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ALGOLOGY

Effect of Oil and Oil Products on Morphofunctional Parameters of Marine Macrophytes

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Abstract—In the present paper, the authors analyzed and generalized data on the oil pollution effect on marine macrophytes at various structural levels.

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The expanding production of crude oil at the continental shelf and shipment and transportation of oil and its products entailed the crucial significance of research on the effect of oil toxicants on marine biocenoses. Coastal phytocenoses are impacted to a greater extent by oil contamination. The significance of marine macrophytes as producers of organic matter and breeding grounds of many fishes and invertebrates is well known. At the same time, data on the effect of oil and oil products on macrophytes are fragmentary and rather contradictive. The present work is an attempt to summarize and to analyze the available data on the oil contamination impact on seaweeds. The study of the response of macrophytes to oil impact is developing in several fields.

PHENOMENOLOGICAL APPROACH

This approach includes nature observations with description of change of projective cover, biodiversity, and size-mass production parameters of seaweeds at oil spill impact. We did not use the data of numerous publications concerning the damage of oil contamination based on quite fair emotions, which, however, lack concrete figures referring to morphofunctional changes in macrophytes subjected to oil impact.

On having reached the coastal zone, the crude oil covers it with a rather thick layer. The "Amoco Cadiz" accident entailed the covering of 200 km of coastline of the Bretagne province (France) by 5–15 cm layer of oil [46]. In such instances macrophytes of the littoral and supralittoral zone are the most vulnerable.

The emulsified oil, differently called "chocolate mousse," can stick to the thalli of algae, overweighing and breaking them. Beyond mechanical damages, the bleaching of thalli was often observed. However, Nelson-Smith [18] recorded that the surface of macrophytes with mucous thallus was not subjected to oil sticking. Algae with mollusc fouling were the exclusion. There is data that littoral alga are more subjected to the alternating effect of spilled oil than deep-sea species [45]. At the same time, these authors stressed that losses of parts of thalli at short-term oil spills do not exceed the total losses of biomass during winter storms.

Comparative analysis of the littoral of Dal'nezelenetskaya Guba as a clean habitat and the polluted littoral of the Murmansk Sea Port, where macrophytes grow on stones covered by a layer of fuel oil, revealed that the clean area had a much greater species diversity of algae, 12 species with a 85–90% projective cover contrary to 4 species with a 15% projective cover recorded in the sea port area [2].

The research carried after the "Tampico Maru" oil tanker crash at the California coast, displayed that one of the key factors limiting the spreading of the brown algae *Macrocystis pyrifera* before the accident was the eating away of the alga by sea urchins belonging to the *Strongylocentrotus* genus. Despite the fact that *M. pyrifera* had contact with the oil film, young sporophytes occurred in mass 2–3 months after the crash. The perishing of zoobenthic species, including herbivorous ones that occurred to be less sustainable to oil impact, was considered to be a cause of the algal growth. The other cause that the triggered growth of *M. pyrifera* was that the crashed oil tanker actually became a wave breaker and provided a favorable hydrodynamic situation in the small bay. (Norph et al., 1964; cit. in [18]).

Dispersants applied at the coast cleansing from oil often enhanced impact of oil contamination to alga, as they were more toxic than the oil [19]. Application of dispersants at the Cornwall coast almost had van-

quished fucus algae and limpets, facilitating colonization of that part of the coast by the green algae, *Enteromorpha intestinalis, E. compressa*, and *Ulva lactuca*, which were typical r-strategists. "The green phase" was replaced next year by seedlings of young sporophytes of fucuses that limpets eagerly commenced to devour, however, leaving intact the remained thalli of adult fucuses [18]. Herbivorous invertebrates vanished after the 1989 oil spill from the "Exxon Valdez" oil tanker crash that facilitated development of epiphyte algae on fucuses and favored the decrease of biomass of elder age groups of the population, while young plants had considerably suffered direct oil impact [54].

