

IMPACT OF HEAVY METALS ON THE PRIMARY PRODUCTION

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ABSTRACT

Effect of different concentrations of some heavy metals on the primary production was studied at two localities near Jeddah (Red Sea), by estimating chlorophyll-a.

Metal toxicity at low concentrations influence the productivity of the phytoplankton, and can be arranged in the following order: $Pb > Zn > Ni > Cd$.

More depress on the phytoplankton productivity took place, when Zn accompanied another/other metal(s) in the media.

Impact of heavy metals on the primary production at the sheltered area (inside Obhur Creek), was relatively higher than that observed at the exposed area (Open Sea).

INTRODUCTION

Phytoplankton species are capable of taking up and accumulating heavy metals many times greater than their concentrations in the surrounding medium (Riley and Roth 1971; Knauer and Martin 1973). Despite their low concentrations in the surface waters of the ocean (Bender et al. 1977; Bruland 1980), ambient concentrations of trace metals can have significant effects on the growth and species composition of phytoplankton communities (Huntsman and Sunda 1981), which in turn can control rates of secondary production. These effects result from the dual role of many metals (e. g. Fe, Mn, Zn, Cu) as either essential micronutrients or as inhibitors of metabolic processes.

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Studies of metal accumulation have also been stimulated by the possibility of using marine organisms as pollution indicators (Bryan and Hummerstone 1973; Clark et al. 1976).

The purpose of this investigation deals with the effect of different concentrations of some heavy metals on the primary production, which in turn can control rates of secondary production.

MATERIALS AND METHODS

The study area (Obhur) is located at about 35 Km north of Jeddah, between lat. 21°42' and 21°47'N, and 39°04' and 39°09'E (Fig. 1).

Obhur Creek is a narrow, winding, connected to the Red Sea, and extends for about 9 Km eastward. It has an average width of 500 m. and a maximum depth of 50 meter (Behairy et al. 1983; Khalil and Ibrahim 1987).

Behairy et al. 1983, confirmed that the seawater at North of Jeddah and Obhur Creek contains levels of heavy metals comparable to those of unpolluted sea and ocean waters.

Two stations were chosen to perform the experiments in February 1983. Station I, is located at 3 Km offshore (exposed area), whereas Station II, lies in the middle of the Creek (sheltered area) (Fig. 1). Plastic bags (30 litres) were used, those constituted a closed system, with a transparent flexiglass lid at the top and walls of double layers plastic material, allowed 95% light transmission. At each station, simultaneously, surface seawater (50 Cm depth) with its natural plankton population were introduced to the plastic bags. This should have ascertained the equal distribution of phytoplankton assemblage in each.

Heavy metals were introduced to the bags using automatic pipette, with concentrations of 1, 2 and 4 ppb of each metal individually, in addition to the following system of combination between metals, with final concentration of 4 ppb:

- 1— Cd + Pb
- 2— Cd + Zn
- 3— Cd + Ni
- 4— Pb + Zn
- 5— Pb + Ni
- 6— Zn + Ni
- 7— Cd + Pb + Zn
- 8— Cd + Pb + Ni
- 9— Cd + Zn + Ni
- 10— Pb + Zn + Ni
- 11— Cd + Pb + Zn + Ni

