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MARINE BIOLOGY

Anthropogenic Influence on the Planktonic Community in the Basin of Mamala Bay (Oahu Island, Hawaii) Based on Field and Satellite Data

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Abstract—The anthropogenic impact on the biomass of coastal plankton communities caused by submerged disposal of urban sewage waters (dumping) was studied. The observations were carried out in August–September of 2002–2004 in Mamala Bay (Oahu Island, Hawaii) using satellite and sea truth methods. An analysis of the variability of the integral indicators of the water column determined on the basis of shipborne measurements allowed us to divide them into two groups: the elements most sensitive to the pollution (heterotrophic bacteria (H-Bact), the phototrophic cyanobacteria *Synechococcus* spp. (SYN), and chlorophyll *a* (CHLa)) and the elements that manifested episodic positive dependence on the inflow of the polluted waters (heterotrophic unicellular eukaryotes, small unicellular algae, the phototrophic green bacteria Prochlorococcus spp., as well as the total biomass of microplankton). It was shown that the submerged wastewater disposal in the region of the diffuser of the dumping device led to an insignificant (1.2–1.4 times, on the average) local increase in the integral biomass of H-Bact, SYN, and in the content of CHLa. A similar but sharper (1.5–2.1, on the average) increase in these parameters was found in the water layers with maximal biomasses. The possible pathways of disposed waters (under the pycnocline, at its upper boundary, and in the entire mixed layer) were analyzed on the basis of studying the vertical displacement of the biomasses of H-Bact, SYN, and prochlorophytes. The possibility of using the optical anomalies distinguished from satellite data as markers of anthropogenic eutrophication caused by dumping was confirmed. Application of such markers depends on the water transparency and on the shapes of the curves of the vertical distribution of autotrophic organisms.

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INTRODUCTION

More than 30000 different chemical compounds are annually dumped in the ocean. Among them, there are stable pollutants, which can be conserved in seawater after dumping and circulate there during tens and hundreds of years.

The near-shore waters, which account only for 10% of the total area of the ocean, are subjected to the main load of anthropogenic impact. The main sources of such impact on the coastal basins are the following: the transport of different substances from land that are used in municipal services and agriculture, the wastes of industrial production buried in the water, the leakages of different chemicals during ship operations, the emergency outflows from ships or leakages from underwater pipelines, the mining of minerals on the continental shelf, and the dumping of industrial and municipal sewage waters using submerged pipelines. The latter source has the greatest influence on the ecosystems of coastal basins.

At present, the amount and intensity of pollution in the World Ocean has reached a very high level. Thus, a decrease in the anthropogenic impact and organization of monitoring of the pollution of oceans and seas and, first of all, of the coastal areas has become an urgent task. One of the most effective means for studying the World Ocean is the application of aerospace methods and technologies [1, 7].

In order to achieve a successful solution of monitoring problems and preservation of the environment in the basins of seas and oceans, it is necessary to carry out multidisciplinary studies of various oceanographic characteristics using remote and in situ means. In 2002–2004, such studies were conducted in Mamala Bay (Oahu Island, Hawaii) [2, 3, 7–9, 14, 15]. While performing the monitoring, panchromatic, multispectral, and hyperspectral space images were obtained from the *IKONOS, QuickBird*, and *EO-1* satellites, as well as radar images from the *RADARSAT* and *ENVISAT* satellites. Information from the *TERRA, AQUA, GOES*, and other satellites was also used [7]. The measurements of the hydrophysical, hydrooptical, and biological parameters of the aquatic medium using sensors installed on stationary moored platforms and vessels were carried out simultaneously with satellite surveys on September 2, 2002; September 13, 2003; and August 16, 2004 [7–9, 15].

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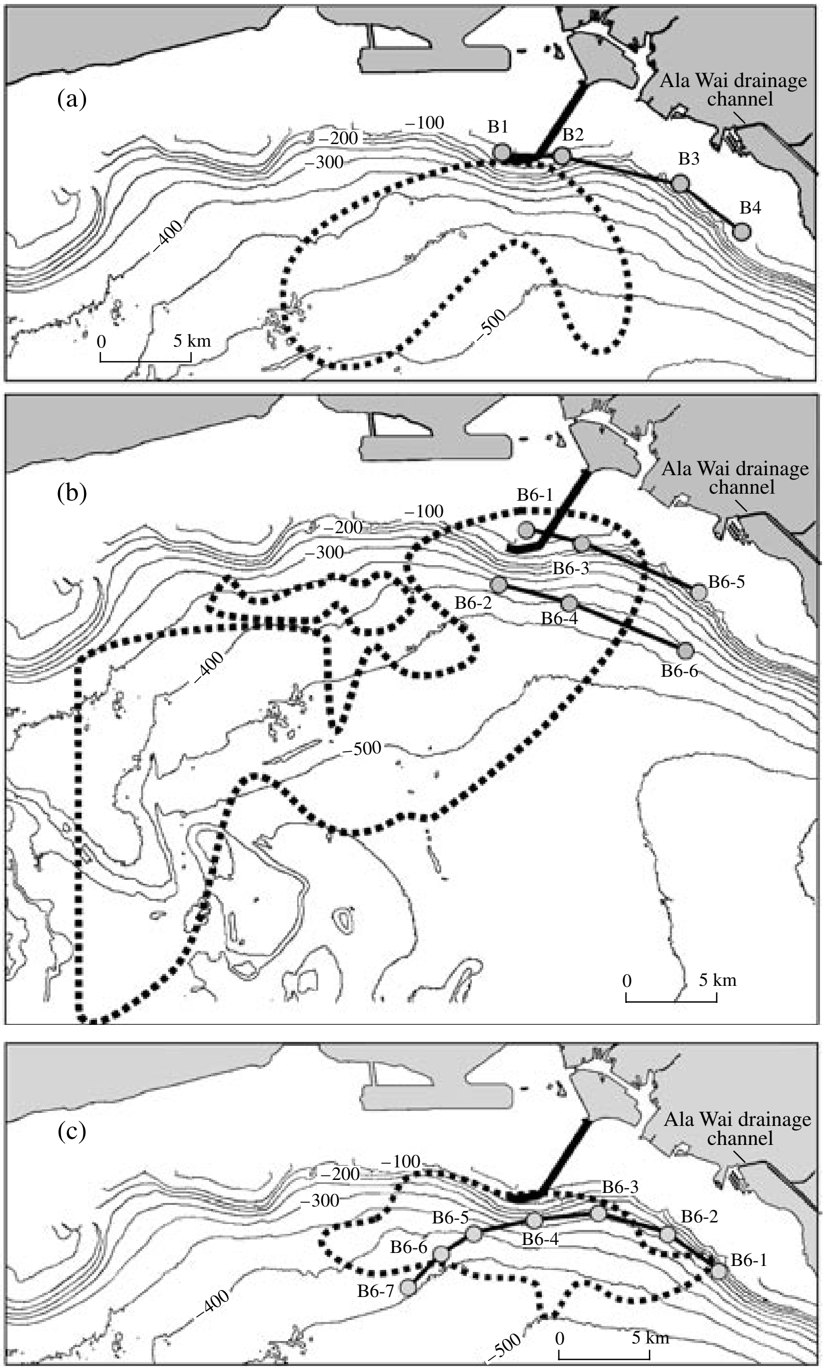

Fig. 1. The results of combining the locations of the biological stations and the boundaries of the optical anomalies, which were distinguished from satellite multispectral images of high spatial resolution obtained from the *IKONOS* satellite on (a) September 2, 2002, and (b) September 13, 2003 and (c) from the *QuickBird* satellite on August 16, 2004.

The main objective of the studies was estimating the influence of the sewage waters on the ecosystem of the coastal basin in the recreation zone of Oahu Island. Wastewater treatment plants (located on Sand Island) provide enhanced primary purification of 70 mln. gallons (318220 m^3) of polluted water a day [12]. The treated flow is directed into the ocean through an 84 inch (~2.1 m) pipeline connected to a diffuser located at a distance of 4630 m from the coastline at a depth of 69–72 m (Fig. 1). The total length of the diffuser is 1036 m. It consists of three sections with 275 lateral holes each with a diameter of 7.8–12.7 cm. The mean speed of the flow through these holes is 3 m/s, while the discharge is 4.48 m^3/s [12].

Owing to the high productivity of the wastewater treatment plants on Sand Island, one can expect a certain impact of the sewage waters on the ecosystem of the pelagic area in the Mamala region. In our study, we limited ourselves to studying the impact of deep-water disposal of these waters on the integral (over the water column) biomass of various planktonic communities and on the character of their vertical distribution.

The waters around Oahu Island are related to the southern part of the North Pacific Subtropical anticyclonic gyre (with a center approximately at 28° N), which is characterized by very low concentrations of nutrients and chlorophyll in the surface layer, i.e., in the layer whose parameters are recorded by multispectral sensors [19]. In these waters, significant seasonal fluctuations of the depth of the upper boundary of the thermocline are observed against the background of relatively constant surface temperature throughout the entire year (usually 24–27°C). Its depth changes from 120 m in the winter to 30 m in the summer [11]. A fuzzy boundary of the North Equatorial Current is located south of Hawaii; its northern branch forms small mesoscale eddies elongated in the latitudinal direction west of the islands, which masks the main circulation. The characteristics of the local currents near Oahu Island strongly depend on tidal phenomena with semidiurnal and diurnal periods and seasonal displacements of large-scale oceanic currents. The currents are generally directed to the west along the coast.

The complex interaction between different currents and water motions can change the general pattern of the distribution of chemical and biological parameters in the region of the wastewater disposal and hamper the study of the anthropogenic influence on the ecosystem of Mamala Bay.

RESEARCH METHODS

Optical anomalies at the surface and in the surface layer of the ocean (~50 m thick) whose optical characteristics are recorded by the multispectral facilities were distinguished from multispectral space images of high spatial resolution obtained from the *IKONOS* (spatial resolution is 4 m) and *QuickBird* (spatial resolution is 2.44 m) satellites, as well as from the *EO-1* satellite (API equipment, spatial resolution is 30 m) [2, 3, 7]. Regions of optical anomalies caused by deep water disposals distinguished from the images obtained by the *IKONOS* and *QuickBird* satellites on different days of the experiment are shown in Fig. 1 as examples. The method of processing was based on the use of the characteristics of the relative variability of the signals in the spectral channels R (630–690 nm), G (520–600 nm), and B (450–520 nm). The details of processing of the multispectral images are described in [2].

