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THE NUTRIENT SALTS IN THE ADRIATIC WATERS

by
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THE NUTRIENT SALTS IN THE ADRIATIC WATERS.*)

by

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The amount of nutrient salts is a very important factor when judging the biological properties of a sea, particularly from the point of view of its productivity. Just to make some indirect inferences on the productivity possible, we shall try, within the limited space of this short paper, to throw some light upon the position of the mentioned nutrient salts in the waters of the Adriatic.

Nearly all the data resulting from the analyses which have beeen made in the Adriatic area up to the end of April 1953 are given here in a condesed form. A total of 100 analyses of nitrate and 125 analyses of total phosphorus concerning the High Adriatic has been worked out. Another total of 391 analyses of $P\text{-}PO_4$ made in the High Adriatic area in 1947 and 1953 has also been worked out, as an additional series of analyses made in 1934. But neither such data as resulting from the analyses of the enclosed waters like the Mljet Lakes (Dalmatia), the Lemski Channel (Istria), or the estuarine region of the Krka or Zrmanja rivers, nor the Nümann's Station A, situated in shallow water close to the coast, have been considered.

All the analyses of phosphate have been made by the Deniège method (H. Wattenberg 1937). The amount of total phosphorus contained in the waters of the North Adriatic has been determined by a method about which no particulars are given by Nümann. For the analyses made by the author of this paper from 1951 to 1953 the Harvey method (hydrolysis in the autoclave) had been applied (H. W. Harvey 1948).

The analyses of nitrate contained in the waters of the North Adriatic (Nümann) have been partly made by the reduction to NH_4 (the first part of the data). Later on this author accepted the method with reduced strychnine. Analyses of NO_3 were made by us in 1952-1953 by applying the

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*) A part of this paper was read before the Ith Congress of Jugoslav Biologists held in May, 1953, in Zagreb.

Harvey method using strychnidine (B. M. G. Zwicker and R. J. Robertson 1944).

The very way in which the mean values were obtained is not a faultless one. The circumstance that the places where samples were taken are not evenly distributed in the area, was frequently left unregarded; the dates of sampletaking also lack an even distribution in the frame of a yeartime. This particularly applies to the nitrate data where the yearly cycle of data is incomplete. But it seems that these facts are not likely to influence in a higher degree the drawing of an approximate picture of the amount of nutrient salts in the Adriatic — the only picture we are able to produce at present.

Free Phosphates

According to the data given by Ercegović (1936) and covering the amounts of these salts found in 1934 in the regions of Maslinica (at depths ranging between 0 and 90 m) and Split, the values are rather low and vary from 0.09 to 1.3 mg/t $P\text{-}PO_4$ during the year of investigation.

Table I

Content of $P\text{-}PO_4$ mg/t in the Waters along the Transversal Profile Split—Vis Island—Palagruža Islet—Mt. Gargano Found at Several Stations of the Middle Adriatic, at Depths Ranging between 0 and 170 m. (The data for 1947/1950 have been taken from the paper by Buljan and Marinković, and the data for 1952/1953 from the paper by Buljan and Špan).

	Minimum	Maximum	Mean	No. of Analyses
31. X. 1947. Split—Biševo Island	0,2	1,6	0,89	7
22. XI. 1947. Split—Biševo Island	1,27	6,75	4,04	11
4. II. 1948. Split—Biševo Island	1,3	4,00	2,28	4
16. II. 1948. Split—Biševo Island	0,8	1,57	1,23	9
27. II. 1948. Split—Palagruža Islet	0,0	4,61	1,50	10
19. III. 1948. Split—Biševo Island	1,6	4,56	3,09	2

Table I (cont.)

	Minimum	Maximum	Mean	No. of Analyses
30. III. 1948. Split—Biševo Island	0,0	0,9	0,47	9
14. IV. 1948. Split—Biševo Island	1,2	5 4	1,77	9
29. IV. 1948. Split—Mt. Gargano	0,6	5,70	2,03	25
13. VI. 1948. Pelegrin—Mt. Gargano	0,2	4,7	2 18	15
17. VII. 1948. Split—Biševo Island	0,9	3,0	1,46	11
10. IX. 1948. Split—Biševo Island	0,7	2,51	1,48	12
21. II. 1949. Split—Mt. Gargano	0 6	5,45	2,25	21
8. VI. 1949. Split—Mt. Gargano	0,6	1,64	1,06	22
8. IX. 1949. Split—Mt. Gargano	0,3	4,4	1 52	26
16. XII. 1949. Split—Palagruža Islet	0,7	1,7	1,30	15
25. II. 1950. Split—Biševo Island	0 5	2 5	1,32	11
5. V. 1950. Split—Biševo Island	0,6	2,3	0,98	11
26. VI. 1950. Split—Biševo Island	0,3	1,6	0 87	11
31. VIII. 1950. Split—Biševo Island	0,0	1,2	0,53	10
27. XI. 1952. Split—Palagruža Islet	0 0	4,40	1,83	18
29. I. 1953. Split—Palagruža Islet	0,0	5,90	1,85	23
1. IV. 1953. Split—Mt. Gargano	0,0	2,3	0,74	26
		Grand Mean	1,66	Total 318

