BIOFOULING POTENTIAL AND ENVIRONMENTAL FACTORS OF SEAWATER AT A DESALINATION PLANT INTAKE[1]

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ABSTRACT

Coastal waters have been widely used by the littoral countries of the Middle East for siting desalination and power plants to take advantage of the availability of unpolluted sea water for establishing cost effective feed intake and once through cooling system. Huge quantities of raw seawater are being withdrawn from the sea for the unimpeded production of freshwater, greatly needed in the region. The effect of marine environment has been found to ramify over the plants, principally as biofouling of intake structures, pumps, seawater piping system, heat exchangers, etc. Despite widespread occurrence, not much information is available on the instances of biofouling encountered in desalination and power plants. The study was aimed at understanding the nature of biofilm formation and its further development on materials exposed to sea water, the composition of biofouling communities in space and time, the succession of flora and fauna in a biofouling environment and the principal ecological factors having a bearing on the phenomenon. Five experiments were carried out over a period of two years representing different seasons. Glass slides, were suspended in the sea on a Diatometer and kept afloat with buoys so that the slides remained constantly submerged in water. The slides, retrieved at pre-determined intervals, were subjected to detailed examination, and the data collected on the parameters mentioned above constitute the subject of this paper. Biofilm showed a growth in thickness for the first three weeks followed by a reduction attributable to sloughing of the biofilm. The biofouling community was composed of 31groups of organisms which exhibited a widely varying pattern of incidence, abundance and succession. The settlement of organisms increased with increased exposure time. Environmental factors such as

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temperature, conductivity, total suspended solids, and dissolved oxygen have been examined in the context of biofouling activity in the sea. The paper discusses the diverse aspects of biofouling within the ecological frame of a coastal intake bay.

1. INTRODUCTION AND REVIEW

Coastal waters of the Arabian Gulf, the Red Sea and the Northern Arabian Sea have been widely used by the countries of the region for siting desalination and power plants. The availability of unpolluted seawater for establishing cost effective feed intake was an inherent advantage. Surface/subsurface intakes or man - made bays studded to the coast, withdraws large quantities of water for the production of the much needed freshwater in the region. The marine environment adjacent to desalination plants naturally exerts a profound influence on the operation and maintenance of these plants. The effects of marine environment on the plant are recognized primarily as biofouling of intake structures, pumps, water boxes, heat exchangers, flash chambers and other plant structures.

Biofouling may be defined as the attachment and subsequent growth of a community of usually visible plants and animals on structures exposed to seawater environment. Man has long been aware of this problem. In the fourth century B. C., Aristotle is reported to have stated that small “fish” (barnacles) were able to slow down ships. Fouling of ship hulls, navigational buoys, underwater equipment, seawater piping systems, industrial or municipal intakes, beach well structures, oil rigs and allied structures are often reported [1, 2]. In the past few decades, the list of affected structures has expanded. Now, reports are common regarding the biofouling that affects Ocean Thermal Energy Conversion Plants, Offshore platforms, moored oceanographic instruments and nuclear and other submarines [3-8]. The impact of bio fouling on sea front structures is staggering. Ships show a 10% higher fuel consumption caused by increased drag and frictional resistance resulting from hull and propeller fouling. Water lines lose their carrying capacity and speed of flow owing to bio fouling growth along pipe systems. The heat exchanger performance declines due to attachment of biofoulants. Many marine organisms themselves face the constant problem of being colonized and overgrown by fouling organisms. Immobile plants and animals are generally exposed to biofouling and consequent loss of species and community assemblages. Biofouling also promotes corrosion of materials. The money and material needed for fouling protection measures are indeed great. It is estimated that the marine industry incurs an expenditure of 10 billion sterling pounds a year to combat the situations arising from biofouling worldwide. A lot of research effort have been devoted to understand the fundamental ecology and biology of fouling environments, organisms, and communities in diverse settings [9-16]. The present study is designed to understand the pattern of bio fouling in relation to the natural ecological setting of a man-made intake bay of a dual-purpose (water and power) plant situated on the Arabian Gulf coast of Saudi Arabia. Data gathered on biofouling in the intake bay are reported in this paper together with pertinent ecological information. The bio fouling potential of the gulf seawater addressed in this paper has a great bearing on other desalination plants located in this region.

2. MATERIALS AND METHODS

Experiments were carried out using a Diatometer fabricated at the Saline Water Conversion Corporation (SWCC) Research and Development Center. The Diatometer - a rack made of vinyl plastic and styroform - was suspended from a raft in the Intake Bay for studying the dynamics of biofilm build up and settlement of organisms. Twelve glass slides (25 x 75mm) were placed in the rack parallel to each other and horizontal to the water surface. The floats on either side of the Diatometers were fixed in such a way that the glass slides remain submerged at all times during the study. The experiment was carried out during 1995-96. Each pair of slide was removed at weekly intervals (7, 14, 21,28,35 &42 days), transferred into a coplin jar containing sterile (0.45 µm filtration) seawater and transported to the laboratory for analyses. Each slide was examined under a binocular microscope equipped with an ocular micrometer for biofilm attachment, density of organisms and biofilm thickness. The number of organism per square centimeter was determined after examining 10 squares on the glass slide. The biomass of biofilm was determined from the wet and dry weights. Samples required for temperature, conductivity, pH, total suspended solids(TSS), dissolved oxygen and chlorophyll data were collected during the fortnightly cruises carried out in the sea during the year. Seawater samples were collected from the surface using a clean plastic bucket. Water temperature was measured using a mercury thermometer with an accuracy of 1°C. Conductivity was measured using a Conductivity Meter (Yellow Springs Instr. Co., USA) and pH, using a pH Meter (Fisher, USA). Total Suspended Solids (TSS) were estimated by filtration through 0.45μm millipore filter paper and overnight drying at 60°C. Dissolved oxygen content and Chlorophyll a were determined following a seawater analyses manual [17].