Water sampling for biological analyses, as well as temperature and salinity records, was carried out in Mamala Bay at four stations on September 2, 2003; at six stations on September 13, 2003; and at seven stations on August 19 and 21, 2004 (Fig. 1, Table 1). In 2002, the measurements were made from the R/V *Hikino* and the boat *Iwalani*; in 2003, from the boat *Imua*; and, in 2004, from the R/V *Klaus Wyrtky.* The gathering and processing of the materials were headed by Professor M. Landry.

Vertical profiles of the temperature and salinity were recorded using SeaBird lowered profilers (SBE 19, SBE 25) and an Ocean Sensor (OS 200). The calculations of the conventional density were based on these data using standard relations. The seasonal pycnocline was distinguished as the layer with the maximal density gradients in the upper layer between 60 and 150 m.

Water sampling was carried out using lines of plastic Niskin bottles 3 and 10 l in volume. The measurements were made in the water layers of 0–60 m (in 2002), 0–70 m (in 2003), and 0–150 m (in 2004). The distance between the bottles in the line was usually 10 m (sometimes, 5 m in the thermocline).

The flow cytometric analysis method (**FCM**) [5] was used to determine the abundances of heterotrophic bacteria (H-Bact), photosynthetic green bacteria Prochlorococcus spp. (**PRO**), and cyanobacteria Synechococcus spp. (**SYN**). This analysis required double sampling of the seawater with a volume of 2 ml; the subsamples were fixed with a 0.5% paraformaldehyde solution (final concentration), and frozen in liquid nitrogen. One hour before the analysis, the samples were dyed in darkness with Hoechst 3342 dye (1 μg/ml) and counted in a Beckman Coulter EPICS Altra flow cytometer equipped with double argon lasers with a power of 5 W, an Orion spray pump for pumping the samples, and an Expo 32 Multicomp software package for calculating the abundance of the three groups of prokaryotes. The double lasers were tuned collinearly: the first was tuned to the ultraviolet range at 225 mW for inducing fluorescence of colored DNA, and the second was tuned to 448 nm at 1.0 W for inducing red self-fluorescence in cells containing chlorophyll. Widely spread data on the mean carbon content in bacteria cells: 11, 50, and 150 fr C/cell for H-Bact, PRO, and SYN, respectively [16], were used to convert the abundances of heterotrophic and photosynthetic bacteria obtained with the facility to carbon biomass.

Microscopic analysis was used to determine the abundance and biomass of heterotrophic (H-Euk) and autotrophic eukaryotes (A-Euk). Water subsamples 50 ml in volume were fixed onboard the ship using 2 ml of a 10% paraformaldehyde solution and were placed on ice for transportation to the coast. The fixed samples were dyed at the laboratory using a 0.033% solution of proflavine (50 μl of dye per one subsample) for 10 min and filtered through black polycarbonate Poretics filters with a pore size equal to 1.0 μm. A DAPI dye (50 mg/ml) was added during the filtration into the filtering funnels. After the end of the filtration, dry filters were placed on glass slide plates and observed using an Olympus BX41 epifluorescent microscope with immersion oil at a magnification of ×400. In the analy-

Table 1. Location of the stations with respect to the diffuser, their depths, and the mean biomasses of heterotrophic bacteria (H-Bact) in the calculation layer in absolute units (mg C/m^3) and percentages with respect to the biomass of H-Bact at the background station (assumed as 100%)

Date	Station	Distance from the middle part of the diffuser to the station, m	Direction from the diffuser to the station	Depth at the station, m	Layer, m	Biomass of H-Bact		Background station
						mg C/m^3	%	
September 2, 2002	B1	712	NW	60	0–60	7.67	118	B4
	B2	1177	E	60	0–60	8.62	133	B4
	B3	4837	E	67	0–60	6.92	107	B4
	B4	6972	SE	67	0–65	6.48	100	B4
September 13, 2003	B6-1	591	N	22	–	–	–	–
	B6-2	1318	SW	340	0–70	10.3	112	B6-6
	B6-3	1622	E	86	0–70	9.59	104	B6-5
	B6-4	2129	SE	400	0–70	9.53	103	B6-6
	B6-5	5450	E	78	0–70	9.2	100	B6-5
	B6-6	5685	SE	400	0–70	9.21	100	B6-6
August 19, 2004	B6-1	5075	SE	160	0–150	9.92	100	B6-1
	B6-2	4179	E	210	0–150	9.56	96	B6-1
	B6-3	2381	E	250	0–150	10.4	105	B6-1
	B6-4	668	S	150	0–150	11.9	120	B6-1
	B6-5	1810	SW	360	0–150	8.6	114	B6-7
	B6-6	2905	SW	420	0–150	7.94	105	B6-7
	B6-7	4148	SW	430	0–150	7.57	100	B6-7
August 21, 2004	B6-1	5993	SE	190	0–150	9.15	100	B6-1
	B6-2	4212	E	220	0–150	9.55	104	B6-1
	B6-3	2179	E	240	0–150	10.3	113	B6-1
	B6-4	714	S	190	0–150	13.9	152	B6-1
	B6-5	1719	SW	360	0–150	11.2	141	B6-7
	B6-6	2860	SW	420	0–150	8.61	108	B6-7
	B6-7	4198	SW	440	0–150	7.96	100	B6-7

sis, autotrophic cells were distinguished from heterotrophic cells by the presence of chlorophyll found by red fluorescence under illumination with blue light [18].

After identification of the species, the calculation and determination of the size of the unicellular organisms was made automatically using Zeiss Image software. The linear sizes measured were used to calculate the volume of the cells by approximating them with known geometrical figures or with combinations of a few simple figures. The cell volume (V, μm^3) was converted to the cell carbon (C, pg) using modified Stratmann equations separately for the nondiatomic algae ($\log C = 0.94 \log V - 0.60$) and diatoms ($\log C = 0.76 \log V - 0.352$) [18].

It should be noted that, on the basis of the microscopic analysis, the H-Euk group included mainly ciliates, zooflagellates, and chlorophyll free dinoflagellates. The A-Euk group consisted of small chlorophyll-containing algae of different systematic groups (including diatoms), as well as of filamentous colonies of the cyanobacteria (blue-green algae) Trichodesmium spp, which is capable of fixing free nitrogen. The proportion of the latter in the total biomass of A-Euk was usually less than 30%. During the calculations, the following size classes were specified for autotrophic and heterotrophic organisms: 2–5, 5–10, 10–20, and >20 μm. Thus, the methods applied for estimating A-Euk and H-Euk allowed us to perform a quantitative account of the total abundance of nanoplankton and small microplankton.

Special methods were used to calculate the biomasses of A-Euk and H-Euk at depths of the water sampling between the reference levels (as well as above and below them). The values of the ratio of the carbon biomass A-Euk to the concentration of monovinyl chlorophyll *a* (mv CHLa) in the water and the ratio of the carbon biomass H-Euk to the carbon biomass A-Euk were

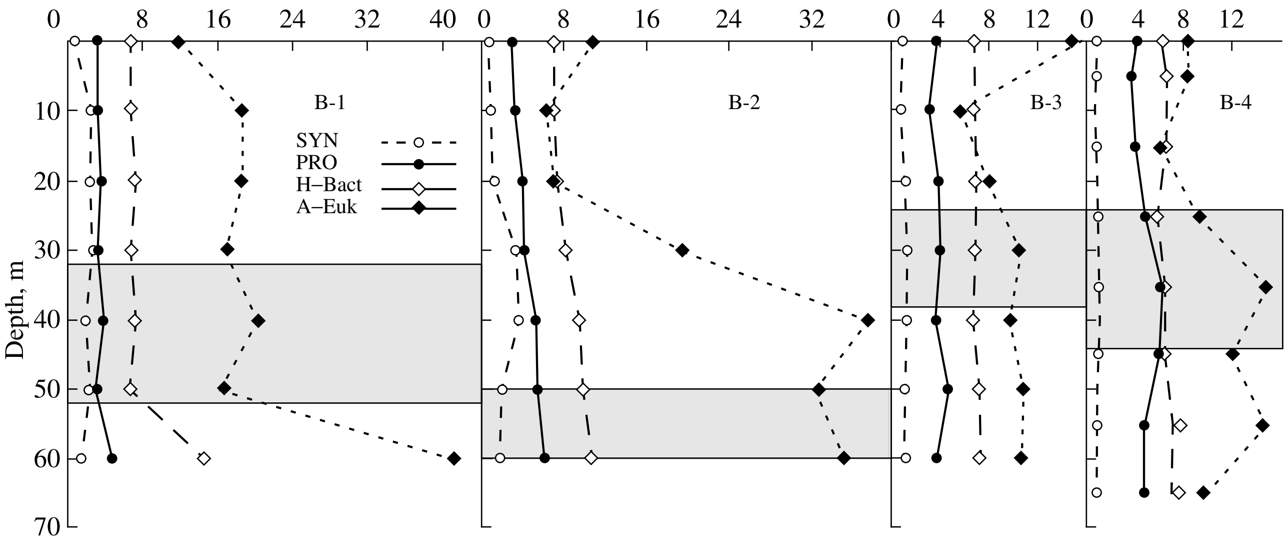

Fig. 2. Vertical distribution of the biomasses (mg C/m23) of heterotrophic bacteria (H-Bact), prochlorophytes (PRO), cyanobacteria (SYN), and autotrophic eukaryotes (A-Euk) at stations B1–B4 occupied on September 2, 2002. The approximate location of the seasonal thermocline is shaded.

calculated at the reference depths. The values of the A-Euk/mv CHLa and H-Euk/A-Euk ratios calculated using this method were extrapolated to the neighboring depths to obtain the curves of the vertical variations in these ratios at all the depths studied in the experiment. The calculation of the biomass A-Euk at nonreference depths was performed using the relation CHLa x (A‘Euk/mv CHLa), while the biomass H-Euk was calculated using the relation A-Euk x (H-Euk/A-Euk). The total carbon content in the small micro-, nano-, and picoplankton (MICRO) was determined as the sum of the chlorophyll containing algae (A-Euk), heterotrophic unicellular eukaryotes (H-Euk), phototrophic bacteria (PRO+SYN), and heterotrophic bacteria (H-Bact).

