bottom water, which penetrates into the Mediterranean, originates probably, after the same author, from the mid-Adriatic deeps. The water which disappears from the mid-Adriatic deeps may be, in turn, replaced by the water from marginal areas through advection or by the means of surface water at time when the stability of water column is insignificant like it was at station A 28 in March 1911. Another possibility is the combination of vertical and horizontal mixing. One such combination was recorded from the Jabuka Pit where, like at station A 28, the water layer was markedly homogeneous, mixed from bottom to surface, on March 1, 1911. Potential temperature of the 0—200 m varied from 11.41 to 11.99°C at station A 13 in the Jabuka Pit (see Fig. 1). Potential density was for the same depth 28.99 to 29.41 δ_t. Not later than at the beginning of February 1912 this layer was not any longer homogeneous down to the bottom. Marked homothermy with increased temperature was recorded down to 150 m below which depth there was the thermocline with cold winter water. Potential density was at all the layers lower than in 1911. Whereas the density was 29.41 δ_t at 200 m in 1911 it fell to 29.18 δ_t at the same isobathe in 1912 and 1913. Moreover, at 250 m depth and at the bottom (265 m) density was much lower than at 200 m in 1911. This density decrease in 1912 and 1913 may be due to the more intensive sinking of cold bottom water in the South Adriatic Pit in 1911. Rapid outflow of colder and denser bottom Adriatic water into the eastern Mediterranean is probably compensated by increased ingression of more saline Mediterranean water into the Adriatic. Such an occurrence was recorded by Buljan (1957) much earlier when analysing the temperature variations of the open Adriatic waters from the NAJADE and CICLOPE collections from the South Adriatic and Jabuka Pit in 1911—1914.

Similar was recorded from the Jabuka Pit after the Second World War. Salinity and temperature data were collected from the stations 46 (43°14'N and 15°12.5'E) and 50 (43°03·5'N and 15°07'E) of the HVAR Expedition in March and April 1949 (Karlovac, 1956).

An analysis of temperature data from station 46 shows the variations between 12.2° and 11.4°C. Homothermy recorded from bottom to surface was similar to that recorded on March 1, 1911. Potential density in 1949 exceeded that in 1911 particularly in the surface layers. Very soon, by the April, i. e. not more than 43 days later, density rapidly decreased in the surface layers, whereas at the bottom (259 m) the water was very cold (10.2°C). The sinking of thicker Jabuka Pit water southwards when it surpasses a defined thickness limit, causes a greater advection of the northern Adriatic water. Such an occurrence was recorded from the station 50 in the Jabuka Pit in April 1949. Cold water was found at the bottom in the same area in February 1951: 11.45°C and 29.42 δ_t (Buljan and Marinković, 1956). The sea water temperature in the Jabuka Pit in February 1951 was almost the same as that at station A 13 in February 1914. These two identical occurrences are indicative of their identical causes.

Pollak (1951) holds that the Adriatic water structure is, due to its shallowness, closely connected with the »weather regime« fluctuations. After this author, the rate of temperature fluctuations in the Adriatic is not known, although there is no doubt that the outflow of the Adriatic water over the Otranto Strait is quite irregular and far from being continuous. Both Buljan (1953) and Zore-Armanda (1963, 1965) also consider that the ingressions of more saline Mediterranean water into the Adriatic do not occur every year but after several years or so at a defined rhythm (Buljan, 1953). The coincidences of cold winters, like those of 1910/11, 1912/13, 1922, 1929, 1941 and 1947 and ingressions of more saline water from the south proved it necessary to continue these studies so as to show that the coincidences of the appearance of more saline water and cold winters were not accidental but constant. To our opinion, the causes of these coincidences are probably due to the influence of climatic factors which show a defined cyclic rhythm (Sorkina and Penjkov, 1973).

Županović (1968) tried to account for this coincidence by the effects of some, other than marine, climatic factors which show a defined rhythm. Vertical convection will penetrate considerable depth only when cold continental polar air masses dominate over the Adriatic for a longer period and frequently enough. It is also the time of very cold Adriatic winters always accompanied by ingressions and advective flows of water from one basin into another (Zore-Armanda, 1984). During the penetration of cold polar air the cooling and evaporation are intensified in the surface layer. Too strong evaporation affects an increase of density of surface water which sinks to the bottom, particularly in the northern Adriatic. Thus the bottom water density attained 29.53 δ_t in the area of the Adriatic Sill in spring 1913. Density was still higher, 29.64 δ_t at 150 m in spring 1949. Higher densities are caused by cold winters to which more pronounced advective intrusions of dense northern Adriatic water into the Jabuka Pit are due. This occurs when the northern Adriatic water surpasses a defined density limit like it happened after the cold winters of 1910/11, 1912/13 and 1946/47.

Occurrences similar to those of 1910/11, 1912/13 and 1946/47 were recorded in 1955/56 and 1962/63 as well.

Thus, for example, when after the severe winter of 1955/56 in February 1956 the surface temperature was 3.2° off the Marjan Cape in the Kaštela Bay (Buljan and Zore-Armanda, 1966), the cold winter water core was again present in the Jabuka Pit. This core was there all year long at 200—265 m depth. The same was recorded from the Palagruža Sill over which this cold water flows to the South Adriatic Pit.

Bottom temperatures in the Jabuka Pit and Palagruža Sill in 1956/57 (Buljan and Zore-Armanda, 1966) are presented in Table 1.

Table 1. Bottom temperatures at station 3 (Jabuka Pit) and 11 (Palagruža Sill) in 1956/57

Depth	1956						1957			
(m)	April		August		November		March		June	
	3	11	3	11	3	11	3	11	3	11
150	11.94	12.56	10.26	—	10.40	14.30	12.75	13.00	12.76	14.15
170	—	10.53	—	—	—	10.87	—	12.18	—	13.96
200	10.13	—	9.58	—	9.59	—	10.50	—	11.91	—
240	9.30	—	—	—	—	—	—	—	—	—
250	—	—	9.45	—	9.59	—	—	—	—	—
260—265	—	—	9.43	—	—	—	—	—	9,95	—

In 1958 temperatures increased at the bottom of the Jabuka Pit and on the Palagruža Sill (Buljan and Zore-Armanda, 1966). After Buljan (1957) temperature increases are due to the periodic ingressions of more saline Mediterranean water. On the contrary, during poorer Mediterranean influence the Adriatic *in situ* factors are better marked. Thus, for example, in March 1962, a marked homothermy was recorded from the Jabuka Pit instead of cold bottom water.

