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**Geochemical Budgets for Carbon and Nutrients
in Intensively Cultured Marine Fish Ponds**

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C: ABSTRACT

It was shown that the major water quality related problem in the earthen ponds in Eilat was occasional mass mortalities of fish. These mass mortalities were caused directly or indirectly by high dissolved oxygen/high temperature which resulted in gas bubble disease and low oxygen/high ammonia. There was no observed suppression of growth rate in these ponds related to water quality conditions as has been found in freshwater ponds.

The fishponds are hypertrophic with high levels of phytoplankton supported by dissolved nutrients produced in the pond by fish excretion and by nutrients supplied in the inflowing water. This inflowing water, which comes from a nearby well, was shown to be predominantly recycled pond water (80%) contaminated with sewage effluent (10%) and the remainder fresh seawater. The major output from the pond was particulate and dissolved matter (60-85%) with only 8-30% of the total input and 30% of the food input being incorporated into fish flesh. It was confirmed that the fish ponds are subject to periodic phytoplankton blooms and crashes. During most of the month, ammonia-N, the principle toxic metabolite produced by the fish and by decomposition processes in the sediment, is removed from the water column by photosynthetic activity. During phytoplankton crashes, ammonia-N accumulates in the pond. Most of the ammonia-N can be accounted for by fish excretion with only a small fraction being supplied by the sediment. The cause of the periodic crashes is grazing by microflagellates. The dynamics of the interactions between microflagellates and phytoplankton has been the subject of specific laboratory studies using chemostats.

Daily oxygen variations allow for calculations of community respiration at night and algal photosynthesis (net and gross) during the day. Respiration rates at the beginning of the night are 4-5 times higher than at the end of the night. Photosynthesis is slightly depressed at noon, possibly caused by photoinhibition.

C analysis of fish, pellets and natural food chain in ponds shows that small growing fish (5-150 grams) may receive up to 50% of their body carbon from the natural food chain. At larger sizes, the component derived from the natural food chain becomes reduced to 20-30%.

The data from the total nutrient budget have been used to develop a mathematical model which has successfully simulated the measured levels of chlorophyll and ammonia-N during the bloom and crash cycle. It will be used to test possible management protocols in the operation of these (and similar) fish ponds.

The protocols developed in this study have been used to study the operation of the new concrete lined circulating intensive fish ponds now being developed in Eilat. The details of the water quality characteristics have been described. The particular combinations of conditions most likely to be of danger to the fish have been recognised. It was shown, using a total nutrient budget and other relevant chemical and biological measurements, that fish excretion and phytoplankton uptake are the dominant processes in these ponds. As is typical of intermediate flow ponds, these ponds are subject to phytoplankton blooms, and crashes caused by microflagellate grazing. During the crashes, macroalgal growth removes some of the excess dissolved nutrients from the water column.

D: Objectives of the original research proposal

Within the BARD grant there were 5 specific objectives listed.

1) "The primary aim was to determine the external geochemical budgets of the nutrient elements N and P. We set out to examine the most important sources and sinks of these key elements in the pond system, how the sources and sinks change with time, and what are the most important processes controlling these changes." The results of these studies have been assembled in Krom et al. (Ref.4) and Krom et al. (Ref. 10 and 15).

2) The second aim was "to determine the external geochemical budget of carbon, the most important element in organic matter. This element is more complex than N and P because of the significant effects of gas exchange with the atmosphere. We planned to use C /C ratios in conjunction with total carbon measurements to understand the carbon transformations which involve gas exchange at the pond surface, phytoplankton photosynthesis and bacterial decomposition processes." As a first major step in this study, a data acquisition system was operated in the pond. The installation of this system took longer than was initially anticipated. Thus far the results obtained from this system have been used to quantify gas exchange, respiration and photosynthesis in the pond for dissolved oxygen (Erez et al., Ref.16 and 17). It is expected later to use these data to look directly at carbon cycling in the pond.

"In addition we will use these isotopes (C / C) to identify the most important components in the food web in a similar manner to that used by Schroeder (1983) in freshwater ponds." This study was completed by Haas (1987) and will be subsequently published as Haas and Erez (Ref. 19).

