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I N T E N S I V E   A Q U A C U L T U R E

as seen by Prof. Avtalion

FOREWORD

The German-Israeli cooperative programme on the "Optimization of Intensive Aquaculture Systems" started in 1977. In this first phase 10 specific projects had been implemented. After two years of experience in the programme a Status Seminar was held in Shefayim/Israel to discuss the progress made so far within the particular projects and to identify areas of mutual interest in aquaculture research.

The contributions to the Status Seminar focussed on four major areas corresponding to the subjects of the cooperative programme:

1. *Fish nutrition, diseases, growth and environmental conditions*
2. *Production of live food for fish farming*
3. *Breeding and controlled reproduction of aquaculture species*
4. *Trends in aquaculture research*

The Seminar was jointly planned and organized by the International Office of the GKSS-FORSCHUNGSZENTRUM GEESTHACHT GMBH (GKSS) and the National Council for Research and Development, Jerusalem (NCRD), which are the contracting parties for the cooperation agreement. We wish to acknowledge the helpful assistance of the GKSS to the European

Mariculture Society in preparing the original contributions of the Status Seminar for publication, thereby providing an opportunity to distribute the experience gained during the first phase of the programme to those interested in aquaculture research and development.

The Editors

H. ROSENTHAL, Hamburg
O.H. OREN, Haifa

S E S S I O N I

FISH NUTRITION, DISEASES, GROWTH AND ENVIRONMENTAL CONDITIONS

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SEAWATER MARICULTURE POND - AN INTEGRATED SYSTEM

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ABSTRACT

In 1975, eight 250 m^2 sea water fish ponds were constructed and operated in the IOLR Mariculture Laboratory in Elat. Since then, ecology and fish farming in these experimental intensive ponds have been studied. Due to very high evaporation rates, the ponds were continuously washed with fresh sea water. Salinities were not allowed to increase above 43‰. Fish (*Sparus aurata*) yields were around 1 ton $dunam^{-1}$ (1000 m^2) yr^{-1} in the first year but have declined considerably since. Primary productivity was measured and found to be 1.3 kg C m^{-2} yr^{-1}. Growing oysters (*Crassostrea gigas*) in the pond runoff water, which was rich in planktonic algae, gave very good results. It is postulated that the decline in fish production is a result of adverse conditions in the ponds due to the extensive feeding and to the very high primary productivity, most of which finds its way to the sediment. There it accumulates and is partially broken down anaerobically. The possibility of using the oysters as an algae-cleaning apparatus will have several advantages: elevating the water quality in the fish ponds by removing organic matter from it, decreasing the amount reaching the sediment, and achieving a very substantial oyster crop. Biological as well as engineering aspects of the system are discussed.

INTRODUCTION

Intensifying the production of fresh and brackish water fish ponds is a trend which has been developed and followed in the last two decades. The common denominator to all is the desire to make fish farming more efficient and more profitable. Shortage of fresh water and land, growing market demand, and the drive for more advanced technology are some of the forces acting behind this trend (Schroeder, 1973; Sarig and Marek, 1974; Tal, 1974). The development and practice of polyculture (multispecies) techniques in fish farming enhanced significantly the intensification of the traditional fish pond (Tang, 1970; Chandhuri et al., 1975; Reich, 1975; Moav et al., 1977; Halevi, 1979). The introduction of aeration to the semi-intensive ponds enabled the farmers to intensify them even further (Bardach et al., 1972; Rappaport et al., 1976).

The search for a substitute for the ever-increasing cost of fish meal brought back the old Chinese method of manuring the fish ponds (Lin, 1954; Tang, 1970; Bardach et al., 1972). A great deal of research effort has been directed towards optimizing and economizing this method (Moav et al., 1977; Rappaport et al., 1977; Rappaport and Sarig, 1978; Schroeder, 1978; Noriega-Curtis, 1979). However, the carrying capacity of any environment is not infinite, and fish ponds are no exception. The problems associated with high density fish stocking are numerous. Some are directly connected with the number of fish, such as oxygen demand, excretory products, inter- and intraspecific competition, while others affect the ponds indirectly through a chain of complicated pathways (Schroeder, 1978; Avnimelech and Lacher, 1979; Rappaport and Sarig, 1979). From the accumulating data in recent literature, it seems that the intensive fish pond undergoes eutrophication processes as a result of heavy feeding (including animal manure) and very high primary productivity. The products of the two find their way to the sediment where they are broken down anaerobically. Some of the chemical species which evolve in these anaerobic processes are believed to act as growth inhibitors and, at times, reach levels that cause heavy fish mortalities (Colt and Tchobanoglous, 1978; Schroeder, 1978; Avnimelech and Lacher, 1979; Rappaport and Sarig, 1979; Seymour, 1980). Ammonia (un-ionized) seems to be the most potent substance that causes ill effects in the ponds and gets the most attention in current research.