Amounts ranging from 0,6 to 2,26 mg/t with a yearly mean value of about 1,5 mg/t were found by Nümann (1941) in the North Adriatic, off Rovinj (Station C, at depths from 0 to 37 m), in 1939. The amount of phosphates, according to Nümann, is never completely consumed in the course of a year.

According to Buljan and Marinković (paper in preparation) and to Buljan and Špan (paper in preparation) the amount of free phosphates ranged (as per Table I) from 0,0 to 6,75 mg/t from 1947 to

Table II

Content of P-PO_4 mg/t at a Station in the South Adriatic off Mljet Island, (N 42° 45.6', E 17° 23'), at Depths Ranging between 0 and 70 m (Buljan).

	Minimum	Maximum	Mean	No. of Analyses
15. III. 1951.	1,24	2,71	1,91	4
19. IV. 1951.	2,05	2,60	2,30	2
18. V. 1951.	1,70	3,90	2,70	4
13. VII. 1951.	1,10	2,00	1,67	4
24. VIII. 1951.	1,00	1,40	1 25	4
4. X. 1951.	1,80	3,29	2,32	4
7. XI. 1951.	0,0	4,10	2,40	4
12. XII. 1951.	0,90	3,20	1,77	3
15. I. 1952.	0,90	1,4	1,17	4
21. II. 1952.	1,6	3,2	2,06	5
4. IV. 1952.	2,5	3,4	3,05	4
8. V. 1952.	0,0	1,7	0 67	4
8. VI. 1952.	0,5	1,0	0,69	4
15. VII. 1952.	0 4	2,4	1,27	4
25. IX. 1952.	0,9	2,8	1,92	4
6. XI. 1952.	0,0	0,2	0,05	4
11. XII. 1952.	1,3	5,1	3,23	3
22. I. 1953.	2 3	3,8	2,95	4
3. III. 1953.	0,2	0,6	0,40	4
		Grand Mean	1,77	Total 73

1950 and during the years 1952/1953 respectively in the region lying between Split, Biševo Island, and Palagruža Islet, that is in the High Adriatic (with depths varying from 0 to 170 m at several stations).

An amount of phosphates ranging from 0,6 to 5,1 mg/t, with a mean value of 1,77 mg/t (Buljan, as yet unpublished data) was found in the course of two years in the South Adriatic (see Table II), at a station lying not distant from Mljet Island, showing a depth of 70 m.

Total Phosphorus

Values varying from 0,2 to 11,7 mg/t P with a mean of 4,8 mg/t P (for particulars refer to Table III) were found by Nümann (op. cit.) at the already mentioned station C, off Rovinj, in the North Adriatic.

According to the data gathered by Buljan and Špan, values ranging between 1,5 and 18,9 mg/t P with a mean of 9,19 mg/t (for

particulars refer to Table IV) were found in the Middle Adriatic, along the transversal profile Split—Palagruža, at seven stations with depths reaching down to 170 m.

Amounts varying from 2,6 to 18,2 mg/t P, with a mean of 6,81 were found in the South Adriatic, at a station off Mljet Island (Buljan). Particulars are shown in Table V.

Table III

Content of Total Phosphorus in the Waters of the North Adriatic, at the Station C, off Rovinj, at Depths Ranging between 0 and 37 m (Nümann 1941)

	Minimum	Maximum	Mean	No. of Analyses
28. X. 1938.	4,8	7,0	6,03	3
4. I. 1939.	8,7	11,7	10,2	2
26. I. 1939.	0,2	0,2	0,2	2
15. V. 1939.	0,24	3,9	2,7	3
9. VI. 1939.	0,21	0,21	0,21	2
24. VII. 1939.	4,2	10,8	7,5	2
22. VIII. 1939.	4,5	4,5	4,5	2
19. IX. 1939.	4,8	6,3	5,5	2
12. X. 1939.	4,5	4,8	4,65	2
9. XI. 1939.	0,2	3,9	2,05	2
		Grand Mean	4,8	Total 22

Table IV.