Similar successions were recorded also in areas of continuous oil drainage into seawater. Kalugina-Gutnik [9, 10] described the changes, which occurred in the Sevastopol Harbor and in the Odessa Port in the 1930–1970s. Pollution of sea coast areas by various toxicants, including oil products, caused the replacement of the long-lived algae of the *Cystoseira* genus, that dominated in the sublittoral zone, by a one year seasonal algal species, mostly of the *Enteromorpha* genus. Such phytocenoses are less productive than the *Cystoseira* communities [10], the abundance of zoobenthos in biotopes formed by the green algae was several times less [25]. The similar phenomena occurred also in Avachinskaya Guba, at which coast the large industrial center Petropavlovsk-Kamchatsky is located [11]. There decrease of the zone of fucus and laminaria algae and their replacement by Ectocarpales (*Laminariocolax, Pylaiella*) and green filamentous algae (*Urospora, Ulothrix*) was observed in the 1990s.

Thus, the oil getting to a coastal area affects the entire ecosystem, entailing selection of the most sustainable forms. In general, the diversity of the plant and animal world of coastal biotopes at oil contamination decreases with opportunistic species (r-strategists) becoming dominant. The K-strategists, or later succession forms, are displaced for some time.

EXPERIMENTAL APPROACH

The given approach is based on the study of the range and mechanism of sustainability to the impact of oil and its products in algae at various levels of their organization.

The Condition of the Photosynthesis Apparatus as a Parameter of the Functional Activity of Macrophytes Subjected to the Impact of Oil Contamination

Most of the researches consider the condition of the photosynthesis apparatus, the photosynthesis rate as a principle, as a parameter of functional activity of macrophytes [22, 30]. Some works quoted data on the variation of pigment composition and practically lack data on the variation of the ultrastructure of chloroplasts [34].

The observation carried after the "Tampico Maru" oil tanker crash, has shown that impact of the emulsion of diesel fuel of 0.1%[1] concentration almost completely arrested photosynthesis in young parts of the *Macrocystis* alga for three days, concentration of the emulsion of 0.01% decreased photosynthesis in 7 days. Crude oil in a concentration of 100 mg/l caused irreversible changes for 6–12 h and, at concentration 10 mg/l, the same changes were observed in 4 days. The reduced fuel oil was the most toxic of the studied agents [35].

Occurring in sea water, the oil undergoes significant changes, some hydrocarbons solves in water, others emulsify, forming "chocolate mousse," and most of the ingredients of crude oil remain in the form of slick on the water surface [19]. A varying effect of the above listed forms of oil on photosynthesis of the Black Sea red alga *Phyllophora* was displayed in the experimental work of Yartseva [34]. The author recorded that the presence of oil in the form of slick with concentration 0.05–1.0 g/l or more inhibited photosynthesis of the alga. The decrease of the photosynthesis rate under the effect of oil slick varied depending on season, being maximal in February through March. The pigment contents decreased proportionally, chlorophyll by 82.5% compared to the control, carotenoids by 87%, and xanthophylls by 80%. The most intense destruction of the thallus, thereof, occurred in younger segments, of which photosynthesis rate was higher.

The oil slick, applied directly to the thallus, impeded photosynthesis rate and decreased activity of the catalase, the enzyme responsible for the decomposition of toxic for plant hydrogen peroxide (H_2O_2), which entailed accumulation of peroxides in cells. The water-soluble part of oil decreased pigment content and affected the activity of the catalase, but augmented, meanwhile, the rate of photosynthesis and accumulation of dry matter [34].

Researches of the Institute of Marine Studies, University of Alaska, USA, displayed the change of the photosynthesis rate in macrophytes, depending on their taxonomic attribution and concentration of toxicants in natural experiments on the effect of oil emulsion and its slick [52]. A significant increase of the photosynthesis rate (the radiocarbon method was applied in the measurement) was observed in some algal species under effect of minor concentrations of oil. Thus, the rate of photosynthesis increased by 80% in ulva and alaria algae at oil concentration 0.7 mg/l, and by 30% in costaria alga at oil concentration 0.007 mg/l. A decrease of photosynthesis rate was observed at rising oil concentrations. In *Enteromorpha intestinalis* the photosynthesis rate measured by the oxygen method decreased almost 8 times for 4 days (up to 1.5 ml O_2/g of dry mass per hour) under effect of oil emulsion at concentration 10–12 mg/l, an insignificant increase of respiration rate

[1] The authors most often use the following values of concentration of oil and its products: 0.1% (V/V) ≅ 1 ml/l ≅ 1 g/l = 1000 mg/l = 1 000 000 μg/l = 1000 ppm.

