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Oyster Production in the Outflow of Salt Water Fish Ponds

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ABSTRACT

Research and development work was carried out during 1985-1987 to study the feasibility of fish/oyster polyculture in an integrated system. The facilities consisted of a semi-closed water circulation system, whereby water from a fish pond rich in phytoplankton was supplied to a tank containing the oysters Crassostrea gigas and Ostrea edulis.

The oysters filtered the phytoplankton and the water with the uneaten algae was then returned to the fish pond. This study focused on the role of the oysters in this system and the ability of the integrated system to sustain rapid oyster growth. Several parameters were monitored, including water temperature, salinity, dissolved oxygen, pH, NH₄, as well as the algal composition and concentration. In addition, oyster growth rates, filtration rates and gonadal development cycles were determined. The results of this study indicate that in the environmental conditions of the integrated system oysters can be adequately maintained. However, the two goals for which the integrated system was designed, efficient biological filtration and intensive growth of the oysters, have not yet been achieved. The present data show that a unit consisting of a single fish pond and an oyster tank cannot be used efficiently in an integrated system. This is mainly due both to uncontrollable algal blooms and monospecific dominance of certain algae. On the basis of the results obtained a reassessment of the design of the integrated system is in order which may be critical to the economic feasibility of setting up a commercial farm.

INTRODUCTION

Growing the edible oyster, Crassostrea gigas, in runoff water from earthen fish ponds proved to be an efficient culture system (Hughes-Games, 1977, 1984). Those experiments were carried out at the IOLR (Israel Oceanographic and Limnological Research, National Center of Mariculture) installation at the H. Steinitz Marine Biology Laboratory (MBL). In that system, phytoplankton blooms developed in four 200m³ experimental fish ponds, fertilized by waste products from the fish in the ponds. This phytoplankton rich water was filtered by oysters cultured in 0.6m³ tanks. Under these conditions, oysters reached a commercial weight of 65 to 75 gr in 9 months, and oyster quality, as measured by the internationally recognized standard method (Westly, 1959) was consistently high. Conversion coefficients were improved so that about 12 gr of fixed nitrogen, as phytoplankton, would produce 1 Kg of whole oyster. A fish pond producing 1 Kg fish per year could produce 2 Kg of oysters (wet weight).

On the basis of these findings at the MBL, an experimental system was built at the new National Center of Mariculture facility (IOLR) to study certain problems before construction of a full scale commercial farm. The new experimental system is based on semi-closed water circulation, whereby phytoplankton rich water is recirculated from fish ponds to oyster tanks. In the oyster tanks the algae are partially filtered by the oysters, and the water is then returned to the fish ponds where the uneaten algae serve as a continuous inoculum to the pond.

The new experimental system at IOLR is considerably different from the experimental system at MBL, particularly in the following areas:

1. Unlike the earthen ponds at the MBL, the new fish ponds are PVC-lined, to prevent the build-up of anaerobic conditions and to increase water quality control.

2. The water is now pumped directly from the sea. At the MBL the water was pumped from a well which was subsequently found to be contaminated by the Lab sewage and pond effluent water, thus increasing nutrient levels (Krom, 1986).

3. In the IOLR system, a single fish pond and oyster trough serve as one separate unit. At the MBL, the oyster trough was fed with the combined runoff water from 4 fish ponds.

The original proposed research objectives for the new IOLR system were:

1. To develop a pilot plant with a semi-closed water circulation system to test the scaling-up of the experimental MBL system.
2. To maximize efficiency of phytoplankton conversion into oyster biomass in relation to oxygen consumption.
3. To optimize microalgae concentrations for best water quality and for maximum oyster growth and minimal pseudofeces production.
4. To develop technical solutions for the removal of solid wastes and fouling organisms from the oysters tanks.
5. To develop methods for minimizing oyster handling.
6. To update marketing research.