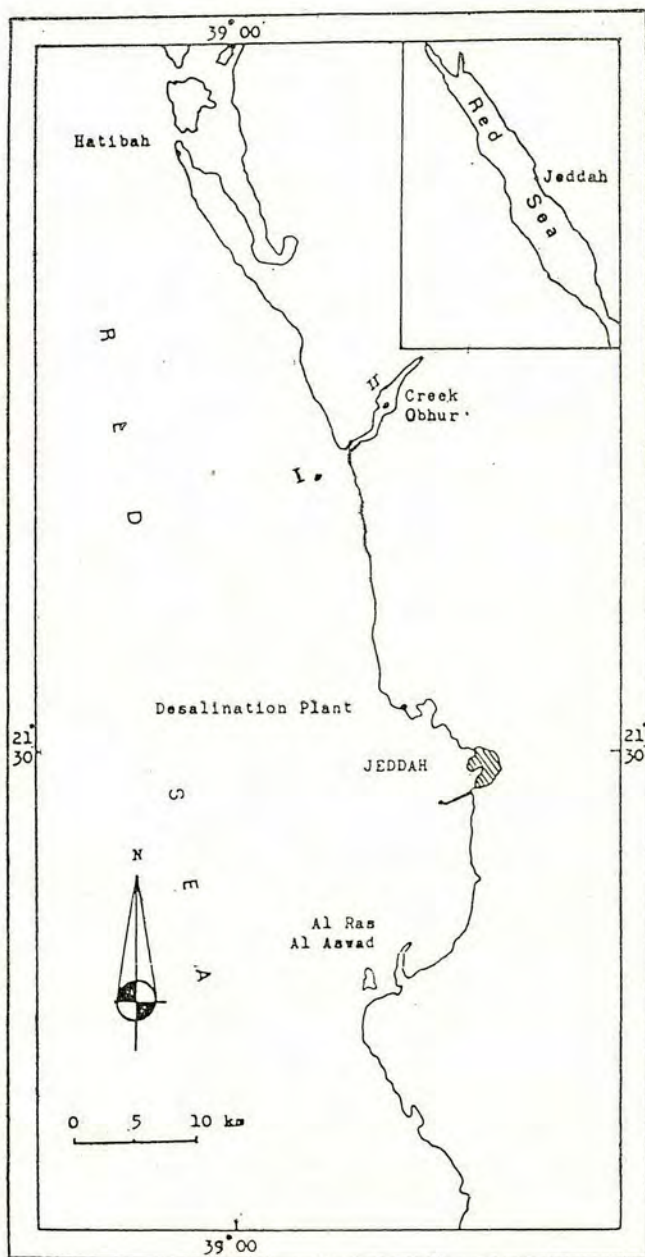


Fig. (1). Map of Jeddah coast (Red Sea) showing the sites of experiments.

Metals were added as the following analytical reagent grade salts: $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, $3\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$, PbCl_2 (anhydrous). During the experiments, the bags were attached to buoys and suspended for 8 hours, at 50 Cm depth subsurface seawater. Controls were provided by parallel systems using the same natural seawater in both stations.

After 8 hours, two replica, 5 litres, were taken from each bag and filtered to estimate chlorophyll-a, according to the method of Strickland and Parsons 1972.

The average temperature in the area during the time of experiments was 25.4°C , while the average of salinity was 39.26 S.

RESULTS AND DISCUSSION

The impact of Cadmium, lead, Zinc and Nickel on the phytoplankton productivity is shown in Fig. 2.

Effect of insertion a single metal:

At a concentration of 1 ppb, both Zn and Pb (separately), had a relatively higher effect on the primary production than those noticed by Cd and Ni (singly). At the Open Sea location (Station I), the primary production was depressed 24% by Zn and 28% by Pb, and Pb respectively, while at the Inside of the Creek (Station II), the primary production was depressed 24% by Zn and 28% by Pb.

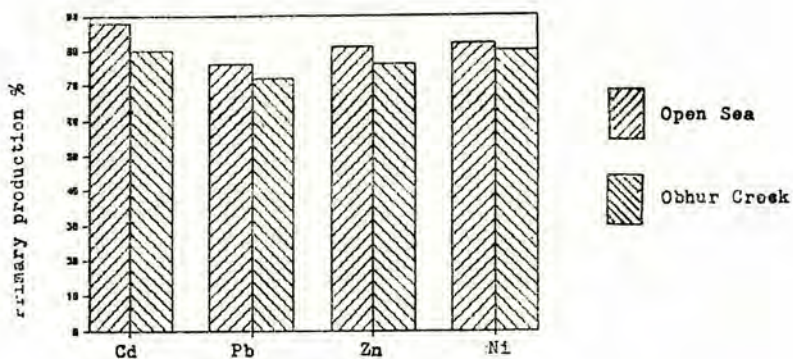
Under identical experimental conditions, Pb reduced the phytoplankton productivity, at Station I, to a double value of that recorded by Cd. Nearly the same observation noticed at Station II (Table 1).