3. RESULTS AND DISCUSSION

3.1 Ecology of the intake

The desalination plant intake where this study was carried out is a man – made bay studded to the coast providing protected pumping stations for drawing the needed feed sea water for the various desalination units. The area experienced the semi-diurnal tidal cycle characteristic of the Arabian Gulf. The lowest tide was 5cm during the period recorded in December and the highest was 211cm recorded in July. Consequent to continuous pumping, a strong unidirectional current exists inside the bay in the direction of the plant intakes creating a unique oceanographic situation in the bay. The wind action on the surface of the bay sets waves in motion which influence the conditions in the experimental zone. The depth of water in the Intake bay ranged from 4 to 5.5m.

Observation in the intake bay showed that the feed water zone of the desalination plant was free from any visible indication of pollution. The surface water temperature of the Intake Bay varied with the seasons in association with climatic changes, with mean values being the highest for summer and lowest for winter. During the study, the temperature ranged between 17.3ºC recorded in January and 30.5^{0}C recorded in July. The mean seasonal temperature was always the highest during summer and the lowest during winter at all the stations. The sea surface conductivity ranged from 53.95 - 65.10 ms/cm in the Intake Bay. The lowest value for conductivity was recorded in January whereas the highest was in June. Seasonally, the mean conductivity value was the highest during the summer season successively followed by Fall, Spring and winter season. The pH of the seawater ranged from 8.16 - 8.76 indicating that the variations in seawater pH remained within narrow limits. The Total Suspended Solids (TSS) ranged from 9.08 - 85.5 mg/l. The highest value was noticed in March and the lowest in October, December, November and July. Seasonal mean was lowest during the fall (10.50 mg/l) and highest during the spring (40 mg/l). Dissolved Oxygen values ranged from 7.27 mg/l in February to 4.44 mg/l in October. The mean value was the highest in the winter and lowest in the fall and the values were found to be healthy for marine life. The productivity in the Intake bay was impressive. Chlorophyll a pigment production varied from 0.04 to 4.2 mg/m^3 . The seasonal mean was the highest during the summer (2.3 mg/m^3).

3.2 Biofilm formation

Observations on the coupons provided the thickness of biofilm formed and the weight it gained during different periods of exposure. Biofilm formation began immediately following the exposure of the clear coupons in the bay. The thickness of biofilm measured during the three experiments showed a maximum of 375µm (March, 96) at the Intake Bay after 28 days (Figure 1). The range of thickness was from 50 to 200µm during March 1995; 50 to 375µm during March 1996, and 110 to 330µm during July 1996. Biofilm showed a growth in thickness for the first three to four weeks and thereafter a reduction attributable to grazing by higher organisms in the water, seasonal variation in water quality and sloughing was observed. The data showed that the biofilm generally attained its maximum thickness within the first three to four weeks in the bay. Biofilm wet weight in the Intake Bay showed minimum values in March 1995 as compared to March and July 1996 (Figure 2). Maximum was found during July 1996. In general, increase in weight was found associated with increased exposure time. Dry weight also showed a similar pattern with relatively higher values in July 1996 (Figure 3). The dry weight also increased with increased exposure time.

Our observations showed that the biofilm formation did not occur in a spectacular way, but was seen to form in a rather slow and subtle form. The sea water which bathes the coupons always has a role in the process. The seawater has a load of suspended particles ranging from 0.12 microns representing the finest clay to 1000 microns representing the coarse sand influencing its transparency and turbidity on a daily basis. According to Abu El-Ella [18], the suspended particles consists of an allochthonus pool (derived from terrestrial organic matter, including air-borne dust), an autochthonus pool (derived from in situ biological production represented by the living plankton, algae and their dead and decomposed body parts) and an anthropogenic pool (derived from industrial, domestic and agricultural wastes). Their role is stated to be significant in the food chain of the sea. The allochthonus input of particles are greater in the Arabian Gulf considering the enormous nature of the sand storms that blow across the region. The suspended particles harbour a rich assemblage of microbial life on it and fine particles are colloidal and they get cemented to surfaces some what loosely by electrostatic or physical forces such as waves, currents and tides in a region [11,19]. The layer of deposit consisting of the microbial flora and colloidal slime thus formed is together called a biofilm. It is thin and transparent in the beginning and becomes brown with the accretion of more particles and attachment of microflora. Organisms, particularly bacteria and fungi which attach and multiply on such films in geometric proportions constitute a very complex matrix of biofilm community encompassing a wide array of food chains.

The earliest phase of biological fouling is the formation of a conditioning film by deposits of suspended particles with lot of humic and fulvic substances. Baier [20] has characterized this conditioning film as consisting of high molecular weight polymeric substances. Bacteria quickly colonize this film. According to Mitchell et al [21], the early attachment of bacteria involves chemotaxis of motile bacteria, reversible sorption, and finally permanent attachment. The attachment of algae appears to involve both positive chemoreception and attachment of specific proteins to bacterial polysaccharides.