(from 2 to 3 ml O_2/g of dry mass per hour) was recorded at that. An inhibition of photosynthesis was recorded in *Cladophora stimpsonii, Ulva fenestrate* and *Laminaria saccharina* under the effect of oil (7 mg/l). No effect of oil emulsion on the photosynthesis rate of *Fucus distichus* was recorded for 4 days at 0.1, 1, 10, 25 and 100% concentration.

Different sensibility of seaweeds to oil was revealed not only among taxonomically distant groups of macroalgae, but also in keen species. Kusk [41] conducted experiments on the effect of water-soluble fraction of light oil (the North Sea) on pure cultures of *Acrosiphonia sonderi, A. arcta,* and *A. centralis.* An indicator of oil toxicity was the rate of the photosynthesis measured in a specially designed by the author chamber with application of potentiometer. Under impact of the water-soluble fraction of light oil, the photosynthesis rate of *A. arcta* decreased by 7% in 2 h of incubation, then increased some, but in 24 h reached only 40% of the initial. Photosynthesis rate of *A. sonderi* decreased gradually by 48% for a day of the experiment. *A. centralis* was less responsive to the effect of the water-soluble fraction of oil, as photosynthesis rate of that alga decreased by 16% for a day. Thus, the photosynthesis rate in studied species of *Acrosiphonia* generally decreased under impact of the water-soluble fraction of oil, but was species specific. In our opinion, such an effect of oil toxicants on keen species of *Acrosiphonia* might be an explanation for the account of the size of the cells of *A. sonderi,* which more than twice exceed that of *A. arcta* and *A. centralis*; that, respectively, increased the surface area of thallus providing greater contact of *A. sonderi* with oil toxicants.

The Black Sea algae *Cystoseira barbata, E. intestinalis* and *Ulva lactuca* (= *U. rigida*) insignificantly decreased their photosynthesis rate under effect of the oil emulsion at concentration 0.1%, and the red alga *Polysiphonia elongata* decreased that parameter 2 times for 2 days of exposition [1, 31].

Various effect of diesel fuel and lubricant on the photosynthesis rate of *Fucus vesiculosus, F. serratus, L. saccharina* and *Palmaria palmata* from the coast of Barents Sea was displayed [22, 30]. The most toxic for fucus algae was diesel fuel and for palmaria and laminaria was lubricant. The authors assumed that the different degree of effect of oil toxicants on photosynthesis of algae was caused by morphological features of the thallus. At the synchronous impact of two oil products, an antagonistic effect was observed. The simultaneous addition, for example, of lubricant and diesel fuel removes the negative effect of the latter on the photosynthesis of *F. serratus*.

We have shown that the photosynthesis rate measured by the radiocarbon method in the same age thalli of bladder wracked from continuous oil pollution and the clean habitat at the littoral of Barents Sea was the same, being 1.02 ± 0.02 mg CO_2/g of dry mass per hour [2]. The composition and quantity of photosynthetic pigments did not differ.

Thus, most algae under acute oil impact decreased photosynthesis rate and increased respiration, which entailed adaptive retuning of the photosynthesis apparatus. Some algae, *F. vesiculosus* e.g., are capable of effective adaptation to negative conditions of continuous impact of oil toxicants.

Impact of Oil Contamination on Reproduction Processes and Early Phases of Development of Macrophytes

Early phases of development of algae are the most responsive to a great number of stresses, including the toxic effect of oil and its products [24, 43].