One of the ways to farm marine fish is to grow them in sea water ponds. Growing fish in such ponds opens new livelihood possibilities in arid regions of the world which are situated close to the sea. However, in such areas the climate is very dry and evaporation rates reach extreme proportions. Assaf and Kessler (1976) calculated the evaporation to be 3 to 4 meters per annum from the Gulf of Elat (Aqaba). Their calculations were confirmed recently by field measurements in sea water fish ponds (Krant, 1979; Motzkin et al., in preparation).

For a one-hectare pond, this rate amounts to some 30-40,000 m^3 yr^{-1}, a quantity that should be returned to the pond in order to maintain the desired water level. Since salinity increases as a result of evaporation, the pond has to be continuously washed with fresh sea water to maintain salinity at accepted physiological levels. As an example, Gulf of Elat water has a salinity of 40 ‰. In order to keep pond water salinity at 45 ‰, 6 % of the water must be replaced daily, using ambient Gulf water. Such rates amount to some 250,000 m^3 $hectare^{-1}$ yr^{-1} (1.5 m average depth). Moving such volumes of water through the pond requires a substantial energy expenditure, which, when translated into economic terms, puts a tremendous burden on the economy of such a system (some US$ 5000 $hectare^{-1}$ yr^{-1} in 1980 energy prices for a farm situated 10 km away from the sea). Therefore it is only rational that such seawater fish ponds should be highly intensive, yielding crops (quantity and market value) that will bring large enough returns to cover this extra expenditure which is characteristic of such a system.

Based on the above considerations, the IOLR Mariculture Laboratory embarked in 1975 on the development of an intensive sea water fish pond. Eight 250 m^2 earthen fish ponds were in operation during a four-year study period. Fish were stocked at a density of 35,000 $hectare^{-1}$. Oysters were grown on the ponds' runoff waters, and yielded high crops (Hughes-Games, 1977, and in preparation). The fish crops decreased over the 3-4 years of experimentation from a substantial 8750 kg $hectare^{-1}$ yr^{-1} to 5380 kg $hectare^{-1}$ yr^{-1} in the first and last years, respectively.

Why did the fish yield decrease? Is it a trend? Is there a way to overcome this trend? Do we face similar problems to those facing the fresh water intensive fisheries? The following will discuss some of the results obtained from a few projects concerning the above problem. We will try to integrate data which have been accumulated over this period from the different projects associated with the ponds, i.e. the pond ecological processes, the fish farming in the ponds and in the floating cages and the oyster farming.

MATERIALS AND METHODS

A. Fish Farming - Ponds

Sparus aurata, as the main species, and *Mugil cephalus* and *Siganus rivulatus* as accompanying species, were stocked in our 250 m^2 sea water fish ponds, at densities of 30-35,000 individuals per hectare. Stocking size varied a little in the different years and ponds, ranging from 7 to 70 g per fish. Water continuously flowed through the ponds at an exchange rate of 40-60% per day. Aeration was introduced mainly during the summer, either to remove excess of oxygen or to replenish it on calm days and nights, respectively. Food was offered either by hand twice a day (six days per week) or by automatic feeders (42% protein pellets, manufactured by us). Food rations were given as percent of fish body weight. The percent decreased as the fish grew larger. The fish were weighed during the year from time to time but not very frequently, in order to minimize handling damages. Before restocking the ponds, they were dried for a few days in an attempt to oxidize the sediment.

B. Pond Ecology

A detailed description of the methods and techniques will be given in another paper (Motzkin et al., in preparation). Briefly, the physico-chemical regime of the ponds was studied. The nutrient fluxes and dynamics were investigated, and carbon, nitrogen, phosphorus and silica cycles were studied and modeled. Phytoplankton dynamics in the ponds was investigated in detail, through population blooms, successions and mortalities. Chlorophylls and primary productivity (C^{14} uptake) were measured. Samples were taken and measurements done once every fortnight. A 24 hr cycle in the pond was studied once a month.

C. Oyster Farming

This work was partially reported by Hughes-Games (1977) and will be reported shortly (Hughes-Games, in preparation). Spat of *Crassostrea gigas* was imported from England. The oysters were grown in trays or suspended from racks in the ponds' runoff water. They were weighed and quality indices were determined once a month. Sexual maturation was followed.

