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Oyster Production in the Outflow of Salt Water Fish Ponds

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OYSTER PRODUCTION IN THE OUTFLOW OF SALT WATER FISH PONDS

Final Report

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ABSTRACT

During the period between November 1979 and June 1983, research and development work were carried out on the problem of oyster production in an integrated mariculture system. Fish were grown in 250 m² earthen ponds. Seawater, which was pumped from a well by the Gulf of Elat coast line, was continuously flushed through the ponds at a rate of 3 m³ per hour, (one turnover every two days). The fish in the ponds (Sparus aurata and Mugil cephalus) were fed a high protein diet (35-42%). From the nutrients released by the fish, together with the intense solar radiation experienced in this area, very dense phytoplankton blooms developed in the ponds. The outflow water, containing the algal population, was passed through oyster troughs. The oysters filtered the algae, fed and grew on them. Food conversion coefficients were measured and were found to be directly correlated to the amount of food offered to the oysters. Oxygen consumption of the oysters was determined.

Fish ponds which were managed to maximize fish growth and not algal production, and thereby oyster production, supported oyster production of close to 20 tons per hectare per annum. The ratio of fish to oyster rearing area was found to be 1:50 respectively, i.e. for one dunam (1000 m²) fish pond, 20 m² total oyster trough area is required.

Algal production was found to be limited in the Elat ponds condition by phosphate and by light. Very rarely it was limited by inorganic nitrogen ions such as NO_3^- or NH_4^+ .

The aquatechnique for growing oysters was developed for the halfshell trade. Upon reaching 1 cm, the oysters were glued to extruded plastic mesh (1 cm) and allowed to grow into the net for a few weeks. Then the net was cut in such a way that each oyster had its own hanger. The individual oyster was then hung from a rack inside a tank. Each rack held approximately 250 oysters. Each tank held 5 racks, one on top of the other, 12 cm apart. The production of each tank reached some 100 kg whole oysters in one year.

Induced reproduction of oysters in Elat was attempted towards the end of the project. The main species experimented with was Crassostrea gigas. Salinity of 25‰ enabled successful larval rearing to the spat stage.

Economic analysis and plans for future research and development work on oyster farming are discussed.

INTRODUCTION

Oysters belong to the phylum Mollusca, class Bivalvia (Lamellibranchia, Pelecypoda), order Filibranchia. They are molluscs with a bilaterally symmetrical body, laterally compressed and enclosed by a shell that develops as two valves. The hinge between the two valves is dorsally situated. In the Ostreidae family the left valve is the larger and is the one which is attached to the substrate. (Borradaile et al 1963, Barnes 1965). Hence the oysters are sessile organisms, which feed by filtering organic particles out from the passing water. Many of the species belonging to this family are intertidal, thus for some period of time every day they are exposed to air. This behaviour enables them to rid themselves from predators and parasites on the one hand, but deprives the feeding time on the other hand. Oysters are considered a delicate food in many parts of the world - Japan, U.S.A., Europe and Australia. Farming oysters has been practiced in growing degrees of sophistication in the last century, but was mainly constricted to natural inshore waters, thus depending on neritic primary productivity. Many reviews were written in the last 20 years on oyster farming under natural conditions and the reader is encouraged to relate to them. (Loosanoff 1965, Quayle 1969, Ryther 1968, Fujiya 1970, Bardach et al 1972, Lutz 1980, Davy and Graham 1982). Members of the Ostreidae family are cosmopolitan in cold, temperate and tropical waters. They live in salinities ranging from brackish water (less than 20 ppt) to salinity way above sea water salinities (above 40 ppt). Some of the species are euryhaline and

eurythermal, they live in a constantly fluctuating environment of the lower intertidal zone. Outstanding among these species is the Japanese oyster Crassostrea gigas which was taken into culture in many different areas of the world (Quayle 1969, Bardach et al 1972). This species together with Ostrea edulis was introduced to the marine fish ponds system of the Mariculture Laboratory, IOLR in Elat. (Hughes-Games 1978).

The seawater fish ponds in Elat were described in details by Motzkin et al (1982) and Gordin et al (1981). They are earthen ponds (lined with clay under coarse sand) of about 250 m² area and 1 m deep. However the size of the ponds is between 230 m² and 140 m³. The ponds receive sea water which is pumped from wells situated 15 meters inland from the mean water line. There is hardly any contribution of fresh or brackish water to the well and the salinity is quite stable at 40‰. The ponds are continuously flushed with fresh sea water at a rate of 3m³.hr⁻¹, thus complete exchange occurs every 2-3 days. This rate ensures that salinity levels in the ponds will not rise above 42-45‰. The ponds are stocked with two species of fish: Sparus aurata - 600 fish per pond and Mugil cephalus - 150 fish per pond. S. aurata, the gilthead seabream, is a carnivorous fish which feeds on molluscs and crustaceans in nature, foraging for them on and inside the sediment. The grey mullet (Mugil cephalus) is an omnivorous feeder, feeding on benthonic algae, detritus and small organisms. Since fish density in the Elat ponds was quite high, the fish were fed intensively, based on the assumption that the pond could

not supply any significant amount of natural food for them. The food for the seabream was especially developed in the Elat laboratory. It contains 40% protein (Kissil 1981, Marais, J.F.K. and G.Wm. Kissil 1979) and 5-10% fat, resulting in an average food convergent coefficient of 1:2.5. Thus, the pond water was enriched in inorganic nutrients coming from two sources: breakdown of fish food and fish feces (mainly nitrogen in the form of ammonia and orthophosphate). The other source was in the incoming well water which was enriched by seepage from the ponds through its sediments: This water contained high levels of silicate and nitrate (Motzkin et al 1982). Levels of nitrogen-nitrate fluctuated between 0 to 32 μg at. N.l^{-1} , orthophosphate-phosphorus between 0.02 to 1.94 μg at. P.l^{-1} and silicate-silica fluctuated from 23 to 120 μg at. Si.l^{-1} . Ammonia concentration was below detection level (less than 1 μg at. N.l^{-1}). However, we think that there was a continuous flux of NH_4^+ from the anaerobic sediment to the overlying water due to the bioturbation by fish searching the benthos for food. NH_4^+ levels in the sediment interstitial water was found to be extremely high (above 200 μg at. $\text{N-NH}_4^+ .\text{l}^{-1}$, Motzkin et al 1982). These high levels of nutrients in the fish pond water coupled with the high level of incident solar radiation stimulated and supported dense phytoplankton blooms. Annual range of light intensity ranged from 1300 (winter) to 2200 (summer) $\mu\text{Einst.m}^{-2}.\text{S}^{-1}$ (Gordin et al 1981, Motzkin et al 1982). Phytoplankton species composition changed from season to season. From January to July Chaetoceros sp. was dominating, reaching levels of up to $12.4 \cdot 10^5 \text{ cell.ml}^{-1}$, accompanied with smaller numbers of Peridinium,

