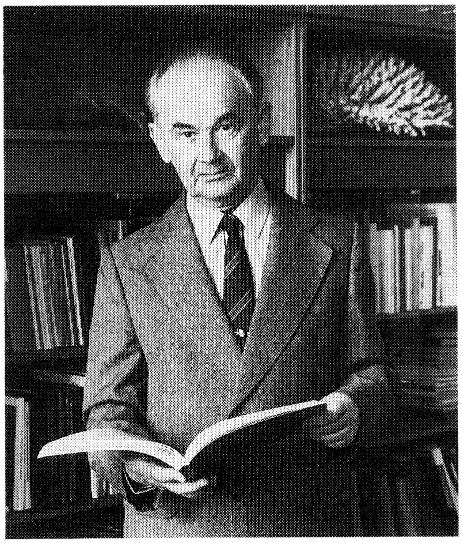
La mer 29: 1-7, 1991
Société franco-japonaise d'océanographie, Tokyo

Article spécial n°7

Cultural eutrophication of the Black Sea and other South European Seas*

Yu. P. ZAITSEV**



The increasing influx of nutritive substances both mineral and organic ranks first among different forms of man-made impact on seas and oceans. This process, having received the name of eutrophication, promotes in natural water bodies a series of interrelated phenomena united under the title "Syndrome of eutrophication" (GOMOIU, 1985). These include algal blooming or a according to E. ODUM (1975) cancerous rates of production, oxygen deficiency in near bottom layers (hypoxia), mass mortality of bottom and near bottom organisms, and the production as a result of protein desintegration of hydrogen sulfide, decrease in water transparency etc.

Eutrophication of coastal waters of seas and oceans has been rapidly developing in the last 20-30 years as a result of intensive agricultural, industrial and other human activity. Besides, the degree of eutrophication for each water body depends on certain geographical, physical, chemical and biological conditions.

The Black Sea as an object of the cultural or anthropogenic eutrophication has attracted the attention of specialists yet in the late 60's. In the north-western part of the Black Sea into which three of the largest rivers-Danube, Dnesrt, Dnepr flow, an increase in concentrations of nutrients and in phytoplankton, especially peridinian algae was observed. These processes quickly enhanced, and in the 1970's a distinct "syndrome of eutrophication", including " red tides" (NESTEROVA, 1979) and mass mortality of bottom organisms (ZAITSEV, 1977) took place. Literature references included many reports on the complex and even critical conditions of the ecosystem of the Black Sea especially on the north-western shelf, where the state of the pelagic and benthic zones in comparison to the 1960's has changed greatly.

For a more complete and objective evaluation of the ecological situation in the region, it was necessary to make comparative investigations of different areas of the Mediterranean Sea Basin, where during the same period the same changes were developing. This paper is the first attempt to comparatively evaluate the level of trophicity of marine waters according to chlorophyll "*a*" content in wide spaces from the Alboran Sea in the west to the Sea of Azov in the east. Chlorophyll "*a*" is found in all live cells, and its concentration thus reflects the amount of phytoplankton on the sea surface.

The system of intercontinental seas connected by the Mediterranean Sea Basin, communicates with the Atlantic Ocean through the Strait of Gibraltar, and with the Indian Ocean through the Suez Canal and Red Sea. The water surface, including the Black and

*Received March 13, 1991
**Odessa Branch Institute of Biology of Southern Seas, Ukrainian Academy of Sciences, 37 Pushkinskaya St., 270011 Odessa, U.S.S.R.

Azov Seas makes up to 2,960,000 square kilometres. The drainage area of all these seas on the territory of Europe, Asia and Africa exceeds 7,000,000 square kilometres. Thus the relation of the surface of terrestrial drainage area to sea surface is close to 2.4. However, for certain seas of this basin this index varies markedly.