The present data showed that in presence of low concentration of a single metal, Pb is more toxic to the phytoplankton growth than Cd. The influence of both Ni and Zn (individually) on the primary production was nearly the same (Table 1).

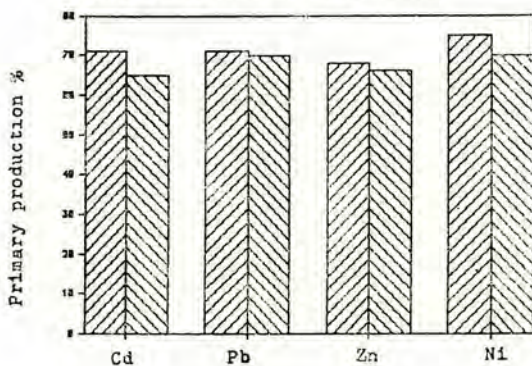
Likewise, at a concentration of 2 ppb of separate metals, the results showed a gradual decrease in the phytoplankton productivity.

Fig. 2, demonstrate nearly an equal effect on the primary production by Pb and Cd, whereas at the same concentration, the influence of Ni was relatively lessen. On the other hand, at a concentration of 2 ppb, Zn depressed the productivity of phytoplankton than did the other metals.

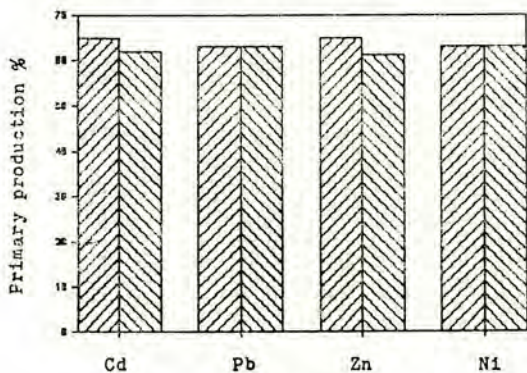
As regards, at a concentration of 4 ppb of metals singly, the results of estimating primary production indicated that, the productivity was depressed markadely at both stations (Table 1).



(a). At concentration of 1 ppb.



(b). At concentration of 2 ppb.



(c). At concentration of 4 ppb.

Fig.(2). Effect of different concentrations of heavy metals on the phytoplankton productivity, during 8 hours of daylight, in situ, Obhur, North Jeddah.

Table (1). Effect of Cd, Pb, Zn and Ni on the primary production of Phytoplankton in Obhur area, North Jeddah.
(St. I: Offshore station; St. II: Middle of Obhur Creek)

Concentration of metals	Stations	Decrease percent in the primary production							
		Cd		Pb		Zn		Ni	
		I	II	I	II	I	II	I	II
1 ppb		12	20	24	28	19	24	18	20
2 ppb		29	32	29	30	32	34	25	30
4 ppb		35	38	37	37	35	39	37	37

Pb and Ni had the same influence, whereas both Cd and Zn had more or less an equal effect, but lower than those observed by the other two metals, particularly at Station I.

Effect of introduce two metals:

Influence of insertion two metals into the media is tabulated in Table 2. It is observed that combination between two metals (final concentration 4 ppb) affect the phytoplankton productivity that was depressed 30-34% and 32-35% at Open Sea Station and Inside Obhur Creek respectively.

Table (2). Effect of interaction of combined metals on the phytoplankton productivity, in situ, at Obhur (North Jeddah)

Combined metals (pairs & groups) final concentration 4 ppb	Decrease percent in primary production	
	Open Sea Station (exposed area)	Creek Station (sheltered area)
Cd+Pb	30	32
Cd+Zn	32	35
Cd+Ni	30	34
Pb+Zn	34	35
Pb+Ni	31	35
Zn+Ni	32	34
Cd+Pb+Zn	40	42
Cd+Pb+Ni	40	41
Cd+Zn+Ni	41	42
Pb+Zn+Ni	41	42
Cd+Pb+Zn+Ni	45	48

During the time of experiments, the existence of both Zn and Pb together in the same media depressed 35% of the productivity of phytoplankton, moreover it was more harmful on the activity of phytoplankton, than the influence of the other pairs of metals.