Gymnodinium and Euglenoid forms. During the fall season Skeletonema sp. was dominating the phytoplankton blooms reaching levels of up to $3.8 \cdot 10^5$ cell.ml⁻¹ (Motzkin et al 1982). Under conditions of low bioturbation rates which are given when the bream stock is young and mullets are not yet introduced, macroalgae would develop in the ponds. Cladophora sp. or Enteromorpha sp. were the most abundant forms in the ponds. These algae would serve as nutrient traps, thus competing successfully with the phytoplankton species. The introduction of grey mullets and the successive increase of the resuspended clay particle load in the water column allows the planktonic algal species to become the domineering photosynthetic organisms in the ponds. Primary productivity (fixation of inorganic carbon by photosynthesis) was measured to be very high, $3.5 \text{ g C m}^{-2} \cdot \text{d}^{-1}$ or $1.3 \text{ kg C m}^{-2} \cdot \text{yr}^{-1}$. This resulted in $32 \text{ kg m}^{-2} \cdot \text{yr}^{-1}$ of wet algal matter (Gordin et al 1981). The continuous water flow through the pond is diluting the algal population, diluting factor of about $0.50 \cdot \text{d}^{-1}$. Hence the algae are being removed from the ponds at a rate which is within the range of the apparent growth rates of the phytoplankton; 0.65 to $1.7 \cdot \text{d}^{-1}$ (Motzkin et al 1982). Oysters were grown in this fish pond system in the past, yielding a substantial crop (Huges-Games 1978). Crassostrea gigas was the main species chosen for this system because of its euryhaline, eurythermal and fast growth characteristics. Some of the phytoplankton species which occur naturally in the ponds are considered as good food species for oysters: Chaetoceros sp., Skeletonema sp. (Walne 1970, Winter 1978) from the quality and size (5μ) point of view. The oysters' growth rates were found to be high

- from less than 1 gr spat to commercial size (more than 65 gr) in 9 to 10 months. One should compare this rate with those reported in the literature (Fujya 1970, King 1978, Quayle 1969, Bardach et al 1972, Ryther 1968, Davy and Graham 1982 and many others). Such a fast growth rate is, economically, extremely advantageous. One of the possible explanations to its occurrence might be the fact that the oysters in the Elat system are beyond their reproductive environmental conditions. The water is too saline to allow reproduction, thus most of the energy gained through the abundant food is channelled to growth rather than to the production of ova and sperm, a process which requires a lot of resources. However this explanation was found to be incorrect in our conditions. On many occasions oysters were found to be ripe, both males (running) and females. On few occasions they even spawned spontaneously in their tanks (in summer months).

The excellent food supply to the oyster does not only result in a rapid growth rate but also in a very high quality index. Quality index of the oyster is a measure of the amount of meat in relation to the shell cavity. The higher the quality index the fatter and meatier is the oyster. The definition of quality index (Westley 1959) is: dry weight of oyster meat (in grams) over the volume of shell cavity (in ml), the result then is multiplied by 100. In a previous study (Hughes-Games 1977) oysters grown in the outlet of the Elat seawater fish ponds had an average quality index of 15.7. Quality indices of 10 and above are considered excellent.

Oyster productivity was also remarkable. In one oyster productivity study the water from four ponds (total area of $250 \text{ m}^2 \cdot 4 = 1000 \text{ m}^2 = 1 \text{ dunam}$) was run through a trough filled with trays on which oysters were resting. The water entered the trough, passed through seven stacks of oyster trays in a plug flow and flowed out at the other end. (plug flow versus mixed flow). Monthly weight gain of the total trough oyster population increased month by month until the oysters were large enough to utilize all the particulate material (algae) in the outflow water of the ponds. From this point on, growth increment for the oyster population leveled out at about 120 kg per 30 days period and remained close to this value for the remaining five months until harvest. The yield was just under 1.5 tons of whole oysters per 1000 m^2 fish pond per year.

The oyster utilization of the algae brought to the trough with the outflow pond water, was not efficient due to the plug flow. It was noted that the oysters at the head of the trough, receiving water straight from the ponds produced a large amount of pseudofeces. Pseudofeces consist of particulate material which is accumulated by the oyster, embedded into mucus and ejected from the incurrent side of the oyster, not passing the digestive system of the animals. The pseudofeces fall to the bottom of the trough and decompose there, thus potential food is lost for the down stream oysters. Pseudofeces are produced by normally feeding oysters as they accumulate unwanted particles and then eject them in the form of pseudofeces, or by oysters receiving too high algal concentrations. This latter was

apparently the case in our trough. It has been reported that $4.5 \cdot 10^5$ cells.ml⁻¹ of 5 μ algal cells is the desired concentration of food for Crassostrea virginica, which is just below the level where they will start to produce pseudofeces. (Winter 1978). At this concentration pumping by the oysters is reduced since the required amount of food can be obtained from a smaller volume of water, but pseudofeces production has not yet started. Since algal concentration in our pond water was regularly two to three fold this amount it was believed that much food of nutritional value was being wasted by its removal in form of pseudofeces. It was therefore inferred that if most of the algal matter produced in the fish pond could be utilized as food rather than wasting of a significant proportion of it as pseudofeces, oyster production could be increased over the previously observed 1.5 tons.dunam⁻¹ .yr⁻¹. The present study was initiated to determine what conversion coefficients could be achieved under various feeding regimes. In order to carry out the study a research facility was constructed which included a shaded area under which the oyster tanks were situated. A pond water supply system was installed which provided continuous flow. A small field laboratory which processed water, algal and oyster samples was also constructed under the shed. The methodology and results are discussed in the respective chapters. Based on the achieved results an economic analysis of potential oyster farming was made taking into account all production costs and yields.

Oyster diseases, to date, have apparently not been a severe problem in Elat. However, there is a sense of insecurity which is

related to the fact that we import all our spat from Europe. Oysters diseases occurred in new farming areas through spat introduction all over the world. In their review book "Aquaculture" Bardach et al 1972 are mentioning quite a number of disease factors which may effect oysters farming to the point of endangering its continuation. To mention a few organisms: flatworms in Japan, a bacterium in Europe which forced farmers to change the farmed oyster species from Ostrea edulis to Crassostrea gigas in the 1960s. In Australia an unexplained phenomenon of alceration occurs every few years causing great mortalities of oysters. The worm Polydora is a common pest to all oysters ruining the shell and then the animal itself. In 1967 a very high mortality was reported in New England due to Minchinia nelsoni (MSX). It is believed that it was introduced to the area by importing spat from infected areas south of New England. (Chew ed. 1982). Diseases occur also within hatcheries, causing great damages (Meyers 1981). Such diseases are caused by protozoan parasites, Meyers (1981) is describing seven such organisms.

