Productivity Relations in Seawater Fish Ponds: A Comparison of Stocked and Unstocked Ponds*

F. Motzkin[1], Y. Cohen[2, 3], H. Gordin[1] and E. Padan[3]

[1] Israel Oceanographic & Limnological Research, Mariculture Laboratory, P.O.B. 1212, Elat, Israel
[2] H. Steinitz Marine Biology Laboratory, P.O.B. 469, Elat, Israel
[3] Division of Molecular and Microbial Ecology, The Hebrew University of Jerusalem, Jerusalem, Israel

ABSTRACT: The interactions between nutrient load, fish activities, and developing phytoplankton were studied in a stocked seawater fish pond as compared to an unstocked seawater control pond. Both ponds received the same nutrient load from a common inflow (2.7 g at nitrogen d^{-1} and 0.065 g at phosphorus d^{-1}); they were flushed at a rate of 0.6 d^{-1}. Apparent growth rates of the phytoplankton varied from 0.62 to 1.7 in the ponds. The stocked fish pond received an extra nutrient load from the fish food (1.9 g at nitrogen d^{-1} and 0.14 g at phosphorus d^{-1}); this was responsible for the higher standing crop observed in this pond, 10 to 53 mg Chl a m^{-3} compared to 4 to 28 mg Chl a m^{-3} in the unstocked control pond. The average daily primary production was 3.5 g C $m^{-2}d^{-1}$ and 2 g C $m^{-2}d^{-1}$ in the stocked fish pond and control pond, respectively. Remarkably, however, both ponds showed the same pattern of monthly periodicity in phytoplankton blooms. The high N:P ratios (18 to 80) in the inflow water and their periodical fluctuations that correlate with the blooms suggest that both systems are phosphorus limited. The tidal pattern in the gulf seems both to induce the periodicity of the inflow water N:P ratios and to govern the monthly cycle of the blooms.

INTRODUCTION

An increase in the productivity of the natural food chain characterizes fresh and brackish water fish ponds stocked either as mono- or polyculture with different species of carp, Tilapia, and grey mullets (Bardach et al., 1972; Moav et al., 1977; Halevi, 1979). Both high standing crop and primary production have been documented in such ponds (Hepher, 1962; Schroeder, 1978; Norriega-Curtis, 1979). This eutrophication is caused by the introduction of inorganic fertilizers, organic manure, and supplementary fish food (Dimitrov, 1974; Hepher, 1975).

During dense algal blooms in these ponds, high photosynthetic activity leads to supersaturated oxygen levels in the water column during the day, and fish mortalities occur due to 'gas bubble disease' (Harvey and Smith, 1961; Pauley and Nakatani, 1967). When the blooms collapse, complete oxygen depletion may occur, resulting in mass fish mortalities in the ponds (Abeliovich and Shilo, 1972; Ellof et al., 1976). Drastic pH fluctuations in the order of 3 pH units within a

diurnal cycle have also been encountered (Abeliovich, 1969; Amlacher, 1970). At the bottom of these ponds anaerobic sediments rich in organic matter develop, and thus the aerobic mineralization processes become inhibited. This inhibition results in dominating anaerobic fermentation, nitrate and sulphate reduction processes, and methane production (Wolfe, 1971; Brezonik, 1972; Cappenberg, 1974). Some of the end products of these microbial activities, such as ammonia and H_2S, have been shown to be toxic to fish and inhibitory to fish growth (Reichenbach-Klinke, 1967; Kinne, 1976; Colt and Tchobanoglous, 1978; Seymour, 1980).

In spite of long traditions of extensive marine fish farming in the Far East, information on intensive fish farming in seawater ponds is lacking (Bardach at al., 1972; Huguenin, 1975). In developing intensive marine aquaculture, the introduction of treated sewage to marine shellfish ponds, accompanied by increased algal biomass, proved to be successful in converting nutrients into the biomass of higher marine organisms (Goldman et al., 1973; Goldman and Ryther, 1975; Ryther et al., 1975).

Recently, intensive marine fish farming in experimental seawater fish ponds was undertaken in the arid

coastal desert area of Elat, Israel, where access to freshwater sources is limited. These seawater ponds were stocked for polyculture experiments with *Sparus aurata* and *Mugil cephalus*. Due to the carnivorous behaviour of *Sparus aurata*, the fish in the ponds were fed with pelleted food (Marais and Kissil, 1979); no other fertilizers were used, contrary to the practices of freshwater fish farming. Seawater fish ponds differ from freshwater ponds in a number of ways: (1) Since the seawater ponds have a continuous inflow of fresh seawater at a dilution rate of $0.58-0.62\,d^{-1}$, temperature and pH are more stable as compared to stagnant freshwater ponds (Krant et al., in press). Salinity fluctuations in the seawater ponds are small despite high evaporation rates of $1\,cm\,d^{-1}$ (Assaf and Kessler, 1976). (2) The seawater supplying the ponds contains excess sulphate, which enhances sulphate reduction in the sediments and thus inhibits methane production (Jørgensen and Fenchel, 1974; Abram and Nedwell, 1978). This is in contrast to the high methane production in the sediments of freshwater ponds (Cappenberg, 1974).