The death of spores of the Black Sea algae *Dilophus fasciola* and *Polysiphonia opaca* was already recorded at an insignificant oil concentration [13, 14, 31]. Thus, spores of *D. fasciola* soon after attachment to substrate ceased development at the phase of germination and formation of a few cells under impact of oil at concentration 0.1–1 ml/l. Tetraspores of *P. opaca* died at oil concentration 1 ml/l, having no time to divide to apical and basal cells.

Germs of the Black Sea algae *Polysiphonia breviarticulata, P. opaca,* and *D. fasciola* retarded in their growth rate under the effect of a lesser concentration (0.01–0.1%) of oil emulsion. The authors [13, 14] also recorded that the apical cell of the germ was perishing first (in the experiments the oil concentration was 1 ml/l), and that caused transversal divisions of the basal cell, while longitudinal divisions were lacking. The death of the cells was concurrent to nonreversible plasmolysis, disturbance of integrity of cellular walls, the change of protoplasm structure. Color of the *Polysiphonia* varied from dark red to grey, and then to black, with grain vanished. The plasmolysis resulted formation of black concretions in cells of *Dilophus* and *Cistoseira.* The dead cells lost contact with the substrate and were easily washed away by water. It is interesting that the growth of germs of the *Polysiphonia* and *Dilophus* on account of lateral divisions was observed in some instances [14]. At the same time, experiments on the *Cystoseira* have displayed that oil in minimum concentrations can stimulate development of germs of the seaweed. For example, the growth rate of the *Cystoseira* exposed to oil emulsion of 0.01% concentration increased 1.1 times, and the growth rate was close to control value at the augmentation of oil concentration up to 0.1% [13].

The oil and its products impact not only algal spores and germs but also the earliest reproductive stages. For example, Steele [53] has shown inhibition of fertilization in fucus algae at oil concentration 2 μg/l, but germination of zygotes of the laminaria was observed by the author at oil concentration 20 μg/l. D.C. Reed and colleagues [50] recorded a 40% decrease of yield of the

spermatozoa of laminaria impacted by sewage waters polluted by oil of 0.01% concentration.

Thélin [55] and Sepanyan [26], analyzing behavior and germination of spores and gametes under the effect of oil contamination, came to the conclusion that motility of fucus antherozooids and laminaria zoospores was not an indicative response of biotesting of sea water polluted by oil and its products. The change of locomotion pattern or the halt of male gametes did not affect fertilization and zygote formation in *F. vesiculosus* at a concentration of oil up to 30 mg/l, and of gasoline up to 5 mg/l.

Male gametophytes of laminaria were more sensitive to oil than female gametophytes and sporophytes of that alga. Inhibition of development was recorded in gametophytes at oil concentration 10–50 μg/l, in sporophytes of 200 μg/l (Hopkin, Kain, 1978, cit. after [43]). The same hypersensibility was also recorded by the authors in fucus spermatozoa. It was assumed that spermatozoa of fucus and male gametophytes of laminaria have a lesser nutrient reserve and a higher respiration rate. The given conclusion did not match the results of other works [49, 50], which evidenced that female gametophytes and ootids of *M. pyrifera* were the most responsive to the impact of sewage waters containing oil products. McLachan and Bidwell [44] came to the conclusion that 2–4-day sporophytes were more responsive to oil contamination than 5–7-day ones.

Thus, algae at early stages of development are the most responsive to the impact of oil and its products. That can be manifested in retardation or complete cease of development of spores and germs. In most species gametophytes, early sporophytes, and younger parts of the thallus are most subjected to the altering effect of oil pollution. Male individuals were more responsive to oil contamination impact, than female ones. In some instances minor concentration of oil and its products can stimulate growth in early sporophytes.