3) "We will examine the ponds of new design which are being built here in Eilat. Using the experience and understanding obtained from the existing ponds, we will determine the geochemical budget in these distinctive designs." For reasons beyond our control, the new ponds were only commissioned in 1986 and brought into routine operation in the spring of 1987. Despite this, a study of the operation of these ponds, based on the experience obtained in the previous studies on the earthen ponds, has been carried out and the results written up as 3 manuscripts (Neori et al., Ref. 9, Krom and Neori, Ref. 15 and Neori and Krom, Ref. 20).

4) "In addition to the overall geochemical budgets, we proposed to carry out preliminary research on internal cycling of the nutrient elements in the ponds. In particular, we set out to examine:

a) The cycles of primary productivity in the ponds, diurnal cycles which have been shown to have a major effect on water quality." The results of these studies have been presented as part of Krom et al. (Ref.3), Krom et al. (Ref. 10), and Erez et al. (Ref. 17).

b) "The major decomposition processes in the ponds and their sediments. We intended to study the nature of the major decomposition processes in the water column directly and by looking at the changes in the external geochemical budget with time. We will be able to determine at least semi quantitatively the major decomposition processes which were occurring within the sediment from measurements of the chemistry of the interstitial waters." The water column processes were quantified in Krom et al. (Ref. 3). The sediment decomposition processes were studied in Blackburn et al. (Ref. 8) and Cameron (1986).

c) "The effect of sediment chemistry on the health of fish. This information can be correlated with simultaneously obtained growth rate data and/or fish mortalities. These data will be of use in devising experiments to determine the biological effects of sub-lethal doses of these two potential toxins." These objectives have been published in Krom et al. (Ref. 2) and Porter et al. (Ref. 6). The data have been important in devising the experimental protocols for Weisbrod (1987) and for a research grant submitted to the Ministry of Agriculture to examine the synergistic effects of pH and dissolved oxygen on ammonia-N toxicity for Sparus aurata.

5). "An additional but not less important goal of this study is to devise and test experimental protocols which will enable us to study the geochemical and biological budgets." These experimental protocols have been and will continue to be used to test the operation of the new design of fish ponds under the various possible operating conditions (Neori et al., Ref. 9, Krom and Neori, Ref. 15 and Neori and Krom, Ref. 20). "It is hoped that eventually we will be able to use the reasoning developed here to devise simple diagnostic tests that could be carried out by the potential user to characterize and manage marine intensive fish ponds." At present this expertise is being put into practice in the operation of the new fish ponds in Eilat and to a lesser extent for the commercial fish ponds of ARDOM also in Eilat.

During the course of this study, several additional studies were carried out in order to answer particular questions which were not anticipated before this study was started.

a) It was found that the existing methods for ammonia-N determination were inadequate, and a new procedure specifically designed for mariculture was developed and subsequently published (Krom et al., Ref. 1).

b) In the course of conducting the nutrient budget, it was found that the input well water was high in dissolved nutrients. A study was carried out to determine the sources of water to the well supplying the fish ponds in Eilat and to determine the significance of this for fish pond management (Ref. 5).

c) Much of this study concentrated on the causes and effects of eutrophication in the ponds. During the work it became clear that in order to calculate the internal nutrient budgets specified in this study, it was necessary to determine the effect of the fish on nutrient cycling in the ponds. Thus a specific study was undertaken to determine the nature and type of excretion of N by Sparus aurata under conditions relevant to the conditions in the pond (Porter et al., Ref. 7). In addition, the data were examined critically to try to quantify the effect of bioturbation by fish on nutrient cycling in the ponds. The results of these estimates are given in Blackburn et al. (Ref. 8) and Krom et al. (Ref. 11).

d) During the course of this study, it was suggested that the cause of the phytoplankton blooms and crashes, which are such an important part of the observed water quality patterns in the ponds, was grazing by flagellates. As a result, Dr. J. Goldman modified the experiments he was planning to do from a study concerned with isotope fractionation during algal growth to an examination of the dynamics of the herbivorous grazing of the microflagellate Oxyrrhis marina, which was found to be present in the new concrete ponds in Eilat. The results of that study are presented below (Goldman et al., Ref. 18).

e) The quality of the data set was such that it was decided to add an

applied mathematician to the research grant (Dr. S. Ellner) and to use his expertise to develop a mathematical simulation model based on the nutrient budgets. The purpose of this model was to help to define more closely the important biogeochemical processes in the fish pond. This work has been published (Ellner et al., Ref. 13). It is proposed to further refine the model somewhat and to use it to suggest and then to test particular management protocols to solve the major water quality problems identified in this study. It is expected that we will further use this model, suitably modified, as a basis to test the operation of the new fish ponds.

f) The expertise developed in this study was used as the basis to devise a new categorization of fish ponds and to look at a comparison of water quality characteristics in seawater and freshwater ponds (Krom and van Rijn, Ref. 12).