Thus, for the Sea of Azov it exceeds 19.0, for the Black Sea- 5.6, for the Agean Sea- 0.7, Adriatic- 2.1, Ionian- 0.3, Tyrrhenian- 0.4. For the rest of the Mediterranean Sea it is 2.6. However, it should be noted that almost 80% pertains to Nile River Basin which after the building of the Aswan dam has greatly decreased its influence on the Mediterranean Sea.

But, this index is non-absolute and not the only criterion for the assessment of the degree of dependence of the land on the sea through surface run-off. However, at present, namely the river waters represent the main source of anthropogenic influence on marine ecosystems. Drainage areas of different seas in the Mediterranean Sea Basin are illustrated in Fig.1.

The term cultural (known as man-made, anthropogenic, accelerated, forced) (ODUM, 1971) eutrophication in special literature has been a widely used syntagm for distinguishing nutrient and organic water pollution caused by human activity.

Data of remote measurements from satellites (ARNONE, LA VIOLETTE, 1986, Ocean Color from Space, 1989) and materials from trditional methods obtained by using ship and buoy measurements (SERBANESCU *et al.*, 1978, FORTESA *et al.*, 1980, BOLOGA *et al.*, 1985, ESTRADA, 1986, VEDERNIKOV, 1987 COSTE, 1987, Dynamics of water, 1988, KOVALEVA *et al.*, 1988, SOUVERMEZOGLOU *et al.*, 1988) have been used for making up schematic maps of the seas of the Mediterranean Sea Basin according to the concentration of chlorophyll "*a*" in the surface water layer (Fig.2.)

Each of these methods has its advantages and disavantages. Thus, contact ship and buoy measurement help in obtaining a wide range of information not only on chlorophyll content, but on the carriers of this pigment-pelagic unicellular algae, on their specific and size composition, number, biomass on other biotic and abiotic parameters of the marine