D. Floating Fish Cage Culture

A few reports were published by members of the IOLR Mariculture Laboratory, Elat, on rearing *Sparus aurata* in floating cages (Pitt et al., 1977; Geffen, 1979; Porter, 1980a,b). There, a complete description is given of the techniques and materials practiced and used in this project. The first four years of this study were done in a protected bay in Dahab, while since 1978 the work is carried out in an exposed site in front of the laboratory in Elat. Fish densities in the cages were as high as 240 m^{-3}. Feeding was done mainly by hand (42% protein pellets), twice a day, six days per week.

RESULTS

The report given here relates only to the results relevant to our problem of decreasing fish yields. We will present results which substantiate this phenomenon as well as those which we believe explain it. We will also refer to results upon which we base our new concept of an integrated sea water culture pond.

A. Fish Yields

Figure 1 shows that the fish-carrying capacity of the sea water ponds in Elat has been declining over the three growing years (1975/6, 1977/8, 1979/80). Food conversion coefficients ranged from 1:1.86 to 1:2.5. The addition of grey mullet to the ponds seemed to improve the food conversion coefficients, but not the total yield. This was expected under the given conditions, since the mullets were utilizing some of the natural food that evolved in the pond. However, the mullets do consume pellets when offered, thus competing with *Sparus aurata.* We believe that the main cause of this phenomenon lies within the ecological system of the fish pond. It should be mentioned here that survival of *Sparus aurata* and *Mugil cephalus* during the entire growth period was in the 90% range. The only mortalities observed were associated with very calm, clear days, when photosynthesis activity in the water column was at its peak. Then, oxygen was found to be in supersaturation (up to 500%), causing bubble disease.

B. Pond Ecology

We will quote here only results which are relevant to our case; the complete system will be described by Motzkin et al. (in preparation).

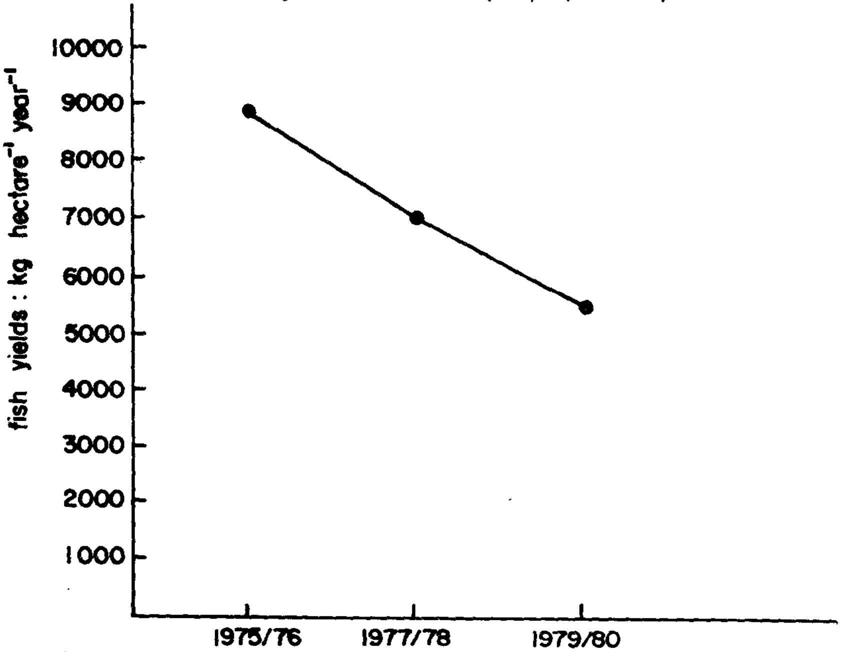

Figure 1. Representative fish yields in the three consecutive growing years in the Elat seawater fish ponds. Note: species *Sparus aurata,* density 31-35,000 hectare^{-1}, 1977/8 year with *Mugil cephalus* and *Siganus rivulatus.*

Temperatures ranged from 12 to 28°C during winter (November-April) and from 23 to 29°C during summer (May-October). Salinity was maintained rather constant between 41.45 ‰ and 42.12 ‰. Light intensity, 1 cm below surface, ranged from 1600 to 2200 μeinst m^{-2} sec^{-1} during summer, and from 1100 to 1870 μeinst m^{-2} sec^{-1} during winter. Minimum light penetration to the bottom was measured at 2% of surface value.