F Description of cooperation

During the first two years of this project, the cooperation was mainly in the form of consultation and advice given by Dr. Goldman during two trips to Eilat. Due to problems of logistics and manpower in Eilat, not all of this advice could be put into practice during the timescale of the field work of this project. However the advice given by Dr. Goldman's has been invaluable in helping to devise the scientific strategy for the study of the new ponds now that the ponds and the lab are physically adjacent to one another and that a marine phytoplankton biologist (Dr. A. Neori) has been added to the team studying water quality in the new ponds.

During the first two years of this project, it was decided during discussions between the three P.I.'s on this project that microbial grazing of the phytoplankton was probably an important process controlling the bloom and crash cycles in the pond. Thus during the third year, samples of live microflagellates were sent to Dr. Goldman where he used his expertise in the use of chemostats to study the dynamics of protozoan grazing and their effect on nutrient cycling.

During the third year of the project Dr. S. Ellner was added to the project. As a result of several discussions concerning the data principally with Dr. Krom but also on occasions with the other P.I.'s in this project, Dr. Ellner was able to develop a Mathematical simulation model for the operation of the ponds. As a result of this model we were not only able to confirm that our comprehensive understanding of the major processes in the pond, but it also allowed us to predict what management protocols might be most suitable when water quality conditions approach critical conditions for the fish.

G Research achievements of the research grant

The development of food production through land-based mariculture technology (seawater ponds) is an attractive proposition since seawater is unlimited along the continental shorelines. It is especially attractive for arid regions where very little fresh water is available for food production. One can imagine that in the future, seawater fish pond farms will be producing large quantities of highly nutritious food for human consumption. Prior to the work in this study, very few systematic studies had been carried out on the water quality problems and processes in marine fishponds. This contrasts to the situation in freshwater ponds which have been studied for many years. Successful commercial aquaculture in freshwater fishponds has been achieved in Israel and in many other parts of the world. It is one of the main achievements of this study that we have achieved a level of understanding of at least one type of seawater fish pond (intermediate flow earthen ponds) which is on a par to that of the best studied types of freshwater ponds. This knowledge has been used to help in the design and operation of the new intensive concrete ponds in Eilat.

The strategy developed in this study to understand the processes occurring in such ponds was similar to that previously used to examine sewage oxidation ponds and polluted lakes. This geochemical budget approach has enabled us to achieve an understanding of all the major processes occurring in this complex ecosystem. Our success in quantifying them can be gauged by the fact that a simulation model has been developed which mimics the major chemical changes in the pond closely. Previous projects using marine biological methods alone have enabled single processes to be quantified but have achieved only limited success in understanding the ecosystem as a whole and thus suggesting ways to manipulate it.

The success of this strategy, in which we set out not only to describe the water quality in the fishponds in detail but also to quantify the relevant processes, can be found not only in the results obtained concerning these earthen ponds (set out in this report), but also in the research program currently being carried out on the new ponds in Eilat. At this time, the National Center of Mariculture in Eilat has 10 experimental seawater ponds in operation. In addition, ARDOM (the cooperative of the kibbutzim of the southern Negev) has several hectares of fishponds in use. The results and expertise obtained in this study are central to the successful operation of these ponds.

H List of Publications resulting from this research project

- (1) Mark those included as part of the first year report
- (2) Mark those included as part of the second year report
- (3) Mark those included as part of this final report