The new experimental integrated system was first operated in September, 1985. After a few months, however, it became clear that the two systems were too different for the results obtained at the MBL to be compared or utilized at the IOLR. For example, oyster growth rates in the new system were significantly lower when compared to those recorded at the MBL system. Therefore, it was not possible to operate the proposed system

as a whole integrated unit as planned. Further basic research on the new system was required, necessitating modification of the primary objectives, in favour of the following ones:

1. The biotic and abiotic factors affecting the ecological dynamics of the integrated (fish/oysters) ponds.

We wished to monitor water quality in the new integrated system and its effect on oyster biology. Diurnal observations of parameters such as salinity, water temperature, pH, NH₄, dissolved oxygen and microalgae density were measured annually to aid our understanding of the integrated system.

2. Gametogenesis and growth rate of O. edulis and C. gigas in the integrated ponds.

After some months of preliminary observations, it was clear that the oysters' growth rate was slow in comparison to that recorded at the MBL facility. These observations convinced us to study the pattern of the oysters' annual growth rate and condition index in the new system as well as to study gametogenesis to which, apparently, much of the energy uptake was diverted. It was of principal importance to know whether spat production was at all possible in our facility, since independence from having to import stocks each year has its obvious advantages: it eliminates any danger of pathogen introduction as well as being independent of outside sources. The results are valuable indicators of the feasibility of the new system for mariculture.

3. Filtration rate and feeding behavior of C. gigas.

In the integrated system the oysters are used as a biological filter. It was important to study the effects of the oysters' clearance rate, oxygen consumption, biodeposition and NH₄ secretion on the entire system, in order to optimize the integrated system.

MATERIALS AND METHODS

a. The experimental system

The new fish/oyster integrated system consists of 7 fish ponds, each of which is connected to a separate V-shaped oyster tank. Four of the ponds are 175 m³ circular, concave ponds of 1m maximum depth, and three are 100 m³ octagonal ponds with vertical walls and 1m average depth. All ponds are lined with black PVC sheets (PVC A-195, Haogen-plast). The octagonal ponds are connected to 2m tanks.

Unfiltered seawater is pumped to the fish ponds from an inlet located 300 meters offshore at a depth of 20 m. The flow rate to the ponds provides an exchange rate of 50% per day. The water is circulated and aerated by means of two electric aspirators (1/2 HP). Water is pumped from each fish pond into an elevated storage tank and from there flowed by gravity through an oyster tank and then again by gravity back to the fish ponds.

In June 1985, the ponds were stocked with gilt-head sea bream Sparus aurata. The fish were fed locally-produced food pellets containing 40% protein. The oyster tanks were stocked with spat and adult C. gigas and O. edulis grown on plastic mesh trays suspended in the V-shaped tanks. Once a day, 10% of the oyster tank volume was rapidly drained from a valve located at the tank bottom to remove settled particulate debris. Once per week the oysters were washed with fresh water.

b. The biotic and abiotic factors affecting the ecological dynamics of the integrated (fish/oysters) ponds.

Water temperature and dissolved oxygen were measured in situ twice a day at 0500h and at 1500h using a YSI oxygen electrode (model 5739). Salinity, pH and flow rate were checked at 1500h daily. Salinity was measured with a refractometer (models-1) and pH was measured with a pH meter (Hanna HI 8424). Ammonia levels were determined every third day at 1500 by an autoanalyser as previously described (Krom, et al., 1985). Four complete diurnal cycles, sampled at three hour intervals, were measured in two of the octagonal ponds (B1, B2). The first two cycles were sampled on the 28th and 29th of August, 1986, a period of relatively high temperature. The third and fourth cycles were sampled on the 29th December 1986 and 1st January 1987, a period of relatively low temperature.

c. Growth and survival of oysters.

1. Annual growth rate: Growth and survival of the oysters connected to two of the octagonal ponds (B1, B2) were measured weekly. The oyster samples were washed, drained on absorbent paper, counted and weighed. At the end of one year's observations, the oysters were weighed for condition index (CI) using the equation:

$$CI = \text{Dry meat weight (mg)} / \text{Whole oyster weight (gr)} * 100$$

2. Spat growth in the IOLR system was compared to the MBL system and the IOLR nursery. In addition to growth rate experiments carried out in the IOLR integrated system, other experiments were conducted at the MBL earthen pond system and at the indoor spat nursery located at the IOLR. Two sets of experiments of two months duration each were carried out during three spawning seasons (1985, 1986, 1987). The growth rate and the condition