Content of Total Phosphorus mg P/t in the Waters along the Transversal Profile Split—Vis Island—Palagruža Islet—Mt. Gargano, Found at Several Stations at Depths Ranging between 0 and 170 m. (Buljan and Špan, as yet unpublished data)

	Minimum	Maximum	Mean	No. of Analyses
31. VII. 1952. Split—Palagruža Islet	3,1	18,9	10,92	18
29. XI. 1952. Split—Palagruža Islet	5,1	17,5	9,83	16
29. I. 1953. Split—Palagruža Islet	1,5	10,7	6,93	23
1. IV. 1953. Split—Mt. Gargano	4,9	12,2	8,07	24
		Grand Mean	9,19	Total 81

Table V.

Content of Total Phosphorus mg P/t in the Waters of the South Adriatic, Found at a Station off Mljet Island, N. 42° 45,6', E. 17° 23', at Depths Ranging between 0 and 60 m. (Buljan)

	Minimum	Maximum	Mean	No. of Analyses
19. VIII. 1952.	2,6	4,7	3,76	4
25. IX. 1952.	3,5	11,0	8,30	4
6. XI. 1952.	4,5	5,4	3,82	3
11. XII. 1952.	4,9	18,2	11,80	3
22. I. 1953.	4,4	9,1	6,30	4
3. III. 1953.	5,4	9,4	6,87	4
		Grand Mean 6.81		Total 22

Nitrates

Values varying from 0,0 to 37,8 mg/t N, with a mean amounting to 7,93 mg/t N-NO_3 per ton of sea water (for particulars refer to Table VI) were found by Nümann (op. cit.) at the Station C, off Rovinj, in the North Adriatic.

Values varying from 0,5 to 37,5 mg/t N, with a mean amounting to 6,29 (see particulars in Table VII) were found by Buljan and Špan along the Split—Palagruža profile.

Researches made off Mljet Island in the South Adriatic yielded values

Table VI.

Content of N-NO_3 in the Waters of the North Adriatic at the Stations C, off Rovinj. Depth 37 m. (Nümann 1941)

	Minimum	Maximum	Mean	No. of Analyses
3. II. 1939.	33,6	37,8	35,3	4
11. V. 1939.	12,6	12,6	12,6	4
15. VI. 1939.	0,0	0,0	0,0	5
24. VII. 1939.	0,0	2,8	0,55	5
22. VIII. 1939.	0,0	2,8	1,1	5
19. IX. 1939.	0,0	4,1	0,82	5
12. X. 1939.	0,0	7,0	1,37	3
18. XII. 1939.	9,8	12,6	11,7	3
		Grand Mean 7,93		Total 34

varying from 0,0 to 15,5 mg/t, with a mean amounting to 2,80 mg $N\text{-}NO_3$ per ton (for particulars refer to Table VIII).

To make a comparison possible, we give also some data on the amount of nutrient salts found in the waters of the British Channel.

May I mention that the British Channel, although not a poor region with regard to organic production and fishery, is not considered an example for the richness of a sea.

Table VII.

Content of $N\text{-}NO_3$ mg/t in the Waters along the Transversal Profile Split — Vis Island — Palagruža Islet — Mt. Gargano, Found at Several Stations at Depths Ranging between 0 and 170 m. (Buljan and Špan)

	Minimum	Maximum	Mean	No. of Analyses
29. XI. 1952. Split—Palagruža Islet	3	37,5	10,3	10
29. I. 1953. Split—Palagruža Islet	1,5	25	5,87	13
1. IV. 1953. Split—Mt. Gargano	0 5	12	2,7	16
		Grand Mean 6,29		Total 39

Table VIII.