Oil Impact on the Content of Protein, DNA and RNA

Beyond variation of growth rate, photosynthesis, and pigment composition, the variation of nucleic acid content was observed in some species of marine macrophytes in an oil-polluted environment [1, 7, 31, 37]. For 3 days emulsified oil in concentration 1 ml/l caused an increase of RNA content by 39% and that of DNA by 21% in *E. intestinalis*, the RNA content increased by 8% in *Grateloupia dichotoma* and *Bryopsis plumosa*. A similar response to the effect of toxicant of the same concentration was recorded in the red alga *Callithamnion corymbosum*, its RNA and DNA content increased by 6 and 34–36%, respectively. Oil effect on the genetical apparatus of kin algal species can vary. Thus, in *Ceramium rubrum* the content of DNA increased by 11% at a stable level of RNA, and in *C. ciliatum* the RNA content dropped to 60% of control at a constant level of DNA. Tsymbal [31] has divided the Black Sea macrophytes to three groups by variation of DNA and RNA content under the effect of oil toxicants. The first group included *P. opaca, G. dichotoma,* and *C. corymbosum.* In that algae a decrease of DNA as RNA was recorded. The second group was pooled of *C. ciliatum* and *B. plumosa*, in which RNA content increased at a stable DNA content. In the third group there were *C. barbata* and *Scytosiphon lomentarius*, which level of DNA decreased at a stable level of RNA. Two macrophytes species, *E. intestinalis* and *C. rubrum,* formed the apart group, in *Enteromorpha* content of the both nucleic acids increased, and in the *Cerarium* only DNA increased. The oil caused not only a decrease or increase of nucleic acid content, but also depolymerization of DNA. The labile fraction of DNA was most responsive to oil impact in *P. opaca* and *G. dichotoma*. The depolymerization of DNA occurred as a result of activation of enzyme systems, but not for a direct effect of oil on DNA. However, no effect of the same concentration of oil (1 ml/l) on depolymerization of the total DNA was recorded in the green algae *Ulva rigida*.

It was shown that no significant deviation of protein content collating with control was recorded in brown algae of the Barents Sea at oil intoxication [7]. No deviation of free nucleotide content was revealed in *F. vesiculosus*, but significant decrease of RNA content was recorded. The other trend was revealed in *L. saccharina*: a decrease of the pool of free nucleotides did not entail visible quantitative changes in nucleic acids. The researchers recorded that oil was not a specific toxicant affecting one specific system, but induced uncoordinated changes in contents of protein, free nucleotides and nucleic acids [7].

Thus, the oil affects content of nucleic acids, composition and ratio of nucleotides in some green and red algae, that can entail transformation of primary DNA structure and of biosynthesis of nucleotides. The genetical apparatus of brown algae have a greater sustainability to oil impact.

Possible Mechanisms of Penetration and Accumulation of Oil Hydrocarbons in Algal Cells

Presently there is no adequate explanation of mechanism of penetration of oil hydrocarbons into the cell of macrophytes. Patterns of absorption of hydrocarbons by oil-oxidizing bacteria are rather well studied. In the opinion of Gusev and Koronelli [3], the fact that hydrocarbons are oxidized intracellularly is beyond doubt, but, to get into a cell, they should have direct contact to the wall of the bacterial cell. However, no enzyme, which carried out active transference of hydrocarbons into the cell, has been revealed by the present. Based on experiments carried out on microorganisms, a number of researchers [5] consider possible a passive penetration of hydrocarbons into the cell. To start oil oxidation, the hydrocarbons should saturate the cell wall up to a certain limit of saturation, then oil-oxidizing enzymes are activated, and “not held” oil hydrocarbons are

adsorbed on the cell wall. In the process of utilization of oil products by the bacterial cell, the adsorbed hydrocarbons come into the cell. Lipids of the cell wall are the basic link in binding hydrophobic hydrocarbons. It was recorded that, with the increase of oil content in the environment, the increase of lipids occurred in the cell [4]. Our research [2] also displayed significantly greater total lipid content in *F. vesiculosus* from habitats continuously polluted by oil, than from clean areas.