index of thirty C. gigas spat were compared in the three systems. Two systems were composed of four batches of 15 individual spat. Two batches were separately placed in two 600L "V" tanks supplied by the effluent water of two 250 m³ earthen fish ponds located at the MBL. The other two batches were placed into a 2m³ tank which was supplied by effluent water from a 175 m³ fish pond, as part of the integrated fish/oyster system. The oysters in these two systems fed on natural food with constant flow rate (1200 liters/hour). In the third system, two batches of 15 individuals were placed indoors at the IOLR nursery. Two 600 liter rectangular tanks were used, the water circulating in a closed system and flowing by gravity from one tank to the other. The spat were fed once a day with 1.5- 2 10⁵ cells/ml a mixture of Tetraselmis suecica, Isochrysis galbana, and Chaetoceros calcitrans (concentration biomass equal). The oysters at the IOLR systems were placed on trays and in an upwelling methods, based on Bayes' model (1981). Relative growth rates were calculated from whole oysters weight from the equation:

$$K = (\ln W_2 - \ln W_1) / (T_2 - T_1)$$

(W₁= the initial mean weight, W₂= the final mean weight and T₂-T₁= the duration of the experiment in days). The coefficient, K, multiplied by 100 yields percent change per day (Warren, 1971).

3. The effect of spatial positioning of C. gigas in the water column. In order to develop an efficient handling method which will be applicable to commercial operation, a total of 90 adults oysters (20-40 gr) were randomly divided into three groups. Oysters in the first group were joined together and suspended in a polyethylene 10mm mesh bag in the water column (bag treatment). In the second group, individual oysters were placed on a tray made of 10mm mesh (lying treatment). Individuals from the third group were hung from hooks in the water column (hanging treatment). Each of the three treatment groups was placed into a separate 80 liter plastic tank connected by an air-lift/gravity recirculation system to a second 80 liter

tank. Temperature was maintained at 22°C. Over a 30 day period, I. galbana was added daily to provide a concentration of 1×10^5 cells/ml for the first ten days, 2×10^5 for the second ten days and 1×10^6 cells/ml for the final ten days. At the end of the experiment, oysters were weighed, and growth rate determined.

In a similar experiment, run concurrently, two more groups of thirty oysters each were transferred to the effluent trough of the earthen fish ponds at the MBL. The oysters were either laid on trays or suspended from hooks, as described above. The growth rate over a three month period was determined from monthly weighings.

d. Filtration rate and feeding behavior of C. gigas

Four complete diurnal cycles were measured in two octagonal ponds (B1, B2). The first two cycles (48 hrs) were sampled in August, the warmest month in 1986. The second two cycles were measured in December 1986 - January 1987, the coldest months. Water samples and dissolved oxygen levels were taken from the inlet and the outlet of the oyster tanks every three hours. The algae were identified using light microscopy and counted using either a haemocytometer slide or a Model ZB Coulter Counter. Clearance rate was determined using the equation:

$$C.R \text{ (cells/gr/day)} = (INL(\text{cells/ml}) - OUTL(\text{cells/ml})) * V * N / W \text{ (gr)}$$

(C.R-clearance rate; INL- No. of algae in the inlet samples; OUTL-No. of algae in the outlet samples ; V - volume of the oyster tank; N- No. daily water exchanges; W-oyster wet weight)

Feeding (clearing) efficiency was determined using the equation:

$$F.E = (INL - OUTL) / INL * 100.$$

In addition, total particulate matter was collected on pre-ashed (500 °C), washed and weighed Whatman GF/C glass fiber filters. The samples were filtered, washed and dried in an oven at 60°C for 24 hrs. The weight of dried material on the filter was considered the weight of the total particulates. After weighing, the samples with filter paper were ashed at 500 °C for 2 hrs., then cooled and reweighed. The difference before and after ashing was taken to be the organic content of the particulates.

e. Gametogenesis of C. gigas and O. edulis in the integrated (fish/ oysters) ponds

In the oyster tank connected to octagonal fish pond B2, 500 and 275 individuals of O. edulis and C. gigas respectively were stocked to provide a total biomass of 25 Kg for each species. Twenty individuals from each species were randomly sampled monthly. Their gonads were dissected and fixed in Davidson's fixative, processed for paraffin histological examination and stained with hematoxylin-eosin. The developmental stage of both O. edulis and C. gigas was assessed in accordance with Mann's (1979) scheme. In addition, gametogenic development of juvenile oysters (3 to 6 months old, 2-5 gr) was followed from May to August 1987 using the same methods.