Insertion of both Ni and Zn to the same media, led to diminish 32-34% of the productivity. The same influence was occurred by Cd + Pb or Cd + Ni (Table 2).

Effect of induction groups of three metals:

When three metals introduced to the same media, the injurious effect of their presence on the phytoplankton productivity apparently increased. Whatever the three added metals, their effect on the productivity were almost the same (Table 2), which depressed 40-42% of the primary production.

The combined effect of three metals on the phytoplankton productivity can be arranged in the following order:

Cd + Pb + Zn = Cd + Pb + Ni,

Cd + Zn + Ni = Pb + Zn + Ni,

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Effect of insertion four metals:

Insertion of the four metals into the media pressed down the phytoplankton activity, leading to a sharp decrease in the primary production, that attained about 48%. (Table 2).

Existence of the four metals (Cd, Pb, Zn & Ni), in the same media, had a powerful effect on the phytoplankton productivity, which overcame the values that estimated whenever introduced to the media such metal singly or in groups.

Generally, it is noticed that the effect of different concentration of heavy metals on the productivity of the phytoplankton at the location inside Obhur Creek, was relatively higher than that observed at the Open Sea Station, which may be due to the poverty in phytoplankton inside Obhur Creek (Khalil and Ibrahim 1987), as a result of slow exchange of the Creek surface water with the Red Sea water (Sheikh 1981), that may affect the replenishment of the nutrients in the surface water inside the Creek, consequently, the phytoplankton growth. Khalil and Ibrahim 1987, indicated that the standing crop and the number of the phytoplankton species at the Offshore location, was nearly about threefold of that observed at the Inside of the Obhur Creek.

Khalil and Ibrahim 1987, recorded 73 species of the phytoplankton belonging to 27 genera, during winter, in which the most dominant and frequent species stated in the following list:

A. Diatoms:

Asterionella japonica
Asteromphalus heptactis
Bacteriastrum delicatulum
Biddulphia sinensis
Cerataulina bergonii
Chaetoceros curvisetus
Climacodium frauenfeldianum
Coscinodiscus concinnus
Eucampia cornuta
Gyrosigma balticum
Lauderia borealis
Nitzschia socialis
Planktoniella sol
Rhizosolenia calcar-avis
Stephanopyxis turris
Thalassionema nitzschioides
Thalassiothrix longissima

B. Dinoflagellate:

Amphisolenia globifera
Ceratium breve
Ceratocorys horrida
Dinophysis miles
Exuviella compressa
Goniodoma polyedricum
Gonyaulax polygramma
Ornithocercus quadratus
Peridinium depressum
Pyrocystis lunula

No significant pollution by heavy metals in the seawater at the shoreline north of Jeddah (Behairy et al. 1983). However, different species vary widely in their metal tolerance and requirements. Therefore, although trace metals in unpolluted water may briefly limit rates of photosynthesis, their primary role lies in regulating species composition and succession (Huntsman and Sunda 1981).

Otherwise, it is also apparent that cells have evolved mechanisms of adaptation to unfavourable trace metal conditions (Anderson and Wall 1978).

The above mentioned data showed that, under identical experimental conditions, the effect of presence of 1 ppb of a single metal in the media for 8 hours (in situ), was depressed about

12-28% of the productivity of the phytoplankton. Besides, Pb was more toxic than the other metals, however, metal toxicity can be arranged in the following order:



This order is nearly followed the Irving-Williams series (Irving and Williams 1948):



Brooks and Rumsby 1965, reported that the order values for several types of shellfish did not strictly follow the Irving-Williams series. They suggested that coordination of metal ions with organic ligands was masked by some other factors such as contamination by, and particulate ingestion of, sedimentary material. Another possible reason for deviation from the Irving-Williams series is that concentrations of essential metals such as Copper and Zinc may be regulated by the organism (Bryan 1971).