One could protect potential oyster hatcheries and farming operations by initiating an induced reproduction programme, thus minimizing the risk of importing diseases, either by spat or spawners. This consideration was a dominant one in our decision to initiate a reproduction programme for both C. gigas and O. edulis. It was felt that even at the present state of development, where no commercial operation was going on, spat should not be imported if possible. Some of the spat shipments we received had other species of bivalve amongst

the oysters we ordered, and some of them even had the worm Polydora. Other pests were not detected, however, we were not confident that some were not introduced.

There is a large volume of literature concerning the artificial propagation of our two species. A major work of research was done by V. Loosanoff and colleagues in Milford Conn. U.S.A., by P. Walne and colleagues in Conway, N. Wales and others. Manuals for oysters seed production, larval rearing techniques, water quality problems and solutions were published in the last 30 years. (Davis 1953, Loosanoff and Davis 1963, Galtstoft 1964, Loosanoff 1965, Walne 1965, Walne 1966, Davis and Calabrese 1969, Calabrese and Davis 1970, Walne and Spencer 1971, Dupuy et al 1977, Mann 1979). The two species that are experimented with in Elat very rarely spawn naturally in our installation to the best of our knowledge. As will be shown in the results section of this final report, the oysters, belonging to the two species, grew extremely well under the conditions provided them in the fish pond runoff water. Their state of health and development was excellent and their gonads quite well developed during summer months.

The summary of the introduction leads to the following statements:

1. During this BARD project, an efficient technique for growing oysters in the runoff water of a seawater fish pond was developed.
2. Basic culture requirements of C. gigas under the artificial conditions were determined (oxygen and food levels, water flow rates, cleaning frequency).
3. A prototype installation for commercially growing oysters is now under planning and shortly will be under construction.
4. Economic analysis of oyster farming under the conditions developed in Elat is available.
5. Reproduction and larval rearing procedures to spat size was developed.

INSTALLATIONS, PROCEDURES, METHODS

An experimental facility for studying basic characteristics of intensive oyster farming was constructed. It consisted of a roofed platform of 100m², housing a small laboratory and office and space for 10 biostats in which the oysters were grown. The biostats were of 600 liters each in volume, had a cylindrical shape and a steep conical bottom. They were made of plastic (polyethylene). Water containing algae from the common outflow of four 1/4 dunam fish ponds was pumped into a 10 m³ storage tank situated two meters above the oyster biostats (water surface to water surface). Water from this header tank flowed by gravity to the biostats. Water entered the biostats through a variable number of horizontal underwater jets pointing tangentially around the tank. This method was used in an attempt to create mixed flow conditions in the tank (as opposed to plug flow) whereby every oyster would experience the same conditions in terms of oxygen, food and metabolite concentrations. When consumption or production measurements of some substance was made in a mixed flow system, then a statement could have been made about the consumption or production of the substance when the oyster was experiencing a certain set of conditions. Water left the biostats from the bottom, entering a common drain manifold. At the distal end of this outlet manifold was a stand pipe which controlled the water level in all the biostats.

In the study done previous to this one, oysters were grown on trays with plastic mesh bottoms. It was found not to be efficient since the oysters had to be washed free of biodepositions (mainly fecal pellets) at growing frequencies, to prevent suffocation. During the washing procedures the oysters had to be disconnected from the plastic mesh, since they started to grow into it, and from each other. This procedure was labour intensive and must have been carried out at short enough time intervals so that the oysters would not die in the interrim. A new method for suspending the oysters was developed. In the new method, oysters of about 1 cm depth (longest dimension) were glued, left (cuped) valve down on strips of extruded plastic mesh which had been stretched on a rigid frame. The frames were immersed in a trough of running pond water for four to six weeks to allow them to grow into the strips of net and thus firmly attach themselves. The strips of net were then cut apart in such a way that left each oyster with one eye of net dorsal to its hinge. Oyster racks consisted of sheets of plastic-coated wire-weld net made of 3 mm wire with 5.5 cm eyes. Oysters were suspended by the eye of the plastic net to which they were attached, below each cross of the wire-weld mesh, using a small plastic split ring. The racks were threaded on four lengths of small diameter pipe with larger diameter pipe, 15 cm in length as spacers. With this method, each oyster was suspended, hinge side up, incurrent and excurrent openings down, in a 5.5 by 5.5 by 15 cm volume of water and had no contact with equipment or with other oysters. Each conical biostat had 5 racks of oysters in the upper cylindrical part of the biostat tank giving a population of about 1250 oysters per

0.6 cubic meter biostat. Oysters grown in this way, either in ponds or in biostats, were found to have very regular shapes and required almost no handling from set out to harvest.

The system was very simple and easy to operate and study. All components were made out of plastic, so that no corrosion interfered with our study. In order to determine whether the biostats behaved in a mixed flow fashion, it was necessary to select and monitor one parameter at various points in them which was present in the inflow water and which was used by the oysters in the biostat. Oxygen was chosen since it could be measured by means of a meter, thus providing instantaneous results and eliminating the need for elaborate, time consuming chemical analysis or algal cell counts.

The determination of the relative mixed or plug flow nature of the system is independent of the calibration of the meter and only depends on the consistency of readings in various parts of the biostat over a short period of time. The measurements were done with YSI Model 57 Dissolved Oxygen Meter calibrated to the salinities which were experienced in the fish ponds (up to 43‰). Algal and organic particle densities in the inflow and outflow water (water from the fish pond and the oysters' biostats respectively) were to be determined in order to calculate food consumption as a function of food densities and food conversion coefficients. Counting algae was possible and therefore done, but counting particulate organic matter

was quite an impossible task. However, it could not be ignored since oysters consumed it. Particulate organic carbon would have been the most representative chemical species to measure, since reduced carbon is the major component in any organic food stuff. However, due to analytical limitations, it was decided to measure reduced particulate organic nitrogen as a measure of the particulate organic matter in the pond water (inflow) and in the outflow water from the oysters biostats. This parameter, PPN (Particulate protein nitrogen) was measured by filtering a water sample with a preweighed GF/C filter, drying the filtered material to constant weight, digesting it and measuring NH_4^+ on a Technicon I autoanalyzer (later on Technicon II autoanalyzer). The inflow to the oysters' biostats was the outflow from the fishponds. Thus, when measuring PPN concentration in it and multiplying it by the flow rate from the ponds, one got a measurement of the productivity of the ponds in terms of particulate protein. The outlet water (from the oysters' biostats), however, in addition to containing unused food, also contained larger particles of feces and pseudofeces. The inclusion of the latter two particle categories in the PPN analysis would have given false food consumption figures upon which the food conversion coefficients were to be calculated. Fortunately, these particles had a settling rate of about 1 cm per second. This characteristic was used to eliminate the feces and the pseudofeces from the biostat outflow sample. A thin tube of 3 mm ID was attached to the stem of a plastic funnel which had a mouth diameter of 5 cm. The funnel was lowered into the biostat to a level below the lower rack of oysters with its mouth downward and with the

tube passing upward over the lip of the biostat and hanging down outside the biostat allowing siphoning. When the biostats were to be sampled, the siphon was started and a volumetric sampling bottle placed to collect the water from each siphon. Due to the low flow rate through the thin siphon tube and the diameter of funnel mouth, the vertical velocity of water across the mouth of the funnel was less than 0.5 cm per second. This flow rate was too slow to entrain particles of feces and or pseudofeces. Algal cells in the inflow and outflow water were counted on a haemocytometer at the initial phases of the study. In the latter part only PPN analyses were done.

