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EXPERIMENTAL SHELLFISH CULTURE ON AN ARTIFICIAL REEF IN THE ADRIATIC SEA

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EXPERIMENTAL SHELLFISH CULTURE ON AN ARTIFICIAL REEF IN THE ADRIATIC SEA

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ABSTRACT

Experiments were carried out on an artificial reef located in the central Adriatic Sea (Conero Promontory) to show the feasibility of using the submerged structures to culture mussels (*Mytilus galloprovincialis* Lamk) and oysters (*Ostrea edulis* L. and *Crassostrea gigas* Thunberg) in open sea areas not suitable for traditional Italian shellfish farming. Nylon ropes were found to be best to collect mussel seed and these collectors showed that mussel settlement extended from early winter until late summer. Highest settlement intensity was observed in late spring–early summer and from the first 5 m under the sea surface. Growth, survival and production of mussels were investigated from three experimental sets. A seasonal Von Bertalanffy length-growth equation was computed for this species under farming conditions. The minimum commercial size (TL = 50 mm) was attained by 50% of mussels after 5 months of growth. After 12 months the total production was about 7 kg of mussels per 1 kg of seed. Special plastic collectors were used to study settlement and to obtain oyster seed for subsequent farming. Oysters showed a short period of settlement, extending from late summer until early autumn. The collectors recovered in September contained the highest density of seed. Growth, survival and production of *O. edulis* and *C. gigas* were estimated for 1 year. For each oyster species, a seasonal Von Bertalanffy growth curve was fitted on size-class data. *O. edulis* showed slower growth than *C. gigas*, in fact they were marketable (TL > 60 mm) after 10 and 8 months of farming respectively, with a production of about 4 kg and 7 kg per collector after 11 months. During the experiment periods a reduction of growth rate, more pronounced for oysters than for mussels, was observed in the winter months.

The first artificial reef in the Adriatic Sea was built in 1974, southeast of the Conero Promontory, by the Istituto di Richerche sulla Pesca Marittima (I.R.Pe.M.). It was designed and established to protect the coastal area against illegal trawling activities, to provide shelter for spawners and juvenile forms, and to supply bivalve larvae (mussels and oysters) with new substrate for settlement (Bombace, 1981).

In the following years investigations were conducted to determine (a) the practicality of this type of artificial reef for suspended mussel and oyster farming; (b) whether the productivity of the reef increased; and (c) the potential for the culture of bivalves in open seas not suitable for traditional farming methods. With these aims the artificial reef at Fregene, central Tyrrhenian (Ardizzone and Bombace, 1983) and, later, the small experimental reef at Portonovo, central Adriatic (Fabi et al., 1985), were developed. In this paper the results of experimental shellfish farming on the Portonovo artificial reef since 1983 are described.

Materials and Methods

Portonovo is a small bay (about 2,200 m in length and 10 m maximum depth), with rocky shores and sandy bottom, where mussels (*Mytilus galloprovincialis* Lamk.) and oysters (*Ostrea edulis* L. and *Crassostrea gigas* Thunberg) grow abundantly on natural banks. Mussels, which represent the main biomass, decrease in number from the tidal level to the bottom. They are gradually replaced by oysters at depths of 6 m. The annual range of water temperature is 4–27°C, without significant differences from the surface to the bottom (Artegiani and Morbidoni, personal communication).

The experimental reef is situated about 0.5 mile offshore at a depth of about 10 m, on a sandy bottom, and it represents a "standard model" from which other larger reefs are to be built. It consists of four pyramids, each of five specially designed concrete blocks (2·2·2 m), placed at the corners of a square, about 20–25 m from each other. The top blocks of the pyramids are connected by steel wires from which cylindrical nylon nets, full of mussel seed, and baskets of oysters are suspended (Fig. 1).