Despite these differences between seawater and freshwater fish ponds, a similar trend in both systems was noted of decreasing yield with increasing pond age. Annual yields in the seawater ponds decreased from $8,750\,kg\,ha^{-1}yr^{-1}$ in the first year to $5,380\,kg\,ha^{-1}yr^{-1}$ in the fourth year (Gordin et al., 1980). Similar but more drastic trends of inhibited growth rates of fish have long been observed in intensive freshwater ponds (Avnimelech and Lacher, 1979; Rappaport and Sarig, 1979). This decrease in fish growth in the freshwater fish ponds is believed to result from the anaerobic end-product metabolites related to the eutrophication process.

The aim of the research work reported here was to study the dynamics of the algal blooms in relation to the eutrophication rates in the seawater fish ponds with an unstocked pond serving as a control.

MATERIAL AND METHODS

Experimental System

Two experimental seawater fish ponds were used at the laboratory of the Israel Oceanographic & Limnological Research, situated in Elat on the Gulf of Elat (Aqaba). Both ponds were rectangular with gradually sloping sides and an average depth of 1 m. The unstocked pond serving as a control pond had an area of $203\,m^2$ and a volume of $144\,m^3$. The other pond had an area of $223\,m^2$ and a volume of $134\,m^3$. The latter was stocked with 600 *Sparus aurata* and 50 *Mugil*

cephalus (average density 5 fish m^{-3}). Both ponds were supplied by filtered seawater which was pumped from a nearby seawater well located 20 m from the shoreline. The flow rate was $3.5\,m^3\,h^{-1}$ to each of the ponds, and it was continuously monitored with a flow meter. The corresponding dilution rate of the control pond was $0.58\,d^{-1}$ and in the fish pond $0.62\,d^{-1}$. All measurements were done weekly, between 11.00 h and 13.00 h, from permanent platforms at the study site in each of the ponds.

Parameters Measured

Primary production was determined by using the ^{14}C assimilation technique (Strickland and Parsons, 1968), modified in the following way: 130 ml Pyrex bottles 'light' and 'dark' were filled with pond water and 100 Ci of carrier free $NaH^{14}CO_3$ (Amersham, England) was added to each of them. The alkalinity was measured according to Strickland and Parsons (1968) and ranged from 2.2 to 2.6 mEqv. A 'dark' and a 'light' bottle were incubated in situ in the ponds at 3 depths: 0, 50, and 100 cm (bottom) for 2 h. The water was then filtered through Whatman GF/F filter paper. The filters were acidified with fumes of concentrated HCl in a vacuum desiccator for 12 h and counted with a Nuclear Chicago 181 B gas flow meter. The 'dark' bottle counts were subtracted from the 'light' bottle counts.

Preliminary measurements of water movements in the ponds demonstrated the rapid mixing rates occur-
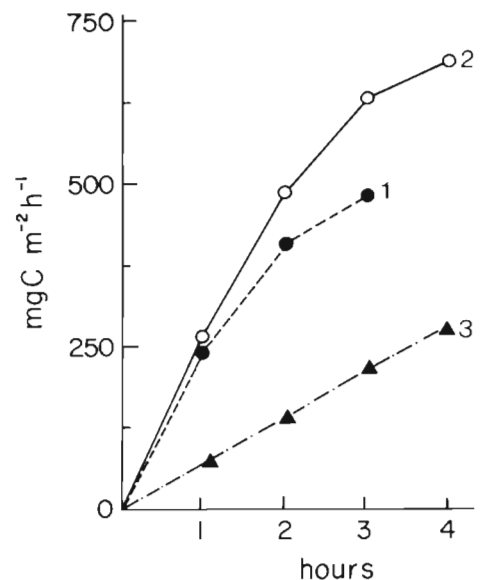

Fig. 1. Time course of primary production experiment, 25 August 1977. (1) Surface water, (2) 50 cm, (3) bottom (100 cm)

ring in them. The residence time of a particle at the surface of the water can be as short as 4 min. This fast mixing was avoided in the closed bottles. However, a time course experiment done during a dense *Skeletonema* sp. bloom in the fish pond has shown that the primary production activity was linear for up to 2-h incubation. Inhibition of photosynthetic activity was only observed during longer periods of incubation (Fig. 1). Therefore, the estimation of the primary production rate was based on a 2-h incubation period.