As mentioned above, oxygen was measured with YSI Model 57 Dissolved Oxygen Meter with a stirrer, calibrated in air saturated water at the temperature of the water to be measured in accordance with manufacturer's instructions, and calculated with correction for salinity.

At the beginning of the experiment an empty rack with its plastic split rings was weighed. Subsequently, oysters were weighed, rack by rack, after hosing off biodeposits. Racks were weighed by suspending them under a grocery balance which was readable to 5 grams. The weight of the rack was subtracted from the combined weight of the oysters and the rack. Since the objective of this project was meant to relate to a farming situation, conversion coefficients were calculated as the amount of particulate protein nitrogen necessary to produce one kilogram of whole oyster, rather than of oyster protein or

oyster meat.

Reproduction work was done in the new hatchery facility of the National Center for Mariculture in Elat, IOLR. Ripe oysters (Crassostrea gigas) of one and a half years old were selected from the grow out unit and induced to spawn by elevating water temperature to 28°C. In some cases sperm was added, in addition to increasing temperature, to trigger spawning. Eggs and sperm were combined in 1000 ml glass beakers with aeration. After approximately one hour equal numbers of fertilized eggs were transferred into two groups of three 184 liter conical bottom fiberglass tanks, filled with filtered sea water. Two salinities were experimented with 40‰ and 25‰ (three tanks per treatment). 24 hours later, when the oyster larvae developed into the shelled D stage, they were filtered through a 45 micron mesh, counted and restocked in new filtered sea water in the above tanks in densities varying between 45 to 160 larvae per ml.

Larvae were fed the microalgae Isochrysis sp. (a tropical species of the genus Isochrysis, which is well adapted to high temperatures and salinities. This species was brought to Elat from the algal collection of Woods Hole Oceanographic Institute, Mass. U.S.A. (The origin of this culture is believed to be in Tahiti). Isochrysis sp. was cultured routinely by the food chain group of the new hatchery. The density of Isochrysis sp. in the oyster larvae tanks was set at $4 \cdot 10^4$ cells per ml. On alternate days the oyster larvae were filtered from the water, counted, measured and then

placed in new water. New algae were added to the tank in the above mentioned concentration. On days when the larvae were not filtered, algae in the tanks were counted and if needed, additional algae were added up to $4 \cdot 10^4$ cells per ml final concentration.

Larvae were allowed to settle on a variety of substrates; washed oyster shells, PVC plates, fiberglass boards, polyethylene sheets and wood. Soon after settling most of the oyster spat was transferred to growing tanks receiving the pond water used in the grow-out biostats unit. No attempt was made this time to use an upwelling technique to produce cultch-less spat. This technique is well known and described in the literature, and it is planned to be used in future. Between the hatchery and the grow-out stages there should be a nursery stage. It is a necessary stage to be used as a quarantine when spat is acquired from an overseas hatchery in order to eliminate or at least reduce the danger of diseases. With the technique of having each individual oyster hanging by itself from a rack, which was developed over the course of this project, this step becomes essential also. One has to grow the cultch less spat to a size of about 1cm before it can be glued to its hanging device. Three different methods for growing the cultch less spat were tried:

1. Air lift method: small oysters were placed in a conical bottom tank of 200 liter with an air lift taking water from the bottom of the cone along with oysters and ejecting the oysters 10 cm below the water surface of the tank. Oysters sank down to the bottom of the tank where they were picked up again by the air lift.

The tank was supplied with a flow of pond water at a rate of one exchange of tank volume per hour.

2. Tray method - Oyster spat were spread out in one layer on mesh bottom trays. Trays were placed in tanks of running pond water.
3. Upwelling method - Oyster spat were placed 10 or more layers deep in 10 liter buckets with mesh bottoms. The buckets were placed in a tank with an overflow pipe through the side of the bucket near its top and through the side of the tank. A flow of pond water was introduced into the tank, outside the buckets. Thus a stream of water was induced to flow up through the oysters and out the overflow pipe.

Results and Discussion

A. Mixed flow characteristics of Biostats

As described in the methods' section, flow characteristics of the water in the biostats was evaluated by measuring oxygen concentrations in the inflow water and at various points throughout the biostat. Many sets of measurements were done during the course of the study and they all followed the same trend. The measurements showed the water in the biostats to be well mixed and homogeneous. Typically, when incoming water to one jet biostat had 8 mg of O_2 per liter around 10 AM, the oxygen concentration in many parts of the biostat, measured over a short period of time (matter of minutes), never varied more than $0.2 \text{ mg } O_{2.l^{-1}}$ (5.4 to 5.6 $\text{mg } O_{2.l^{-1}}$). In three jets biostats the variation was the same, however the oxygen concentration was higher (6.4 to 6.6 $\text{mg } O_{2.l^{-1}}$). The same was true with the five jets biostats, even though the oxygen level was still higher (7 to 7.2 $\text{mg } O_{2.l^{-1}}$). This characteristic was common to all biostats, not influenced by the number of jets coming in. Based on these results it was concluded that the biostats' water had nearly a mixed flow system. Thus measurements, other than oxygen, which were carried out in this study, sampling different parameters like temperatures PPN (particulate protein nitrogen), NH_4^+ , NO_3^- , pH, alkalinity, algal species composition, were considered as fair representatives of the populations, in the biostat, they were coming from.

B. Oyster's Growth and Productiona. general

Fig. 1 Growthrates of oysters in 10 biostats under 5 different regimes of flowrates. Numbers indicate number of jets going into biostats.

= 1 jet, 500 L/hr
 = 2 jets, 979 L/hr
 = 3 jets, 1350 L/hr
 = 4 jets, 1630 L/hr
 = 5 jets, 2000 L/hr

Figure 1 describes the rate of growth of oysters which were maintained at 5 different regimes. All conditions, but fish pond water flow rates, were the same in all biostats. From a certain flow rate and up ($1350 \text{ liter.hr}^{-1}$) we could not detect significant differences between treatments. Flow rates determined two essential factors; amount of food brought into the biostats and amount of oxygen supplied to them. As long as the oysters were small - first four months into the study oysters were smaller than 5 grams each, all biostats showed the same growth rate. The inference was that the 500 liter per hour were enough to sustain the 1250 oysters in the biostat and enabled them to grow at a maximum rate. Up to the fifth month there was no advantage to the higher flow rates (1000, 1350, 1630 and 2000 liters per hour). From the middle of the fifth month the oysters in the biostats receiving only 500 liters per hour, of pond water, started to lag behind the others. This difference in growth rate maintained itself until the end of the experiment seven months later. The final mean weight of the oysters, at the end of this period, in the one jet biostat was 45.5 grams. The average monthly growth rate was 4.14 grams. From a statistical point of view this treatment was significantly slower than the other treatments. (significantly slower growth rate - see slopes of curve in figure 1.). Since individual oysters, selected at random from each rack, were not weighed, it was impossible to calculate the growth rate variance of each tank. Whole racks, from each biostat were weighed, after cleaning, and weight of rack subtracted. The result was the weight of all the whole oysters of the rack. (see methods chapter).

