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ALGAE AS INDICATORS OF SEA WATER POLLUTION BY POLYCYCLIC ARENES

Protection of the environment, including water, presupposes a knowledge of the environmental state. For these purposes elaboration of scientific grounds of a fixed control system is urgently needed. This system should provide maximal information, being accurate and effective, give a survey about the situation of the immediate present, and furnish a basis for the prognostication of the state of environment for ensuing years and decades.

For a reliable evaluation of the pollution of water bodies by polycyclic arenes all compounds comprised in water should be determined separately at least four times a year. However, according to I. Veldre with co-authors (Велдре et al., 1983), 12 polycyclic aromatic hydrocarbons have been already determined in our waters so far. Such an amount of work would be beyond the power of any institution dealing with monitoring, to say nothing of the indispensable equipment — the high pressure liquid chromatograph is by no means available for every institution. However, the control over the state of water is necessary. For these reasons benzo(a)pyrene (BP) has been applied as an indicator for the evaluation of the pollution of water bodies by polycyclic arenes. In many respects this approach is grounded, since BP is a frequent and a very active compound; besides, it is extremely resistant to the effects of environmental conditions. According to published data it forms about 66% of carcinogenic polycyclic arenes comprised in water, and approximately 30% of those accumulated in bottom sediments (Велдре et al., 1983).

Doubtlessly, the determination of BP concentration simplifies the control, but its evaluation in the water contains some disadvantages. Firstly, the data obtained through water analyses reflect the situation at the immediate present, which, however, undergo rapid changes. A sample taken from a stream may prove considerably cleaner than the surrounding water, or vice versa. Secondly, the sampling should be performed by seasons; however, this leads to the increase in the number of analyses and makes the investigation too labour-consuming.

Hitherto studies have shown that in water basins BP accumulates both in bottom sediments as well as in aquatic plants and animals where its concentration is 10 000—100 000 times as great as in the water. Proceeding from the above, we started with the study of some water plants, wishing to establish species most suitable for serving as indicators. BP accumulates also in fish; however, the latter are very mobile and cannot be applied to the evaluation of carcinogenic pollution in a certain area of a water basin so successfully as stable bottom plants. *Nuphar luteum*, particularly its floating leaves in which BP concentration is higher, has been acknowledged as the best indicator of BP pollution for

Lake Võrtsjärv, Central Estonia (Veldre et al., 1982a). One sampling at the end of the vegetation period, when BP concentration is highest, will serve for using indicator plants. However, here one should not forget that the plants do not only accumulate carcinogens but also transform them (Ирха, Кукк, 1983).

The investigation of pollution in the bays of the Baltic Sea showed that in the sea water BP concentration ranges from 0.0004 to 0.004 $\mu g \cdot l^{-1}$, and varies with species (Veldre et al., 1982b). We studied the BP concentrations in different species of algae and phanerogams from various areas, attempting to find out regions with the lowest degree of pollution. The work was also aimed at the elucidation of indicator species most suitable for the evaluation of the pollution of bays by polycyclic arenes.

All together 140 samples were collected from 17 spots. 10 different species, including 6 species of algae, were subjected to studies. The sampling, preparation of samples for analysis and quantitative evaluation of BP concentrations have been described earlier by I. Veldre et al. (1981).

Results

BP concentration in red algae *Furcellaria lumbricalis* varies with areas. For the Gulf of Finland it was lowest in the plants from the coastal waters of the Suurupi Peninsula. It was somewhat higher in the algae

Table 1

BP concentration in *Furcellaria lumbricalis*

Area	Date	Number of analyses	BP concentration, $\mu g \cdot kg^{-1}$ $\bar{x} \pm S_{\bar{x}}$
Suurupi	Sept. 1977	4	0.181±0.069
Western coast of Saaremaa Island	Sept. 1977	6	0.837±0.26
Kassari Bay	July 1978	4	0.223±0.089
Kassari Bay	July 1980	3	0.69 ±0.08
Western coast of Saaremaa Island	July 1980	4	1.86 ±0.51
Northern coast of Vormsi Island	April 1982	3	0.29 ±0.04

Table 2

BP concentration in *Fucus vesiculosus*

Area	Date	Number of analyses	BP concentration, $\mu g \cdot kg^{-1}$ $\bar{x} \pm S_{\bar{x}}$
Suurupi	autumn 1977	2	0.48
Käsmu	autumn 1977	2	1.895
Kaberneeme	May 1978	6	2.07±1.35
Kaberneeme	May 1980	3	1.61±0.09
Kaberneeme	May 1981	3	0.43±0.26
Kaberneeme	Sept. 1981	3	1.15±0.35
Suurupi	May 1982	3	5.59±1.6
Kaberneeme.	May 1982	3	21.2 ±6.7
Vergi	May 1982	3	2.9 ±2.8
Northern coast of Vormsi Island	May 1982	3 (1 below sensitivity)	0.1
Kaberneeme	Sept. 1982	2	0.35

at the northern coast of Vormsi Island. The highest BP concentration was determined in the plants at the western coast of Saaremaa Island (Table 1).