RESULTS

a. Biotic and abiotic factors

Water temperature in the oyster tanks fluctuated between 11.2° and 28.7° C with diurnal variation of $4\pm 2^{\circ}$ C in winter and $8\pm 2^{\circ}$ C in the summer (Fig. 1). In August 1986, during the 24 hour sampling period in the oyster tanks (Fig. 2), temperature increased from $24\pm 1^{\circ}$ C at 03:00 - 06:00 to $27\pm 1^{\circ}$ C at 13:00-16:00.

During December 1986, water temperature increased from $14\pm 1^{\circ}$ C at 05:00-07:00 to $16\pm 1^{\circ}$ C at 12:00-13:00 (Fig. 3). In both months at extreme temperatures, similar diurnal temperature trends were observed in the fish ponds and oyster tanks.

From February 1986 to September 1986, the oyster tanks were aerated and the oxygen levels ranged from 5.3 to 10.5 mg/l. From September 1986 to January 1987, oxygen levels of unaerated oyster tanks ranged from 3.9 to 8.9 mg/l (Fig. 4). In August, 1986, during the 48 hour sampling period the dissolved oxygen in the oyster tank increased from 4.9 mg/l at 03:00 h. to 7 mg/l at 14:30 h. (Fig. 5). In December 1986 the unaerated oyster tank oxygen levels ranged from 2.8 mg/l to 8.2 mg/l at 04:00 and 14:00 p.m. respectively (Fig. 6).

Figure 1:

Temperature profile for tank B1. Data from 1.2.86-30.1.87.

Figure 2:

48hours temperature profiles for tank B1. Data from 3.8.86-5.8.86.

Figure 3:

24hours temperature profiles for tank and pond B1. Data from 29.12.86-30.12.86.

Figure 4:

Oxygen profile for tank B1.
Data from Feb. 2nd 1986 to
Jan. 30th 1987.

Figure 5

48h oxygen profiles
for tank and pond B1.
Data from 15:00h on
August 3rd 1986 to
15:00h on August 5th
1986.

Figure 6:

24h oxygen profiles for tank and
pond B1. Data from 12:00h on
December 29th 1986 to 12:00h on
December 30th, 1986.

Ammonia levels fluctuated throughout the year between 2 and 50 mM (Fig. 7). Salinity was constant throughout the year at 41.5 ± 0.5 ppt. pH measured during 1986 ranged between 7.52-8.67 (Fig. 8). The highest pH level in August (8.70) was recorded at 16:00-18:00 h. and the lowest level (7.82) at 06:00-09:00 h. The highest pH level (7.63) in December was recorded at 1200-1300, and the lowest (7.22) at 0100 (Fig 9, 10).

Figure 7:

Ammonia profile for tank B1. Data from February 1st, 1986 to January 30th, 1987.

Figure 8:

pH profile for tank B1.
Data from February 1st 1986
to January 30th, 1987

Figure 9:

48h profile for tank and
pond B1. Data from
15:00 Jan. 3rd 1986 to
August 5th 1986.

Figure 10:

24h profile for tank and pond
B1. Data from 12:00h on Dec.
29th 1986 to 12:00h on Dec.
30th, 1986.

Fish feces and uneaten food, in combination with the strong solar irradiation, enabled production of high concentration of microalgae. Five microalgal blooms occurred in pond B1 during 1986: Tetraselmis sp. in February-March (6×10^5 cells/ml), Chlorella sp. in April-May (1.5×10^6 cells/ml) and again in September-October (1.2×10^6 cells/l), Chaetoceros sp. in June-August (0.5×10^6 cells/ml) and unidentified microalgae from November through January (Fig. 11). Between the blooms, low concentrations (0.01 - 0.5×10^6 cells/ml) of unidentified flagellates and dinoflagellates were observed.