Fig.2 Conversion efficiencies of oysters receiving 5 levels of food. Grams nitrogen (PPN) needed to produce 1 kg of whole oyster and final weight of individual whole oyster in each of the treatments. Small bars indicate the range of the two replicates of each treatment.

From looking at figures 1 and 2 it is not clear whether the two to five jets biostats were different from each other. The slopes (Fig. 1) are not significantly different from each other. The slopes represent the growth rate. There was somewhat slower growth in the two jet biostats between the fifth and the eighth month, compared with biostats receiving three to five jets. From the eighth month on, except for one four jet biostat, all the two to five jets biostats showed the same growth rates. Other than the above differences we could not identify any significant deviations from the general oysters growth pattern of the two to five jet biostats. By the eleventh month oysters in the five jets tanks (2000 liters per hour = 3.3 exchanges per hour) gave the best result averaging 75 grams per oyster. The remaining treatments were close behind. One of the tanks receiving three jets (1350 liter per hour = 2.25 exchanges per hour) had oysters averaging 73 grams, its pair had 70 gram oysters, while the four jets biostats, receiving 1630 liter per hour had oysters averaging 72 grams in one biostat and 66.5 in the other. The two jets biostats, having a flow rate of 1000 liter per hour (1.67 exchanges per hour) had the second smallest oysters at the end of the eleventh month, 65.5 grams and 63.5 grams in the two biostats, but this is not significantly different from the other biostats. (3 to 5 jets). (see fig. 1 and 2).

In order to explain the growth patterns which evolved during the experiments, detailed studies of feeding and respiration of the oysters were carried out. Tables 1-3 give the data concerning feeding and respiration of three biostats receiving different quantities of

the fish ponds water. It covers a period of 27 hours. Many runs like that were done during the course of the study.

Table 1: Oxygen, PPN (particulate protein nitrogen) levels and consumption of a one jet biostat holding 60 kg of whole oysters, i.e. 12 kg of oyster's living tissue. O_2 is expressed in $mgO_2.l^{-1}$, O_2 consumption in $mgO_2.kg^{-1}$ (living tissue). hr^{-1} . PPN is expressed in μg at.N. l^{-1} and consumption of PPN in μg at.N. $Kg^{-1}.hr^{-1}$. Flow rates are in liters per hour. CI is combined fish pond water inflow.

Hour	CI(O_2)	CI(PPN)	Flow rate	(O_2)in biostat	(PPN)in biostat	O_2 Con- sumption	% O_2 removal	PPN consum- ption	%PPN removal
0800	5.48	19.91	497	3.71	18.56	73	32.3	55.91	6.78
1100	8.44	16.9	499	5.8	3.02	109.78	31.28	577.2	82.13
1400	10.12	25.36	502	7.14	10.9	124.66	29.45	604.91	57.02
1700	11.44	28.56	502	8.15	12.10	137.63	28.76	688.58	57.63
2000	9.3	25.33	497	6.6	9.51	111.82	29.03	655.21	62.45
2300	7.05	28.05	505	4.6	9.29	103.1	34.75	789.48	66.88
0200	5.9	20.91	497	3.6	6.84	95.26	38.98	582.73	32.71
0500	5.31	19.68	488	3.1	6.48	89.87	41.62	536	67.07
0800	6.31	25.03	485	3.64	9.51	107.51	42.22	627.26	62.00
1100	9.11	21.82	488	5.51	9.07	146.4	39.52	518.5	58.43
Mean	7.85	23.15	496			109.9	34.79	563.58	55.31
2SD $\bar{x}$	1.35	2.4	4.29			13.82	3.39	123.2	13.28

Table 2: Oxygen, PPN (Particulate Protein Nitrogen) levels and consumption of a three jets biostat holding 89.2 kg of whole oysters, i.e. 17.84 kg of oyster's living tissue. O_2 is expressed in $mgO_2 \cdot l^{-1}$, O_2 consumption in $mgO_2 \cdot kg^{-1}$ (living tissue) $\cdot hr^{-1}$. PPN is expressed in $\mu g \text{ at.N} \cdot l^{-1}$ and consumption of PPN in $\mu g \text{ at.N} \cdot kg^{-1} \cdot hr^{-1}$. Flow rates are in liters per hour. CI is combined fish pond water inflows.

Hour	CI(O_2)	CI(PPN)	Flow rate	(O_2)in biostat	(PPN)in biostat	O_2 Con- sumption	$\%O_2$ removal	PPN consum- ption	$\%PPN$ removal
0800	5.48	19.91	1252	5.1	15.48	26.73	6.9	310.89	22.25
1100	8.44	16.91	1234	7.18	8.3	87.15	14.93	594.17	50.83
1400	10.12	25.36	1271	8.45	10.54	118.98	16.5	1055.84	41.56
1700	11.44	28.56	1309	9.52	21.29	133.54	16.78	533.43	25.45
2000	9.3	25.33	1290	7.2	13.33	151.85	22.58	867.71	47.37
2300	7.05	28.05	1543	5.32	13.33	149.63	24.54	1273.15	52.48
0200	5.9	20.91	982	4.14	9.89	96.88	29.83	606.59	52.70
0500	5.31	19.68	1252	4.01	12.56	91.23	24.48	499.68	36.18
0800	6.31	25.03	1252	5.0	13.76	91.93	20.60	790.92	45.02
1100	9.11	21.82	1252	7.15	7.74	137.55	21.51	988.12	65.53
Mean	7.85	23.15	1263.7			108.55	19.86	752.05	43.84
2SD $\bar{x}$	1.35	2.45	84.8			24.04	4.04	186.98	8.2

Table 3: Oxygen, PPN (Particulate Protein Nitrogen) levels and consumption of a five jets biostat holding 94.6 kg of whole oysters, i.e. 18.92 kg of oyster's living tissue. O_2 is expressed in $mgO_2 \cdot l^{-1}$, O_2 consumption in $mgO_2 \cdot kg^{-1}$ (living tissue). hr^{-1} . PPN is expressed in $\mu g \text{ at.N.l}^{-1}$ and consumption of PPN in $\mu g \text{ at.N.Kg}^{-1} \cdot hr^{-1}$. Flow rates are in liters per hour. CI is combined fish pond water inflows.