BP concentration in brown algae *Fucus vesiculosus* varies with areas more than in *Furcellaria lumbricalis* (Table 2). All the BP concentrations in plants are given in μg·kg⁻¹ of dry weight.

The lowest BP concentration was discovered in bladder wrack at the northern coast of Vormsi Island. High BP concentration was observed in the algae from the coastal waters of the Suurupi Peninsula. However, it proved still higher in the plants from the coastal waters of the Kaberneeme Peninsula in May 1982. In *Fucus vesiculosus* BP concentration is higher than in *Furcellaria lumbricalis*. This is likely due to the fact that bladder wrack grows in shallow waters (ca 0.5—8 m), and, hence, closer to the polluted water surface than *Furcellaria lumbricalis* (5—15 m). Due to low water salinity, the red alga *Furcellaria lumbricalis* is not distributed east of Kunda, while bladder wrack is abundant only as far as Mahu (western part of the Narva Bay) (Кукк, 1978), farther eastwards it occurs in the form of scattered patches at tips of peninsulas. For the above reasons these species cannot serve as BP indicators for the eastern part of the Gulf of Finland. Therefore we collected green algae of the species *Cladophora glomerata* and *Enteromorpha intestinalis* which occur also in the eastern part of the Gulf of Finland (Кукк, 1979). In the above species BP concentration is considerably high because these algae grow in shallow coastal waters that are strongly polluted by oil (Tables 3 and 4). BP concentration was extremely high in *Enteromorpha prolifera*. In the plants collected near the settlement of Ust-Luga it ranged

Table 3

BP concentration in *Cladophora glomerata*

Area	Date	Number of analyses	BP concentration, $\mu g \cdot kg^{-1}$ $\bar{x} \pm S_{\bar{x}}$
Gakovo 1	May 1978	4	1.4 ±0.65
Gakovo 2	May 1978	3	1.22±0.19
Sosnovy Bor	June 1979	4	4.8 ±0.9
Sosnovy Bor	May 1980	4	1.15±0.06
Sosnovy Bor	May 1981	5	0.66±0.47
Sosnovy Bor	Sept. 1981	2	2.67
North-East Estonia	Sept. 1981	2	2.82
Toolse	Sept. 1982	3	1.29±0.5
Bolshaya Izhora	Sept. 1982	3	3.48
Bolshoi Bor	Sept. 1982	3	4.44
Glebotchevo	Sept. 1982	3	0.48±0.14
Primorsk	Sept. 1982	3	0.75±0.06

Table 4

BP concentration in *Enteromorpha intestinalis*

Area	Date	Number of analyses	BP concentration, $\mu g \cdot kg^{-1}$ $\bar{x} \pm S_{\bar{x}}$
Sosnovy Bor	May 1978	3	0.69 ±0.16
North-East Estonia	June 1979	3	7.117±4.634
Sosnovy Bor	Sept. 1980	3	5.56
Kaberneeme	Sept. 1981	3	1.05 ±0.21
Sosnovy Bor	May 1982	3	background

from 8.06 to 29.3 μg·kg^{-1}, being 18.68 μg·kg^{-1} on the average. Both in *Cladophora glomerata* and *Enteromorpha intestinalis* BP concentration was higher in North-East Estonia and Sosnovy Bor. The influence of thermal pollution was observed on *Enteromorpha intestinalis* in Sosnovy Bor. In the eastern and north-eastern parts of the Gulf of Finland *Enteromorpha intestinalis* reaches 16 cm in length, while in Sosnovy Bor the length of the thalli may attain 1 m (Кукк, 1980).

In the plants from different areas BP concentration is variable. If one should compare BP concentrations in different species collected from one and the same area, e. g. *Furcellaria lumbricalis* and *Fucus vesiculosus*, then in the Gulf of Finland in the Suurupi Bay these values are 0.181 and 0.48 μg·kg^{-1}, correspondingly, and at the northern coast of Vormsi Island 0.29 and 0.1 μg·kg^{-1}. BP concentration was also determined in the red alga *Phyllophora truncata* (0.73 μg·kg^{-1}).

Four species of phanerogams were subjected to studies. The highest BP concentration was determined in *Zannichellia palustris* and *Potamogeton pectinatus* (Table 5). This is due to the circumstance that *Zannichellia palustris* grows near the water level, and *Potamogeton pectinatus* has floating leaves. In this way they experience a greater effect of oil pollution than *Schoenoplectus tabernaemontanii* and *Phragmites australis* which almost entirely extend high above the water. Up to the present no fixed standard has been established for the BP concentration in plants, and therefore the concentration in one or another species cannot be given relative to the standard.