Termperature and density recorded from the stations 6228 (Miller et al., 1970) at the end of February 1962 and from station 3 (Buljan and Zore-Armanda, 1966) at the beginning of March 1962, both in the Jabuka Pit, are presented in Table 2.

Table 2. Temperature and σ_t at stations 6228 (ATLANTIS) and 3 (BIOS) in the Jabuka Pit

Depth (m)	»Atlantis« (6228) Febr. 2, 1962		»Bios« (3) March 3, 1962	
	T°	σ_t	T°	σ_t
0	12.95	29.05	13.00	29.09
10	12.95	29.05	12.94	29.11
20	12.95	29.05	12.94	29.13
30	12.94	29.05	12.94	29.14
50	12.94	29.04	12.94	29.19
75	12.95	29.06	12.94	29.09
100	12.95	29.05	12.94	29.07
150	12.93	29.05	12.94	29.11
200	12.93	29.05	12.96	29.10
250—255	12.93	29.05	12.96	29.09

As shown by Table 2, potential temperature at 0—255 m depth varies from 12.93 to 13.00°C and potential density from 29.04 to and 29.19 δ_t. The obtained data are indicative of the homothermy. The water that disappeared from the Jabuka Pit was recorded from the Otranto Strait (Miller, 1963).

The author tried to bring into connexion the occurrence of this important phenomenon in the Jabuka Pit and the respective hydroclimatic factors which occur at defined time intervals. »Weather regime« effects are of great significance in the Adriatic owing to its mean deph of 239 m and particularly owing to the depths below 100 m which constitute about one third of its total volume. Therefore, no wonder, that temperature changes are rather frequent in individual seasons, particularly in surface layers.

The obtained data on the Adriatic thermal structure in spring 1962 may lead us to assume that vertical convection of water masses in March 1962 probably affected the advective motions of the sea water in both directions. Thus, for example, more saline Mediterranean water, with mean salinity 38.7‰ (Županović and Zore-Armanda, 1963) was recorded at the bottom of Palagruža Sill not later than in September 1962.

The occurrence of more saline water at the Palagruža Sill and in some parts of the Jabuka Pit Buljan (1953) called »medium ingressions«. This resulted from the intesive mixing of water masses in the Jabuka Pit like it happened in March 1962. At that time, as well, the outflow of »colder Jabuka Pit water« took place as well as the intensification of advective flow of the more saline Mediterranean water into the Adriatic. The sinkings of the denser waters from the Jabuka Pit seems to be immediately compensated by the penetration of Mediterranean water. This, to a certain extent, was proved by Buljan (1953) who accounted for the occurrence of »medium ingressions« which preceded strong ingression in the areas of the Palagruža Sill and Jabuka Pit.

At the same time, the occurrence of the Mediterranean water on the Palagruža Sill in September 1962 may be indicative of the possibility of advective motions of the north Adriatic deep water towards the Jabuka Pit.

in spring-summer caused by the effects of the same climatic factor. Thus, not later than in September 1962 the bottom temperatures were 10.5 to 11.0°C at stations 44, 47 and 48 (closer to the coast) in the Jabuka Pit. The analysis of graphs obtained by bathythermograph for both more and less offshore stations of the Jabuka Pit are indicative of such a possibility (Fig. 2).

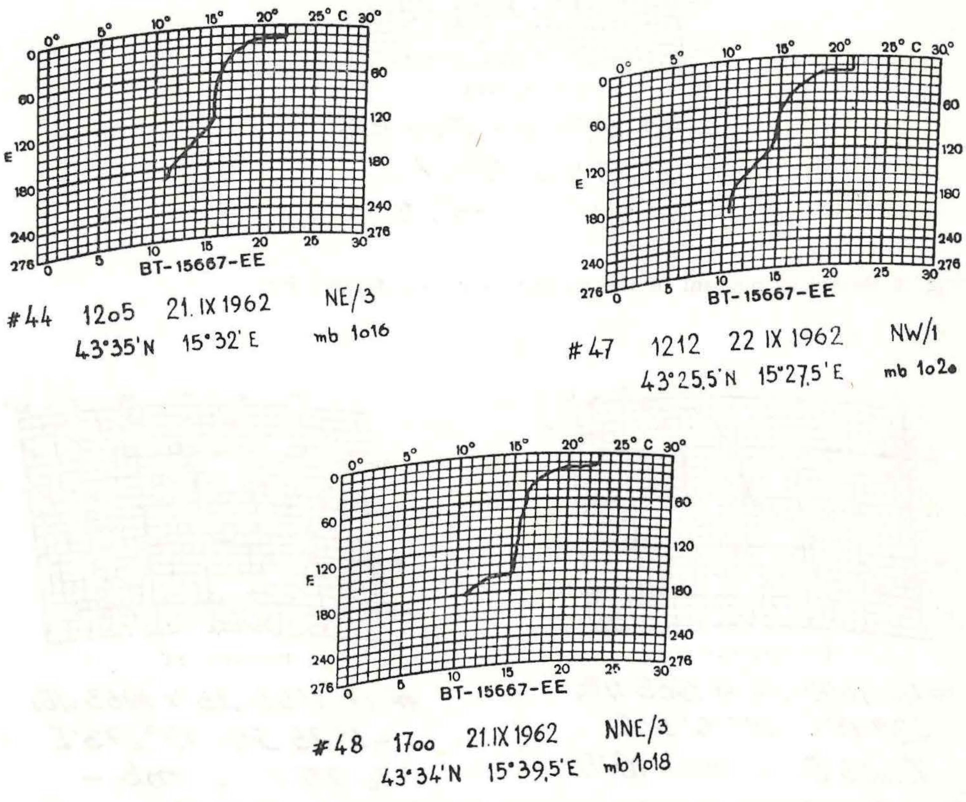

Fig. 2. Bathythermograms of the stations 44, 47 and 48 in the Jabuka Pit.