Costerton [22] has reported the mechanism of biofilm attachment. Basically, biofilm consists of bacterial cells and a hydrated matrix (90% water). Bacteria and algae form the initial micro -colonies. A study of a live biofilm using the confocal scanning laser microscope reported by Costerton revealed that many species of bacteria tend to form micro-colonies within a biofilm and between these aggregates of cells lie the hydrated matrix in the form of water channels. The cells reproduce and eventually form a mature biofilm. It is also explained that cells of one species may associate with those of another species for mutual physiological benefit and eventually become a powerful microbial consortium that serves as a surface for settlement of algae and higher organisms.

Biofouling on the plant structures, whenever occurs, appears to mimic the events and their sequences in nature.

3.3 Biofouling Community

Many groups of plants and animals are recognized as foulers. Even though they belong to different groups they exhibit certain common characteristics. The attachment on the coupon surface starts with the formation of the conditioning film and followed quickly by the primary biofilm which consists of bacteria, benthic diatoms and filamentous algae. In the tropical waters, the primary biofilm is chiefly made of diatoms and algae with a relatively small proportion of other organisms, where as in the temperate regions bacteria represent the chief component of primary biofilm [23]. The primary biofilm community that settled on the coupons was largely composed of diatoms with fewer representatives of invertebrate organisms.

The most important members of the fouling community were the diatoms. Protozoa, hydrozoa, nematoda, annelida, crustacea and bryozoa also settled on the coupons, not in large densities. Altogether, 31 genera of organisms were present in the biofouling community in the bay. The diatoms was represented by five families, namely, Coscinodisceae, Soleniae, Biddulphiae, Fragilariae and Naviculoideae. Melosira sp., Thalassiosera sp., Coscinodiscus sp.,and Skeletonema sp. formed the Coscinodisceae family. Leptocylindrus sp. and Biddulphia sp. represented families Soleniae and Biddulphiae, respectively. The largest number of genera that could be seen in the biofouling community came from families Fragilarioideae and Naviculoideae, each represented by seven genera. The former included Striatella sp., Grammatophora sp., Licmophora sp., Climacosphaenia sp., Fragilaria sp., Synedra sp. and Thalassiothrix sp., and the latter included Navicula sp., Pleurosigma sp., Trachyneis sp., Amphiprora sp., Nitschia sp., Surirella sp. and Gyrosigma sp.. The blue green algae and the green algae were represented solely by Trichodesmium and Enteromorpha, respectively.

When the relative abundance was examined, Navicula sp., Licmophora sp., Nitzschia sp. and Enteromorpha sp. were found to be dominant in terms of numerical abundance and frequency of incidence in the Intake Bay. Coscinodiscus sp., Biddulphia sp., Grammatophora sp., Pleurosigma sp., protozoans and balanus were next in importance, whereas Melosira sp., Thalssiosira sp., Leptocylindricus sp., Striatella sp., Climacosphaenia sp., Fragilaria sp., Synedra sp., Thalassiothrix sp., Tropidoneis sp., Amphiprora sp. and Surirella sp., were the least important components. Biofouling organisms such as serpulids (tubiculous worms), balanus (barnacle), clams, oysters and bryozoans were present in low numbers during the third and fourth weeks. Copepods, amphipods and nematodes occurred only occasionally.

3.4 Generic diversity and succession

Biofilm generic diversity observed at the Intake Bay is given in Figure 4. In January 1995, highest generic diversity was found after 28 days. However, in the subsequent two experiments carried out during February and March 1995, high diversity was observed even from the seventh day. Experiments during March and July 1996 also showed increase in generic diversity with increase in exposure time up to 35 days. Maximum generic diversity was found in March 1996, with 18 genera (Figure 4). In summary, it may be stated that, except in the February and March experiments, the generic diversity showed an increase with exposure time up to four weeks. Greater diversity is an indication of a stable community [24]. Most of the members in the community are sessile in nature and have very restricted food source. They depend on water currents for their food and sustenance. During the present series of diatometer studies, the biofouling community was dominated by diatoms, and within the known community assemblages reported from tropical waters, the structure of this community was not very complicated. It appears that the exposure periods of the coupons have greatly influenced the settlement pattern of organisms. Long duration experiments are needed to understand the development of mature climax communities that really pose serious macrofouling problems in desalination plants. A study of this nature is in progress in the SWCC Research and Development Center.

Succession of species is an important ecological event that ensures the survival of a biofouling community. Coupons exposed for fifteen days were found to be colonized by a biofilm community dominated by Amphiprora sp.(49%). When the period of exposure was increased to 30 days, the earlier set of species was succeeded by Licmophora sp.(74%) indicating an instance of rapid growth and multiplication resulting in a succession of species on the coupon. Similarly, Grammatophora sp. and Nitzschia sp.

which were dominant in the first fifteen days at the Intake Bay declined after 30 days of exposure. On heavily fouled surface, one could see that the community gets settled as many layers of organisms representing a very strong, vibrant and complicated web of food chain. Unimpeded succession is attributed as the reason for the development of intensely fouled surfaces.

3.5 Seasonal variations

Total number of diatoms settled during the experiments in 1995 and 1996 showed wide fluctuations (Figures 5and 6). Density of settled diatom was more during 1996. While the maximum diatom density of 3700 cells/cm^2 was noticed in the spring of 1995, the density was 110,000 cells/cm^2 in the summer of 1996. Although the method of enumeration followed was the same, there was an inter-annual variation presumably caused by seasonal variation in the environmental features of the intake bay. It is known that the Gulf seawater gets totally flushed out into the Arabian sea in 3 to 5.5 years [25] and this could be presumed to be the reason for the annual variation that was encountered now. However, long-term data are needed to validate this possibility. In general, the number increased with increased exposure time. Maximum diatom numbers were found in the fourth week.