In mycobacteria mycolic acids were revealed, which, thanks to available long aromatic chains, play the role of binding the substrate for hydrocarbons of oil and its products. In the environment, which was not polluted by oil, the specified acids are enable to bind lipids, waxes, carbohydrates, and proteins but change of the source of hydrocarbon in the environment stimulated synthesis of mycolic acids [3]. Mycolic acids were found only in saprophytic mycobacteria; in other oil-oxidizing micro-organisms (arthrobacteria e.g.), hydrocarbons are supposed to come into the cellular wall through special sites. The formation of "channels" with electron dense content was revealed in some microorganisms cultivated in hydrocarbon containing media. A presence of lipopolysaccharide that partially comes out and binds hydrocarbon substrate, then penetrates into the cellular wall and is broken up by enzymes, was supposed [3].

The possibility of the sorption of microorganisms on the cell wall was considered by a great number of researchers [36, 40, 42, 47]. Some authors recorded that, when oil was sorbed on the cell surface of algae, it was decomposed much faster (Zeppa, Schlotzhauer, 1983; cit. in [24]).

Revealing of the mechanism of penetration of oil hydrocarbons into the cells of macrophytes (interaction of oil hydrocarbons with the cell surface of macrophytes) is one of the main tasks in the solving of the problem of acclimation of algae to oil pollution. Those are surface layers of cells that are engaged in photosynthesis in most of the dominant algae of the littoral.

Reddin and Prendeville [48] had revealed that oil hydrocarbons are capable of destroying plasmalemma, substituting membrane lipids and increasing its permeability. Research carried out by the authors on the effect of aviation and diesel fuel, lubricants, and kerosene on the permeability of plasmalemma in *Fucus serratus* and *Laminaria digitata* has shown that the increase of permeability of the surface membrane of cells of laminaria occurred already for one hour of exposure to an environment with toxicant. The maximum occurred in 4 h, then membrane permeability increased slightly. In the tooth *Fucus serratus* minor variation of membrane potential was recorded at action of diesel fuel, while machine oil, kerosene, and aviation fuel did not cause a deviation in magnitude of membrane potential during 24 h. The authors related toxicity of the diesel fuel to the prevalence of benzene hydrocarbons in its composition, which is few in kerosene and lubricant, and to its high viscosity that facilitates long-term contact of toxicant with the surface of alga.

As was recorded above, the penetration of oil hydrocarbons into cell cytoplasm of macrophytes can entail damage of the membrane complex and structure of the cellular matrix. At the same time, oil hydrocarbons are capable of being accumulated in the cell up to a certain limit without visible traces of damage to the plant as a whole. Such effect was observed mostly in macroalgae, which for a long-term period were in an oil-polluted environment [13, 15, 32, 33].

Red algae of the Mediterranean and Black Seas are specified with content of a wide spectrum of normal alkanes (from C_{15} up to C_{24}) both of autochthonous and allochthonous origin. In the green algae *Ulva* and *Enteromorpha*, the availability of n-pentadecane was recorded, which was characteristic also for brown algae. It was determined, that hydrocarbon composition of algae growing in clear and polluted areas differed significantly. Thus, *C. corymbosum*, e.g, from a clear area contained only n-C_{17}, and the alga from the polluted harbor contained unbranched alkanes ranging from C_{15} up to C_{25}. Intrinsic hydrocarbons of *E. intestinalis* were normal alkanes C_{17} and C_{19}, and assay from the oil port contained paraffins from C_{17} up to C_{24} [13].

Macroalgae are capable of accumulating not inherent hydrocarbons, for example, isoprenoids [57]. It is supposed that algae can include oil hydrocarbons into their metabolism [1]. The given circumstance, probably, explains the fact that low-level concentrations of crude oil and its low-molecular ingredients are capable of stimulating the growth of algae to a certain degree, which does not exclude the regulatory function of oil hydrocarbons as growth factors (Clegg, Koevening, 1974; cit. in [21]). The metals contained in oil and functioning as trace elements apparently took some part [39].

Thus, interaction of oil hydrocarbons with the cellular wall of algae entails its partial or complete destruction, at the same time there are some unrevealed mechanisms facilitating accumulation of oil hydrocarbons into the cell and their incorporation into the cell metabolism.