The above mentioned graphs from the stations 44, 47 and 48 show that the outflow of colder water from the northern Adriatic towards the Jabuka Pit was recorded as early as in September 1962 (10.5°C). This phenomenon was still intensified after the very cold winter of 1962/63 when the cold water (9.58°C) was recorded from the Palagruža Sill already at the beginning of March 1963. At the same time the temperatures recorded at the bottom of station 51 in the Jabuka Pit (Buljan and Zore-Armanda, 1966) by reversible thermometer were also very low: Om (23.7°C); 100 (14.9°C); 150 (10.1°); and 260 m (9.2°C). Still colder Jabuka Pit water was recorded from station 50 in the close vicinity of station 3 (43°04'N and 15°06'E) in May (Fig. 3) as well as from the stations 46 and 47 in September and October 1963 (Fig. 4).

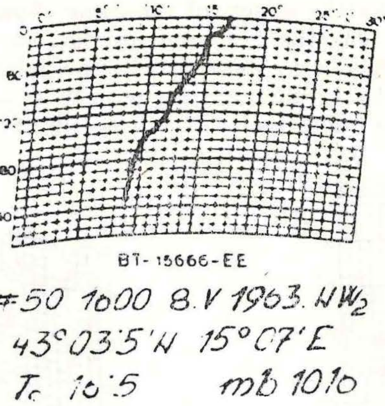

Fig. 3. Bathythermogram of the station 50 in the Jabuka Pit.

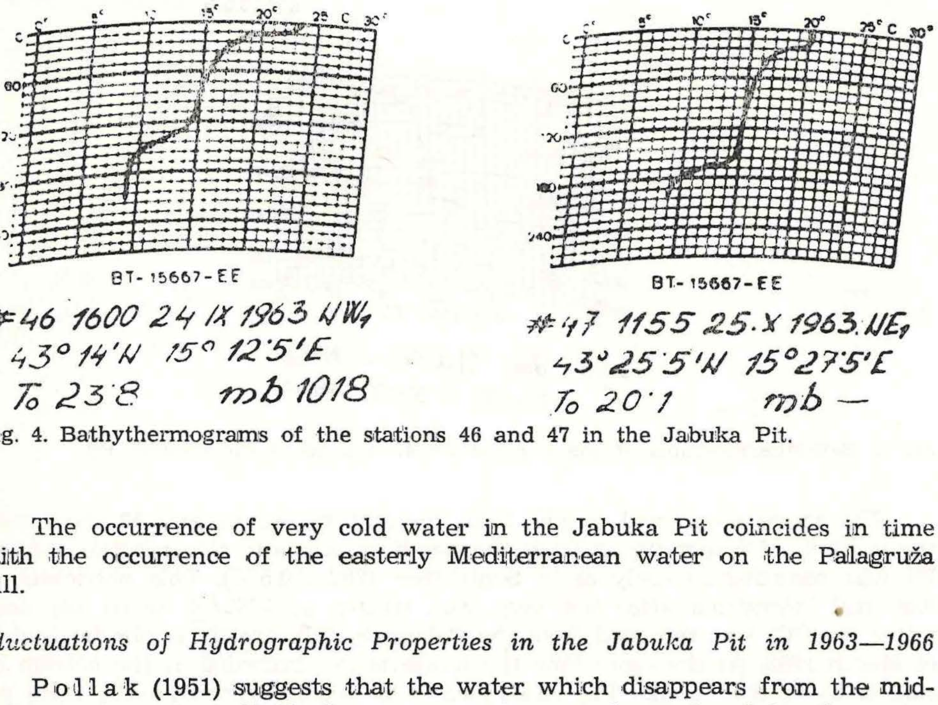

Fig. 4. Bathythermograms of the stations 46 and 47 in the Jabuka Pit.

The occurrence of very cold water in the Jabuka Pit coincides in time with the occurrence of the easterly Mediterranean water on the Palagruža Sill.

Fluctuations of Hydrographic Properties in the Jabuka Pit in 1963—1966

Pollak (1951) suggests that the water which disappears from the mid-Adriatic deeps in individual years may, in turn, be replaced by the water from adjacent areas by advection or by the surface water when stability of water column is insignificant. The same author also offers another possibility, a combination of vertical and horizontal mixing which was recorded from the Jabuka Pit in 1963—1966.

B u l j a n (1953) considers that periodic ingressions of more saline and nutrient rich Mediterranean water into the Adriatic are accompanied with the respective temperature increase of the open Adriatic waters, particularly southern and middle Adriatic waters in winter.

However, in addition to a temperature increase of the open middle Adriatic waters in winter, the rise of colder water from deep layers to the surface (upwelling) was recorded from the Jabuka Pit stations, particularly the more offshore ones, in spring-summer. These data refer to May 1963, June 1964, 1965 and 1966 and to September and October 1963, 1965 and 1966.