Settlements of the diatom Nitzschia sp. was maximum (3700 cells/cm^2) in January 1995 after 28 days. However, during February, the settlement was poor (500 cells/cm^2) presumably due to temperature variation that occurs towards the end of the Winter season. In March 1995, the density of this genus was 3200cells/ cm^2. It may be seen that Nitschia sp. started to colonize the coupon from the very first week onwards (Figure 7). The occurrence of Nitzschia sp. was most dominant in the year 1996 (Figure 8). The experiment in March 1996 showed an abundance of 21,000 cells/cm^2. In the July 1996 experiment, maximum incidence was found after seven days (18,000 cells/cm^2). But the population suffered a decline afterward and remained very low even after 42 days of exposure.

Navicula sp.displayed a pattern of settlement in which the peak settlement occurred after 14 days during February and March 1995 with a decline in settlement afterwards (Figure 9). The density of Navicula sp. was very high during 1996. In March 1996, the number was around 5000 cells/cm^2 after the first week followed by a decline and a subsequent peak after 28 days resulting from recolonization. The experiment in July 1996 showed the maximum density of 24000 cells/cm^2 in the first week (Figure 10). Thereafter, population density suffered extensive destruction. A further profusion in settlement was seen after 35 days. The pattern of protozoan settlement during the experiments in 1995 and 1996 are depicted in Figures 11and 12. The experiments in 1996 showed higher density of biofouling organisms than in 1995. Whereas the spring experiment showed peak settlement after three weeks, the summer experiments showed the peak after seven days. Such changes are presumed to occur due to water quality changes in the bay, seasonally and inter-annually. The incidence of other groups was low in frequency and density.

3.6 Ecological parameters and biofouling

Parameters such as temperature, conductivity, pH, TSS and chlorophyll showed seasonal fluctuations in the intake bay. It is known that several factors influence the formation of the conditioning, slimy film (primary film) and settlement of fouling organisms. Temperature of water plays a very significant role in the settlement of organisms. In the warmer seas of the world biofouling takes place at all times of the year, where as in the cool waters it is more pronounced only during the warmer months [23]. Some organisms show a seasonal maximum and others show a total absence during some months. The present data also showed seasonal variations in the pattern of fouling in the intake bay.

Another factor of great importance is the load of suspended particles observed in the bay. The TSS values observed in the bay were much higher than the same noticed in the open sea adjacent to it during winter and spring periods making the coupons vulnerable for biofouling. This situation can be attributed to the prevailing current in the bay caused by the continuous pumping of the feed seawater. The current collects huge quantity of suspended particles and organic matter from the open sea and transports the same into the intake bay. The resulting elevated TSS values stay for six months during the year, increasing the biofouling potential of seawater in the bay. Many organisms can settle even when the water is flowing. While algal spores can settle within minutes of contact in water flowing up to 10 knots, barnacles settle within 24 - 48 hours of contact in flows up to 1.3 knots. Most fouling is stated to occur when there is no flow

[26]. Tides, light and color of seawater are also cited as factors influencing the pattern of biofouling [27].

The biological productivity of the intake bay was found to be a predisposing condition for biofouling. The values for chlorophyll production obtained during the study were higher than the previously reported values from the Arabian Gulf [28, 29]. According to a report for the same period, phytoplankton and zooplankton were richer in the intake bay than in the open sea because of the embayment effect caused by the construction of the intake break waters [30]. Many organisms of known biofouling nature such as larvae of polychaetes (serpulids), barnacles and molluscs were seen in the plankton in good numbers. The presence of suspended particles and a good number of organisms of settling nature create a natural setting that encourages biofouling of available surfaces in the bay.

The role of substratum is of paramount importance in the formation of the primary film and settlement of organisms. Many organisms prefer slimed surfaces [31]. Barnacles and serpulid polychaetes exhibit strong preference for slimy layer for settlement. The layer actually entraps them on the surface and makes it difficult for them to leave. The slime changes the color of the surface making it more attractive and it provides abundant food for the young settlers. Surface chemistry such as the chemical nature of surface adherent particles and that of materials themself, is also known to influence biofouling [32]. Whereas dissolved oxygen and availability of light promote the settlement of diatoms and algae in open water environments, it is not so with the macrofouling larvae which gets settled in the dark, oxygen deficient environments of plant equipment and tubes. Their growth is guided by other factors such as a firm foothold, enough dissolved oxygen and plenty of food. The economics of clean heat exchangers in the power and desalination industry, clean hulls for ships and submarines, etc. are driving engineers and scientists in the pursuit of finding a more lasting solution to the problems caused by biofouling.

4. CONCLUSIONS

The present study was focused on the pattern of biofouling that occurs on glass coupons exposed in a desalination plant intake bay on the shores of the Arabian Gulf. The seawater in this man-made intake bay exhibited higher biofouling potential than the open sea. Biofilm showed a growth in thickness during the first three to four weeks followed by a period of reduction. Increase in Biofilm wet and dry weights were found associated with increased exposure time. The biofouling community, consisting of 31 genera of organisms, was dominated by diatoms in all the experiments performed. Navicula sp., Licmophora sp., Nitschia sp. and Enteromorpha sp. were the numerically abundant species in the community. Highest generic diversity was found in the 28 day old community. A succession of species in relation to periods of exposure was also discernible. The density of settling organisms showed seasonal and inter-annual variations. Although, in many cases exposure period was a factor that influenced the density of settlement, it was not so in all situations. A long term study is needed to understand the formation of complex biofouling communities which may pose serious problems for marine installation and materials exposed to it.