In the presence of 2 ppb of a single metal in the media, Zn depressed the productivity of the phytoplankton more than those observed by the other metals (Table 1). Moreover, a marked changes in the order of toxicity was noticed, comparing with that of a concentration of 1 ppb of a single metal. However, a replacement in the order of metal toxicity took place as follows:



This order agrees with that given by Canterford et al. 1978 and Bowen 1966 for plankton and does not follow the Irving-Williams series.

At a concentration of 4 ppb of a metal, the productivity was depressed markedly and the toxicity effect of the four metals was nearly the same (Fig. 2-c).

Bryan 1969, observed that relatively more zinc was taken up by *Laminaria digitata* the lower the zinc concentration in the medium. Gutknecht 1965, stated that this relationship would be expected if uptake were due to adsorption or ion-exchange processes.

For each metal the percentage uptake generally decreased with increasing external metal concentration (Canterford et al 1978).

Concentrations of trace metals in the surface waters of the ocean can have significant effects on the growth and species composition of phytoplankton communities (Huntsman and Sunda 1981), which in turn can control rates of secondary production. These effects result from the dual role of many metals (e. g. Fe, Mn, Zn, Cu, Co) as either essential micronutrients or as inhibitors of metabolic processes. All trace metal micronutrients, are toxic at sufficiently high concentration and, therefore, demonstrate a range

of concentrations optimal for growth or metabolism above and below which adverse physiological effects occur (Cross and Sunda 1985).

Other trace metals with no known physiological function (e. g. Cd, Hg, Ag, Pb) exert biological effects only through their toxicity. Natural variations in ion activity of some heavy metals can influence phytoplankton growth and species composition in the marine environment (Sunda and Guillard 1976; Anderson and Morel 1978).

The present data showed that more depress on the phytoplankton productivity takes place, when Zn accompanies another metal (in the medium) as dual.

The metal-metal interactions are an important environmental factor in controlling trace metal toxicity to phytoplankton (Sunda and Huntsman 1983). Bartlett et al. 1974, observed that cadmium had an additive effect on zinc induced inhibition of the green unicell, *Selenastrum capricornutum*, besides it antagonized the inhibitory effect of copper.

Braek et al. 1976, found that low (non-toxic) levels of zinc enhanced copper inhibition of growth of *Thalassiosira* and *Skeletonema*. However, much more frequently toxic and non-toxic metals (including essential metals) have been found to interact competitively, so that the latter decrease toxic metal uptake or inhibition. Thus, calcium has been observed to antagonize manganese toxicity (Gerloff and Skoog 1957) and zinc was found both to reduce cadmium uptake (Cossa 1976) and to relieve copper inhibition or growth in *Phaeodactylum tricornerutum* (Braek et al. 1976).

When Zn in its turn was increased to inhibitory concentrations, its effect on growth could be partially overcome by addition of magnesium (Braek et al. 1976).

Likewise, Foster and Morel 1982, pointed out that cadmium toxicity to *Thalassiosira weissflogii* can be reversed by iron, because cadmium interferes with iron metabolism.

Salinity and temperature may also strongly affect metal uptake. Although in the case of salinity, part of the effect may be due to shifting chemical equilibria (Sunda et al. 1978).

Huntsman and Sunda 1981, indicated that competition among metals and physiological interactions between metals and other factors such as nutrients can affect cellular response.

Cross and Sunda 1985, demonstrated that the bioavailability of trace metals (e. g. Cu, Zn, Cd, Mn) to marine organisms is related quantitatively to the free metal ion activity, rather than the total dissolved metal concentration.

Since phytoplankton may be found living under a wide range of trace metal concentrations and activities, it is clear that at least some species have evolved mechanisms for adaptation to growth at both high and low metal availabilities.

The present study showed that the phytoplankton productivity was affected markedly when different concentration of a single, dual or groups of heavy metal(s) were inserted to the media.

At a concentration of 1 ppb of heavy metals, the metal toxicity can be arranged in the following order:



Increasing the concentration of metal(s) in the media led to a replacement in the order of toxicity.

More depress on the primary production took place, when Zn associated other metals in the media.

Effect of heavy metals on the phytoplankton productivity at the location of inside Obhur Creek was relatively higher than that noticed at the offshore area.

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