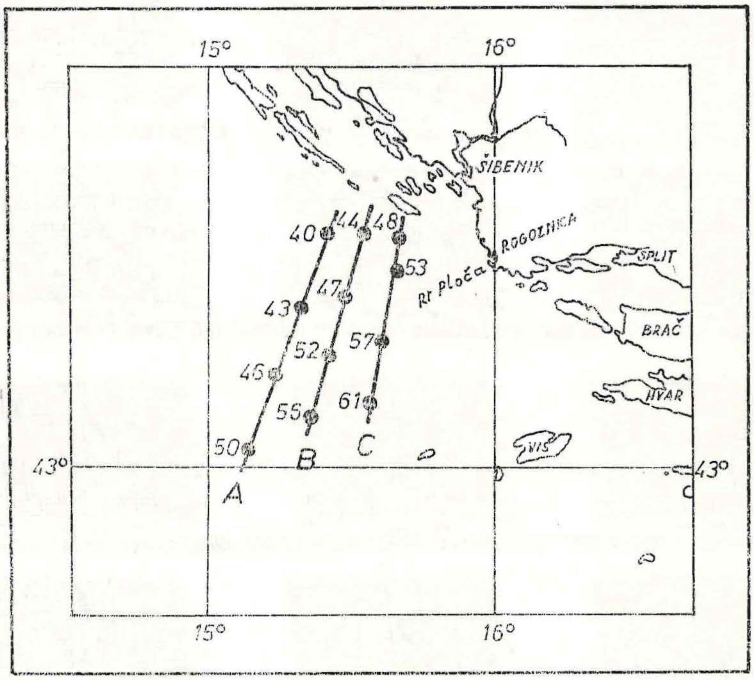

Fig. 5. Positions of stations along the profiles A, B and C in the Jabuka Pit.

Station positions are presented in Fig. 5. Profiles A, B and C are transversally located. Temperature variations at respective profiles are given by graphs in Figs. 6 and 7.

The analysis of temperature variations in individual years as presented in Fig. 6, shows very low bottom temperature at Profile A in May 1963 ($\leqslant$ 9°C). Markedly low temperatures at the bottom of Jabuka Pit in spring 1963 are probably due to the very severe winter of 1962/63. This cold water core at the bottom reached, as mentioned above, the Palagruža Sill in March 1963 (B u l j a n and Z o r e - A r m a n d a, 1966). Northerly winds blowing most frequently from the land, late melting of glaciers in the Alps as well as the discharges of the River Po and other north Adriatic rivers considerably contributed to this. As a consequence of these factors (and, as well, many others) the rather rapid outflow of the Adriatic waters from the »mid-Adriatic deeps«, was, probably, compensated by an increased ingression of warmer eastern-Mediterranean water in the intermediate layer. The temperature increase of bottom water at profile A in June 1964, 1965 and particularly 1966 is indicative of intensified advective motions of the waters from the southern Adriatic and Mediterranean respectively.

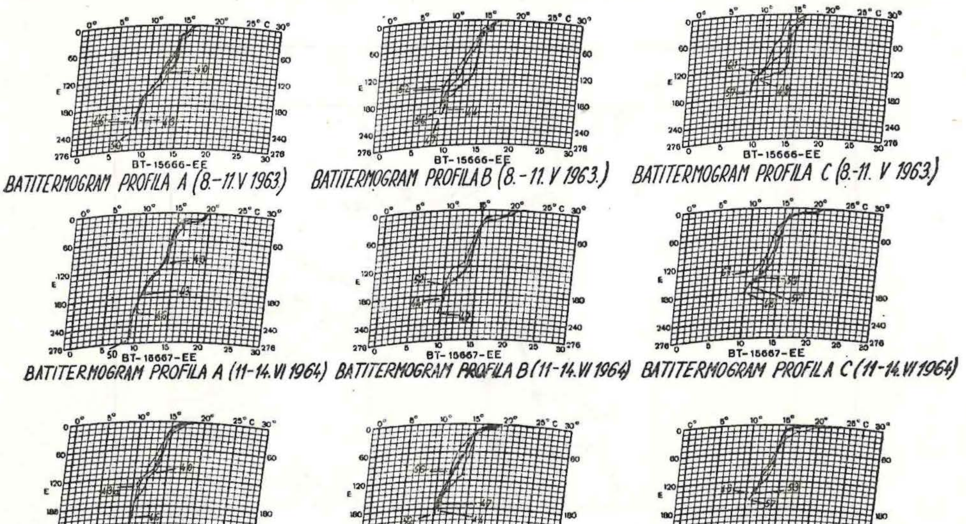

Fig. 6. Bathythermograms of the profiles A, B and C in the Jabuka Pit in May 1963 and June 1964, 1965 and 1966.

Bottom temperature variations at profiles B and C, more strongly affected by the land, show certain differences. Thus in May 1963 considerable temperature differences for the 40—160 m depths were recorded between the stations closer to the coast and the more offshore ones. The water was colder on more offshore stations. At the bottom the water temperature was the same on both profiles (≥ 9°C). The rise of colder water from deep layers to the surface (upwelling) was particularly pronounced in June 1964, 1965 and 1966 at the more offshore stations.

The variations of temperatures of the sea water in the Jabuka Pit, given by the graphs in Fig. 7, show similar trends in September and October 1963, 1965 and 1966. Low bottom temperatures (9°C) were recorded both in September and October 1963. The temperature of 9—10°C was recorded from 156—252 m depths at station 50. On the contrary, in October the sinking of

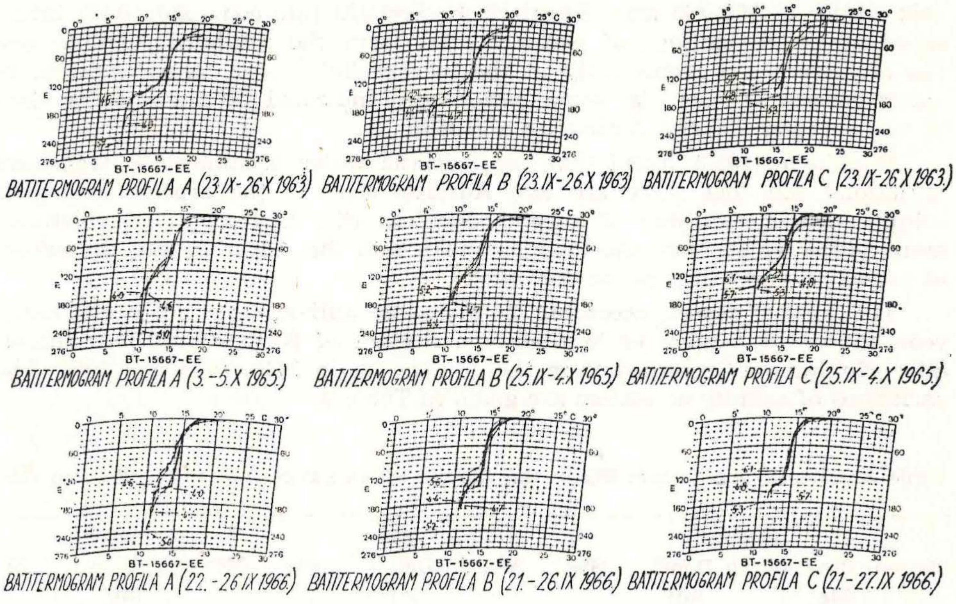

Fig. 7. Bathythermograms of the profiles A, B and C in the Jabuka Pit in September and October 1963, 1965 and 1966.