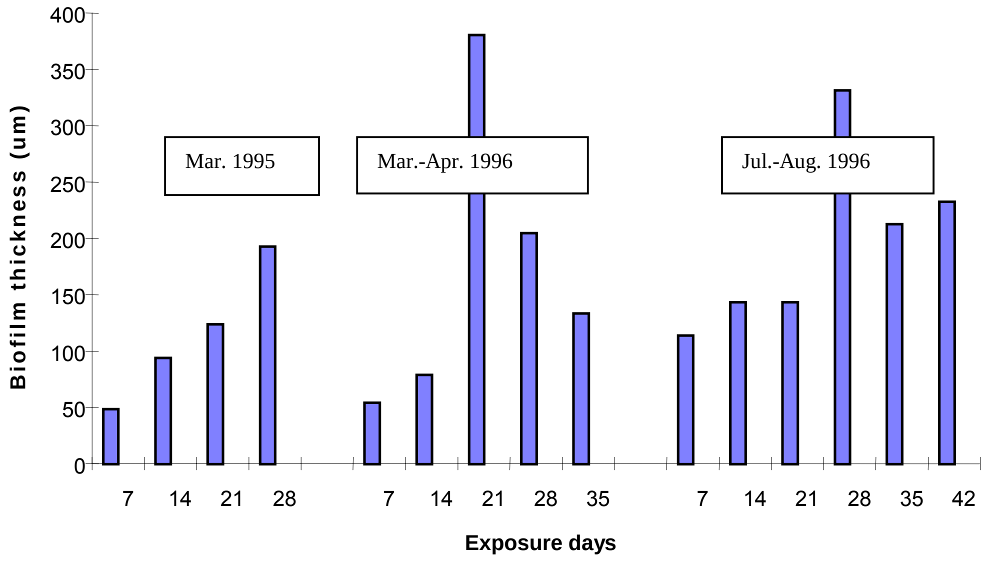

Figure 1. Thickness of biofilm on glass coupons in the Intake Bay.

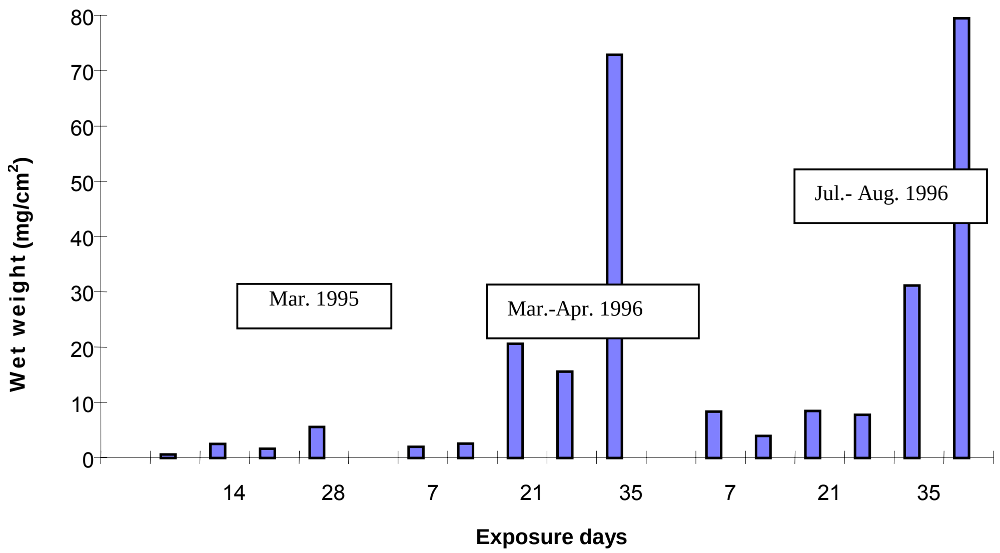

Figure 2. Wet weight of biofilm formed on glass coupons exposed in the Intake Bay.

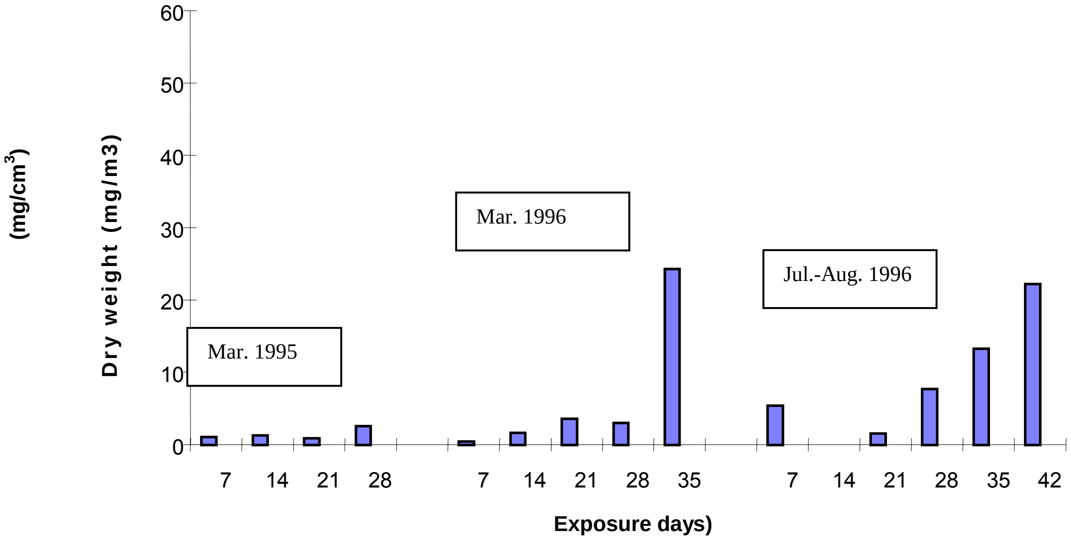

Figure 3. Dry weight of biofilm formed on glass coupons exposed in the Intake Bay.