Determination of the total chlorophyll *a* content calculated as the sum of the concentrations of the monovinyl (mv CHLa) and divinyl (dv CHLa) chlorophylls was carried out using the HPLC method [5]. The seawater samples (2 l) collected with Niskin bottles at all the levels studied were filtered through GF/F Whatman glass fiber filters with a diameter of 25 mm. The pigments were extracted over 24 hours in 3 ml of 100% acetone in darkness at 0°C after the cells were destroyed by ultrasound. Kantaksantin (50 µl solution in acetone) was added to all the samples as an internal standard. The purifying of ready extracts was performed by centrifuging, after which they were analyzed using a Varian HPLC analytical system. The concentrations of pigments were calculated using internal and external standards.

RESULTS OF THE STUDIES

Distribution of Plankton on September 2, 2002

During the experiment, biological sampling was carried out at four stations (B1, B2, B3, and B4) on the shelf (60–70 m). Stations B1 and B2 (closest to the diffuser) were located at a distance of 0.7 and 1.2 km from the middle of the diffuser (Table 1, Fig. 1a). During the experiment in the basin of Mamala Bay, the easterly or northeasterly wind was weak (3–6 m/s). An anomalous structure spreading in the southwestern and southeastern directions from the diffuser was distinguished as a result of processing satellite multispectral images obtained on September 2, 2002 (Fig. 1) [3, 7]. As seen from the figure, all four stations were located beyond the optical anomaly distinguished from the satellite image. Stations B1 and B2 were located at a distance of only a few hundred meters from its northern boundary.

In order to describe the mechanism of the polluted water impact on the epipelagic ecosystem and to determine the possible pathways of propagation of polluted waters in the water column near the shelf break, as well as over shallowwater areas, it is necessary to perform a detailed analysis of the vertical changes in the biological parameters.

The vertical distribution of the biomass of planktonic communities at stations B1–B4 is shown in Fig. 2. The biomass of cyanobacteria appeared to be very low and approximately the same at all the stations except for B2, where a small smooth maximum of the SYN biomass was observed in the layer of 30–40 m (over the pycnocline). Prochlorophytes (PRO); heterotrophic bacteria (H-Bact); and, especially, autotrophic eukaryotes (A-Euk) increased their biomass close (1 km) to the diffuser (station B1) in the near-bottom layer under

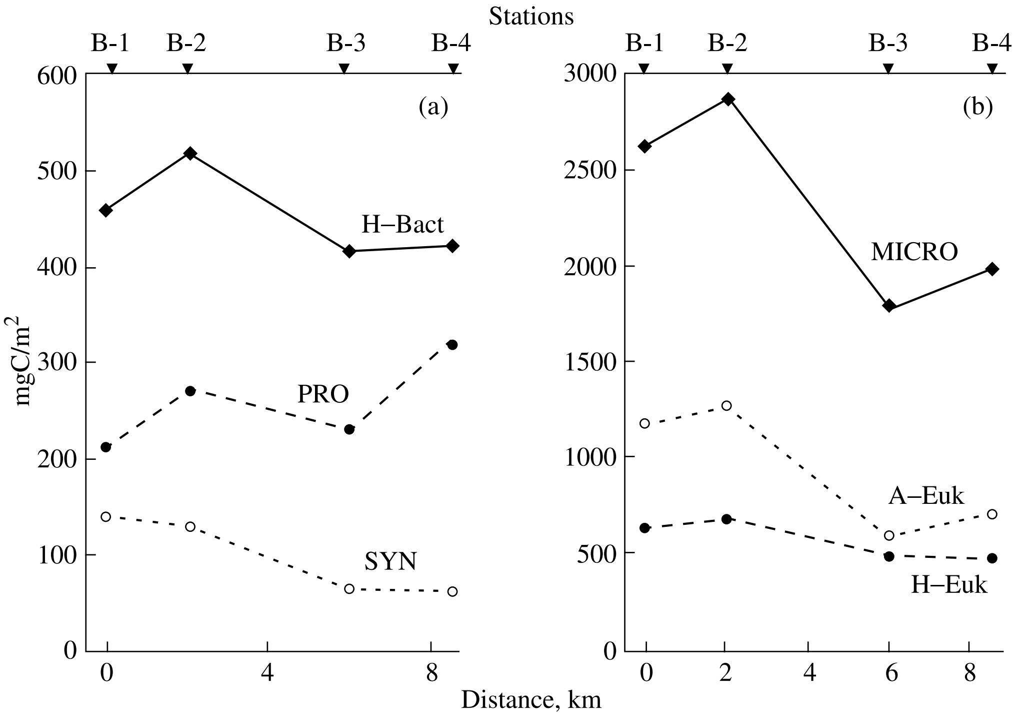

Fig. 3. Distribution of integral values of the biomass (mg C/m^3) of different groups of microplankton in the layer of 0–60 m over section B1–B4 carried out on September 2, 2002. (a) Heterotrophic bacteria (H-Bact), cyanobacteria (SYN), and prochlorophytes (PRO); (b) total microplankton (MICRO), autotrophic eukaryotes (A-Euk), and heterotrophic eukaryotes (H-Euk).

the pycnocline (60 m), while, at station B2 located at a greater distance from the end of the pipe, the biomass increase was found in the water column of greater thickness (40–60 m) and was poorly manifested (for PRO and H-Bact) (Fig. 1a, and 2).

The impact of the sewage waters on the marine ecosystem usually leads to an increase in the abundance of heterotrophic bacteria and planktonic algae in the epipelagic zone [4]. On the basis of this statement and the analysis of the curves shown in Fig. 2, one can conclude that the polluted water located immediately at the diffuser (station B1) under the pycnocline displaces over 1.2 km to the east covering the location of station B2 and occupying a thicker layer (40–60 m) in the pycnocline and over it. No plume of polluted waters was traced at a greater distance (>4 km) to the east.

The intense development of planktonic communities in the wake of polluted waters was reflected in the integral values (over the water column) of the H-Bat, SYN, A-Euk, H-Euk (heterotrophic eukaryotes), and MICRO (H-Bact + PRO + SYN + A-Euk + H-Euk) biomasses (Fig. 3). The maximal values of these parameters were observed at stations B1 and B2. These peaks were best manifested (relative to the minimum over the section) for cyanobacteria and autotrophic eukaryotes.

The mean carbon biomasses of H-Bact in the layer considered (in absolute units and in percent of the H-Bact biomass at the background station) are presented in Table 1 to estimate the degree of the impact of the polluted waters on the heterotrophic bacteria at different stations. Station B4, which is most remote from the diffuser, was assumed to be the background one over section B1–B4. It is seen from Table 1 that the strongest influence of the polluted waters on the biomass of H-Bact was found at station B2, where the absolute value of this parameter reached 133%. It is noteworthy that the particular features of the propagation of the polluted waters over the shelf on September 2, 2002 (deeper than 40 m) related to the tidal regime and currents possibly led to the absence of the surface optical anomaly at stations B1 and B2 (Fig. 1a), which were the richest as estimated on the basis of all the biological parameters except for prochlorophytes (Fig. 3).

Distribution of Plankton on September 13, 2003

The measurements of the biological parameters on this day were carried out over two sections along the coast: on the shallow-water shelf over a depth of 22 m (station B6-1), along the 70-m depth contour (stations B6-3 and B6-5), and in the region of the sharp depth increase over depths of 340–400 m (stations B6-2, B6-4, and B6-6) (Fig. 1b, Table 1). Owing to the restriction of the thickness of the layer studied to the upper 20 m at station B6-1, the data of this shallow-water (22 m) station were not used for estimating the integral values of different parameters.

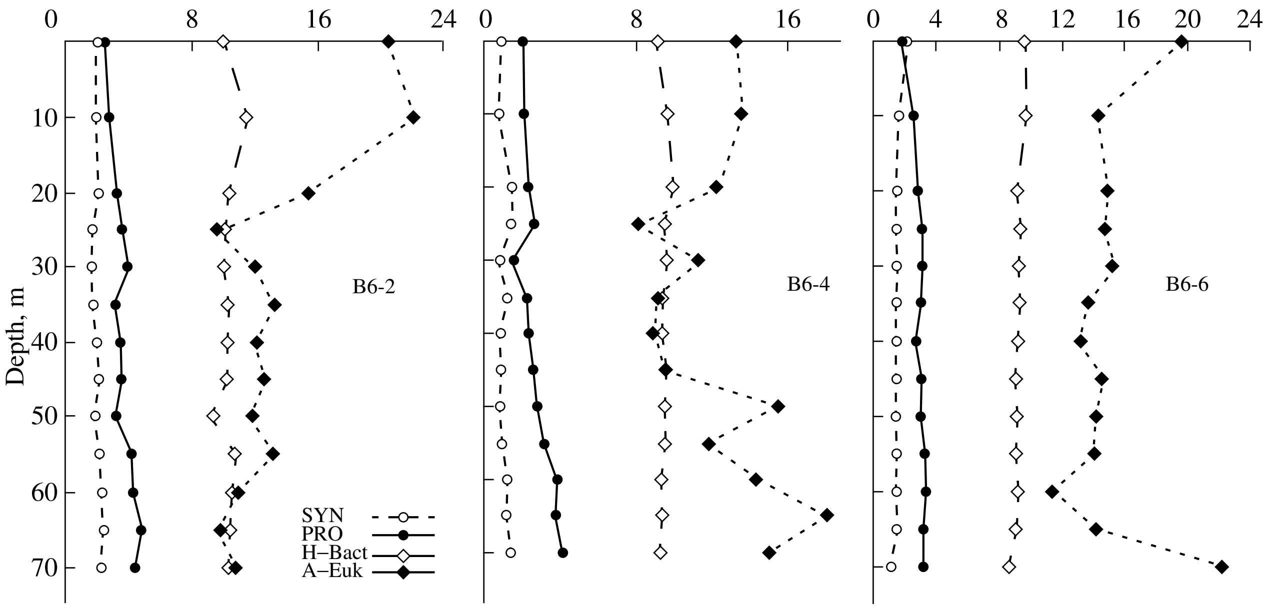

Fig. 4. Vertical distribution of the biomass (mg C/m^3) of heterotrophic bacteria (H-Bact), prochlorophytes (PRO), cyanobacteria (SYN), and autotrophic eukaryotes (A-Euk) at stations B6-2, B6-4, and B6-6 occupied on September 13, 2003. The location of the seasonal pycnocline is not shown because it was not present in the layer of 0–70 m.