Figure 11

Algae concentration during 1986

There was a positive correlation between algal concentration , pH levels and dissolved oxygen levels and an inverse relationship between the algae concentration and NH levels.

b. Growth and survival

1. Annual growth rate:

After one year's growth (1986-1987) the average weight of C. gigas and O. edulis spawned in May 1986 was 15 ± 8 gr and 13 ± 7 gr respectively, (Fig. 12, 13). Growth rate varied in different months. From July to December the C. gigas showed slow growth rate, which increased in winter and early spring. The condition indices of C. gigas and O. edulis were significantly higher ($p < 0.01$: t-test) during winter 28.5 ± 3.1 and 27.3 ± 5.5 respectively, compared to 16.5 ± 2.8 and 14.2 ± 3.7 during summer. High mortality (30%-40%) was observed during August-September (Fig. 14) and the total annual mortality was 40% of the population.

2. Spat growth in the nursery, earthen ponds and integrated ponds.

Low mortality (2-8%) was observed during the entire course of these experiments (Table 1). The oyster spat reared in the earthen fish pond effluent (at the MBL) grew significantly faster (4.9% per day, $P < 0.01$) than the spat reared in the integrated pond (3.0% per day). In the outdoor systems at the MBL and the IOLR the oysters spat grew significantly faster ($P < 0.01$; ANOVA) than the spat in the indoor nursery (Table 1). No significant growth rate differences were observed between spat in trays and upwelling system. No significant differences were observed in the condition indices among the sites, treatments or years.

Figure 12:

Growth rate of *C. gigas* using trays method. Data from July 2nd 1986 to Sept. 2nd 1987.

Figure 13:

Growth rate of *O. edulis* using trays method. Data from July 22nd 1986 to September 2nd. 1987.

Figure 14:

C. gigas mortality during 1986-87.

table 1

Growth rate, survival and condition indices in the nursery, integrated system and earthe ponds using upwelling and trays methods.

Date	Location		Initial Weight()	Final Weight(gr)	Growth Rate (% per day)	Condition Indices	Mortality (%)
1985	MBL	Trays	0.218±0.13	4.27±0.15	4.9	-----	-----
1986	Nursery	Upwelling	0.210±0.11	1.315±0.65	3	31.81±11.11	2
		Trays	0.229±0.07	1.218±0.79	2.8	35.59± 7.31	6
	Integrated system	Upwelling	0.210±0.09	1.95± 0.16	3.7	31.12± 2.75	8
		Trays	0.431±0.23	2.61± 1.1	3	32.01±12.30	6
1987	Nursery	Upwelling	0.16±0.08	0.98± 0.37	3	35.00±12.1	3
		Trays	0.14±0.05	0.85± 0.23	3	34.00±8.35	3
	Integrated system	Upwelling	0.15±0.07	1.81± 0.12	4.1	39.35±7.38	6
		Trays	0.143±0.09	1.74± 0.13	4.1	40.50±6.31	4

3. Effect of spatial positioning of C. gigas in the water column.

The average weight gain per oyster was 0.19%, 0.23% and 0.15% per day at algal concentration of 1×10^5 , 2×10^5 and 1×10^6 cells/ml respectively for the "hanging treatment". For the "lying treatment" the respective average gain per oyster per day was 0.19%, 0.18% and 0.08%. There was little to no growth of the oysters in the bag treatment at any algal concentration. In oysters grown in the fish pond effluent, the average percent weight gain was 0.27% and 0.21% per day for the "hanging" and the "lying" treatments respectively, at a mixed algal concentration of 60000 ± 20000 cells/ml (Table 2).

Table 2

Growth rate of the oysters in different positions.

Algae density (cells/ml)	Treatment	Growth rate per day
100,000	Hanging	0.19%
	Lying	0.19%
200,000	Hanging	0.23%
	Lying	0.18%
1×10^6	Hanging	0.15%
	Lying	0.08%
Fish ponds (M.BL) ($60,000 \pm 1000$ cells/ml mixed algae)	Hanging	0.27%
	Lying	0.21%

c. Clearance rate and feeding behavior of C. gigas .