Hour	CI(O_2)	CI(PPN)	Flow rate	(O_2)in biostat	(PPN)in biostat	O_2 Consumption	% O_2 removal	PPN consumption	%PPN removal
0800	5.48	19.91	1800	5.26	9.85	20.93*	4	957.1	50.5
1100	8.44	16.9	1838	7.48	10.07	93.26	11	663.5	40.41
1400	10.12	25.36	1878	8.96	11.99	115.14	11.46	1327.11	52.72
1700	11.44	28.56	1878	10	17.99	142.93	12.59	1049.2	37
2000	9.3	25.33	1878	7.5	12.42	178.67	19.35	1281.45	50.96
2300	7.05	28.05	1920	5.55	16.63	152.22	21.3	1260.38	44.28
0200	5.9	20.91	1878	4.7	16.28	119.11	20	459.57	22.14
0500	5.31	19.68	1838	4.2	14.35	107.83	20.9	517.79	27.08
0800	6.31	25.03	1838	5.48	16.71	79.66	13.01	808.25	33.24
1100	9.11	21.82	1920	7.59	10.28	154.25	16.68	1171.1	52.89
Mean	7.85	23.15	1866.6			127	16.26	949.54	41.12
2SD $\bar{x}$	1.35	2.45	24.16			21.4	2.84	204.18	7.01

* This point was declared as an outlier.

These data are in agreement with figures 1 and 2 and explain the differences between the different treatments. Table 4 summarizes the differences between the three treatments which are detailed in Tables 1-3.

Table 4: Comparison between Oxygen consumption (mg O₂.Kg oyster⁻¹.hr⁻¹), PPN consumption (µg at N.Kg oyster⁻¹.hr⁻¹) of three oyster biostats experiencing three different fish pond water flow rates. Figures given are averages with 2SD of the mean as confidence limits; of 10 individual data points taken during 27 hrs sampling period at three hours intervals. (Oxygen and PPN were 7.85 ± 1.35 mg.l⁻¹ and 23.15 ± 2.45 µg at N.l⁻¹ respectively.)

	1 jet	3 jets	5 jets
Living biomass (kg)	12	17.84	18.92
Flow Rate (liter.hr ⁻¹)	496±4.29	1263.7±84	1866.6±24.16
Oxygen consumption	109.9±13.82	108.55±24.04	127±21.4
Oxygen removal %	34.79±3.39	19.86±4.04	16.26±2.84
PPN consumption	563±123.2	752.05±186.98	949.54±204.18
PPN removal %	55.31±13.28	43.84±8.2	41.12±7.01

b. Oxygen Consumption

It was quite apparent that oxygen levels in the incoming water from the fish pond reflected photosynthetic and respiratory processes in the pond. High levels occurred from 10-11 AM to 8 PM (above saturation), due to intensive photosynthesis, and dropped during the night period to a level below saturation (4 to 5 ppm of O_2) reflecting O_2 consumption by the pond community - fish, algae, bacteria and sediments. Oxygen consumption followed oxygen levels in incoming water. Correlation between oxygen concentration in the incoming water and oxygen removal (respiration) was strongest in the one jet biostat and less so in the three and five jets biostat. We used the Kendall's Rank Correlation Test. (Tate and Clelland 1957). The one jet biostat had a correlation (a Tau value) of 0.77 which was significant at the .01 level. For the three and five jets biostats the Tau value was 0.42 (both biostats) which was significant at the 0.15 level. Few conclusions concerning the dynamics of oysters' respirations can be drawn from our results:

- 1) Oysters adapt themselves to the level of dissolved oxygen in the water. The higher the supply of oxygen the less efficient they are in extracting it from the water. On the other hand, if oysters were acclimated to low oxygen levels, in general, they would be very efficient in extracting oxygen from the water. Oysters which were living in the biostat receiving only 500 liters per hour were systematically removing a larger

percent of the dissolved O_2 from the water than did oysters receiving 1350 or 2000 liters per hour. (34.8%, 19.9% and 16.3 respectively).

- 2) Oxygen uptake by the oysters, i.e. respiration rate, was more or less the same for all treatments. In all treatments the daily oxygen average consumption was around 110 mg O_2 per kg of oysters' living tissue (excluding shell) per hour. This figure is in agreement with a recent work published in 1983, (Gerdes. 1983). However the higher the oxygen supply was to a given tank the greater the difference was between the maximum and the minimum uptake. (see Fig. 3). Oysters in the one jet biostats had a moderate daily oxygen consumption curve. They were able to extract O_2 from the water at the low oxygen level periods in the incoming water at a very efficient way - 41 to 42 percent of the available oxygen. (see table 1). Whereas the maximum removal rate of oxygen by the oysters living in the five jets biostat was 21% (Table 3). We are seeing here a long range adaptation to given oxygen minima and maxima by oysters.

Fig.3

Typical daily oxygen consumption curves of oyster biostats. Data taken from tables 1-3.

1 jet 469 l/hr
3 jets 1263 l/hr
5 jets 1867 l/hr

- 3) Of great biological interest is the way in which the oysters react to low oxygen levels. They seem to carry the remembrance of periods of low oxygen into periods in which the oxygen levels in the incoming water have increased. (Fig. 4). It is more obvious and emphasized in the five and three jets biostats. It seems that the oysters have a respiration lag period when moving from low to high oxygen levels. It is a characteristic which should influence oyster farming techniques, since it must influence the general metabolism of the animal. The farmer should maintain oysters under conditions where oxygen is abundant at all times and not limiting. This can be done by supplying the system with oxygen during the late night and early morning hours. It will minimize fluctuations, may increase feeding and reduce danger of mortality due to oxygen deficiencies.

Fig.4 Typical daily oxygen consumption curves by the oyster biostats. Data taken from tables 1-3. Oxygen consumption is plotted against oxygen concentration in fish pond water flowing into the oyster biostats. Arrows indicate direction of sampling sequence during 27 hours, starting at 08:00 a.m. and ending at 11:00 a.m. the next day.