During the measurements in the study region, the wind was predominantly northeasterly, while its velocity varied from 5 to 8 m/s. At the beginning of September 2003, Mamala Bay found itself in the region of an intense atmospheric cyclone accompanied by stormy weather. In September 2003, as a result of intense wind mixing, the well-mixed quasi-homogeneous layer reached a depth of approximately 70 m. The thermocline was located in the layer of 80–100 m. An extensive optical anomaly spreading in the southeastern direction from the diffuser (Fig. 1b) was found in the image of the region of the wastewater disposal obtained on September 13, 2003, from the *IKONOS* satellite [2, 7]. As seen from the figure, only stations B6-5 and B6-6 located at a distance of 5.5–5.7 km east of the sewage water diffuser appeared beyond the boundaries of the anomaly. The other shelf (B6-1 and B6-3) and slope (B6-2 and B6-4) stations were located within this zone.

An analysis of the vertical distribution of the biological parameters demonstrated that the major part of them (excluding A-Euk) were uniformly distributed over the upper 70-meter layer studied in the experiment both at the slope (Fig. 4) and shelf stations. It is likely that the cause of this uniformity lies in the great depth of the upper mixed layer (~70 m) in the period of the observations. Peaks of the biomass of small phytoplankton (A-Euk) were found in the surface layer and over the thermocline (Fig. 4) unlike the other plankton groups studied in the experiment.

An analysis of the distribution of the integral values of the plankton parameters at the stations located in the region of the sharp depth increase showed that the influence of pollution led to an increase in the biomass in the region of the diffuser (station B6) only for SYN, H-Bact, and PRO (Fig. 5a). No influence of the other parameters studied in the experiment (A-Euk, H-Euk, MICRO, and CHLa) was found. The character of the variations of the planktonic communities over the shelf section between stations B6-5 and B6-3 (Fig. 5b) appeared to be approximately the same as that found in the region of the sharp depth increase between stations B6-6 and B6-4 (Fig. 5a).

It should be noted that the increased values of the biomasses of SYN, H-Bact, and PRO were found at stations B6-2 (Fig. 5) and B6-1 located within the boundaries of the optical anomaly. At similarly located stations B6-3 and B6-4, practically no increase in the SYN, H-Bact, and PRO biomasses was found. These results indicate that, in September 2003, a positive influence of the sewage water disposal on the biomass of the heterotrophic and phototrophic bacteria was found over selected regions of the optical anomaly zone. Unlike September 2002, in 2003, no such influence was found beyond this zone.

Distribution of Plankton on August 19 and 21, 2004

During these days, biological samples were taken at seven stations (B6-1–B6-7). Stations B6-1–B6-4 were located on the shelf break over sea depths of 150–250 m, while stations B6-6–B6-7 were located in the region of the depth increase (360–440 m) (Fig. 1c, Table 1). The upper 150-m layer of the ocean was studied at all the stations.

During the field research, the wind speed varied from 4 to 9 m/s, while its direction changed from north-

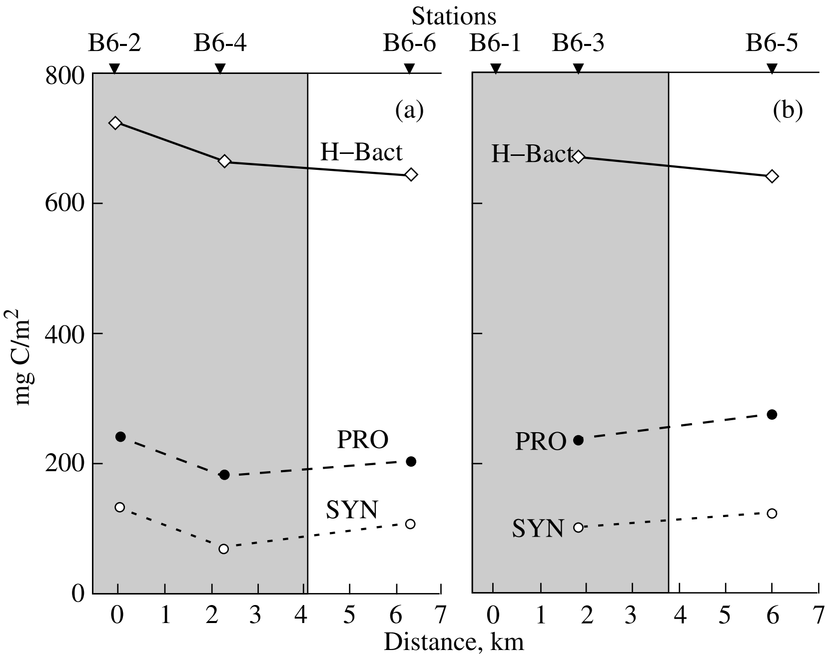

Fig. 5. Distribution of integral values of the biomasses (mg C/m^3) for different groups of microplankton in the layer of 0–70 m over sections (a) B6-2–B6-6 and (b) B6-1–B6-5 on September 13, 2003. The shaded segments of the sections correspond to the region of the optical anomaly at the surface. The notations of the microplankton groups are the same as in Fig. 3a.

westerly to northerly (August 19, 2004) or the wind direction was random (August 21, 2004). The optical anomaly distinguished from the *QuickBird* satellite image on August 16, 2004, was elongated from the east to the west, and its size was the following: from the north to the south, it was approximately 3.5 km long, and, from the east to the west, it was approximately 12 km long (Fig. 1c) [3]. As seen from Fig. 1c, stations B6-3–B6-6 were located within the zone of the optical anomaly. Only the stations most distant from the diffuser to the southwest (B6-7) and east (B6-1 and B6-2) appeared beyond the boundaries of the anomaly.

In this respect, the most interesting is to analyze the vertical distribution of heterotrophic bacteria (H-Bact), which feed on dissolved and suspended organic substances. It is seen in Fig. 6 that the H-Bact biomass increase in the water column at station B6-4, which is located most closely to the diffuser, occurred mainly due to the increase in the number of bacteria cells in the upper layers of the seasonal pycnocline and in the lower part of the upper quasi-homogeneous layer (**UQL**). It is obvious that these layers of the water column were, first of all, enriched by dissolved and suspended organic matter supplied from the wastewater disposal device.

An analysis of the vertical distribution of cyanobacteria (Fig. 7), prochlorophytes (Fig. 8), and chlorophyll *a* (Fig. 9) allows us to make a similar supposition related to the mineral salts of the main nutrients (N, P, Si). Such an analysis showed that the maximal (in the water column) biomass of the biological parameters listed (SYN, PRO, and CHLa) was found at station B6-4 (or B6-3) as well as in the lower layers of the UQL or in the upper layers of the seasonal pycnocline. An enrichment of the water layers located above and below the upper boundary of the seasonal pycnocline with mineral salts and organic matter can occur when polluted waters flow down over the upper layer of the latter. It is clear that such a mechanism of spreading of the polluted waters is possible only if a thermohaline stratification exists on the outer shelf and in the region of the depth increase.

During the experiments, water samples were taken in practically the entire water column of the active layer of the ocean (150 m) with a step of 10 m. Such a high-quality survey of the vertical profiles of the different biological parameters allowed us to obtain sufficiently reliable estimates of their integral values over the water column. An analysis of the variations of these integral values over section B6-1–B6-7 (Fig. 1) made it possible to divide the parameters studied into two groups that differ from each other by the character of the polluted water impact on them.

The first group includes parameters that exhibited a notable increase during both surveys (on August 19 and 21) at the station (or stations) most closely located to the diffuser of the wastewater disposal device. Such parameters are the biomass of the heterotrophic bacteria (Fig. 10), the biomass of the photosynthetic cyanobacteria Synechococcus spp. (Fig. 10), and the chlorophyll *a* content (Fig. 11), which was determined as the sum of the monovinyl and divinyl chlorophylls *a* (monovinyl chl*a* + divinyl chl*a*).