Table 5

BP concentration in phanerogams

Species	Area	Date	Number of analyses	BP concentration, μg·kg^{-1} $\bar{x} \pm S_{\bar{x}}$
Schoenoplectus tabernaemontanii	Vergi	Sept. 1980	6	1.05±0.23
	Vergi	May 1982	2	0.88
	Sosnovy Bor	May 1982	3	all below sensitivity
Potamogeton pectinatus	Ust-Luga	Oct. 1979	3	5.95±2.8
	Sosnovy Bor	Sept. 1981	3	4.2 ±0.42
Zannichellia palustris	Vergi	May 1982	3	5.09±1.3
	Ust-Luga	May 1982	3	7.54±1.64
Phragmites australis	Ust-Luga	May 1982	3	0.03

Table 6

BP concentration in plants in different vegetation periods

Species	Area	Year	BP concentration, μg·kg^{-1} $\bar{x} \pm S_{\bar{x}}$	
			spring	autumn
Fucus vesiculosus	Kaberneeme	1981	0.43±0.26	1.15±0.35
	Kaberneeme	1982	21.2 ±6.7	0.35
Enteromorpha intestinalis	Sosnovy Bor	1978	0.69±0.16	5.56
Cladophora glomerata	Sosnovy Bor	1981	0.66±0.47	2.67
Schoenoplectus tabernaemontanii	Vergi	1980	0.88	1.05±0.2

In perennial bladder wrack, the BP concentration appeared higher in the spring of 1982 than in the autumn of the same year; in green algae, vice versa, it was higher in autumn, i. e. at the end of the vegetation period (Table 6).

Conclusions

If the average BP concentration ranges in the water from 0.0004 to 0.004 $\mu g \cdot l^{-1}$, then in algae it fluctuates between 0.1 and 18.68 $\mu g \cdot kg^{-1}$ and in phanerogams between 0.03 and 7.54 $\mu g \cdot kg^{-1}$.

The brown alga *Fucus vesiculosus* should serve as the main object for further studies as it inhabits relatively shallow waters and is easy to collect without floating devices. *Fucus vesiculosus* is abundant in the whole coastal sea, except the eastern part of the Gulf of Finland where it is successfully replaced by green algae *Enteromorpha* and *Cladophora*. Of phanerogams, *Potamogeton pectinatus* and *Zannichellia palustris* may serve as indicators, especially when estimating the state of inner bays. Green algae and phanerogams should be collected at the end of the vegetation period when they show the highest BP concentration. Studies have revealed that the area of Ust-Luga experiences the highest degree of pollution, whereas the coastal waters remaining north of Vormsi Island represent the cleanest region.

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VETIKAD KUI MEREVEE POLÜTSÜKLILISTE AREENIDEGA SAASTUMISE INDIKAATORID

Artiklis on esitatud andmed benso(a)püreeni (BP) sisalduse kohta Läänemere erinevatest lahtedest kogutud vetika- ja kõrgemate veetaimede liikides. On selgunud, et BP akumuleerub mereveest nii õistaimedesse kui ka vetikaisse, kusjuures merevee keskmine BP sisaldus ei ületa 0,004 μg/l, vetikates kõigub see 0,1—18,68 μg/kg ja õistaimedes 0,03—7,54 μg/kg. Esialgsete tulemuste põhjal võib oletada, et vetikad akumuleerivad veest rohkem BP-d kui õistaimed. Vetikaist sisaldasid BP-d kõige rohkem *Enteromorpha* liigid ja kõige vähem *Furcellaria*. Kõige madalama BP sisaldusega olid Vormsist ja kõige suuremaga Ust-Lugast kogutud vetikad.

Kevadiste ja sügiseste proovide võrdlus näitas, et mitmeaastastel vetikatel (*Fucus*) ei ole BP sisalduse muutumises kindlat seaduspärasust, kuid üheaastaste vetikate puhul on sügisel, vegetatsiooniperioodi lõpul BP sisaldus suurem kui kevadel.

Merevee polütsükliliste areenidega saastumise indikaatoriks võib Käsmust kuni Vormsini kasutada põisadrut, Soome lahe idaosas aga rohevetikate liike *Cladophora*'t või *Enteromorpha*'t. Et saada rohkem võrdlusandmeid eri vetikaliikide BP sisalduse dünaamikast, tuleb uurimistöid selles valdkonnas jätkata.

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ВОДОРОСЛИ КАК ИНДИКАТОРЫ ЗАГРЯЗНЕНИЯ МОРСКОЙ ВОДЫ ПОЛИЦИКЛИЧЕСКИМИ АРЕНАМИ

В статье приводятся данные о содержании бенз(а)пирена (БП) в некоторых видах водорослей и высших водных растений отобранных из различных бухт Балтийского моря. Результаты работы показывают, что водоросли накапливают БП из морской воды; среднее содержание БП в морской воде не превышает 0,004 мкг/л, а содержание его в водорослях колеблется от десятых долей до десятков мкг/кг сухого вещества. По предварительным данным можно полагать, что водоросли накапливают из воды больше БП чем высшие водные растения. Наибольшие количества БП содержали виды энтероморфа, наименьшие — фурцеллария. Наименьшие концентрации БП были обнаружены в водорослях из Вормси, наибольшие — в Усть-Луге.

Сравнение весенних и осенних проб показало, что у многолетних водорослей (фукус) не обнаружено закономерностей в содержании БП, а у однолетних количество БП осенью, в конце вегетационного периода, больше, чем весной. В качестве индикатора загрязнения морской воды полициклическими аренами для участка Балтийского моря от Кясму до острова Вормси можно рекомендовать фукус, а для восточной части Финского залива — зеленые водоросли: кладофору или энтероморфу.