Light penetration was measured throughout the water column at 10 cm intervals with a L1-185 A quantum/radiometer/photometer equipped with a L1-192 S underwater quantum sensor that measured the photosynthetically active radiation in the 400–700 mμ wavelength range. The results were expressed in Einsteins s^{-1} m^{-2}.

Dissolved oxygen and temperature were measured with a YS1-54 oxygen analyzer equipped with an oxygen and temperature electrode. Oxygen electrode measurements were corrected using Winkler titration (Strickland and Parsons, 1968). The pH and alkalinity were determined by the Strickland and Parsons (1968) titration method. Dissolved inorganic nutrients (N-NH_4, N-NO_2, N-NO_3, P-PO_4, Si-SiO_2) were determined according to Grasshoff (1976).

Chlorophyll *a*, *b*, and *c* concentrations were determined in 1 l of pond water according to Strickland and Parsons (1968) using the following conversions:
(a) Chlorophyll *a*: 11.6 E_{6650} − 1.31 E_{6450} − 0.14 E_{6300};
(b) chlorophyll *b*: 20.7 E_{6450} − 4.34 E_{6650} − 4.42 E_{6300};
(c) chlorophyll *c*: 55.0 E_{6300} − 4.64 E_{6650} − 16.3 E_{6450}.

Phytoplankton was collected from the water column and preserved in 2% Lugol solution. Cell counts and identification were done microscopically using a Neubauer Haemacytometer (Clay-Adams).

RESULTS

We studied the interactions between nutrient load, fish activities, and developing phytoplankton by following simultaneously physical, chemical, and biological parameters in a stocked pond and an unstocked control pond.

Physical and Chemical Parameters

Previous studies have shown that both experimental ponds are completely mixed (Krant, 1979). Salinity in both ponds was stable, varying from 41.45‰ to 41.81‰ during winter, and from 41.81‰ to 42.18‰ during summer. Throughout the period studied (November 1977 to January 1979), the temperature of both ponds
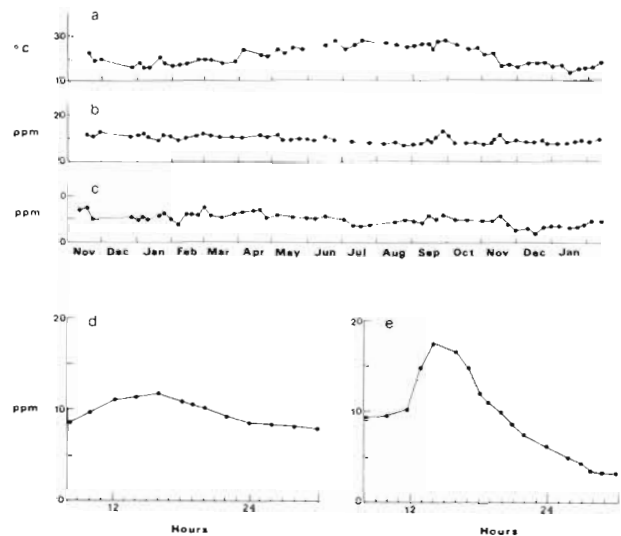

Fig. 2. (a) Annual temperature (°C) regime in the water column. (b, c) Annual regime of dissolved oxygen (ppm) in the water column of control pond and fish pond, respectively. (d, e) Diurnal cycle of the dissolved oxygen (ppm) of control pond and fish pond, respectively, on 19 November 1978

was followed weekly and found identical (Fig. 2a). The lowest temperatures were observed during winter (November to April); they varied from 8 °C in January to 26 °C in April. During the warm summer months (May to October), temperatures varied from 21 °C in October to 29 °C in July/August. The annual pH and alkalinity ranges in the ponds fluctuated only slightly, from 7.5 to 8.5 and from 2.2 to 2.6 mEqv, respectively.

The diurnal cycle of dissolved oxygen in the water column of the control pond (Fig. 2d) ranged from 7 ppm at dawn to 13 ppm at 14.00 h. In the fish pond the same pattern, though more pronounced, was observed ranging from 3 to 18 ppm (Fig. 2e). The annual regime of dissolved oxygen (Fig. 2b,c), based on measurements done at 11.00 h, exhibited the range of fluctuation observed within the diurnal cycle.