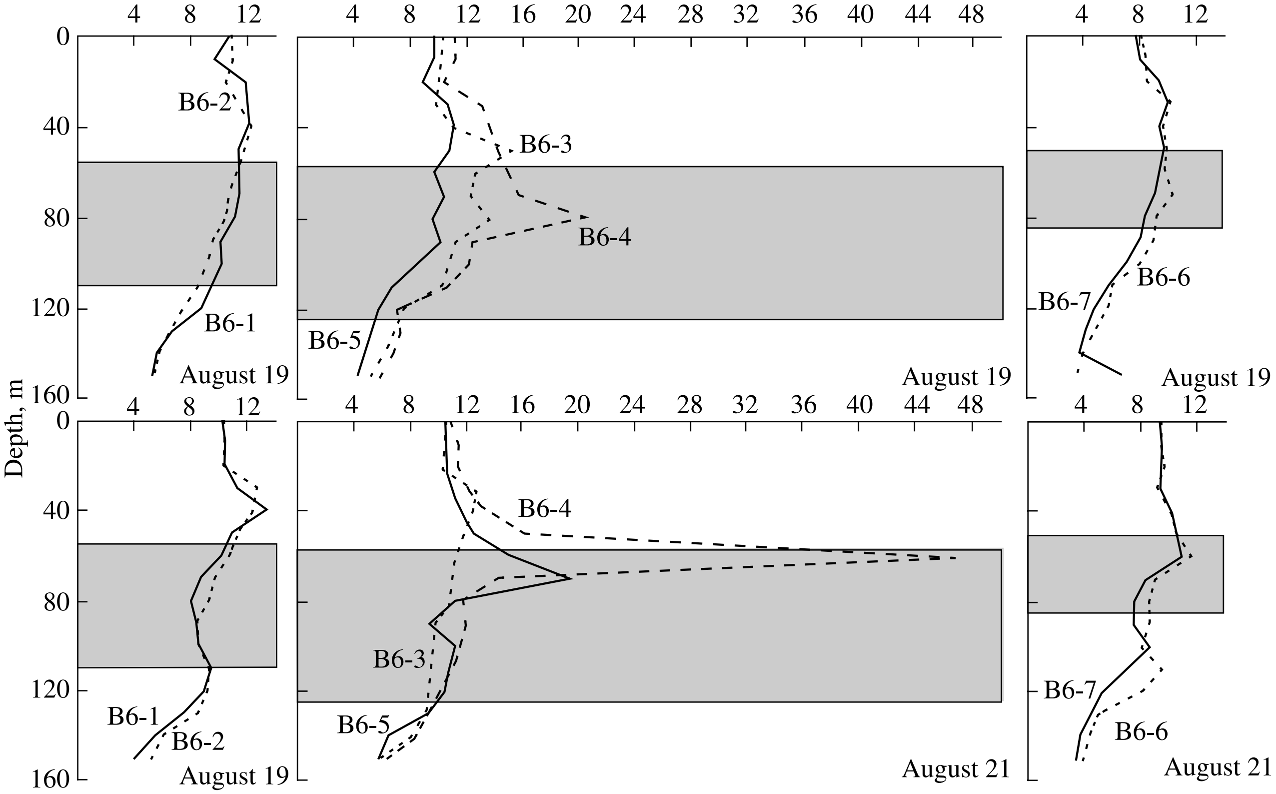

Fig. 6. Vertical distribution of the biomass of heterotrophic bacteria (H-Bact, mg C/m^3) at stations B6-1–B6-7 occupied on August 19 and 21, 2004. The approximate location of the seasonal thermocline is shaded.

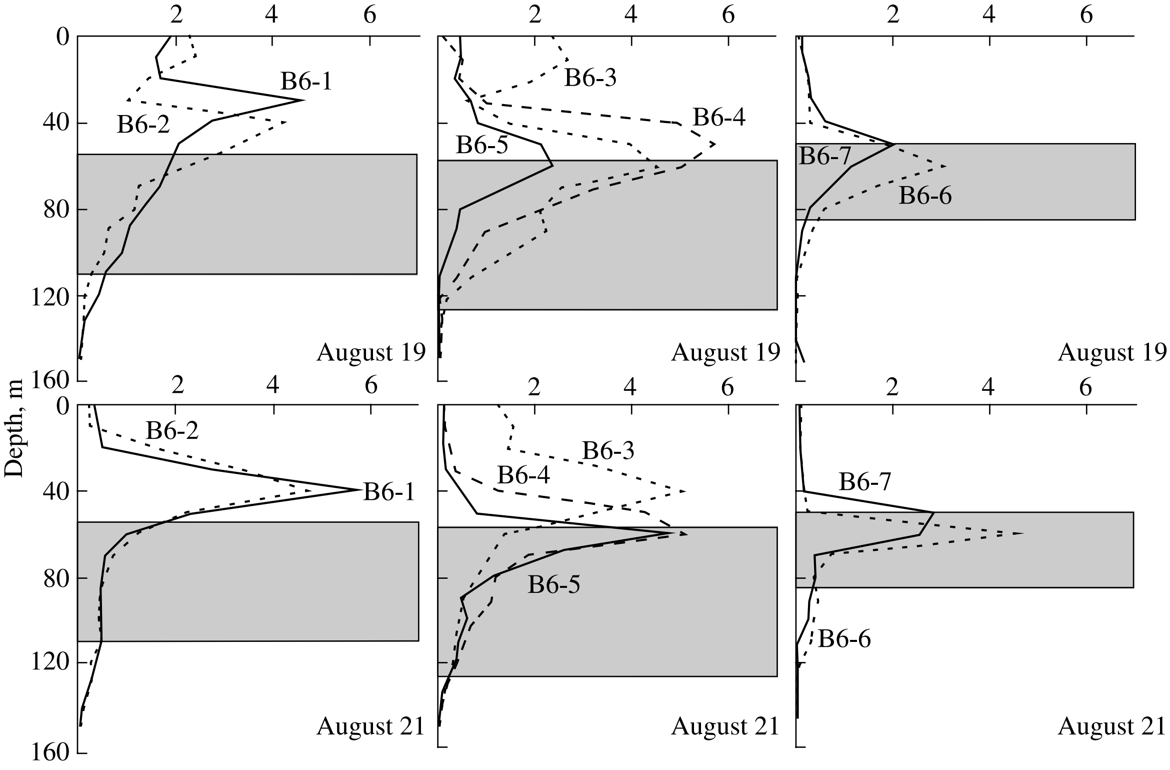

Fig. 7. Vertical distribution of the biomass of cyanobacteria (SYN, mg C/m^3) at stations B6-1–B6-7 occupied on August 19 and 21, 2004. The approximate location of the seasonal thermocline is shaded.

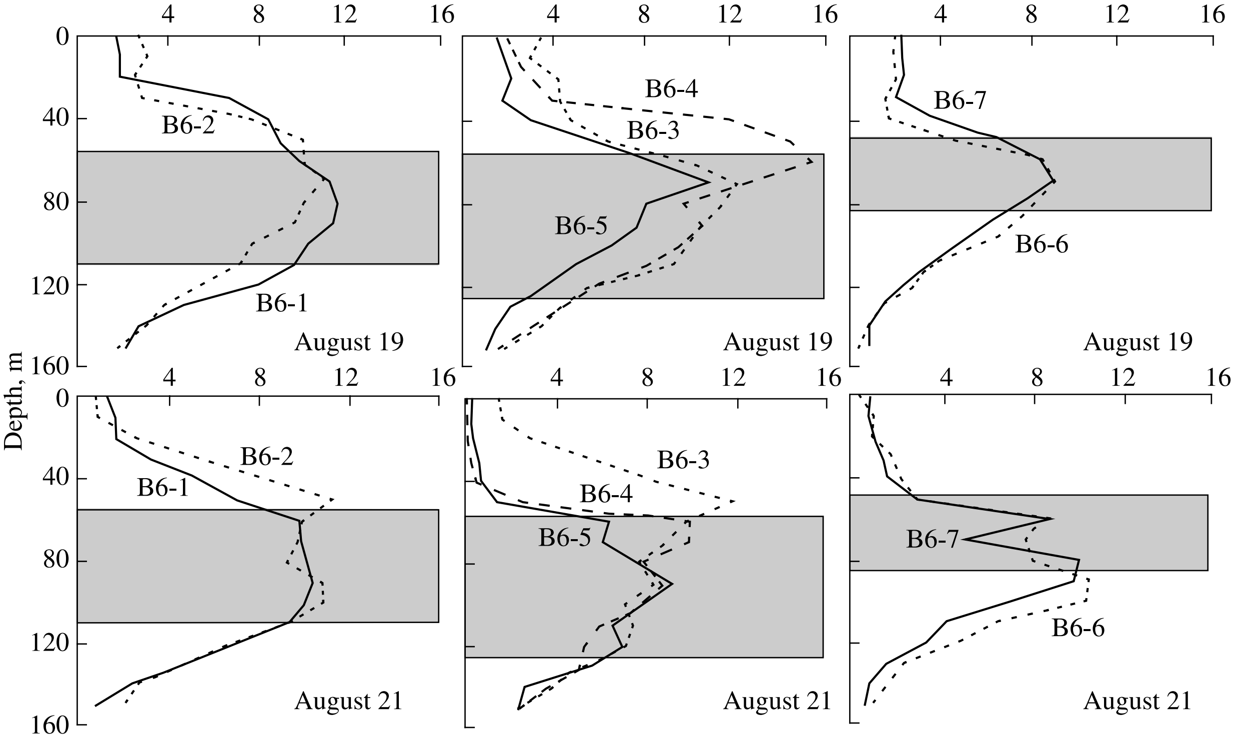

Fig. 8. Vertical distribution of the biomass of prochlorophytes (PRO, mg C/m^3) at stations B6-1–B6-7 occupied on August 19 and 21, 2004. The approximate location of the seasonal thermocline is shaded.