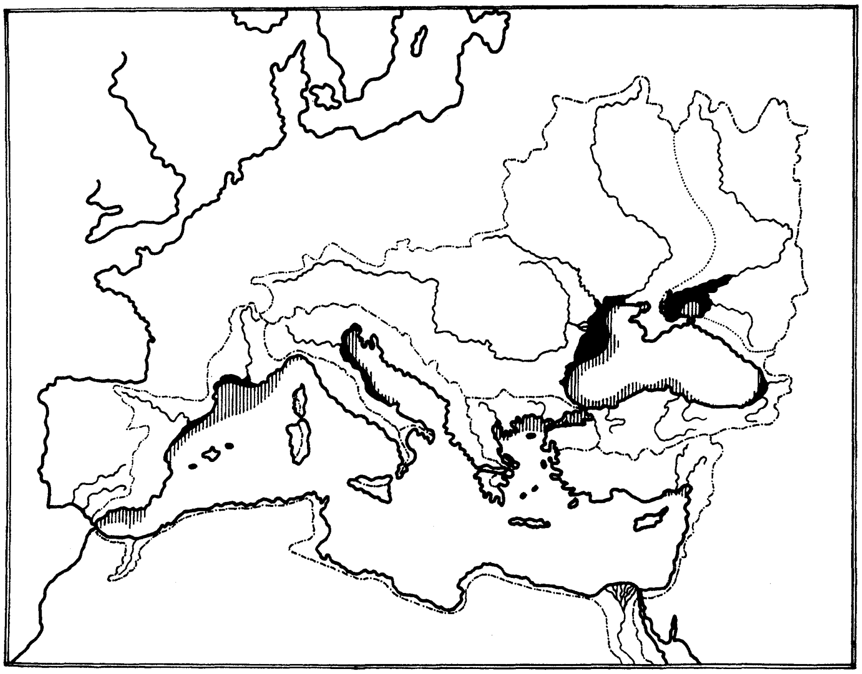


Fig. 1. Drainage basins (—·—·—·) of different seas of the Mediterranean basin

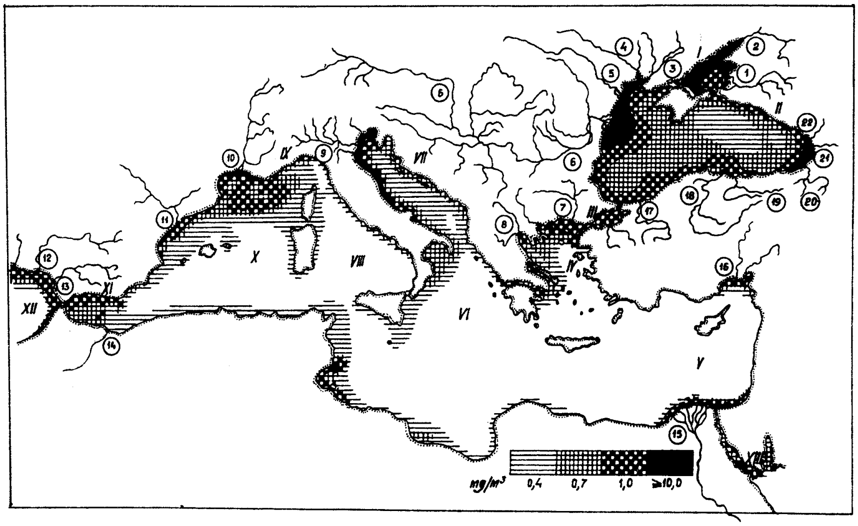


Fig. 2. Cultural eutrophication of the Mediterranean basin

Seas:
I. Sea of Azov
II. Black Sea
III. Sea of Marmara
IV. Aegean Sea
V. Levantine Sea
VI. Ionian Sea
VII. Adriatic Sea
VIII. Tyrrhenian Sea
IX. Ligurian Sea
X. Algero-Provencal Basin
XI. Alboran Sea
XII. Atlantic Ocean
XIII. Red Sea

Main Rivers:
1. Kuban
2. Don
3. Dnepr
4. Southern Bug
5. Dnestr
6. Danube
7. Maritza
8. Vardar
9. Po
10. Rhône
11. Ebro
12. Guadiana
13. Guadalquivir
14. Moulouya
15. Nile
16. Ceyhan
17. Sakarya
18. Kizil Irmak
19. Yesil Irmak
20. Coruh
21. Rioni
22. Inguri

environment. However, for this purpose lengthy expedition are necessary. During this period of time the parameters of the marine environment may change, and then the data on the maps may prove to be tentative.

Information received from satellites is practically instant. For example, a two minute satellite scene with help of a CZCS (Coastal Zone Color Scanner) from Nimbus 7 contains two million pixels that cover an area of two million square kilometres. If the same measurements were carried out on board ship, (speed- 11 knots), it would have taken more than 11 years (Ocean Color from Space, 1989).

That is why when using modern methods for studying seas and oceans and man-made changes in their ecosystems, best results may be obtained by combining the data of remote and contact measurements.

The space survey of the whole Mediterranean Sea which served as the basis for making up the map, indicating eutrophicated areas, was fulfilled in May, 1980 (Ocean Color from Space, 1989). In the following 10 years, in certain areas this process has been progressing markedly. That is why materials obtained from expeditions in many countries in the last decade have been considered in the map.

From Fig.2 it is clear that the greater part of the Mediterranean Sea proper until the present time remains oligotrophic with minimum amounts of phytoplankton. This is especially noted for the eastern part of the sea. In spite of that the Nile enters at this point with its drainage area exceeding 2,800,000 square kilometres and annual run-off of 73 cubic kilometres, the influence of this river on the Mediterranean Sea, after the building of the Aswan dam, in 1970, was greatly diminished. It has had a negative effect on biological productivity and fisheries in this region (SESTRINI *et al.*, 1989) and on solid river load.