The annual mid-day ambient light regime measured at the pond site (Fig. 3a) showed exceptionally high insolation during summer, reaching 2200 µE m^{-2} s^{-1}; it decreased to only 1300 µE m^{-2} s^{-1} during winter. The percentage of light reaching the bottom of the control pond varied from 17% to 78% incident illumination during the study period (Fig. 3b); it showed drastic monthly fluctuations. As expected, these variations can be correlated with phytoplankton blooms (Figs. 4a, 6a). In addition, annual variations were observed in the form of increased light penetration during the summer which corresponded to the high incident light at this period (Fig. 3a). Much less light, 2% to 4% of the incident, penetrated to the fish pond bottom (Fig 3c). This was the result of high turbidity of the water column in the fish pond, 7–14 Klett units measured at
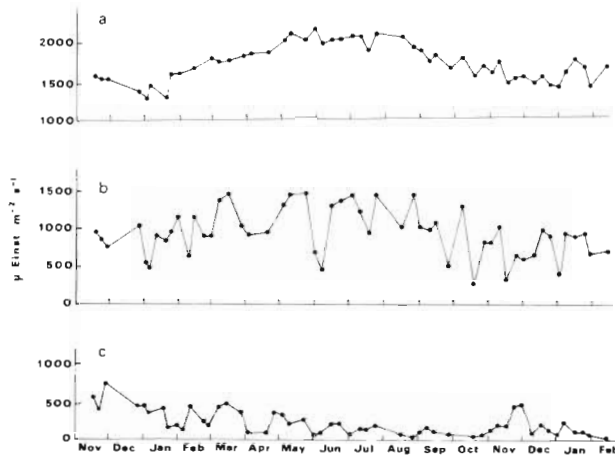
Fig. 3. Annual regime of light intensity (μ Einsteins $m^{-2}s^{-1}$) at (a) pond site, (b) control pond bottom, (c) fish pond bottom

790 nm, compared to 1 Klett unit monitored in the control pond. This turbidity was mainly caused by resuspension of silt which resulted from fish stirring up the sediment. Sedimentation trap studies showed that the resuspended particles account for 86 % to 93 % of the suspended material in the water column and range from 101.9 to 109.8 g $m^{-2}d^{-1}$. The suspended silt dampened the monthly fluctuations as compared to the control pond, and the same low light intensity reached the bottom throughout the year (Fig. 3c).

Phytoplankton and Primary Production

The concentrations of chlorophylls a, b and c in control and stocked fish ponds are shown in Fig. 4a and b. In the control pond, the range of chlorophyll a concentrations was between 4 and 28 mg Chl a m^{-3}; much higher levels of 10 to 53 mg Chl a m^{-3} were observed in the fish pond. Strikingly, both ponds exhi-
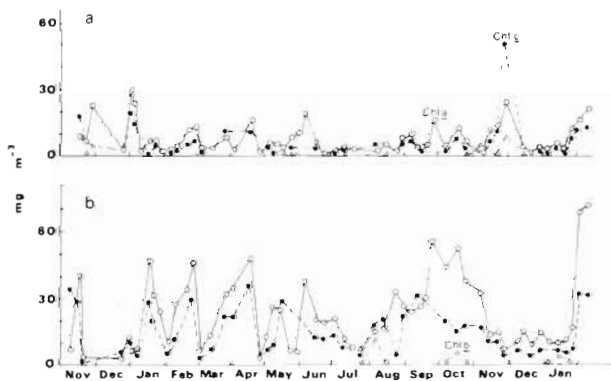

Fig. 4. Chlorophyll a, Chlorophyll b, and Chlorophyll c concentrations (mg Chl m^{-3}) during study period; (a) control pond; (b) fish pond

bited drastic monthly fluctuations but only slight seasonal effects. The standing crop of phytoplankton reached its lowest values during the summer.

Chlorophyll c followed chlorophyll a ranging from 2.5 to 19 mg Chl c m^{-3} and from 5 to 35 mg Chl c m^{-3} in the control and fish ponds, respectively. This corresponded to the dominating centric diatomous blooms of the ponds (Fig. 6a, b). The occasional appearance of chlorophyll b in both ponds correlated with sporadic Chlamydomonas sp. blooms (Fig. 6a b).

Consistent with the chlorophyll concentrations, the primary production was higher in the fish pond as compared to the control pond excluding one exceptional peak in November/December 1978. Primary production rates varied from 68 to 600 mg C $m^{-2}h^{-1}$ in the control pond and from 107 to 953 mg C $m^{-2}h^{-1}$ in the fish pond (Fig. 5a, b). The average daily primary production was 2 g C $m^{-2}d^{-1}$ and 3.5 g C $m^{-2}d^{-1}$ in the control and fish ponds, respectively. Accordingly, the annual primary production was 0.75 kg C $m^{-2}yr^{-1}$ in the control pond while in the fish pond it was 1.3 kg C $m^{-2}yr^{-1}$