Clearance rates and feeding efficiency were found to be inversely correlated to algal concentrations (Fig. 15, 16). At high algal densities (3.52×10^5 cells/ml) clearance rates and feeding efficiencies were highly variable. Maximum clearance rates were higher in high algal densities than in low algal densities (5.27×10^4), but feeding efficiencies were comparatively lower (13% and 40% respectively). In addition, differences were determined in clearance rate, oxygen consumption and ammonia excretion between adult and juvenile oysters and between both populations in winter and summer (Table 3). In December (average water temperature: 16°C) the clearance rate for both, juvenile and adult oysters was approximately 25% of the clearance rates in August. In both winter and summer, although the clearance rate of spat was higher than adults, oxygen consumption and ammonia excretion was higher for the adults. Biodeposition was positively correlated with algal concentration, ranging between 45 gr per Kg oyster per day in relatively low algal concentration and up to 125 gr per kg oyster per day in relatively high algal concentrations.

Figure 15: Clearance rate (inlet-outlet) of *C. gigas* over 48hrs observation. Data from 3.8.86-5.8.86.
(B1 - 3.52×10^5 cells/ml; B2 - 5.27×10^4 cells/ml)

Figure 16: Clearance efficiency of *C. gigas* over 48hrs. Data from 3.8.86-5.8.86.

Table 3

Summary of results of clearance rate and feeding behavior in Crassostrea gigas oyster and spat during August and December 1986.

The results shown represent a 48h average of 16 readings taken at 3h intervals.

	August		December	
	B1(spat)	B2(adult)	B1(spat)	B2(adult)
Biomass(kg)	15	15	7	32
$\bar{w}$ (gr)	0.275 ± 0.15	30.1 ± 15.3	1.00 ± 0.71	$35. \pm 17.2$
No. of oyster	54545	500	7000	950
No. of algae (cells/ml)				
inlet	$3.52 \cdot 10^5$	$5.27 \cdot 10^4$	$5.88 \cdot 10^5$	$6.52 \cdot 10^5$
outlet	$3.10 \cdot 10^5$	$3.21 \cdot 10^4$	$5.34 \cdot 10^5$	$6.49 \cdot 10^5$
Clearance rate (cells/day gr)	$9.38 \cdot 10^7$	$5.06 \cdot 10^7$	$2.9 \cdot 10^7$	$1.15 \cdot 10^7$
Efficiency	13%	40%	9.15%	6.13%
Oxygen consumption (g/day gr oyster)	$1.7 \cdot 10^{-4}$	$6. \cdot 10^{-4}$	$5.16 \cdot 10^{-4}$	$9. \cdot 10^{-4}$
Biodeposition (g/kg oyster day)	75	45	80	125
Ammonia secretion (Mm/kg oyster day)	1.38	5.01	1.13	3.05

d. Gametogenesis of O. edulis and C. gigas in the integrated system.

Gametogenesis in O. edulis commenced in November (30% active oysters) when the water temperature ranged from 18 to 24 °C (Table 4, Fig.1, 17). The development continued uninterrupted through December to January when water temperature fell to $14 \pm 2^\circ$ C. Spawning commenced in February, increased to its highest peak in April, when water temperature

ranged from 16° to 22°C (60% ripe oysters), stabilized in May (20% ripe oyster) and sharply declined in June-July. Gametogenesis of C. gigas began in February-March when water temperature ranged from 12° to 23°C (40-60 % active oysters). Spawning commenced in May when water temperature was 22° to 28° C. and 40% of the oysters were ripe (10% spent), increased to peak in June-July when 70-80% were ripe (20% spent), and sharply declined in August, and by September 90% of the oysters were spent (Table 4, Fig. 18). A sexual asynchrony in gametogenic development was observed in each of the two species, with the males becoming ripe earlier than the females. Three to four month old juveniles of both species showed an initial gonadal development in May-June, with both male and female ripening in June-August. In the fish-oyster pond system, the oyster larvae survived only 3-4 days; new spat were never observed.