Role of Microorganisms in Interaction of Oil and Macrophytes

Algae are the substrate for the original microperiphyton community, with diatoms and microorganisms taking a dominating part. It was shown, that among several hundreds of strains of bacteria isolated from lamella of laminaria, most were heterotrophic forms and bacteria decomposing as alginic acid as a wide spectrum of organic compounds including oil [8]. Among the Black Sea algae, the maximum quantity of bacteria manifesting lipolytic activity (i.e., ability to reduce fats to lower acids) was revealed in green algae of the *Cladophora* genus, in other macrophytes the

ratio of lipolytic and nonlipolytic bacterial strains was 1 : 1 [20].

Green and red macroalgae can be a "reservoir" for sea yeast of the *Candida* genus, while kelps (fucuses and laminaria) are capable of hindering the development of the yeast excreting phenol compounds [51]. Similar patterns were also recorded in higher water plants [16, 17]. It is known, that mixed cultures of bacteria utilize oil hydrocarbons faster than monoculture [12]. Key factors affecting this process are sea water temperature, oxygen content, fluctuations of pH level, availability of biogenes, concurrently with some other factors, such as change of the chemical compound of oxidized material, structure of the microbian community, occurrence of decay, and metabolites of bacteria [4, 12, 27, 36]. Now there is a proven explanation of the mechanism of the symbiotic relation of higher water plants (common reed and cattail, etc.) and concomitant microflora [23]. There is a close relation between excretory activity of higher water plants and the dynamics of concomitant microflora, which can be controlled by a dosed administration of nitrogen and phosphorus. Formerly Khailov [28, 29] has shown that marine macrophytes are also capable of excreting various exometabolites into the marine environment, sometimes rather significant amounts, which that stimulate or depress development of phytoplankton and periphyton, i.e., macroalgae from a specific ambient environment, determining and monitoring species composition, dynamics of growths rate, and population of belonging organisms, including oil-oxidizing bacteria.

The research of Wrabel and Peckol [56] corroborated the common notion that there is a complex mechanism of interaction of macro- and microalgae with microorganisms, in particular, with oil-oxidizing bacteria. On the one hand, macroalgae are substrate and by excreting various metabolites form ambient living environment, on the other hand, oil-oxidizing bacteria decomposing oil hydrocarbons and including them in metabolism also excrete some spectrum of substances in the environment, which are capable of significantly facilitating the development of macroalgae. It was shown in the course of experiments [56] that the microbian community using brown alga *F. vesiculosus* as substrate enables the utilization of oil and its products as much as possible in the presence of nitrogen and phosphorus compounds, decreasing their toxic effect by several times. On those grounds, it is suggested to use fucus algae for recycling oil-polluted seawater, principally around oil producing platforms.

CONCLUSIONS

The data obtained at the present time display that the oil is a complex nonspecific toxicant, affecting all planes of vital activity of algae, from the subcellular and cellular level, and confining the population and interspecific interactions of organisms. The response of macrophytes to high concentrations of oil and its products can be manifested by a decrease of species diversity and projective cover, decrease of life span, growth rate and photosynthesis of adult individuals, concurrently with inhibition of the development of spores, gametophytes and germs.

The effect of a minor concentration of oil can be positive for one seaweed and negative for others. Various forms of oil (solved, emulsified, film) cause a response of macroalga varying on duration to the stress effect. The effect of oil is species-specific to marine macrophytes. The degree of effect of oil ingredients depends on environmental factors, light intensity, temperatures and salinity of seawater, availability of biogenes, etc.

In general, despite the alterating effect of oil and its products on macrophytes, the microalgal community is sustainable enough against the impact of the given factor. That was achieved by specific retunings, both at microlevels of the individual and at macrolevels of the entire coastal ecosystem. Now acclimation mechanisms of algae to oil contamination are insufficiently clear. It is possible to assume that during evolution some inhabitants of the littoral developed the ability to include oil hydrocarbons into their metabolism. Another probable way of surviving in an oil-contaminated environment is the development of natural symbiotic associations, when the surface of the thallus is covered with the film of microorganisms, mostly of oil-oxidizing forms.

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