Large rivers such as the Ebro, Rhone and Po with annual river run-off about 120 cubic kilometres flow into the Adriatic and northwestern part of the Mediterranean Sea. As a result highly trophic areas have been created lately along the coast line of South Europe (Catalonia, Provence, Coté d'Azur, Italian Riviera). From the middle of the 1980' s hypertrophic areas have been formed along the north and west coast line of the Adriatic Sea causing a critical situation in these areas in coastal waters and on the shore. The Po River proved to be the main source of eutrophication in the Adriatic. Although it has a compratively small drainage basin (75,000 square kilometres). It flows through a territory having intensive farming, animal raising and industrial enterprises.

Mineral and organic nutrients enter the Alboran Sea with surface and current waters from adjacent Atlantic Ocean areas, where the Guadalquivir, Guadiana and Tagus Rivers enter from the Pyreneen peninsula.

On the opposite north-eastern line of the Mediterranean, the highly trophic waters in the region of the Iskenderun Bay are created by waters of the Ceyhan and Seyhan Rivers.

Thus, it becomes clear that the most widely eutrophic areas of the Mediterranean Sea are near the estuarine river regions and adjacent waters which carry nutrients of agricultural and industrial origin, fortified with sewage waters from largely populated habitats located along the lower river currents.

The Mediterranean Sea with its area of 2,500,000 km^2 and volume of 3,700,000 km^3 has 473 km^3 of river water entering annually (SESTRINI *et al.*, 1989). The Black Sea with a surface area of 422,000 km^2, with a slow vertical turbulence of water masses, and limited water exchange through the Bosphorus Strait has about 350 km^3 of river run-off entering, including 203 km^3 from the Danube, annually (SKOPINTSEV, 1975). That is why the surface of the water of all the Black sea pertains to mesotrophic and eutrophic, while the zone of Danube water influence- to hypertrophic (ZAITSEV *et al.*, 1989).

Finally, the Sea of Azov with its area of 39,000 km^2 and a maximum depth of 13 metres, in years of hevy rainfall receives more than 40 km^3 of river waters (BRONFMAN, KHLEBNIKOV, 1985). For this reason the Sea of Azov has undergo an "eutrophication syndrome", including mass mortality of bottom organisms, many decades prior to the present period of total eutrophication of coastal marine waters (ZENKEVICH, 1963).

Thus space and ship measurements shows that antropogenic eutrophication at present is widely spread in coastal marine waters of the South Europe. Its main source is river water or according to Odum (1971)- outwelling.

As to degree of cultural eutrophication some seas and areas of the Mediterranean Sea Basin can be arranged in the following order, decreasing: Sea of Azov, Black Sea, Adriatic Sea, Sea of Marmara, Gulf of Lyon, Aegean

Sea, Balearic, Alboran, Ligurian, Tyrrhenian, Ionian and Levantine Seas, and central parts of the Algero-Provencal Basin, and the eastern half of the Mediterranean Sea.

The whole area of the Sea of Azov, almost one-quarter of the Black Sea surface, the northern half of the Marmara Sea, almost one-fifth of the Adriatic Sea and others are subjected to algal blooming.

The largest hypertrophic area in the Mediterranean Sea Basin is located in the north-western part of the Black Sea opposite the USSR, Roumania and Bulgaria in the zone of influence of the Danube, Dnestr and Dnepr rivers. It takes up an area of 100,000 km^2. The largest abundance and biomass of plankton organisms, which react positively to marine water eutrophication, have been noted here. Thus the number of phytoplankton cells (with peridinians predominating) reaches up to 800,000,000 / 1 with biomass of $1000 g/m^3$ (SUKHANOVA *et al.*, 1988), while the infusorian *Mezodinium rubrum*- 4,600,000 / 1 and $280 g/m^3$, correspondingly (TUMANTSEVA, 1985). As to *Noctiluca miliaris* in neuston layer (0-5cm) it may attain extreme indices for the Seas and oceans, exceeding $6,800,000,000/m^3$ and 500 kg/m^3 (ZAITSEV *et al.*, 1988). The highest number of the new ctenophore species introduced from the Atlantic Ocean *Mnemiopsis leidyi* was also noted in the north-western part of the Black Sea. The abundance of this animal in coastal waters may exceed 500 specimens per cubic metre.