Table 4: Gonadal development of C. gigas and O. edulis

Month	<u>C. gigas</u>								<u>O. edulis</u>							
	% of ripe oyster		inactive		active		ripe		spent		% of ripe oyster		inactive		active	
	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
January	--	--	12	6	--	2	--	--	--	--	--	10%	6	4	3	5
February	--	--	14	--	--	6	--	--	--	--	10%	20%	6	--	4	4
March	--	20%	6	--	6	4	--	4	--	--	10%	30%	1	--	5	2
April	10%	20%	--	--	6	8	2	4	--	--	20%	40%	--	--	3	1
May	10%	30%	2	--	--	8	2	6	--	2	30%	20%	--	--	--	--
June	20%	50%	--	--	2	--	4	10	2	2	10%	10%	--	--	3	3
July	30%	30%	--	--	--	--	6	10	--	4	10%	10%	--	--	3	1
August	10%	10%	2	2	--	--	2	2	4	12	--	10%	2	2	--	4
September	10%	10%	--	--	--	--	2	2	8	8	--	--	3	4	2	3
October	10%	10%	4	4	--	--	2	2	4	4	--	--	8	2	3	3
November	--	10%	2	2	--	--	--	2	10	4	--	--	6	8	2	4
December	--	--	6	14	--	--	--	--	--	--	--	--	7	8	1	3

Table 4, fig 17, 18

Figure 17:
Breeding cycle of
O. edulis during
1986-87.

Figure 18: Breeding cycle of *C. gigas* during 1986-87.

DISCUSSION

After two years of observations of the dynamics of the fish/oyster polyculture system, it is clear that oysters can be adequately integrated into such a scheme. Although some gonadal development did occur and showed marginal growth, the main goals for which the integrated system was designed, for both intensive oyster growth and efficient biological filtration, have not been achieved.

a) Growth rate

In the earthen ponds in the MBL system (Fig. 19) and in the IOLR PVC-lined system, the oysters showed extreme seasonal fluctuations in both growth rate and gametogenesis. In both systems, pic values were recorded during winter and spring (December-June), and both were arrested during summer (August-October). In contrast, growth rates and gametogenesis observed in Europe and the U.S.A. occurred during summer and are minimal during winter.

Figure 19:

The slow growth rates during the winter are attributable to the relatively low temperature and scarcity of food (Malouf & Breese, 1978). In Eilat, there was sufficient microalgae during the summer, therefore the poor oyster development may be due to relatively high water temperature (26-28 C) and/or low quality of microalgae. Although at the MBL and the IOLR the annual pattern of fluctuations in growth was similar, oysters at the MBL grew significantly faster than those at the IOLR. At the MBL the oysters reached commercial size in one year (60-80 gr and 30-50 gr per year for C.gigas and O. edulis, respectively). During a similar period at the IOLR C. gigas reached to 14-18 gr and O. edulis reached to 12-16 gr. These significant differences in growth rate could be critical for the economic feasibility of setting up a commercial farm.

Several hypotheses may explain the faster growth rate in the MBL system:

1. The MBL system utilized earthen ponds, whereas the IOLR fish ponds are PVC-lined. As a result the water in the MBL system is rich with suspended sediments (Motzkin et al., 1982; Krom, 1986). It is well known that suspended sediment in the medium increases the oysters' growth rate by increasing the digestion efficiency and/or decreasing the loss of excreted material (Ewart, 1985; Urban, 1988). In addition, the water quality in the earthen ponds was affected by the anaerobic processes and rich microfauna compared to the relatively "sterile" system in the PVC-lined ponds.
2. At the MBL, oysters were fed with the runoff water from 4 fish ponds, always resulting in a mixture of algal species. At the IOLR, each fish pond and oyster tank served as one separate unit, with oyster being fed with a runoff from a single fish pond. This resulted in a monospecific algal diet which at certain times of the year was perhaps of poor nutritional value for the oysters or certain species of algae could not be digested due to the oysters' inability to break down the algal cell wall.

It is well known that oysters grow faster when fed on a mixed algal diet (Helm, 1977; Walne, 1970).