The primary production rates in both ponds at a depth of 50 cm often exceeded those measured at the surface (Fig. 5a, b). This was probably due to photoinhibition at the surface layers resulting from high insolation in this area (Fig. 3a). Below the inhibited surface layer, primary production in the control pond was constant throughout the water column suggesting equal light conditions down to the bottom throughout
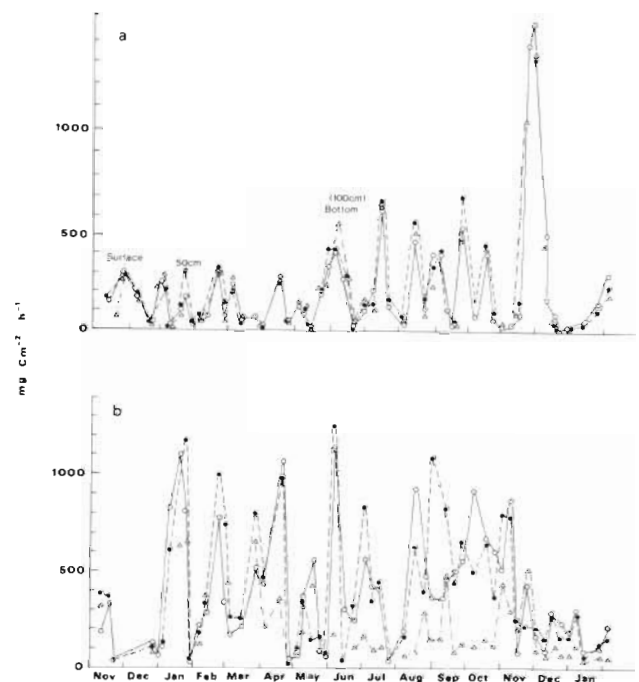

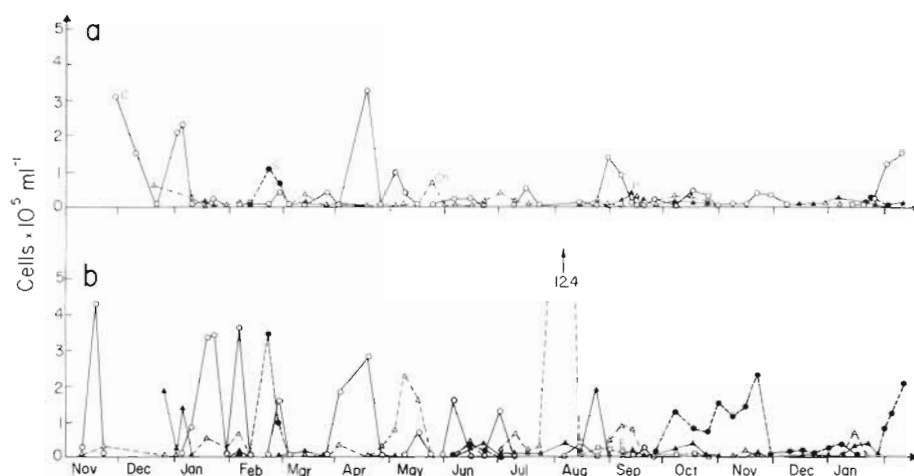Fig. 5. Primary production (mg C $m^{-2}h^{-1}$) in (a) control pond and (b) fish pond

Fig. 6. Phytoplankton concentration ($\# \times 10^5$ cells ml^{-1}). (a) Control pond; (b) fish pond. C: *Chaetoceros* sp., S: *Skeletonema* sp., Ch: *Chlamydomonas* sp., P: *Peridinium* and *Gymnodinium* forms, E: *Euglenoida* sp

the year. The lower values observed during summer, as compared to winter measurements, implied that light-inhibiting conditions prevailed throughout the water column during this season (compare with Fig. 3b). On the other hand, primary production rate at the bottom of the fish pond was only 10 % of that of the midwater value suggesting conditions of light limitation. This is probably due to the high silt suspended in the fish pond (86–93 % resuspended particles). Nevertheless, due to the very vigorous mixing allowing a particle to cross the pond in 4 min (unpubl.), each organism was exposed to a certain light condition for only a short period. Accordingly, the specific activity was virtually identical in control and fish ponds and ranged from 2–50 mg C mg Chl^{-1}h^{-1}, characteristic of light satura-tion. Furthermore, the primary production in general exhibited the same monthly periodicity as did the standing crop of chlorophyll.

The phytoplankton blooms corresponded with the monthly periodicity of the chlorophyll and primary production in both, control and fish ponds. The blooms which appeared every month lasted in general from 14 to 45 d in both ponds (Fig. 6a, b). The dominating phytoplankton species in the control pond was *Chaetoceros* sp. which appeared in concentrations of up to 3.5×10^5 cells ml^{-1} (Fig. 6a). It appeared in the control pond throughout the year without particular seasonality. Other phytoplankton species – *Skeletonema* sp., *Chlamydomonas* sp., and both *Peridinium* and *Gymnodinium* types – were usually present in small numbers and formed sporadic minor blooms. As opposed to the control pond, the phyto-plankton in the fish pond exhibited seasonality.