Content of $N.NO_3$ mg/t in the Waters of the South Adriatic, at a Station off Mljet Island, with Depths Ranging between 0 and 60 m. (Buljan)

	Minimum	Maximum	Mean	No. of Analyses
8. V. 1952.	1	1	1	3
8. VI. 1952.	1	3,5	1,42	3
15. VII. 1952.	0,0	2,0	0,83	3
19. VIII. 1952.	0,0	0,5	0,15	3
25. IX. 1952.	1,5	2,2	1,80	3
6. XI. 1952.	1,1	15,5	5,7	3
11. XII. 1952.	3.0	4,0	3,5	3
22. I. 1953.	2,5	12,0	6,3	3
3. III. 1953.	3,5	5,2	4 5	3
		Grand Mean 2,80		Total 27

A SHORT DISCUSSION OF DATA

Free Phosphate

The mean values of free phosphates vary in different regions as follows:

Table IX

	mg $P\text{-}PO_4/t$
North Adriatic 1939	1,6
Middle Adriatic 1934 (Ercegović)	0,65
Middle Adriatic 1947-1953 (Buljan and Špan)	1,66
South Adriatic 1951-1953	1,77
British Channel 1947-1948	9,56

Remark: The datum referring to the British Channel has been obtained by processing some of the data published by F.A.J. Armstrong and H. W. Harvey (1950).

But by considering the data with regard to the Middle Adriatic profile only (Split—Biševo Island—Palagruža Islet), the mean values were found to be the following:

Table X

	mg $P\text{-}PO_4/t$
1947	2,46
1948	1,75
1949	1,53
1950	0,92
1952/53	1,47

We shall only briefly comment on these two small tables. It seems that we can deduce from Table IX that the content of $P\text{-}PO_4$ tends to sink in the South-North direction. It also results from that table that the ratio between the amounts found in the Adriatic and those found in the British Channel is highly in favour of the latter. The waters of the British Channel contain for about 6,0 times as many phosphates as those of the North Adriatic and for about 5,4 times as many as the inshore waters of the South Adriatic.

Table X reminds us of the existence of a fluctuation of the amounts of phosphates occurring in the Adriatic over a series of years. The largest quantity found in the Middle Adriatic happened to be in 1947 and it was sinking towards 1950, to rise again in 1952/1953.

The question arises whether this fluctuation of free phosphates in the Adriatic has any connection with the fluctuation of salinity, occurring there at intervals of several years, as it has been recently established (see (M. Buljan, 1953). It happened even in 1947/1948 that large masses of saltier water entered the Adriatic from the Mediterranean, thus adding new quantities of salt to the waters of the Adriatic. It seems that the increase of salt content produced in such a way occurs in the Adriatic every ninth year, and, in a lower degree, perhaps every 4,5 years also. When those masses of saltier water, coming from the deeper layers of the Mediterranean, enter the Adriatic, considerable amounts of phosphates and nitrate may also penetrate the Adriatic Sea. I should mention that the deeper layers of the waters of the Ionian Sea are rather rich in nutrient salts (Thomsen H. 1931) if compared with the waters of the Adriatic.

Abundant catches, which occurred a year or two after the noticed increases of salinity in the Adriatic, may also have had some connection with the inflows of saltier water in 1912/1913, 1938/1939, and 1947/1949. This is but a hypothesis for the time being, which will be either accepted or given up on the basis of future observations. The next growth of salinity in a higher degree may be expected in 1956/57, and a weaker one had probably happened by the end of 1952, judging from the salinity data for the Middle Adriatic we gathered at that time.

Total Phosphorus

The following mean values for total phosphorus have been found in various regions of the Adriatic:

Table XI

		Pctal P mg/t
North Adriatic	1931	4,8
Middle Adriatic	1952 1953 . .	9,19
South Adriatic	1952 1953 . .	6,6
British Channel	1947/1948 . .	15,0

Remark: The datum referring to the British Channel has been obtained by processing some of the data published by F.A.J. Armstrong and H. W. Harvey (op. cit.).

Table XI hints to the fact that the Middle Adriatic is richer in total phosphorus than the North or South Adriatic. This seems to be caused by the influence of the High Adriatic which is deeper and shows an abundance of those substances when compared with the coastal areas of that

sea. We learn further that the amount of total phosphorus found in the British Channel is in average for about 1,6 times as high as that found in the Middle Adriatic.

Another circumstance must be added here. It was put by Nümann that the productivity of a sea is probably dependent on the ratio between the amounts of free phosphates and total phosphorus found in that sea. The larger the relative quantity of free phosphates, the more favourable are the conditions for production. The picture of ratios for the Adriatic is given in Table XII.

Table XII

	Free $P\text{-}PO_4$		Total P
British Channel	63,7	:	100
North Adriatic	33,3	:	100
Middle Adriatic (1947-53) . . .	18,1	:	100
South Adriatic	26,8	:	100

Something about one third to one seventh of phosphorus is found in the free phosphate form in the Adriatic, whilst as many as two thirds of phosphorus are found in the form of free phosphates in the British Channel.