C. Feeding

We measured oysters food stuff in terms of PPN (particulate protein nitrogen). We felt that this was a good measure of productivity and could be followed in a routine way. Dry matter, which could have been sampled in the same way, contained a large fraction of suspended sediment (silt and clay) which gave us a great deal of interference in the analysis. The same was true with organic matter. For these reasons we chose nitrogen in the particulate proteinaceous form as the measure for feeding rates of the oysters in the biostats. Algal production in the fish ponds was not constant during the periods of study. As mentioned above it fluctuated from month to month due to fluctuations of nutrients concentrations, mainly orthophosphate. However, within one day, fluctuation in the algae density was relatively small. When translated in terms of PPN it was not more than $23.15 \pm 2.45 \mu\text{g at.N.l}^{-1}$ for the demonstrated day in Tables 1-3. (in order to convert that term into dry organic matter one should do the following: multiply by 6.25 - conversion of carbon to nitrogen based on the C:N ratio in phytoplankton 100:16, then multiply that by 12 to convert $\mu\text{g at}$ of carbon into weight, then multiply that by 2.5 based on the ratio of organic matter to carbon. The factor, then, comes to 187.5. In the given example the $23.15 \mu\text{g at. N}$ represent 4.340 mg of dry organic matter per liter). The oysters removed the organic matter from the water at efficiencies which were related to the water residence time in the biostats. In the one jet biostat, which had 500 incoming liters of pond water per

hour, (0.83 exchanges per hour) the oysters removed 55 ± 13 percent of the organic matter. Water exchange rates per hour in the three and five jets biostats were 2.1 and 3.1 respectively. The removal of the organic matter in terms of PPN was 43.84 ± 8.2 and 41.12 ± 7 percent respectively. Generally, it can be inferred that the oysters were not very efficient, under the condition they were grown, in removing the algae from the water. The most efficient were the oysters living in the one jet biostat, reaching a maximum removal rate of 82 percent at one period (see Table 1). Even though these oysters grew much slower than the oysters in the three and five jets biostats they did not remove more than 55% of the passing algae on the average. They allowed close to 50% of the available algae not to be utilized by them even though they grew in general at a rate of 60% of the oysters in the five jets biostats. It may be concluded therefore, that in the one and probably two jets biostats; 500 and 1000 liters per hour respectively, oyster growth was limited by the ability to filter algae from the water at rates higher than 55% of the available algae on the average. However the situation seems to be more complicated than just blaming the oysters for inefficiency. There were times during the day that they reached removal of 82 percent of the available algae, and others only 32 percent were removed. In the three and five jets biostats fluctuations in removal rates were also very significant; 65.5 and 53 percent maxima respectively, 22 as minima in both. We could not find correlation of this behavior to any parameter in the system, at least not a direct one. At no time did the oysters stop feeding completely, it was never measured. The feeding rates of the

oysters seemed to be erratic. No correlation was found between oxygen removal and PPN removal by the oysters. (indication for the connection between feeding and respiration). No correlation was found between feeding and respiration. No correlation was found between oxygen concentration and PPN removal or oxygen concentration of the incoming water three hours earlier, like the correlation that was found between oxygen removal and oxygen concentration in the previous sampling period. Only the oysters in the one jet biostat showed a week correlation between the oxygen concentration in the previous sampling period and the PPN removal. (at the .2 level). In general, we can conclude that food was not limited during the study, but the oysters in the biostat receiving only 500 liters per hour had difficulty in extracting it from the water. Whether it is rational at this point to try and force them to extract from the water 80 percent of the available food by supplying oxygen artificially has to be decided experimentally.

Studying Figure 2 reveals that oysters in the one jet biostat (500 liters per hour) were the most efficient growers. They needed only 9.5 grams of nitrogen to produce one kilogram of whole oysters. The least efficient ones were the oysters in the five jets biostat (2000 liters per hour) which required 15.5 grams of nitrogen (as PPN) to produce one kilogram of whole oysters. The oysters in the five jets biostat consumed PPN at a rate which was about 60 percent higher than the ones in the one jet biostat, (see Table 4). They also grew faster at more or less, the same difference. This evidence is

contradicting , somewhat, to our conclusion that oysters were not limited by food. At this point we choose to leave it at that, waiting further investigation. Oyster farming, in future, will have to compromise between economic considerations and supplying the oysters with the optimal growth conditions.

The conditions devised for the oysters in the Elat system enabled them to grow at a very fast growth rate. Oysters of two years of age in Japan will weigh not more than 65 grams. At their third summer they will reach 90 to 100 grams. (Fujiya 1970). The American oyster will take five years to reach this size. We think that high food density (compare to near shore situation), its quality and the relatively high temperatures even in winter are among the domineering factors which enable C. gigas to perform so well in our system. At the rate of oyster growth which was demonstrated in this study one can extrapolate the oysters yield one should expect from a one dunam of fish pond. By moving the fish pond water through the oyster trough and back to the pond at the rate which gave the best growth rate in our study (2000 liter per hour per 1250 oyster), the oysters will filter no more than 50 percent of the algae, the remainder will serve as a continuous inoculum to the fish pond. 1250 oysters require then, 48 m^3 per day of pond water, 1000 m^2 in one dunam will support $20.83 \cdot 1250 = 26041$ oysters. This should be considered as a minimum value. Based on carbon fixation considerations, 1.3 kg C per m^2 per year, it should support over four tons of marketable per year per dunam of fish pond. In one year they will reach 82.36 grams each or

2145 kilograms of whole marketable oysters. The value of this crop in terms of U.S. dollars is 5300\$ (2.5 dollar per kg). The area which is needed to grow the oysters is not more than 1/40 of the fish pond area.

The first pilot plant of integrated fish and oyster ponds will be built this coming summer (1984) on the premises of the new National Center for Mariculture in Eilat. This experimental farm will be constructed and operated according to the results arrived at in this study whenever the oysters part in the system is concerned. 10 integrated systems are planned which will be operated either in pairs (fish pond to oyster trough) or in any combination amongst them required for a given experiment.

D. Oyster Reproduction

There were two main reasons to the initiation of the oysters' reproduction programme. The first one was our desire to reduce the chance of introducing diseases with the imported spat. The second one was our understanding that no viable industry can rely on imported seed. The industry should be able to supply itself with all the spat it needs for the growout operation. The first reason was an immediate one, since with the few spat shipments we received also unwanted organisms and we felt threatened. The art of oyster reproduction is quite well documented in the literature, however each hatchery has its own peculiarities, special conditions and problems. One cannot just copy techniques. One has to adopt and modify them according to the local conditions.

Crassostrea gigas origin is in the western Pacific Ocean. Its cultivation was started and brought to a very large industry in Japan. Conditions there are very different than those in Elat. Salinity is never higher than 30 PPT, algal species assembly is different, annual temperature regime is less extreme than in Elat. In spite of these differences the C. gigas grown in the Elat mariculture system develop their gonads naturally. They even were seen to be spawning during the summer months spontaneously in their tanks. But we never observed spat fall anywhere in our system. In all attempts made in the lab to spawn the Japanese oyster, spawning occurred. Temperature was elevated in winter or spring to 27°C. In summer, when ambient

temperature was high (above 25°C.), the would be spawners were conditioned at low temperature (18 to 20°C.) and then, temperature was raised to 27°C. and the oysters would spawn. At times, to trigger spawning, running sperm would be added to a group of spawners and then spontaneous spawning would occur, releasing the gonadal products into the medium.

Ostrea edulis also was spawned by more or less the same techniques, however it was more difficult to follow since they brood their larvae inside the shell. Since we did not spawn one oyster at a time we cannot testify as to their individual fecundity. However, with a group of up to ten oysters it is quite common to get over 30 million fertilized eggs. At present spawning of the two species is done routinely in the National Center for Mariculture in Elat.