colder water to the bottom (station 43) is indicative of the outflow of water from the Jabuka Pit. The same occurred at profiles B and C. The station 52 at profile B was sampled in September and the stations 44 and 47 in October 1963. The low temperatures at the bottom in the Jabuka Pit in September and October are also probably due to the very cold winter of 1962/63 like those in May and June. This our assumption is supported by the fact that in September 1962 the temperature was 11.0°C at station 44 and 15.0°C at station 47 (profile B). However, in October 1963 temperature was much lower (≥ 9°C) at the same stations.

The increase of temperature in the bottom and intermediate layers in September and October 1963 shows similar variations to those in May and June. So the bottom temperature at profile A was: 9.0°C (1963), 10.0°C (1965), and 11.0°C (1966); and at profile B (the bottom temperatures at stations 44 and 47 in 1962 are taken here) temperature differences by individual years were: 10.5—11.0°C (1962), ≥ 9.0°C (1963) and 11.5°C 1966.

B u l j a n (1965, 1966) and Z o r e - A r m a n d a (1969) recorded minimum temperatures also from the areas of the islands Hvar, Vis and Palagruža in spring-summer. These authors hold that these low temperatures may be due to the divergence and upwelling of water in those areas. Upwelling in the vicinity of more offshore islands in spring-summer and temperature differences between the open sea and coastal area are attributed to advection influence which is probably more intensive in the open sea.

The increase of deep water temperature in the Jabuka Pit after the cold winter of 1962/63 may, therefore, be brought into connexion with intensified advective motions of water masses from the southern Adriatic and the Mediterranean respectively in the intermediate layer. These motions of water masses are for the same period also indicated by the salinity data (Buljan and Zore-Armanda, 1966).

Buljan (1953) found that the Adriatic water is subject to long-term variations and that there are two Adriatic aspects: the aspects of higher salinity (salted Adriatic) of shorter duration (the ingressions of relatively more saline water from the Mediterranean into the Adriatic) and the aspect of normal salinity (less saline Adriatic).

The former aspect, according to the same author, does not occur every year but shows a more or less periodic rhythm of fluctuations. This fluctuation rhythm was recorded from the Jabuka Pit in 1948, 1958 and 1966. The variations of salinity at bottom are given in Table 3.

Table 3. Variations of botom S‰ in the Jabuka Pit in summer of 1948, 1958 and 1966

Station	Profile	1948 Month	Depth (m)	S‰	1958 Month	Detph (m)	S‰	1966 Month	Depth (m)	S‰
40	A	VII	176	38.12	IX	177	38.35	VI	165	38.57
46	A	VII	211	38.31	—	—	—	VI	220	38.35
50	A	VIII	251	38.42	—	—	—	VI	260	38.26
44	B	IX	201	38.46	IX	204	38.33	VI	196	38.44
47	B	VII	194	38.60	IX	195	38.42	VI	194	38.42
52	B	IX	181	38.48	IX	182	38.37	VI	190	38.37
56	B	VII	185	38.46	IX	185	38.33	VI	170	38.37
48	C	VII	183	38,55	IX	184	38.37	VI	167	38.46
53	C	IX	171	38,60	IX	174	38.30	VI	170	38.44
57	C	VII	152	38.17	IX	153	38.40	VI	160	38.39
61	C	IX	139	38.44	IX	145	38.40	VI	140	38.44

It appears from Table 3 that bottom salinity in the Jabuka Pit in 1948 and 1966 exceeded that at the same stations in 1958. Higher salinity in 1948 and 1966 is indicative of the fact that the Adriatic was dynamically better connected with the Mediterranean in those years than in 1958. The analysis of variations of mean values (1948: 38, 53; 1958: 38, 35; 1966: 38, 42) in the Jabuka Pit in summer is indicative of the motion of the eastern Mediterranean water in the intermediate layer to the Jabuka Pit over the Palagruža Sill, and at the same time to the channel area of the middle Adriatic (Županović, 1961).

Salinity increase in the Jabuka Pit in individual years may be taken as a good indicator of the movements of water masses in the Adriatic which result in better catches of both pelagic and demersal fish.

The occurrence of this phenomenon in the Jabuka Pit at respective time intervals is, to our opinion, due to relevant climatic-hydrographic changes which occur periodically in the Adriatic as well. So, as a consequence of the cold winter of 1962/63, from 1963 on the sea water transparency showed constant reduction due to increased eutrophication. The highest transparency reduction was recorded during the time of eastern Mediterranean water influence in 1967—1970, which resulted in an enormous increase of biological production in the Adriatic (Buljan and Zore-Armanda, 1979). Transparency was lowest in the Jabuka Pit in spite of the position of this Pit in the open sea and relatively great depth. In these years the sinking of denser water from the Jabuka Pit was recorded also in winter (February, 1966) that is during the season in which the water outflow is otherwise not significant (Trotti, 1972). The phenomenon of very intensive mixing of different water masses probably, after the same author, takes place at the greatest Jabuka Pit depths. This outflow of denser water from the Jabuka Pit to the South Adriatic Pit via the Palegruža Sill was also recorded by Buljan and Zore-Armanda (1966) in summer what is in broad agreement with our analyses of temperature and salinity.