Mass mortalities of bottom organisms which at beginning of the 1970's have been observed in large areas of the north-western Black Sea shelf, take up to 10,000 km^2 in the economic zone of the USSR alone (ZAITSEV, 1989). Due to hypoxia, from 100 to 200 tons of aquatic organisms die per one kilometre of sea bottom. This includes 10-15 tons of fish-both commercial and non-commercial, adult and juvenile forms. Mass mortalities cease when homothermal autumn sets in with enhancement of turbulent water mixying. Larvae begin to inhabit the bare shelf zones. They are carried by water currents from marginal biotops and shelf zones which do to not undergo mass mortalities. Benthic populations are renewed, and this process continues until the next period of oxygen deficiency, the cycle repeating once more.

Besides harming fisheries, cultural eutrophication of marine waters causes great losses in other fields of economy. This is expecially noted where coast zones are used for recreative and tourist purposes. Algal blooms changes the usual organoleptic quality of the water. It becomes brownish in colour, slimy an unpleasant smell. Aerosol particlels enter the atmosphere from blooming marine waters containing toxic substances and microorganisms. The decrease of water transparency due to mass phytoplankton production lowers the penetration of solar radiation to the bottom, and hinders or exclude the development of benthic macrophites. Mass mortality of benthic organisms creates conditions for intensive reproduction of pathogenic microorganisms and this is a direct hazard to human health.

All these phenomena are more or less characteristic for many coastal waters of the South Europe in the Black and Azov Seas, on the northern shores of the Sea of Marmara and Prince Islands, some bays of the Aegean Sea, the north and westhern shores of the Adriatic, the shores from Marseilles in France to Valencia in Spain and others.

This man-made ecological situation occurring along the densely populated coast of Southern Europe reflects the necessity for more close international cooperation. Only with combined efforts can a multilateral study of "the eutrophication syndrome" be acheved, and as a result joint practical measures can be taken for improving the condition of coastal waters in the Mediterranean Basin.

Due to widely spreading eutrophicated marine areas in the World Ocean, it should be taken into consideration that surface water containing large amounts of plankton and neuston organisms has a temperature till 2-3 degrees higher than water depleted of suspended hydrobionts. It is known also that many plant and animal planktonic organisms aids in evaporating water up to 2-3 times more intensively with the help of flagella movements.

Such an influence on the mechanism of climate forming processes is also a very important ecological consequence of eutrophication of seas and oceans. However, this problem is beyond the scope of this paper.

References

ARNONE, R. A. and P. E. LA VIOLETTE (1986): Satellite definition of the biooptical and thermal variation of coastal eddies associated with the African Current. Journ. of Geophysical Research, **91**(2), 2351-2364.

BOLOGA, A. S., Z. P. BURLACOVA, V. D. TCHMYR and V. I. KHOLODOV(1985): Distribution of chlorophyll *a*, phaeophytin *a* and primary production in the western Black Sea (May, 1982). Researches marines I.R.C.M. Constanta, **18**, 97-115.

BORONFMAN, A. M., E. P. KHLEBINIKOV(1985): Basis of reconstraction. Leningrad: Gidrometeoizdat, 272 pp.(in Russian).

COSTE, B. (1987): Les sels nutrientifs dans le bassin occidental de la Mediterraee. Rapp. Comm. Int. Mer Mediterr., **30**(3), 399-410.

ZATS, V.I. and Z.Z. FINENKO (Eds) (1988): Dynamics of water and productivity of plankton in the Black Sea. Institute of Oceanography, Academy of Sciences USSR. Moscow., 432 pp. (in Russian).

ESTRADA, M.(1986): Mareas rojas. Inv. Techn. Inst. Pesq. Barcelona, **132**, 1-16.