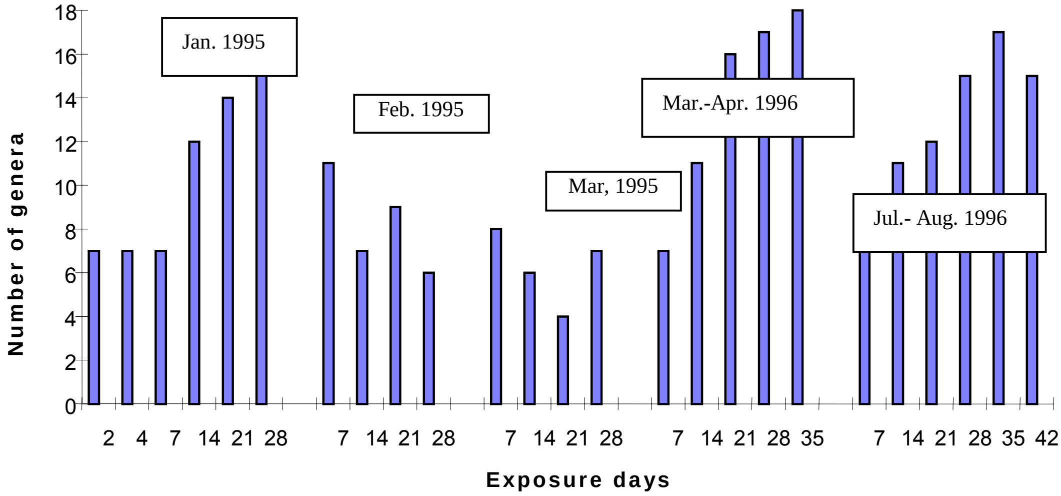

Figure 4. Biofilm generic diversity at the Intake Bay during 1995-96.

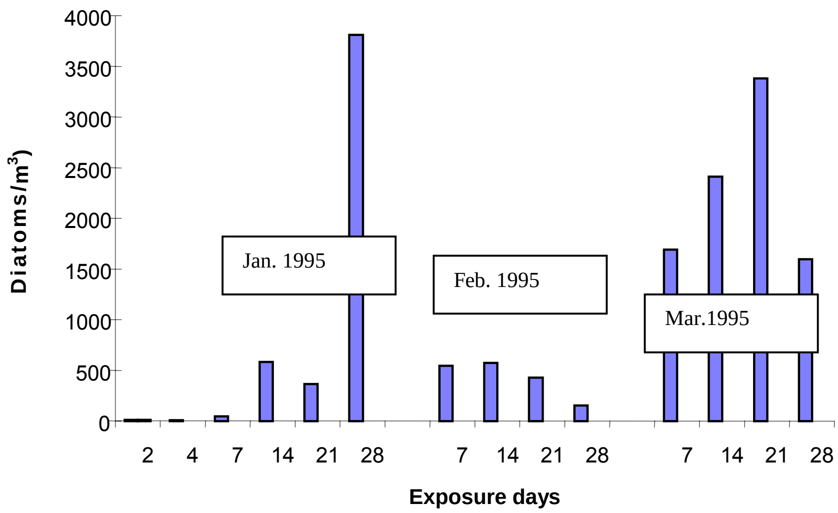

Figure 5. Total number of diatoms settled on glass coupons exposed in the Intake Bay during 1995

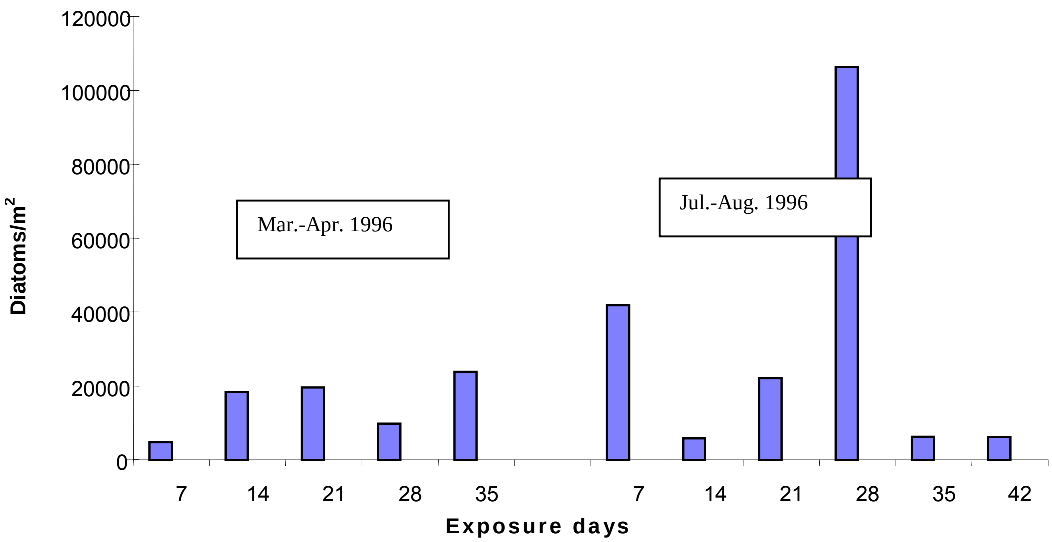

Figure 6. Total number of diatoms settled on glass coupons at the Intake Bay during 1996