Accordingly, the Jabuka Pit may be taken as a good indicator of different oceanologic phenomena in the Adriatic. This was indirectly suggested by Štirn (1972). This author, studying general oceanologic properties of the northern Adriatic in 1965 concluded that the $\geqslant 29.70\ \delta_t$ densities were common in the northern Adriatic in February and March. This characteristic phenomenon is, after the same author, of great importance for the regulation of oceanographic regime of not only the Adriatic but also of the Ionian Sea and Mediterranean basins. The highest densities in the northern Adriatic were recorded in the winter-spring from the surface layer waters of highest salinity which, cooling, sink to the bottom wherefrom flow southwards. Deep waters of equal density are frequently encountered from bottom to surface during the same season. Nutrient salts which sink together with dense winter waters from the Adriatic into the eastern Mediterranean are deposited in the Jabuka Pit (Faganelli, 1969). Their reactivation from deep layers to the surface is probably due to »upwelling«. In this way nutrients are transported to the euphotic, bioproductive layer which plays an important part particularly along the eastern Adriatic coast in summer (Županović, 1969a).

The importance of local components in this process was proved by the most recent studies of some dynamic properties of the eastern Adriatic coastal area (Zore-Armanda et al., 1979). These studies have shown that the W flow direction in the surface layer is an onshore flow in the larger part of the coastal area. With respect to the fact that this flow direction is more frequent in the colder periods it is due to bora, that is NE wind, rather frequent in the areas of Blitvenica and Jabuka Pit driving the surface layer water offshore. The second quadrant directions are prevalent in the bottom layer (NE, E and SE), which are compensatory flows to the surface layer flow.

The onshore flow (NE and E) is of great importance since it carries deep layer water to the coastal area. In this way the circulation between the coastal area and the open sea is established which is reflected upon the »upwelling« occurrence in the Jabuka Pit in spring-summer.

The most recent studies show that the Jabuka Pit is the richest Adriatic area as to the nutrient salts (except for the organic phosphorus). Buljan et al. (1975) proved this fact stating that: »... Jabuka Pit is the area richest in all nutrients (except in P-org.). It acts as a supplier of all nutrients for the Palagruža Sill and the South Adriatic Pit. This conclusion is based on the well known fact that in the Adriatic the waters from all parts of this sea are mixed (no stagnant waters!). We explain the mentioned role of this Pit by its position, which allows the use and gathering of nutrient salts which come from the shallower and richer north Adriatic.«

The fact that the Jabuka Pit is rich in nutrient salts must logically be reflected upon the plant and animal life of this area. The occurrence of »upwelling« in the Jabuka Pit (Županović, 1969a) adds also to this situation. Cold waters, rich in nutrients, rising to the surface (as a consequence of climatic factors) increase the production of this and adjacent areas. It is most probable that by the »upwelling« occurrence, the deep Jabuka Pit waters, which are, as already shown, rich in nutrients affect large catches at Blitvenica (Buljan, 1974).

The occurrence of this phenomenon in the Jabuka Pit at defined intervals, allowed the author of this account (Županović, 1968) to bring some hydroclimatic changes into connexion with the long-term fluctuations of sardine catches along the eastern Adriatic coast through centuries (Županović, MS).

Deductive biological effects of hydroclimatic changes

Petterson (1926) found very high coincidence between cold winters, hydrographic changes and herring catch near Bohuslän. Very big catches between 1876 and 1897 near Bohuslän were, after the fame author, affected by invasions of high salinity water bearing Bank herring in to Skagerrak. The same author also recorded that there were ten ice winters between 1875 and 1897, of which some were so severe that sea traffic was stopped for one or two months.

This, after Le Danois (1938) was the period of great transgressions of the Atlantic waters which coincided with famous »miraculous« catches of Norwegian herring. Easton (1928) also held the 1875 to be markedly cold in western Europe. The lowest annual mean air temperature for the 1858—1908 period in Hvar, middle Adriatic, was also recorded in 1875 (Županović, 1968). In the Adriatic, like in the north Europe, the ingressions of more saline Mediterranean water into the Adriatic were recorded (Buljan, 1953). In these years of increased salinity and temperature following the cold winter of 1874/75, considerable catches of sardine were realized along the eastern Adriatic coast, evidenced by their been exported from Dalmatia (Faber, 1883).

The connexion between cold winters which cause lower minimum in the northern Adriatic and affect the increase of salinity of the Adriatic basin by the Mediterranean water, was also recorded after the Second World War (Buljan, 1953; Zore, 1956). These increases of salinity due to the Mediterranean water do not occur regularly but at a defined rhythm. These changes are probably, to the opinion of the author, caused by some climatic changes directly connected to the differences between hydrographic factors in the northern Adriatic and those in the southern Adriatic and the Mediterranean.

Županović and Zore-Armanda (1963), and Županović (1968) studied the relationship between climatic factors, hydrographic changes and sardine catch at Vis Island in the middle Adriatic. The obtained relationship between sardine catch at Vis in 1875/1889 and that in 1948/1962, both periods following strong ingression of more saline waters into the Adriatic, show highly significant correlation between these two periods ($r = 0.8712$; $P/t/ > 6.3989 = < 0.001$). Highly significant value is indiciative of their identical causes.

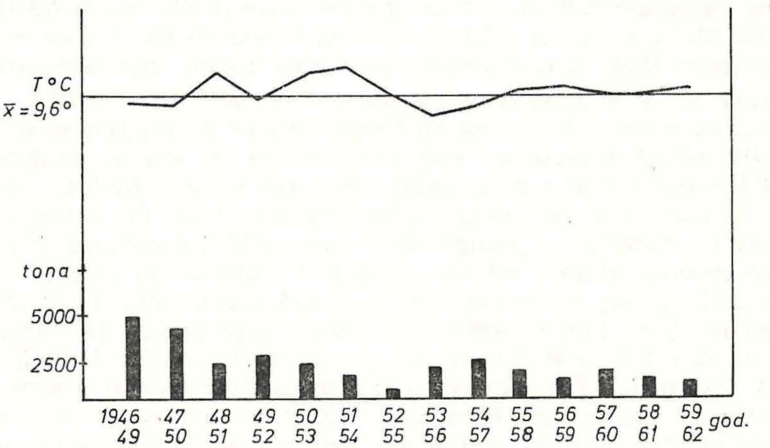

Fig. 8. The relationship between mean air temperature and sardine catch in the area of the middle Adriatic three years later. The first series of years refers to the mean air temperature, and the second one to the sardine catch.