In the fish pond, *Chaetoceros* sp. dominated most of the blooms from January to July in concentrations of up to 4.5×10^5 cells ml^{-1} (Fig. 6b). In the period July to September, the phytoplankton blooms consisted mainly of *Chlamydomonas* sp. reaching concentrations of up to 12.4×10^5 cells ml^{-1} with smaller numbers of

Peridinium and *Gymnodinium* types and euglenoid forms. During the transition period of September and through the winter, *Skeletonema* sp. was the dominant phytoplankton component appearing in concentrations of up to 3.8×10^5 cells ml^{-1} (Fig. 6b).

Dissolved Inorganic Nutrients

Dissolved inorganic nitrogen (N-NO$_2$ + N-NO$_3$) in inflow and pond waters is summarized in Fig. 7a, b and

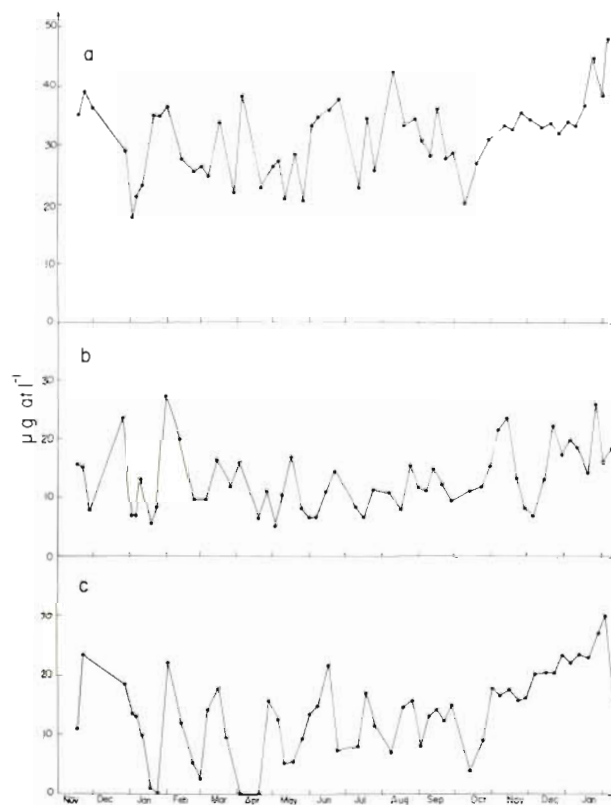
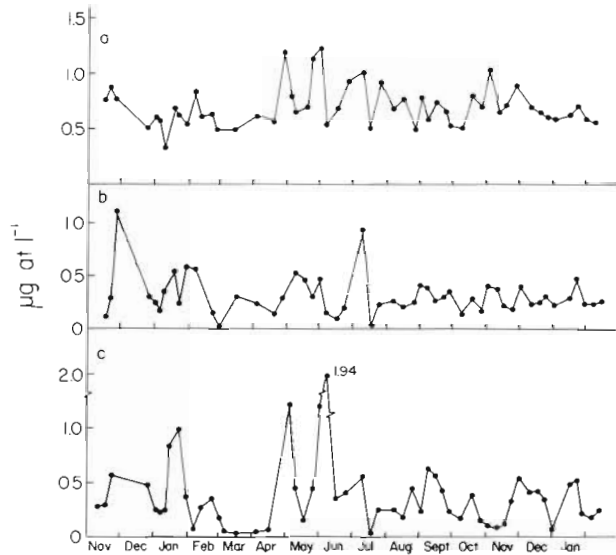Fig. 7. Dissolved inorganic nitrogen (µg at l^{-1}). (a) Inflow water; (b) control-pond water; (c) fish-pond water

Fig. 8. Dissolved inorganic phosphorus (μg at l^{-1}). (a) Inflow water; (b) control-pond water; (c) fish-pond water

c. The dissolved inorganic nitrogen concentrations in the inflow showed drastic monthly fluctuations ranging from 18 to 44 g at Nl^{-1}. The dissolved inorganic nitrogen in the water column of the ponds fluctuated monthly according to the periodicity of the phytoplankton blooms, the peaks of the blooms coinciding with the dissolved nitrogen troughs (Figs. 4a, b; 5a, b). The range of dissolved inorganic nitrate concentration in the control pond varied from 5 to 28 μg at Nl^{-1}, while in the fish pond the range was from 0 to 32 μg at Nl^{-1}. Concentrations of ammonia were found to be below detection levels – less than 1 μg at l^{-1}.

The concentrations of dissolved inorganic orthophosphate (P-PO$_4$) in inflow and pond water of control and fish ponds are summarized in Fig. 8a, b and c. Like the dissolved nitrogen, the dissolved inorganic orthophosphate concentrations in the inflow water fluctuated monthly with concentrations ranging from 0.3 to 1.25 μg at Pl^{-1}.