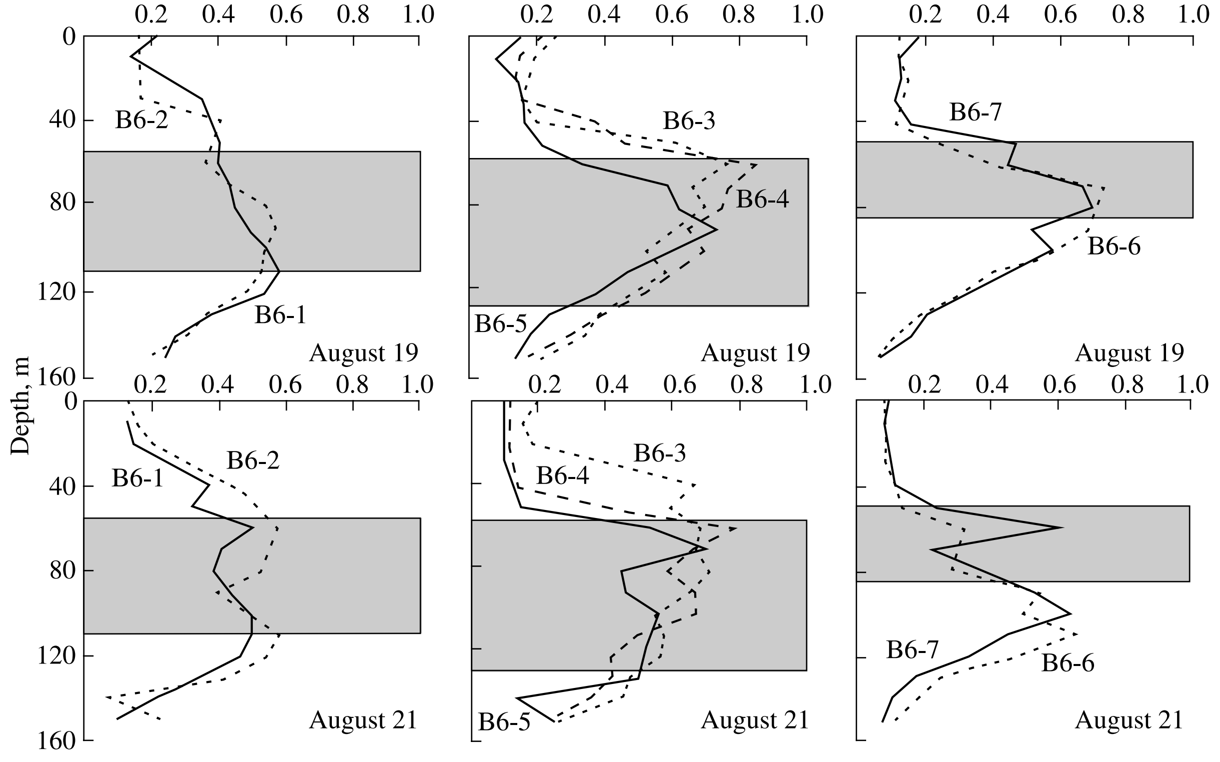

Fig. 9. Vertical distribution of the chlorophyll *a* content (CHLa, mgC/m^3) at stations B6-1–B6-7 occupied on August 19 and 21, 2004. The approximate location of the seasonal thermocline is shaded.

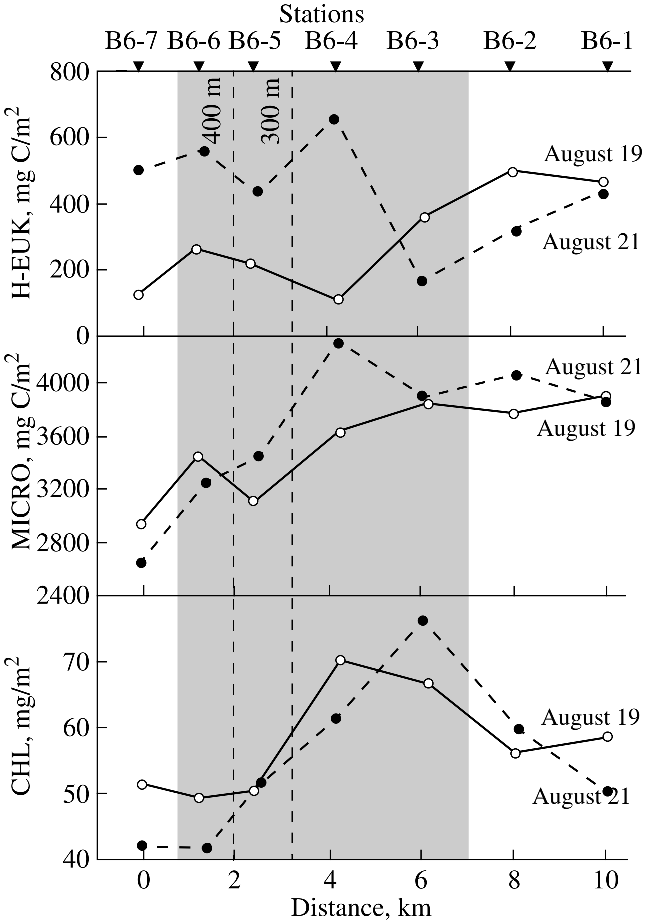

Fig. 10. Distribution of integral values of the biomasses of heterotrophic bacteria (H-Bact), cyanobacteria (SYN), and prochlorophytes (PRO) in the layer of 0–150 m over section B6-1–B6-7 occupied on August 19 and 21, 2004. The vertical dashed lines show the location of the 300- and 400-m depth contours. The shaded segment of the section corresponds to the region with the optical anomaly at the surface observed on August 16, 2004 (see Fig. 1).

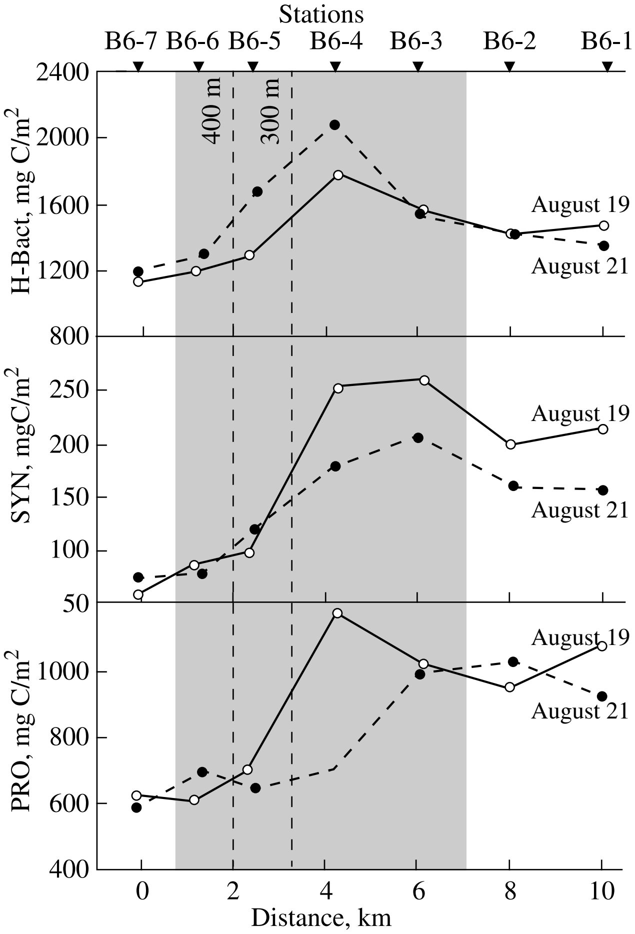

Fig. 11. Distribution of the total content of chlorophyll *a* (CHLa) and the integral values of the biomasses of microheterotrophic bacteria (H-Euk) and microplankton (MICRO) in the layer of 0–150 m over sections B6-1–B6-7 occupied on August 19 and 21, 2004. The notations (vertical dashed lines and shading) are the same as in Fig. 10.

The second group includes the parameters that notably increased only during one of the two surveys (on August 19 and 21) at the stations most closely located to the diffuser of the wastewater disposal device. This group includes microheterotrophic bacteria (zooflagellates and infusoria) (Fig. 11), the photosynthetic bacteria Prochlorococcus referring to prochlorophytes (Fig. 10), and the total biomass of microplankton (Fig. 11). Small phytoplankton (A-Euk) was also conventionally included into the second group, although no increase in its biomass in the region of the headband of the pipe on August 19 and 21 was recorded.

The difference between the biological parameters obtained at the shallowest stations B6-1 and B6-2 (at sea depths of 160–220 m) and at the deepest stations B6-6 and B6-7 (at sea depths of 420–440 m) attracts attention in Figs. 10 and 11. The ratios of the mean values of the parameters calculated at stations B6-1 and B6-2 to the similar mean values at stations B6-6 and B6-7 were equal to 2.1–2.9 for cyanobacteria (SYN), 1.5–1.7 for prochlorophytes (PRO), 1.2–1.3 for microplankton (MICRO), and 1.1–1.3 for heterotrophic bacteria (H-Bact) and the chlorophyll *a* content (CHLa). On August 19, the ratio for microheterotrophic bacteria (H-Euk) was equal to 2.5, and, on August 21, it was equal to 0.7.

Thus, almost all the biological parameters that responded in one or another way to the transport of the polluted waters had greater values on the shelf than in the region of the sharp depth increase. It follows from this fact that a correct estimate of the influence of the polluted waters on the ecosystem requires that the biological indicators measured near the diffuser of the wastewater disposal device at shallow water station B6-4 (<200 m) be compared with the similar parameters that were measured at shallow water stations B6-1 and B6-2 located at the greatest distances from the headband of the disposal pipe (as was considered above).

A comparison of shelf station B6-4 with deeper stations B6-6 and B6-7 is less correct due to the different productivities of the shelf and slope waters. It is reasonable to compare the results obtained at the two latter stations together with the results at station B6-5, because these three stations can be referred to as purely slope stations. We used station B6-7 as an additional background station for this group. This significantly increased the effect of the influence of the pollution on the biomass of H-Bact at stations B6-5 and B6-6 (Table 1).

It is seen from Figs. 10 and 11 that the impact of the polluted waters on the biological parameters of the first group manifested itself on the shelf in the depth range 150–250 m in the regions with anomalous optical properties of the water. At deep-water stations (>350 m) occupied over the continental slope (stations B6-5 and B6-6), practically no influence of the polluted waters on these biological parameters was found (except for H-Bact on August 21, 2004) regardless of the manifestation of the optical anomaly in the surface layer at these stations (Figs. 1, 10, and 11). The latter statement is less explicit than the one related to the shelf stations. This is related to the fact that the decrease in the bioproductivity with the distance from the diffuser in the southwestern direction was simultaneously facilitated by two factors (anthropogenic and natural): the greater distance from the source of the pollution and the weakening of the influence of the shelf on the pelagic ecosystem. Correct distinguishing of the influence of the anthropogenic factor could be possible only after performing a reference section from a "pure" shelf free from the direct impact of submerged disposal in the direction toward greater sea depths.

DISCUSSION

The anthropogenic impact on the basins of seas and oceans leads to a decrease in the biological resources and to a change in the properties of the seawater that makes it undesirable for industrial use and recreation purposes. The ecological consequences of the impact of pollutants on marine organisms are rather diverse. Such consequences include eutrophication, which leads to a reconstruction of the structure and functioning of the ecosystem, biological effects at the level of organisms (genetic, physiological, and biochemical), as well as the appearance of pathogenic microflora in the water and its accumulation by filtering hydrobionts.