E. Larval Rearing

The major question asked in our first runs of larval oyster rearing had to do with the optimal salinity in which to rear the larvae. In the literature it is mentioned that optimum salinity for larval development is between 23 and 28 ppt. (Bardach et al 1972). Since our sea water in Elat reaches salinity of 40 ppt it was quite apparent that the forcing of oysters to reproduce may end up as a failure in rearing the larvae. Therefore two salinities were tried in the experiments: 40 ppt. and 25 ppt. The other variable in the experiment was stocking densities of the fertilized eggs in the rearing tanks. Three densities were used for each salinity: 40ppt. had initial densities of 45, 85 and 138 fertilized eggs per ml. 25 ppt. had initial densities of 80, 122 and 158 fertilized eggs per ml. Every second day, after the shelled D stage was developed, the larvae were filtered through 45 micron mesh, measured, counted and restocked in filtered sea water fiberglass tank. Algae, Isochrysis sp. density was made up to $4 \cdot 10^4$ cell ml⁻¹ every day. The results are illustrated in Figures 5-6. In all 40 ppt treatments the larvae grew slower than in the 25 ppt ones. 10 days after stocking the larvae in the 40 ppt treatments had an average size of 135 μ while the ones in the 25 ppt treatment were 180 μ . At the eye spot plus foot stage most of the larvae in the 40 ppt treatment died off reaching size of 200 to 280 μ . Of the three populations we ran in the 40 ppt treatment only about 100 larvae survived and went through metamorphosis. The larvae developing in the 25 ppt grow quite well all the way to 300 μ . There

they more or less stopped probably awaiting suitable substrate and conditions to settle. The preferable water salinity for the oyster larvae to settle is mentioned in the literature as 18 to 15 ppt. (Bardach et al 1972). In general we can say that 25 ppt is a fair salinity for the oysters' larvae to develop.

Spat were made to settle on washed oyster shells and on a variety of plastic materials. Soon after settlement most of the oysters spat were transferred to growing tanks receiving the same pond water used to grow adult oysters. Some of the spat were grown in the hatchery on Isochrysis sp. Spat which were transferred to pond water grew much faster than oysters which were kept on the monoalgae diet. Spat in the pond water grew from 100 mg to 1 gr in one month while the ones in the hatchery fed only Isochrysis barely reached 200 mg during one month of growth.

Fig. 5: Growth and survival curves of 3, 40 ppt salinity, larval rearing tanks. Growth curve represent all three tanks. Broken vertical lines represent the range. All tanks were stocked with 48 hours old larvae. All tanks were combined on the 19th day.

- a) All oyster seived through 110 μ mesh, only oysters which were retained on the mesh were allowed to continue experiment.

Fig. 6: Growth and survival curves of 3, 25 ppt salinity, larval rearing tanks. Growth curve represent all three tanks. Broken vertical lines represent the range. All tanks were stocked with 48 hours old larvae.

- a) All oyster seived through 110 μ mesh, only oysters which were retained on the mesh were allowed to continue experiment.

F. Economic analysis:

The results of this project concerning culture of oysters, combined with results concerning fish farming in seawater ponds, including these ponds major ecological processes enabled us to prepare an economic analysis of oyster farming. This analysis relate to oysters in a situation of monoculture as well as in an integrated system with fish. The economic analysis were made with the help of Mr. Dan Rimon and Yoram Porat from the Volcani Institute of Agricultural research and Ministry of Agriculture respectively. Two regimes are analysed: The first one deals with an integrated system culturing fish and oysters. The second one deals with culturing oysters only. Prices of products were evaluated conservatively and production cost are detailed according to our experience during the last few years.

Table 5: Production cost analysis of rearing the oyster Crassostrea gigas in two systems: Integrated with fish and in monoculture. Prices are given in U.S. dollars.

item	Integrated System			Monoculture		
	quantity	price per unit	total value	quantity	price per unit	total value
Income:						
S.aurata	1250 kg	4.25	5312			
M.cephalus	600 kg	2.5	1500			
C.gigas	2000 kg	2.5	5000	2500	2.5	6250
total			11812			6250
Expenses:						
fish food	3125 kg	0.6	1875			
fertilizers						350
fry	6000 (*)	.15	900			
spat	25000	.016	400	31250	0.016	500
sea water (pumping and circulation)			1500			1500
general (interest, drugs, misc.)			1500			500
labor	20 50		1000	15 50		750
Capital	15000 (**)		2520	7500 (***)		1222
total			9695			4822
Profit			2117			1428

Comments:

(*) 6000 is the number of fry needed to stock one dunam resulting in the above yield. They are divided into 5000 S. aurata and 1000 M. cephalus

(**) 15000 dollars in the total investment need for one dunam of integrated system. This sum is divided into 7500 U.S. dollar installation of 15 yrs longitivity, resulting in a coefficient of capital return (10% interest rate) of .131. This factor gives an annual return of 982.5 U.S. dollars. The other 7500 U.S.dollars is of longitivity of 7 yrs, having a coefficient of .205 (10% interest), resulting in an annual return of 1537.5 U.S. dollars.

(***) Capital investment totals 7500 of 10 yrs. average longitivity, making a coefficient of .163 resulting in 1222 U.S. dollars as annual return.

10% annual interest was taken as our national interest. Labor was estimated rather roughly, based on our experience in our experimental work. Most of the labor goes into providing each oyster with its hanger (glueing the oysters on extruded plastic mesh, cutting it and putting it on its hook which is attached to the rack.) According to our understanding, this work can be mechanized, thus saving more than 70% of the labor going into oyster production.

It is felt, that the integrated system and/or oyster culture can provide profitable livelihood to many workers in the southern Arava Valley in Israel, or any desert area which is situated not too far away from the sea.

Conclusions:

Listed are the conclusions which have been drawn from the results of the oyster culture project.

1. The biostat system which was constructed for studying the growth pattern of the edible oyster Crassostrea gigas, supplied with fish pond sea water, had a true mixed flow. All parameters; dissolved or suspended in the water were evenly distributed within the biostat.
2. The growth rate of the oysters depended on the flow rate of the fish pond water through their biostats. At least 1350 liters per hour of this water were needed to support an unhindered growth rate of 1250 oysters all the way to marketable size.
3. To produce one kilogram of whole oyster, 10 to 15 grams of particulate proteinaceous nitrogen (PPN) were needed.
4. The ponds algal production in the terms of fixed carbon was found to be 1.3 kg of carbon per m² per year. (Motzkin et al.1982).

This quantity of carbon will be equivalent to 208 gr of fixed nitrogen. Assuming 30 percent efficiency it will support the production of 4.16 kg of whole oysters. (or 4.16 tons of oysters per dunam per year).

5. To increase efficiency of oysters growth, oxygen should be supplied to oyster culture in late hours of night and early hours of morning.
6. Oysters produced in the integrated system were of high quality.
7. Economic analysis of oyster farming points towards a profitable food production potential.
8. Oyster can be spawned and their larvae reared under the condition developed in Elat.

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