In the water column, the dissolved inorganic orthophosphate followed the monthly phytoplankton bloom fluctuations with a range of 0 to 1.2 μg at Pl^{-1} in the control pond, and 0.02 to 1.94 μg at Pl^{-1} in the fish pond.

Dissolved silica was very high in the inflow and fluctuated between 40 and 140 μg at Si l^{-1}. In the water column of the control pond, the dissolved silica ranged from 12 to 141 μg at Si l^{-1}, while in the fish pond it was 23 to 120 μg at Si l^{-1}.

DISCUSSION

Clearly, the phytoplankton biomass of the fish pond was much higher than that of the control pond.

Whereas in the former, the average chlorophyll a concentration is 8 mg Chl a m^3, in the latter it was 80 % higher. Both ponds were supplied from a single well. Hence, both ponds received the same nutrient load in the inflow which amounted to an average of 2.7 g at nitrogen d^{-1} and 0.065 g at phosphorus d^{-1}. The fish pond, however, received an extra nutrient load from fish food which amounted to 1.9 g at nitrogen and 0.14 g at phosphorus d^{-1}. This extra load was probably responsible for the higher standing crop observed in the fish pond. Furthermore, this response of the phytoplankton to the addition of nutrients may indicate that a nutrient limitation existed in these ponds. Strikingly, indeed, both ponds showed the same pattern of monthly periodicity. Phytoplankton blooms synchronously appeared in both ponds and developed within 7 to 22 d. Thereafter, a rapid collapse of the biomass
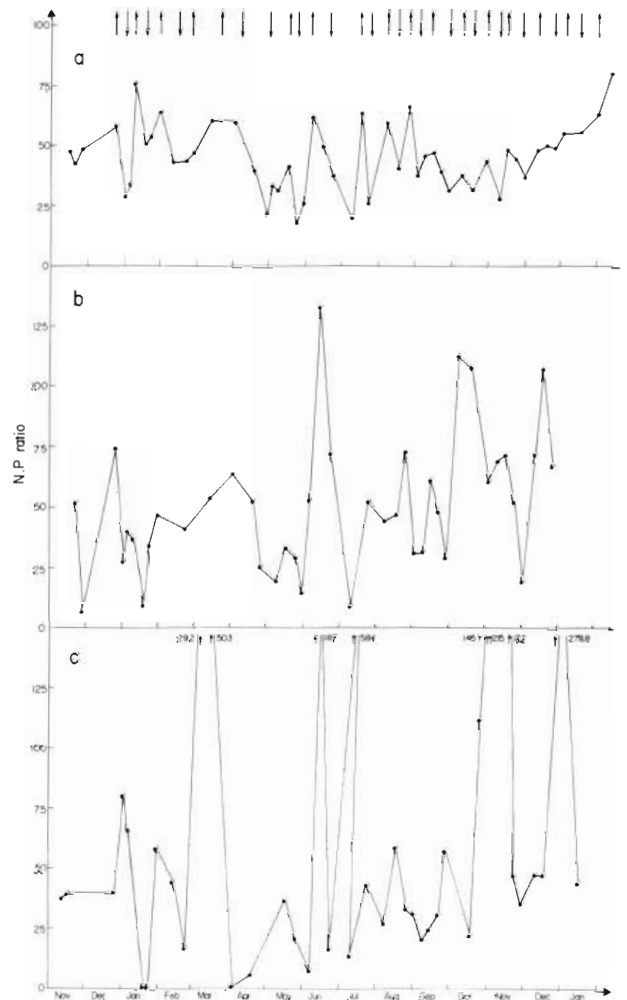

Fig. 9. N:P ratio in inflow water (a), control-pond water (b), and fish-pond water (c). Average daily tide in Gulf of Elat in 1977–1979 varied from +40 mm to −45 mm (Israel Meteorological Service). Occurrence of monthly high tide (↑) and low tide (↓) is indicated

ensued within 7 to 22 d. It must be concluded that a common nutrient in both ponds became limited every month; it was most likely related to the common water source.

It was observed that the N:P ratio in the inflow water was high, ranging from 18 to 80 (Fig. 9a). Furthermore, drastic monthly fluctuations were observed which clearly correlated with the blooms, suggesting that the system was generally phosphorus limited. Thus, the monthly decrease in the N:P ratios in the inflow correlated to the rise of the phytoplankton bloom, while the N:P ratio increase corresponded to the phytoplankton collapse. The N:P ratio fluctuations in the pond were a function of both the N:P ratio of the inflow water and the activity of the phytoplankton blooms. Hence, the fluctuations in the pond N:P ratios were more drastic and rapid, ranging from 8 to 140 and from 2 to 584 in the control and fish ponds, respectively (Fig. 9b, c). Toward the peak of the bloom, the N:P ratios decreased rapidly due to active uptake of nutrients by the phytoplankton. After the collapse of the bloom, the N:P ratios increased temporarily and the mineralized nutrients were washed out of the pond. It should be noted that nitrogen limitation may develop very rarely as seen in low N:P ratios of 2 to 8 (Fig. 9b, c). The dissolved silica was found to be abundant in the inflow and in the ponds throughout the study period and can thus be ruled out as a possible limiting factor.