On the basis of the research in rivers and lakes, it was shown that the dynamical balance between nutrients and the growth of bacteria and microalgae is conserved in oligotrophic waters [20]. During the eutrophication caused by dumping, this balance is broken and, first, a sharp increase in the abundance of heterotrophic bacteria is observed. After these bacteria reach their maximal abundance, the phytoplankton uses the excessive nutrients and a sharp increase in the biomass of algae is observed. An increase in the abundance of bacteria and algae inevitably leads to an increase in the populations of different microheterotrophic bacteria (zooflagellates and infusoria), whose development in time is close to the succession changes induced by the transport of sewage waters into the water medium. The scheme of this kind of succession in seawater has not been studied so far.

A comparative analysis of the main results of the hydrobiological studies in Mamala Bay carried out in 2002–2004 was performed on the basis of the data obtained during individual surveys (see above). Of special interest in this analysis is the comparison of the mean values of the different characteristics of the ecosystem for the studied water column in the region of the diffuser (Table 2). On the basis of the data presented in this table, one can reach a conclusion about both the absolute and relative values of the parameters of the planktonic communities presented here. For the major part of the parameters studied here, the range of the variability was low (max/min = 1.8–2.3). Only for the autotrophic eukaryotes (A-Euk) and heterotrophic eukaryotes (H-Euk) was this range significantly greater (max/min = 9.4–14.8) due to the peak in their development over the shallow-water (<70 m) shelf on September 2, 2002. Judging from the mean data presented in Table 2, heterotrophic bacteria (33%) and autotrophic eukaryotes (30%) played the dominating role in the microplankton in the region of the diffuser. At station B1 located on the shallow-water shelf, the proportion of H-Bact decreased to 18%, while the proportion of A-Euk increased up to 45%. It is possible that such variations in the composition of the microplankton are characteristic of the Hawaii Islands shelf region subjected to anthropogenic influence.

Let us compare the results presented in Table 2 with the values of similar parameters obtained in other regions of the tropical Pacific. Mean values of different parameters of the planktonic community in the high-nutrient low-chlorophyll (HNLC) waters of the eastern regions of the equatorial zone, in oligotrophic western regions of the equatorial zone, and in oligotrophic subtropical waters located north of Oahu Island (ALOHA station) are presented in Table 3. A comparison of the latter data with Table 2 points to an increase in three parameters (H-Bact, SYN, and A-Euk) and to a decrease in the PRO in Mamala Bay as compared to the open ocean waters around Oahu Island. It should be noted that the absolute values of the major part of the plankton characteristics in Mamala Bay (Table 2) were close to the values of similar parameters in the eastern regions of the equatorial zone (Table 3).

It is seen in Figs. 3, 5, 10, and 11 that the transport of sewage waters in Mamala Bay leads to an insignificant increase in the integral values of a number of bio-

Table 2. Mean content of chlorophyll *a* and mean biomass of different planktonic communities in the calculation layer at the stations occupied in the region of the diffuser

Station	Date	Distance from the diffuser, km	Depth at the station, m	Layer, m	Mean biomass in the layer, mg C/m^3						CHLa, mg/m^3
					H-Bact	PRO	SYN	A-Euk	H-Euk	MICRO	
B1	September 2, 2002	0.7	60	0–60	7.67	3.56	2.32	19.6	10.5	43.6	–
B6-2	September 13, 2003	1.3	340	0–70	10.3	3.47	1.93	14.1	5.96	35.8	0.22
B6-4	August 19, 2004	0.7	190	0–150	11.9	7.84	1.70	2.09	0.71	24.3	0.47
B6-4	August 21, 2004	0.7	190	0–150	13.9	4.71	1.19	4.50	4.39	28.7	0.41
Mean value					10.9	4.89	1.79	10.1	5.39	33.1	0.37
					32.9%	14.8%	5.41%	30.5%	16.4%	100%	

Note: H-Bact are heterotrophic bacteria; PRO are prochlorophytes (*Prochlorococcus* spp.); SYN are cyanobacteria (*Synechococcus* spp.); A-Euk are autotrophic pico-eukaryote algae; H-Euk are heterotrophic unicellular eukaryotes; MICRO is the total microplankton; CHLa is chlorophyll *a* (dv CHLa + mv CHLa).

Table 3. Mean biomass of different planktonic communities in the calculation layer in three regions of the tropical Pacific. Ranges of fluctuations of the given characteristic (min–max) or its mean value (M ± σ) are given. The notations are the same as in Table 2

Region	Latitude	Layer, m	Mean biomass (mg C/m^3)				Reference
			H-Bact	PRO	SYN	A-Euk	
Eastern equatorial	2°N–1°S	100°–150°W	7.88 ± 1.39	7.25 ± 1.90	1.47 ± 0.51	4.76 ± 1.36	[16]
	0°N	140°W	10.1–1.07	4.0–5.3	0.90–1.10	6.60–9.50	[6]
	12°N–12°S	140°W	3.74–9.02	1.25–7.5	0.11–1.80	0.91–4.91	[17]
Western equatorial	2°N–2°S	160°–180°E	–	8.60 ± 3.60	0.35 ± 0.39	0.66 ± 0.34	[16]
	0°N	175°E	4.84–6.00	1.25–3.75	<0.5	–	[13]
Oligotrophic subtropical (ALOHA station)	22°45′N	158°W	4.88 ± 1.31	9.15 ± 2.25	0.26 ± 0.17	0.54 ± 0.27	[16]

logical parameters, which allows us to suggest a low anthropogenic eutrophication in the region of the diffuser of the wastewater disposal device. We used the eutrophication factor (**EF**) as a quantitative estimate of this phenomenon. This factor is calculated as the ratio of the absolute value of a selected biological parameter at the stations closest to the diffuser to the value (or mean value) of this parameter at background stations. As background stations, considered those with close depths more or less free from the direct influence of anthropogenic factors (so-called conventionally clean waters). In the calculations of the EF, we considered stations B3 and B4 of the survey on September 2, 2002; station B6-6 of the survey on September 13, 2003; and stations B6-1 and B6-2 of the survey on August 19 and 21, 2004 to be background stations.

The values of the eutrophication factor were calculated for the stations located at a distance not greater than 1.3 km from the diffuser (Table 4). The mean values of these measurements at stations B1 and B2 (due to the close values of the parameters studied) were used for the measurements carried out on September 2, 2002. On the basis of the analysis of the mean values of the eutrophication factor given in Table 4, one can suggest that the cyanobacteria (EF = 1.43), the heterotrophic bacteria (EF = 1.25), and the chlorophyll *a* content (EF = 1.21) appeared to be the most sensitive to the pollution. The other parameters studied in the experiment (PRO, A-Euk, H-Euk, and MICRO) differently responded to the transport of pollution (positively or negatively), which led to very low mean values of the EF, which only slightly differed from 1.0 (0.99–1.13) (Table 4). It is noteworthy that the maximal influence of the polluted waters on the planktonic communities was found at stations B1 and B2 on the shelf on September 2, 2002. Unlike the mean values, the eutrophication factor here reached 1.90 for autotrophic eukaryotes and 2.13 for cyanobacteria.

Thus, in the summer–autumn period of 2002–2004, cyanobacteria; heterotrophic bacteria; and, in some

Table 4. Eutrophication factors (EF) calculated from the integral biomasses of different planktonic communities and the integral content of chlorophyll *a*. The notations are the same as in Table 2

Station	Date	Distance from the diffuser to the station, km	Depth at the station, m	Layer, m	Eutrophication factor						
					H-Bact	PRO	SYN	A-Euk	H-Euk	MICRO	CHLa
B1 + B2	September 2, 2002	0.7–1.2	60	0–60	1.17*	0.88*	2.13*	1.9*	1.36*	1.46*	1.50**
B6-2	September 13, 2003	1.3	340	0–70	1.12	1.19	1.24	0.95	0.84	1.01	0.98
B6-4	August 19, 2004	0.7	190	0–150	1.22	1.16	1.22	0.47	0.22	0.95	1.23
B6-4	August 21, 2004	0.7	190	0–150	1.49	0.72	1.12	0.64	1.76	1.09	1.12
Mean value					1.25	0.99	1.43	0.99	1.05	1.13	1.21

Notes: * Mean EF values for stations B1 and B2.
** EF value for station B2.

Table 5. Eutrophication factor (EF) calculated from the maximal values of the biomass of different planktonic communities and concentrations of chlorophyll *a* in the water layers studied in the experiment. The notations are the same as in Table 2

Station	Date	Distance from the diffuser to the station, km	Depth at the station, m	Layer, m	Eutrophication factor						
					H-Bact	PRO	SYN	A-Euk	H-Euk	MICRO	CHLa
B1 + B2	September 2, 2002	0.7–1.2	60	0–60	1.77*	1.03*	2.60*	2.60*	1.46*	2.03*	1.98**
B6-2	September 13, 2003	1.3	340	0–70	1.20	1.38	1.10	0.98	1.09	1.08	0.87
B6-4	August 19, 2004	0.7	190	0–150	1.68	1.39	1.30	0.40	0.35	1.04	1.48
B6-4	August 21, 2004	0.7	190	0–150	3.60	0.94	0.98	0.66	2.49	2.05	1.45
Mean value					2.06	1.19	1.50	1.16	1.35	1.55	1.45

Notes: * Mean EF values for stations B1 and B2.
** EF value for station B2.

cases (on the shelf), autotrophic eukaryotes were the most sensitive to pollution in Mamala Bay. This conclusion corresponds to the results of the long-term studies of the influence of submerged disposal of wastewater on the structure of planktonic communities performed in the coastal regions of the Black Sea [4].