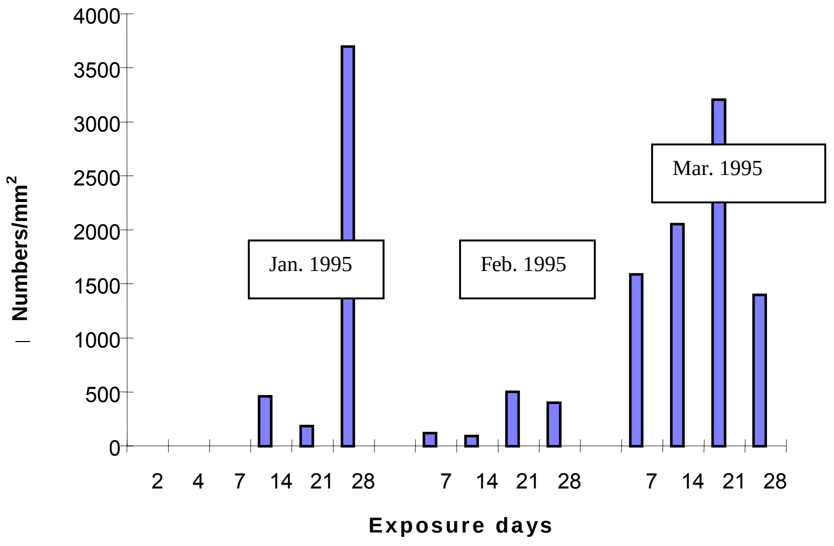

Figure 7. Settlement of *Nitschia* sp. on glass coupons exposed in the Intake Bay during 1995

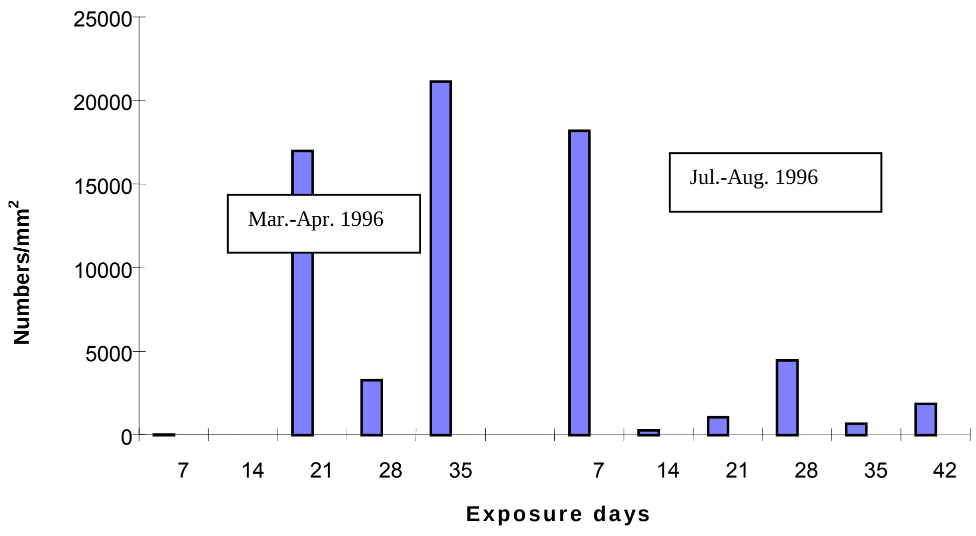

Figure 8. Settlement of *Nitschia* sp. on glass coupons exposed in the Intake Bay during 1996

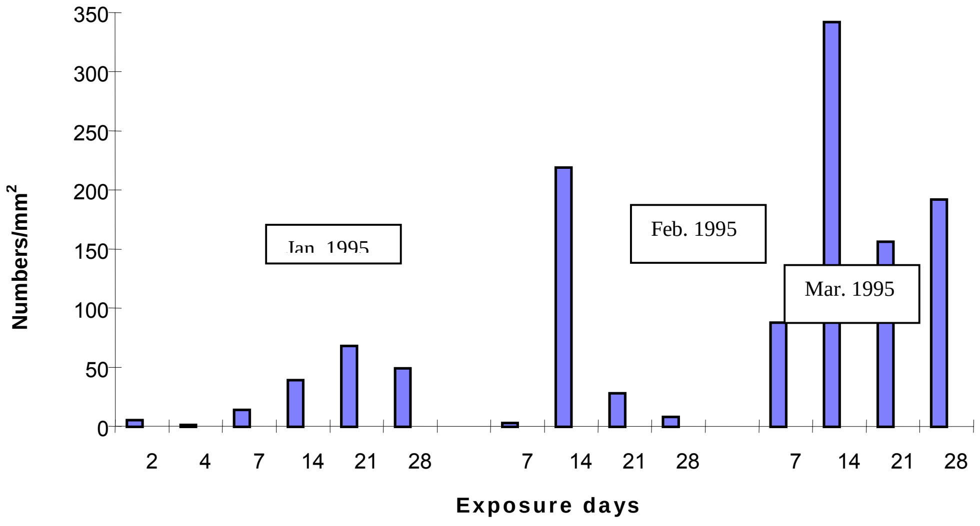

Figure 9. Settlement of *Navicula* sp. on glass coupons exposed in the Intake Bay during 1995