3. Juvenile oysters growing at the IOLR developed gonads at the age of 3-4 months; gonadal development greatly reduces growth rate. There are no data recording the commencement of gonad development in the oysters at the MBL.

b) Biological filtration

The results demonstrate that, in general, oysters can be used as a biological filter. However, a unit consisting of a single fish pond and an oyster tank with a constant oyster biomass is not adequately efficient for several reasons:

1) The phenomenon of algal crashes in the integrated system can be attributed to predation, competition, nutrient limitation, treatment with pesticide against fish parasites and water exchange. Observations during the past two years indicate that the algae blooms are unpredictable and not subject to control. A constant biomass of oysters in one pond with unpredictable blooms and crashes may lead to inefficient biological filtration. To compensate for periods of bloom or crash, oysters would have to be moved into and out of the affected pond systems. This is too labor intensive to be economical.

2) For a given biomass of oysters clearance rates vary widely between adults and juveniles, summer and winter and different hours during the day. In order to compensate for these fluctuations, either oysters will have to be moved or the flow rate from the ponds will have to be regulated. Neither of these alternatives is acceptable.

3) Algae blooms in the fish ponds are always monospecific. Some algae

species are indigestible, thus causing low filtration efficiency when they are blooming. Therefore a fish pond experiencing an algal bloom will not be adequately filtered.

The results demand a reassessment of the design of the integrated system at the IOLR to more closely reflect the positive attributes of the MBL system. The following is the outline of a scheme which incorporates the results of this study with the results from the MBL system (Hughes-Games, 1977, 1984) and includes features based on hypothetical solutions to problems which were discussed above.

To minimize fluctuations due to variations in algal density and species composition, effluent from several fish ponds will be collected in a central pond as was done at the MBL. This central pond will be earthen rather than PVC-lined. In addition, the variety of algal species contributed to this central pond will presumably provide a more balanced diet to the oysters. From the central pond the water will be pumped through V-shaped tanks containing the oysters in suspended trays. In the tanks the oysters will act as a biological filter. Water temperatures and algal density will be controlled by diluting the fish pond effluent with fresh sea water at the inlet of the oyster tanks. If the water in the tank has been sufficiently cleared it will be pumped back to the fish culture ponds, otherwise it will be recirculated back into the central pond. A preliminary prototype of this system is currently being investigated.

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RECOMMENDATIONS

From the above results, it follows that various modifications of the system should be considered. It is recommended, therefore, that:

1. In order to modify the existing system of a single fish pond and oyster tank that serve as one separate unit, it will be necessary to build a complex which includes an earthen pond which will serve as a reservoir to receive the runoff water from all the fish ponds. This pond will contain a variety of microalgae species and will serve as a buffer against blooms and crashes occurring in the individual ponds and will lead to a balanced diet for the oysters.
2. In the summer months when water temperature reaches 26 C and during the time of algae blooms when pH levels are more than 8.6, it will be necessary to increase the dilution of the fish pond effluent with additional fresh seawater as it enters the oyster tanks. This will consequently reduce the water temperature and pH levels.
3. Spat production in the hatchery should be concentrated during July-September, so that spat reared during August - November will be ready to stock in the outdoor system in November, when the growth rate is optimal. Oyster spat should be transferred to the grow-out system at a weight of 0.2gr.
4. Tray and upwelling systems are recommended for rearing spat. Tray culture, rather than bag or hanging methods, is recommended for adults. Although hanging oysters often show a faster growth rate, the extra labor invested in the initial hanging of the oysters needs to be evaluated.
5. The difference in growth rate between IOLR and MBL system should be

analyzed relative to the following criteria: The importance of suspended sediment, mixed algae, dissolved organic matter in the medium and early mature oyster.

DESCRIPTION OF COOPERATION

Discussions and consultations were held at the Virginia Institute of Marine Science between the principal investigator and the cooperative investigator, Prof. M. Castagna, after two years' research effort.

Meetings were held between experts in the field at their respective facilities. In Hatfield Marine Science Center, Oregon State University - with Prof. C. Langdon. In the School of Fisheries, University of Washington - with Prof. K. Chew and in the University of Maryland, Dept. of Zoology - with Prof. D. Bonar.