The seawater well supplying the waters of the ponds is hydrologically connected to the littoral of the Gulf and groundwater. The dissolved primary nutrient concentrations in the littoral were measured to be only 0.15 to 0.36 µg at $N l^{-1}$ nitrate and 0.03 to 0.08 µg at $P l^{-1}$ phosphate (Sournia, 1977). These concentrations were much lower than those in the well, strongly indicating that the groundwater was the major nutrient contributor to the well. The salinity of the well was slightly lower (10 %) than that of the open Gulf (Krant et al., in press).

Yet the fluctuations in the N:P ratios in the well waters, as measured in the ponds' inflow waters, correlated with the tidal pattern measured in the Gulf. Inflow N:P ratios were lowest at monthly low tide and highest at monthly high tide (Fig. 9a). It is suggested that the tide differentially changed the contribution of nutrients from the groundwater and seawater and thus affected the N:P ratio. The mechanism of this influence, however, is not yet clear. The tide-controlled fluctuations in the N:P ratio of the inflow water were correlated with the phytoplankton blooms in the ponds. At low tide, when the N:P ratio in the inflow water was low, the phytoplankton bloom developed; and during the high tide, when the N:P ratio was increased in the inflow water, the blooms collapsed.

Regardless of the drastic fluctuations, the overall

primary production level in the fish pond amounted to 1.3 kg $C m^{-2} yr^{-1}$ which is similar to that observed in freshwater fish ponds (Hepher, 1962; Norriega-Curtis, 1979). An increased phytoplankton production could probably be obtained by additional phosphate input during high tide periods when phosphorus limitation was observed. Preliminary results confirm this prediction. After the elimination of nutrient limitation, the system would ultimately be light limited, due to the high silt density in the fish ponds. The removal of the silt would therefore lead to higher productivity until the system would again reach light limitation due to self shading. As calculated from the cell concentrations and the dilution rates, the apparent growth rates of the phytoplankton during the blooms varied in the control pond from 0.62 to $1.60 d^{-1}$ and in the fish pond from 0.64 to $1.70 d^{-1}$. The apparent growth rates of the phytoplankton corresponded with the highest values observed in other nutrient-rich marine waters (Thomas, 1977). Hence, it is unlikely that the phytoplankton production could be enhanced by an increased dilution rate.

It is apparent that the addition of fish food, and the presence of fish, resulted in a faster eutrophication rate in the fish pond as compared to the control pond. Linear regression of the annual fluctuations in chlorophyll a have shown that the slope of the regression line corresponds to a daily increase of 0.032 mg Chl $a m^{-3} d^{-1}$, compared to a negligible increase of merely 0.00057 mg Chl $a m^{-3} d^{-1}$ in the control pond. The very slow rate suggests that the fish pond had reached the steady state.

Although the overall production in the seawater fish ponds was similar to that of freshwater fish ponds, the former did not reach conditions as stagnant as those observed in the latter ponds. The seawater fish ponds were continuously flushed at a dilution rate of $0.6 d^{-1}$ and the wind vigorously mixes the water. Hence, only very rarely, when there was no wind and when the mixing stopped for a long time during a dense bloom, did occasional fish mortalities occur due to high oxygen. The very short retention time of the water prevented a buildup of fish growth-inhibiting factors in the water column. Nevertheless, a decrease of the fish growth rate was observed in the marine fish ponds (Gordin et al., 1980). Temporal but frequent increase in harmful substances during the dramatic monthly collapse of the bloom must be considered as a factor inhibiting the fish growth. Preliminary daily measurements showed that even during bloom collapse, the concentrations of ammonia did not exceed 1–2 µg at l^{-1}. Another possibility is the accumulation of fish-growth inhibiting substances in the sediment. Preliminary observations have shown up to 12 % dry organic matter in the sediment. The interstitial water in the

organic sediment contained up to 200 µg at $N-NH_4$ l^{-1} and up to 300 µg at sulfide. Both compounds have been shown to be harmful to fish (Reichenbach-Klinke, 1967; Amlacher, 1970; Kinne, 1976). It was observed that the fish in the ponds frequently dug into the sediments and thus were exposed to the very high concentrations of ammonia and sulfides. These exposures may have had a cumulative effect which may have resulted in growth retardation. The possible role of the sediments in the biology of the fish ponds is currently being studied in Israel and elsewhere.

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