FORTEZA, V.,A. MARTINES TABERNER and G. MOYA (1980): Approximation to chlorophyll *a* distribution in the Balearic Sea (Northern Mediterranean). Rapp. Comm. Int. Mer Mediterr., **31**(2), 224

GOMOIU, M. T. (1985): Problems concernant l'eutrophication marine. Researches marines. I.R.C.M. Constanta, **18**, 59-95.

KOVALEVA, N. V., E. M. RUSNAK and N. A. BERLINSKY (1988): Production and destraction indices of water masses in the north-western part of the Black Sea in summer 1988. Dep. in VINITY. 04.07.89. No. 4422-1389, 1-14(in Russian).

MILLER, A. (1983): The Mediterranean Sea. A physical aspects. Estuaries and enclosed seas. (ed. by R. H. Ketchum). p.219-238.

NESTEROVA, D. A. (1979): Development of the peridinian *Exuviaella cordata* and "red tide" in the north-western part of the Black Sea. Biologya Morya, p. 24-29. (in Russian).

Ocean Color from Space (1989): Prepared by the NSF/NASA, Woods Hole Oceanographic Institution, Goddard Space Flight Center, University of Miami and University of Rhode island, p. 7. 15 ill.

ODUM, E.P. (1971): Fundamentals of Ecology (3rd edition). Sanders Comp., Philadelphia, 574 pp.

SERBANESCU, O., I. PECHEANU, I. CUINGIOGLU and R. MIHNEA (1978): Le Danube come agent d'eutrophication de la mer Noire. IV-es Journ. Etud. Pollut. Antalya: CIESM, p. 457-459.

SESTRINI, G., L. IEFTIC and I. M. MILLIAM (1989): Implications of expected climate changes in the Mediterranean region: an overview. UNEP Regional Seas Reports and Studies, UNEP, **103**, 1-46.

SKOPINTSEV, B.A. (1975): The formation of modern chemical composition of Black Sea waters. Leningrad: Gidrometeoizdat, 336 pp. (in Russian).

SOUVERMEZOGLOU E., R. Psyllidou, E. HATZIGEORGIOU, I.PAMPIDIS and P. SAMARA (1968): Distribution of nutrients and oxygen in the Eastern Mediterranean Sea. National Center for Marine Research, Athens, p. 72-74.

SUKHANOVA, I. M., N. V. FLINT and G. HIBAUM (1988): *Exuviaella cordata* red tide in bulgarian waters (May to June, 1986). Marine Biol., **99**, 1-8.

TUMANTSEVA, N.I.(1985): "Red tide" in the Black Sea. Okeanologiya, 25(1), 130-132. (in Russian).

VEDERNIKOV, V. I. (1987): Primary production in the Black Sea in the spring 1984. Contemporary state of the ecosystem in the Black Sea, Moscow, Nauka, p. 105-118. (in Russian).

ZAITSEV, YU. P. (1977): Contemporary state and expected changes in the biology of the north-western part of the Black Sea due to protection and exploitation of its resources. Investigations of biological resources and their protection in the southern seas. Kiev, Naukova Dumka, p. 48-51. (in Russian).

ZAITSEV, YU.P. (1990): Anthropogenic eutrophication of the seas of the Mediterranean Sea Basin. Dep. in VINITI 12.02, No. 778. B90, p. 1-15. (in Russian).

ZAITSEV, YU. P., G. P. GARCAVAYA, D. A. NESTEROVA and L. N. POLISCHUK (1989): The Danube-the main source of eutrophication of the Black Sea.

Gidrobiologichesky zhurnal, **25**(4), 21–23. (in Russian).

ZAITSEV, YU. P., L. N. POLISCHUK, E. V. NASTENKO and G.M. TROFANCHUK (1988): Super high concentrations of *Noctiluca miliaris* Suriray in the neuston of the Black Sea. DAN Ukr. SSR. Ser. B, No. 10, p. 67–69. (in Russian).

ZENKEVICH, L.A. (1963): Biology of the Seas of the USSR. Moscow, Izd-vo Acad. Nauk. USSR, 740 pp. (in Russian).