1. Krom, M.D., Grayer S. and Davidson A. (1985) An automated method of Ammonia determination for use in mariculture. Aquaculture 44: 153-160. (1)
2. Krom, M.D., Porter, C., and Gordin, H. 1985a. Causes of fish mortalities in semi-intensively operated seawater ponds in Eilat, Israel. Aquaculture 49: 159-177. (1)
3. Krom, M.D., Porter, C., and Gordin, H. 1985b. Description of the water quality conditions in a semi-intensively cultured marine fish pond in Eilat, Israel. Aquaculture 49: 141-157. (1)
4. Krom, M.D., Porter, C., and Gordin, H. 1985c. Nutrient budget of a marine fish pond in Eilat, Israel. Aquaculture 51: 65-80. (1)
5. Krom, M.D. 1986. Sources of water to the seawater well which supplies the fish ponds in Eilat: Implications for pond management. Water Res. 20(4): 463-469. (3)
6. Porter, C., Krom, M.D., and Gordin, H. 1986. Effect of water quality on the growth rate of Sparus aurata in marine fishponds. Aquaculture 59: 299-315. (2)
7. Porter, C.P., Krom, M.D., Robbins, M.G., Bricknell, L. and Davidson A. (1987) Ammonia excretion and total N budget for gilthead seabream (Sparus aurata) and its effect on water quality conditions. Aquaculture. 66: 287-298. (3)
8. Blackburn, T.H., Lund, B.A., and Krom, M.D. (in press) C- and N-mineralization in seawater fish pond sediments. Accepted for publication in Mar. Ecol. Prog. Series. (3)
9. Neori, A., Krom M.D., Cohen, I., and Gordin, H. in press. Water quality conditions and particulate chlorophyll a of new intensive seawater fishponds in Eilat, Israel: daily and diel variations. Accepted for publication in Aquaculture. (3)
10. Krom, M.D., Erez, J., Porter, C.B., and Ellner, S. (In press) Phytoplankton nutrient uptake dynamics in earthen marine fish ponds under winter and summer conditions. Accepted for publication in Aquaculture. (2)
11. Krom, M.D., Porter, C., Robbins, M., Bricknell, L., and Davidson, A. 1986. Effect of Sparus aurata, a carnivorous fish, on the water quality conditions in earthen marine fish ponds. In, Proceedings of the Third International Conference: Environmental quality and ecosystem stability. Jerusalem, Israel, 1-4 June, 1986, Bar Ilan Press, Ramat Gan, Israel, 295-305.

12. Krom, M.D. and van Rijn, J. (1988) Water quality processes in fish culture systems; processes, problems and possible solutions. Invited review article . Proceedings of the European Aquaculture Society meeting in Amsterdam June 1987.

13. Ellner, S.E., Krom, M.D. and Brauer F. (1988) Modelling and management for seawater fishponds. Proceedings of the Trieste Research Conference on Mathematical Ecology, Trieste, 1986 (T.G.Hallem, L.J.Gross and S.A.Levin, eds) World Scientific, Singapore, 215-236. (3)

14. Krom, M.D., Neori, A., Cohen, I., and Gordin, H. in press. Water quality processes in the new intensive seawater fishponds in Eilat, Israel: A study involving the use of total N budget. Proceedings of Aquaculture Engineering: Technologies for the future. 20th-23rd June, 1988 Stirling.

15. Krom, M.D. and Neori, A., in prep. Water quality processes in a concrete circulating seawater fishpond; a study involving the use of a total nutrient budget. submitted to Aquaculture. (3)

16. Erez, J., Krom, M.D., and Neubirt, T. in prep. Daily oxygen variations in marine fish ponds, Eilat, Israel. to be submitted to Aquaculture.

17. Erez, J., Krom, M.D., and Neubirt, T. in prep. Community metabolism in marine fish ponds. submitted to Mar. Ecol. Prog. Ser. (3)

18. Goldman, J.C., Dennett, M.R. and Gordin, H. in prep. Dynamics of herbivorous grazing by the heterotrophic dinoflagellate Oxyrrhis marina submitted to Mar. Ecol. Prog. Ser. (3)

19. Haas, Y. and Erez, J. in prep. The food chain in marine fish ponds: Carbon isotopes approach. to be submitted to Mar. Ecol. Prog. Ser. (3)

20. Neori, A. and Krom M.D. (in prep). Auto and heterotrophic microbial biomass in relation to water quality in intensive seawater fishponds in Eilat. to be submitted to Mar. Ecol. Prog. Ser.

Theses published as part of this project

1. Cameron, R.M. (1986) The effects and consequences of sulphate reduction in sediments of semi-intensive marine fish ponds Eilat, Israel. M.Sc. thesis , University of Leeds.

2. Haas, J. (1988) Carbon cycling in earthe marine fish ponds in Eilat: Stable-isotope approach. M.Sc. thesis, Hebrew University.