Nitrates

We must stress at once that, although a considerable number of analyses of anorganic phosphate is available, the analyses of nitrate found in the Adriatic are rather insufficient for an accurate analysis of nutrient salts occurring in that sea. About a hundred analyses of our own which are at our disposal will have to serve our purpose for the time being. Small quantites of nitrates are, however, found in the Adriatic waters. According to the data given in tables VI, VII and VIII, the following are the mean values for various regions of the Adriatic:

Table XIII

	$N\text{-}NO_3$ mg/t
North Adriatic	7,93
Middle Adriatic	6,29
South Adriatic	2,80
British Channel	51,1

Remark: The datum referring to the British Channel has been obtained by processing the data published by L.H.N. Cooper (1937).

The above table shows that, contrary to phosphates, the amount of nitrate tends to grow less in the North-South direction, which circumstance is likely to be explained by the insufficient number of data. Moreover, the quantities of nitrate in comparison with the data concerning the British Channel, show values which amount only to about 1/19 to 1/7. The position of the Adriatic versus the Channel as regards nitrate is, then, by far less favourable than in the case of phosphate (somewhere about 1/7) or total phosphorus (1/3 to 3/5).

I should finally point out to an opinion presented by N ü m a n n, which seems to be justified and which is particularly strengthened by our data. According to N ü m a n n the principal factor responsible for hindering the production in the Adriatic is, perhaps, not the phosphates but the nitrates. It seems that the regeneration of free phosphates can more easily be performed from the organically bound phosphorus than nitrate can be regenerated from the organic matter containing nitrogen, so a given quantity of P takes part in the production of a sea several times during a year, whilst the convertibility of nitrogen from organic compounds in the sea water into a nitric form or into some other simple nitric compound is much more restricted. Consequently, there easily occurs a deficiency of nitric compounds needed for the vegetal assimilation.

Our data covering the Middle and the South Adriatic, being of a more recent origin than those gathered by N ü m a n n for the North Adriatic, show that the conditions as to the amounts of nitrate found in the Middle and South Adriatic in 1952/1953 were less favourable than those recorded for the North Adriatic.

There is a fact to which I should like to point out here, namely, that the deep layers of the Mediterranean waters (e. g. the Ionian basin) contain considerable amounts of nitrate, exceeding 100 mg $N\text{-}NO_3$ per ton of sea water. It is not to be excluded that the growth of salinity in the Adriatic, caused by the inflow of Mediterranean waters in larger quantities than usual (partially originating from the d e e p e r layers of the Mediterranean) as it was established for certain years, e. g. 1947-1949, brings about an enrichment of the Adriatic waters with so badly needed nitrates. That fact for itself was likely to stimulate production and consequently to cause abundant catches to be caught in the Adriatic, similar to those which occurred in 1949 and 1950. Most unfortunately, however, no analyses of nitrate are available for the Adriatic covering the period of time extending from 1947 to 1950, which would probably justify the above hypothesis.

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HRANJIVE SOLI U VODAMA JADRANSKOG MORA

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Kratak sadržaj

U radu su izneseni i obrađeni skoro svi podaci količina fosfata ($P\text{-}PO_4$), ukupnog fosfora (P-totalni) i nitratnog dušika ($N\text{-}NO_3$) u jadranskim vodama, dobiveni od raznih autora, koji su istraživali ovo more. Za usporedbu su doneseni i neki podaci ovih hranjivih tvari u području Britanskog kanala.

Postoji izvjesna tendencija, da količina fosfata opada u Jadranu idući od juga prema sjeveru. Podaci sadržaja slobodnih fosfata u vodama srednjeg Jadrana pokazuju kolebanje u toku istraživanog razdoblja od 1947. do 1953.

Ukupni fosfor se nalazi u znatnijim količinama otvorenog i dubljeg Jadrana, nego li u priobalnim područjima.

Omjer $P\text{-}PO_4$: P- total je nepovoljniji u Jadranu, nego li u vodama Britanskog kanala.

Nitrati se u jadranskim vodama nalaze u sitnim količinama. Sadržaj nitrata je nepovoljniji nego li sadržaj fosfata, u usporeñenju sa prilikama koje vladaju u Britanskom kanalu.

Izneseno je mišljenje, da postoji veza između kolebanja sadržaja hranjivih soli u Jadranu sa povremenim ulijevanjem mediteranske, posebno dubinske vode, u Jadranski bazen, koje se nekih godina vrši u znatnim razmjerima. Izneseno je mišljenje i o povoljnom uplivu tih ulijevanja (ingresija) mediteranske vode na organsku produkciju u Jadranu.

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