Tait and Martin (1965) pointed to the clear association between the intrusions of cold water of Arctic origin and fish stock in the Faroe-Shetland channels. High, medium and low herring catches in the area of Minch in 1920—1959 were dependent on very strong, medium or non-intrusions of cold Arctic water into the Faroe-Shetland channels three years before.

This example shows that the instrusions of cold Arctic water in the Faroe-Shetland channels causes the increase of production of water masses what further bears better fish recruitment during these »Arctic« years well reflected upon better commercial catches three years later.

Županović (1968) found similar situation for the Adriatic sardine. Graphical presentation of the correlation between sardine catch and air temperature in the 1946—1962 period is given in Fig. 8. Meteorological data on air temperature were made available by the meteorological observatory »Marjan«, Split and data on catch for the earlier Split county (Brač, Hvar, Vis) including also Makarska district, were obtained from the Institute of Statistics for the Socialist Republic of Croatia.

The graphs in Fig. 8 show very clearly, even though not completely (since the data on temperature give mean temperatures), the coincidence of cold winters and better sardine catches three years later.

Here too, like for herring in Minch, climatic factors affect better fish recruitment during intrusion of cold and dry »polar« anticyclone, what is reflected upon better sardine catches three years later.

This correlation between hydroclimatic changes was still better marked in the Jabuka Pit after very cold winter of 1962/1963. After marked homothermy at station 3 in March 1962, not later than in September of the same year the eastern-Mediterranean water of high salinity (38.7‰) was recorded from the Palagruža Sill as well as the intrusion of the north-Adriatic cold water into the Jabuka Pit (10.5°C). This phenomenon was better marked in spring-summer 1963. It is indicative of a very strong ingression after very cold winter of 1962/63 following »medium« ingression of 1955/56.

Increased effects of the eastern-Mediterranean water, particularly in the 1967—1970 period, caused not only the increase of organic production but affected the increase of sardine catch along the eastern Adriatic coast. This increase of catch may be brought into connexion with the better biological conditions for survival of younger fish stages which consequently results in increased biomass of year classes available to commercial fishing. The analysis of age frequency of sardine catches proves this assumption. It was found that sardine of the first to eight year classes were present in catches. Individuals of the third and fourth age groups made up the bulk of catches (48.76%). Fish of the first year class and those older than five were poorely represented in the catches from this fishing ground (Sinovčić, 1985). Maximum catches of third and fourth age groups fully coincide with the maximum sardine catches in the 1963 through 1980 period. The correlation between sardine catch along the eastern Adriatic coast and temperature variations at the bottom of Jabuka Pit in spring (March-June) periods of the 1955—1980 are presented by the graphs in Fig. 9. Correlation was calculated for the period 1963 through 1980. The correlation coefficient ($r = 0.79$; $P/t/ < 0.001$) is highly significant what is indicative of the apparent correlation between hydroclimatic changes and sardine catch along the eastern Adriatic coast. The Jabuka Pit where mixing of water masses is best evident, as mentioned in the Introduction chapter, is best suitable for the observations of this phenomenon since the mixed water masses are of different origin.

Pucher-Petković and Zore-Armanda (1973) and Karlovac, J. et al., (1974) continued the same analysis but with far more elements, taking into account the same »regulator« that is the advection of the eastern-Mediterranean water caused by climatic factors, which affect the long-term Adriatic production. The analysis of small pelagic fish catch statistics, primary production and climatic conditions three years earlier, indicates the same phenomenon.

According to the same authors, primary production conditions, that is climatic conditions throughout the three year period affect the secondary production but are most effective »in the year of spawning«. The statements of the authors seem as if being a simple addition to the experience of the north Adriatic fishermen over centuries which account for their good and bat catches in individual year by »... the conditions which cause them«. Among these the conditions at the time of spawning hold the top position, since »if the sea was rough all was going to be well, and if the sea was calm nothing was going to be well« (A n o n, 1960).

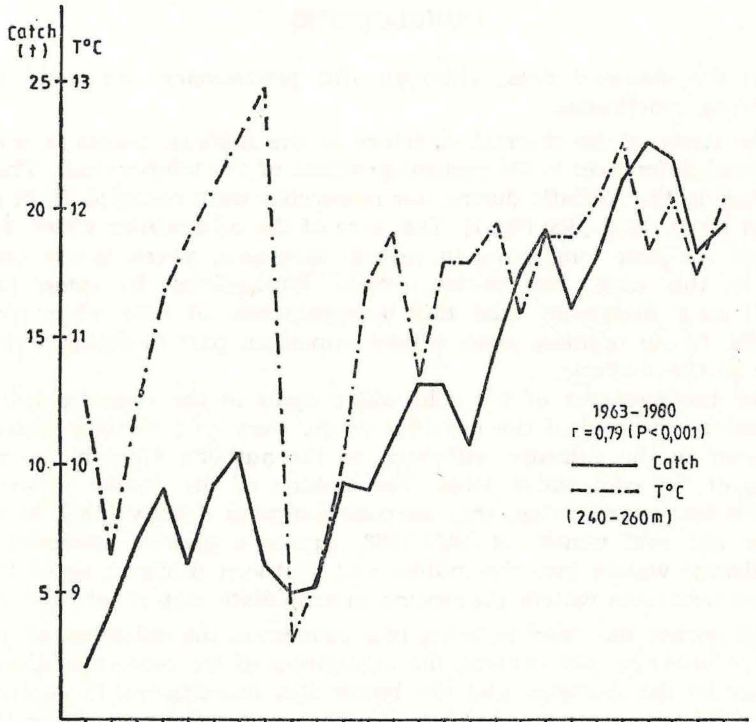

Fig. 9. The relationship between bottom temperature (240—260 m) in the Jabuka Pit and total sardine catch along the eastern Adriatic coast in the 1963—1980 period.