The commonest phytoplankton algae in the above ponds were found to be *Chaetoceros* spp., followed by *Skeletonema* sp., *Chlamydomonas* sp. and an array of pennate diatoms and dinoflagellates. Their densities reached levels of 4.2×10^5 cell cc^{-1}. Chlorophyll a concentrations varied from 11 to 53 mg m^{-3}. During a one-year period, 17 blooms of phytoplankton were observed and studied. The blooms lasted from 11 to 42 days each. Most of the blooms were nitrogen-limited at their peak (nitrogen concentration fluctuated from 34.5 μg At N l^{-1} to zero), but some seemed to be phosphorus-limited (phosphorus concentration fluctuated from 1.114 μg At P l^{-1} to zero). Some of the blooms were so thick that light became a limiting factor at the deeper water layers of the ponds.

Annual primary production was measured and calculated to be 1.3 kg C m^{-2} yr^{-1}, resulting in 32 kg m^{-2} yr^{-1} of wet algal matter.

The sediment of the ponds was analyzed for its organic matter content. It was found to reach a 15% level. The sediment appeared to be completely reduced, and when stirred, omitted H_2S gas.

C. Oyster Farming

Growing the edible oyster *Crassostrea gigas* in the pond runoff water gave crops (extrapolated) of 13 tons $hectare^{-1}$ yr^{-1}. The oysters fed on the phytoplankton which was produced in the fish ponds. The system was not very efficient, since the pond water came into the oyster trough at one end of it, thus forcing the upstream oysters to produce pseudofeces, while the downstream ones starved (Hughes-Games, in preparation). The quality index of the oysters was very high throughout the growth period (Hughes-Games, 1977, and in preparation). No sexual maturation of the zero age class was observed in the Elat population (Hughes-Games, in preparation).

D. Floating Fish Cage Culture

The results were similar for the two locations in which the system was tested, i.e. protected waters and an exposed area (Dahab and Elat, respectively). The best results achieved in these experiments were at densities of 200 fish m^{-3} per cage. Fish reached a market size of 250 g in 16 months from hatching. Best food conversion coefficients were around the 1:2.5 ratios.

DISCUSSION

In searching for an explanation of the decreasing yields of our fish ponds and for ways to solve this problem, we have analyzed the data accumulated from all the above-mentioned projects.

High density of fish, as such (crowding, social inhibition, etc.), as a cause of the above was ruled out. Our cage experiments proved that *Sparus aurata* can be stocked at densities as high as 240 fish m^{-3}, reaching a biomass of 72 kg m^{-3} without any noticeable ill effects (Pitt et al., 1977; Porter, 1980a,b). The major difference between the ponds and the cages lies in the quality of the water in the two habitats. Even on a very calm day, when water current velocity does not exceed 1/16 of a knot (3.2 cm sec^{-1}), water will be fully exchanged in a cage of 6 x 6 x 3 m (H) every 3 to 4 minutes. Such an exchange rate will prevent any build-up of metabolites and will maintain high oxygen levels. We can define such waters as being of infinite high quality. In the ponds, however, the situation is very different. The ecological study of our ponds indicates a very intensive organic build-up there, even though the fish density is some 70 times lower than that in the cages. This build-up is supported by two sources - the fish food (around 2.5 kg m^{-2} yr^{-1}) and the phytoplankton productivity, which is stimulated by nutrients regenerated from the digested and defecated fish food. Most of the organic matter from the two sources eventually finds its way to the sediments. There it is broken anaerobically, through different pathways. Thus, reduced compounds are released into the water which are usually toxic to living organisms, such as H_2S, NH_3-NH_4 and perhaps small organic molecules. We have experienced heavy instant mortalities when the bottom of the pond was disturbed, and the volume of water above the sediment was small. Knowing the food-searching behavior of *Sparus aurata*, by which it digs a little in the sediments, one can assume that some of these toxins affect the fish adversely throughout the growing period. The periodic exposure of the fish to these compounds may be responsible for the observed decreasing growth rates and thus pond yields. As was mentioned in the Introduction, a similar situation occurs in the intensive fresh water fish ponds.

The IOLR Mariculture Laboratory has recently undertaken a thorough study of the pond sediment, emphasizing the anaerobic metabolism dynamics. Data generated from this study will enable us to qualify and quantify such processes as H_2S and NH_3-NH_4 production. How do such processes relate to the organic load of the sediment? What are the rates of organic build-up and breakdown in the sediment? Are they related (and if so, how) to the fish population of the pond?

In the meantime, we are continuing our drive to intensify the production of the seawater ponds. The income that they generate must be large enough to cover energy costs caused by pumping fresh seawater to compensate for evaporation. The oyster farming was integrated into the fish pond system, thus adding a very substantial income to it. Moreover, the incorporation of the oysters into the system will enable us to improve the water quality tremendously. The idea of the