An analysis of the data obtained in our experiments showed that the polluted waters transported from the diffuser spread predominantly in specific layers of the water column (see above). Owing to such propagation, it is possible to expect a stronger impact of pollution on planktonic communities at specific levels as compared to their mean impact averaged over the water column. The values of the eutrophication factor were calculated using the maximal values of the biomass of different planktonic communities and of the chlorophyll *a* concentration in the water layers studied here (Table 5) to check this supposition. From a comparison of Tables 4 and 5, it is possible to reach a conclusion about the increase in the influence of the pollution on planktonic communities at specific levels as compared to the similar influence on plankton in the entire water column (1.65 times for H-Bact, 1.20 times for PRO, 1.05 times for SYN, 1.17 times for A-Euk, 1.29 times for H-Euk, 1.37 times for MICRO, and 1.20 times for CHLa). The insignificant differences between the eutrophication factors in the water column and in the layers with the maximal plankton biomass and the similar tendency in their variations makes the application of integral characteristics for estimating the influence of the polluted water on the biological parameters well grounded.

However, it is likely that a comparison of the mean EF values calculated in the water column (Table 4) and in the water layers with the maximal biomass (Table 5) can give additional information about the pathways of spreading of certain pollutants. For example, heterotrophic bacteria (EF = 2.06) appeared to be the group of plankton organisms most sensitive to pollution in the layers with maximal biomasses, while cyanobacteria (EF = 1.43) were the most sensitive group in the water column between depths of 60 and 150 m. This difference is possibly related to the fact that suspended and dissolved organic matter (food source of H-Bact) spread in thinner water layers than phosphates and nitrates (the main food source of SYN) do.

It is noteworthy that, in the Black Sea, in the centers of shallow-water outfalls, the bacterial biomass is more than one order of magnitude greater (i.e., EF > 10) than in the conventionally clean water [4]. In Mamala Bay, the values of the EF did not exceed 2.1 in the water column (Table 4) and 3.6 in individual layers (Table 5), which points to the low influence of the polluted waters on the planktonic communities. It is possible that, in the summer–autumn period, the hydrometeorological conditions in Mamala Bay facilitate more rapid removal of sewage waters from the shelf regions into the open sea. It is not excluded that, in other seasons, the influence of pollution would more strongly manifest itself.

The rate of dilution and removal of waste waters from submerged outfalls from the coastal zone strongly depends on the pathways of their propagation. The solution of this problem requires special experiments with dying of the polluted waters with luminescent dyes and their high-resolution satellite monitoring. The following concept is based on a comparison of the results obtained (Figs. 2, 4, 6–9) with the results of processing the space multispectral images (Fig. 1) combined with the hydrological data on the current fields.

At the beginning of September 2002, the polluted waters spread predominantly in the southwestern direction, because, on the basis of the hydrological data at all the levels, an alongshore water transport with dominating southwestern direction 220° [8] was observed. Such transport is characteristic of Mamala Bay, which is located in the zone of the influence of the North Equatorial Current. The polluted water that accumulated under the pycnocline in the region of the diffuser (station B1) was transported over a distance of only 1–2 km in the eastern direction (where biological measurements were carried out) before penetrating into the pycnocline and into the lower levels of the upper mixed layer. It is likely that the deep water maximum (40–60 m) of algae and prochlorophytes found at stations B1 and B2 (Fig. 2) had no influence on the anomaly distinguished from the satellite image (Fig. 1a) due to the high turbidity of the shelf waters. In September 2002, the relative transparency in the study region determined on the basis of a white disk with a diameter of 30 cm was equal to 27–35 m.

In September 2003, judging from the hydrological observations, a very complicated and unstable pattern of currents was observed in Mamala Bay. Similarly to September 2002, southwestern transport dominated in the region of the diffuser at all the depths studied. At the same time, at a distance of 3 km east of the diffuser, the dominating transport was directed to the northwest and north, and, at a distance of 7 km southeast of the diffuser, a strong variability of the direction of the currents was observed: southeastward, northward, and northwestward transports accompanied by strong fluctuations were found. This kind of circulation, along with the high thickness of the upper mixed layer (70 m) equal to the depth of the diffuser location, facilitated a mosaic distribution of the polluted waters (Fig. 1b) and led to mixing between the layers with increased concentration of pollutants. The shape of the curves of the vertical distribution of the biomass of heterotrophic bacteria and cyanobacteria in the upper 70-m layer (Fig. 4), as well as the very low EF values calculated from the maximal biomasses of H-Bact (1.20) and SYN (1.10) (Table 5) in the water column, corresponds to the latter statement. It should be noted that, when the thickness of the upper mixed layer is high (70 m) as was observed on September 13, 2003, the eutrophic influence of the pollutants on the planktonic communities in the region of the optical anomaly was probabilistic: it was positive at stations B6-1 and B6-2 and was absent at stations B6-3 and B6-4 (Table 1, Fig. 5).

In August 2004, the direction of the flow in the region of the diffuser was basically opposite to the general directions of the currents. The distribution of the direction of the currents had a double-mode structure. The dominating directions of the currents were 270–320° and 100–130°. The latter had a greater probability. Owing to the unusual direction of the currents, the shape of the optical anomaly at the surface was also unusual, being elongated from the west to the east (Fig. 1c).

Since section B6-1–B6-7 in 2004 crossed the optical anomaly practically in the longitudinal direction (Fig. 1c), the most valuable results were obtained during these studies. The positive influence of the pollution on the sensitive biological parameters was observed at shallow-water stations (B6-3 and B6-4) located over the shelf break in the zone of the optical anomaly (Figs. 10, 11). Most strongly, this influence manifested itself at station B6-4 closest to the diffuser at the boundary of the upper mixed layer and the seasonal pycnocline (Figs. 6–9). Such distribution of the biological parameters allows us to believe that polluted waters ascended in the region of the diffuser to the upper boundary of the seasonal thermocline and spread along this boundary in the eastern and western directions. In August 2004, the similarity between the curves of the vertical distribution of cyanobacteria (SYN) and prochlorophytes (PRO) in the region of the diffuser provides indirect proof of the existence of such a mechanism of propagation of the polluted waters in Mamala Bay. In the oceanic regions free from anthropogenic influence, the latter group of planktonic organisms reaches maximal development in deeper layers (at 0.1–10% of the surface irradiance, E_0) than cyanobacteria (at 10–100% E_0) [10]. Such a difference in the vertical distributions of SYN and PRO was observed at stations B6-1, B6-2, B6-6, and B6-7 located at a distance of 3–6 km from the diffuser (Figs. 7, 8). At stations B6-3 and B6-4 located at a distance of 0.7–2.3 km from the diffuser, both groups (SYN and PRO) reached their maximums in the same layer (40–70 m) (Figs. 7, 8). It is likely that such coincidence of the location of the maximums of SYN and PRO is related to their positive response to the transport of polluted waters precisely in this layer.

It is noteworthy that the increased content of chlorophyll at the upper boundary of the pycnocline (40–80 m) at stations B6-3–B6-5 (Fig. 9) was undoubtedly reflected in the space image (Fig. 1c) due to the greater transparency of the waters studied (43–55 m). Stations B6-1 and B6-2, at which no clearly manifested deep maximum of chlorophyll was detected (Fig. 9), appeared beyond the limits of the zone of the optical anomaly (Fig. 1c).

In conclusion, let us consider the problem of the size of the zone in which eutrophic influence of the deep outfall of sewage waters on the planktonic communities can be found. It is clear that the correct solution of this problem requires that the region of the diffuser and the optical anomaly at the surface should be covered with a network of stations. None of the surveys of the experiment completely suited these requirements (Fig. 1). Thus, the conclusion given below about the size of the zone subjected to the influence of the deep-water outfall of the sewage waters should be considered only as a preliminary one. On the basis of the surveys carried out in the region (Tables 1, 4; Figs. 3, 5, 10, 11) it is possible to conclude that the disposal of polluted waters in Mamala Bay in the summer–autumn season led to an insignificant (1.2–1.4 times on average) local increase in the integral biomass of heterotrophic bacteria, cyanobacteria, and the chlorophyll *a* content in the regions located at a distance of 1.2–4.8 km east, 0.7–2.9 km southwest, and 0.7 km north and northwest of the diffuser. In the regions located at greater distances from the diffuser (more than 5 km to the east and more than 3 km to the southwest), no notable influence of the sewage waters on the planktonic communities sensitive to pollution was found.

CONCLUSIONS

As a result of the research of the hydrobiological parameters, it was found that the range of variability for the majority of the biological parameters studied was not wide (max/min = 1.8–2.3). Only for autotrophic eukaryotes (A-Euk) and heterotrophic eukaryotes (H-Euk) was this range greater (max/min = 9.4–14.8) due to the peak of their development in the immediate vicinity of the diffuser of the wastewater disposal device. It is possible to suppose that sharp gradients of some biological parameters exist at a distance of 1.0–1.5 km from the outflow of the sewage waters into the marine medium.

The disposed waters led to an insignificant (1.2–1.4 times on the average) local increase in the integral biomass of heterotrophic bacteria, cyanobacteria, and the content of chlorophyll *a* in the regions located at a distance of 1.2–4.8 km east, 0.7–2.9 km southwest, and 0.7 km north and northwest of the diffuser. In the regions most distant from the diffuser, no notable influence of the sewage waters on the planktonic communities sensitive to pollution was found.

An analysis of the values of the eutrophication factor allowed us to distinguish a stronger influence of the pollution at specific levels as compared to the similar influence on plankton in the entire water column.

The calculated values of the eutrophication factor in individual layers and in the entire water column in the region of the outfall show a low influence of the polluted water on different elements of the planktonic community. It is possible that, in the summer–autumn season, the hydrometeorological conditions in Mamala Bay provide a more rapid removal of the sewage waters from the shelf regions and the regions of sharp depth increase into the open sea. It is not excluded that, in the other seasons, the influence of the pollution more strongly manifests itself. Benthic communities can be subjected to such influence to the greatest degree due to the accumulation of toxicants in interstitial waters.

A comparison of the zones of pollutant spreading distinguished in the space multispectral images obtained from the *IKONOS* and *QuickBird* satellites with the results of the processing the hydrobiological data demonstrated their good general agreement. This confirms the possibility of using multispectral space images for determining the regions of anthropogenic impact with increased water eutrophication.

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