The most recent observations of the behaviour of small pelagic fish, that of sardine in particular, by means of echo-integrators prove the above. At the »rough sea«, between 3 and 3.5 Beauforts, fish concentrations were larger than during slightly agitated or calm sea (A n o n, 1985).

Perhaps these rich catches may be partly attributed to »*insufficiently high temperatures of the sea*« as reported by the same representative from Palestrina in 1855 (Anon, 1960). Županović (1955, 1968, 1969a and b) agrees with this possibility when stating that better sardine catches during cold seasons may be brought into connexion with the *cooling of surface water* which causes better concentration of adult sardine due to the mixing of water masses of different origins.

If cold winters are frequent enough (1962/63; 1967/68, 1972/73; 1978/79) the above mentioned factors may, probably, have cumulative effect on the sardine population in the Adriatic as it happened in the 1963—1980 period.

CONCLUSIONS

From the obtained data, although still preliminary, we could come to the following conclusions:

1. The study of the thermal structure of the Adriatic points to some very distinct local differences in the vertical gradient of the temperature. The lowest temperature in the Adriatic during our researches were recorded from the area of Jabuka Pit in 1962 (See Fig. 1). This core of the cold winter water, although present all the year long, even in several successive years, is not constantly present in this area, but shows certain fluctuations. In some years, in March, it may disappear. Just this disappearance of cold water from the Jabuka Pit, to our opinion, plays a very important part in forming the water structure of the Adriatic.

2. The temperatures of the cold water cores in the Adriatic seem to be determined by the cold of the previous years. Very cold winters which periodically occur in the Adriatic, influence, to the author's opinion, an intensive activation of the cold water cores. The sinking of the denser waters in the Jabuka Pit southwards when they surpass a certain density limit, as the case was after the cold winter of 1962/1963, causes a greater advection of the North Adriatic waters into the middle and southern Adriatic, or of the more saline Mediterranean waters (Levantine intermediate water) into the Adriatic.

3. The author has tried to bring into connexion the existence of a certain coincidence between cold winters, the ingressions of the eastern Mediterranean deep water in the Adriatic, and the better fish recruitment in »polar« years which is reflected in commercial catches three and more years later (See Fig. 8). Here we think, in the first place, of the penetration of the polar air masses, showing a cyclic rhythm, in the eastern Mediterranean and in the Adriatic. Vertical convection will penetrate considerable depths only in the time when the cold polar air masses are dominanting for a longer period of very cold winters in the Adriatic and frequently enough. It is also the period of very cold winters in the Adriatic always accompanied by advective intrusions of the eastern Mediterranean (Levantine) intermediate water in the Adriatic and very high sardine catches.

Very high value of correlation coefficient ($r = 0.79$) between the bottom temperature in the Jabuka Pit and the eastern Adriatic sardine catch from 1963 through 1980 (see Fig. 9) is *highly significant* ($P < 0.001$).

If cold winters become more frequent (as during 1962/63—1968/69) such factors might probably have cumulative effects on the sardine population in the Adriatic.

4. Furthermore, the author has found that sardine catch fluctuations in the Adriatic, coincided, after the cold winter of 1962/63, also with the catch of other species in the northern hemisphere. By basing it on this he has concluded, just like some other authors did, that the cause of sardine catch fluctuations should be studied in relation to world-wide common climatic conditions.

5. Recent changes of fish stock in the North Sea show similar trend to that of sardine and other pelagic species catches in the Adriatic. The identity of these occurrences points to the eventual common causes. Therefore it is not at all surprising to find some interrelated biological phenomena in quite distinct and far apart regions in the northern hemisphere. These phenomena, frequently recorded, are probably, due to common climatic factors (Cushing and Dickson, 1976; Cushing, 1978) and their effects on the fish stocks, and particularly on their recruitments, may be common to a certain extent (Cushing, 1982).

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BIOLOŠKI EFEKTI HIDROKLIMATSKIH PROMJENA U SREDNJEM JADRANU

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KRATKI SADRŽAJ

Na osnovu analize hidroklimatskih promjena u srednjem Jadranu (Jabučkoj kotlini) i ulova srdele na istočnoj obali Jadrana (Slika 9), mogli bismo izvesti preliminarni zaključak da postoji uska povezanost između klimatsko-hidrografskih promjena i dugoročnih fluktuacija u lovinama srdele. Odgovarajuće klimatske promjene cikličkog karaktera, praćene prodorom hladnog i suhog polarnog zraka u istočni Mediteran i u Jadran, su se pokazale kao dobar indikator prevalentnih *ekoloških uvjeta*, karakterističnih za pojavljivanje srdele u Jadranu. Odatle i tvrdnja autora da su bolji ulovi adultne srdele pojavom ingresija, kao i bolje nadživljavanje larvalnih i juvenilnih stadija nakon mriještenja, odnosno boljeg ulova istih u momentu njihove prve dostupnosti komercijalnom lovu, posljedica *boljih bioloških uvjeta* u tim periodima. Takvu jednu pojavu na istočnoj obali Jadrana imali smo nakon veoma hladne zime 1962/63.

Sličan trend ulova srdele, kao i ostalih vrsta pelagične ribe u Jadranu, pokazuju i recentne promjene stock-a u Sjevernom moru. Istovjetnost pojava bi ukazivala i na eventualne zajedničke potencijalne uzroke. Zato nije nimalo iznenađujuće ako postoje izvjesne međusobno povezane biološke pojave između raznih, iako distanciranih regiona, u sjevernoj hemisferi.

Te ne tako rijetke pojave su najvjerojatnije povezane odgovarajućim zajedničkim klimatskim događajima, čiji efekti na riblja naselja, a naročito na njihovo regrutiranje koncidiraju u izvjesnoj mjeri.