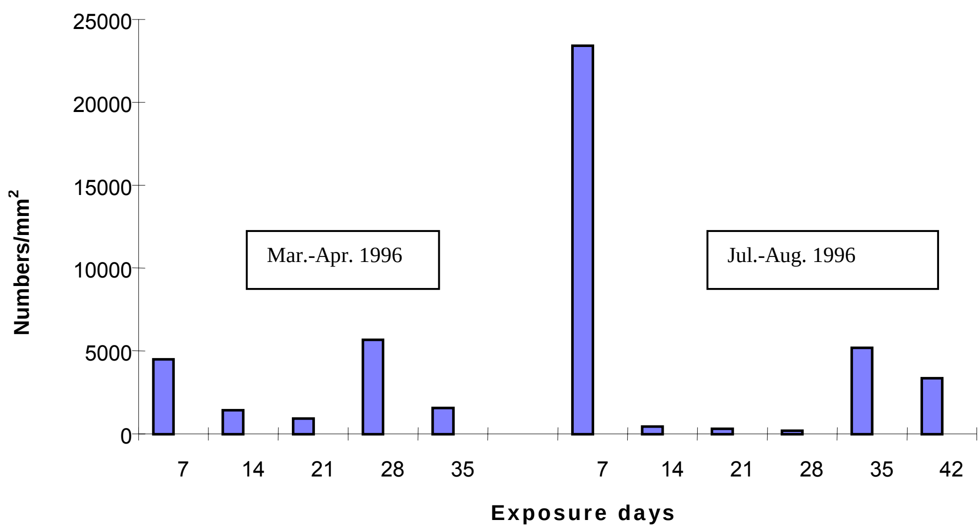

Figure 10. Settlement of *Navicula* sp. on glass coupons exposed in the Intake Bay during 1996

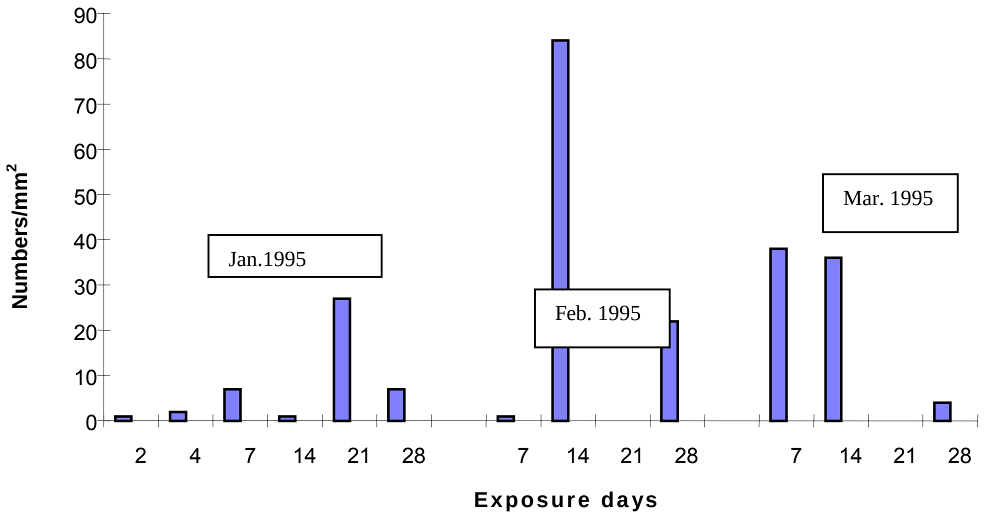

Figure 11. Settlement of protozoa on glass coupons exposed in the Intake Bay during 1995

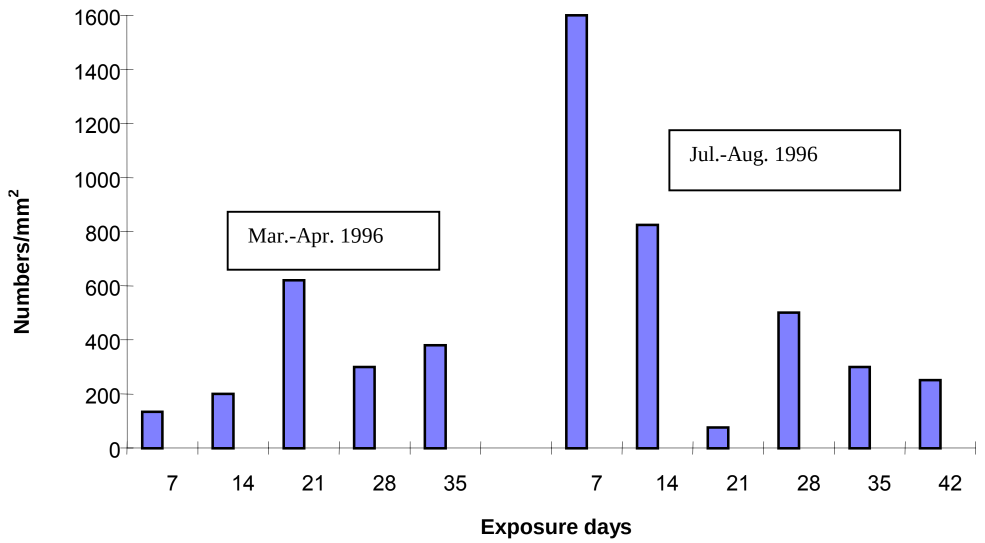

Figure 12. Settlement of protozoa on glass coupons exposed in the Intake Bay during 1996

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