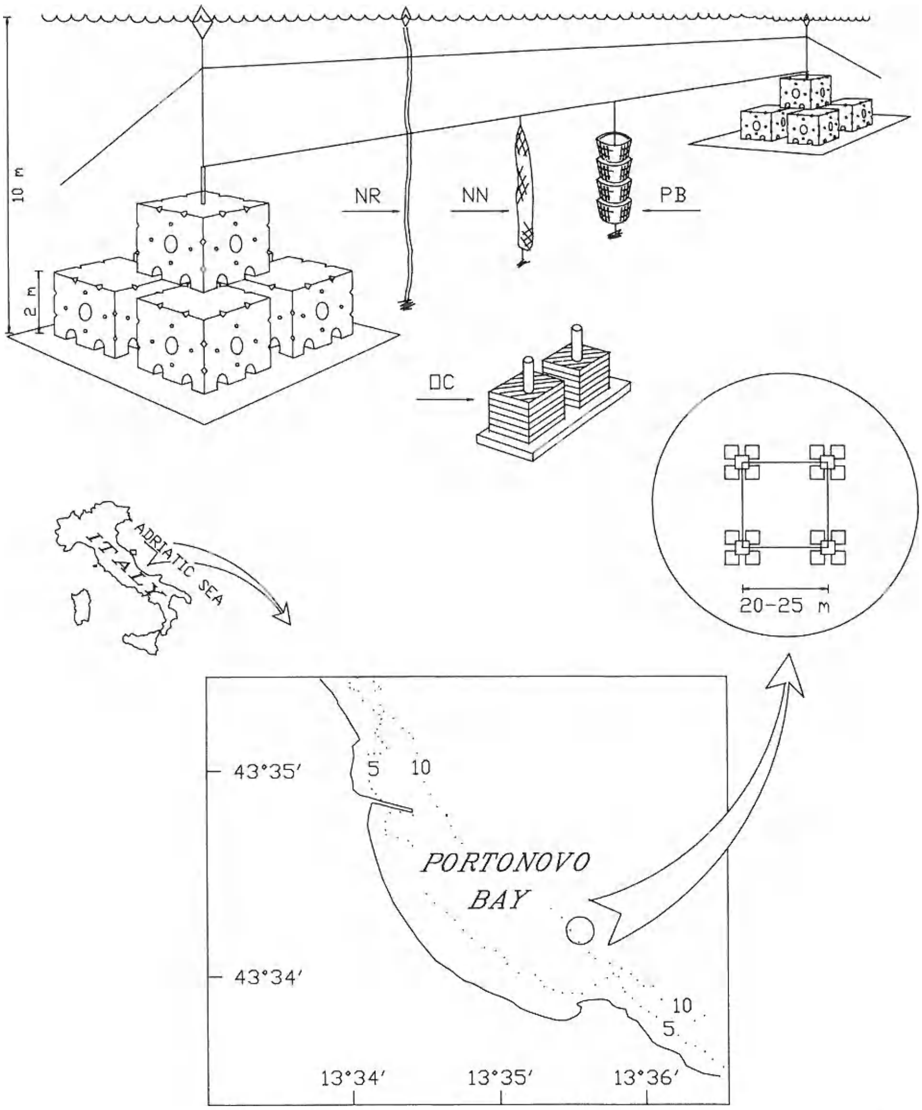

Figure 1. Location of the artificial reef of Portonovo off the east coast of Italy in the central Adriatic Sea. Artificial reef shown with four groups of concrete modules arranged in squares (20–25 m on sides). Perspective view of two concrete modules with nylon rope (NR), nylon net (NN), oyster collectors (OC) and plastic baskets (PB) used for mussel and oyster culture.

In April 1983, ropes of three different materials (nylon, plastic and manilla) were tested as mussel seed collectors. Nylon proved to be the best material for this purpose, because high densities of young mussels were observed on it and it did not rot (Fabi et al., 1985). From May to September 1984 and from June 1986 to September 1987, time and depth of mussel settlement were investigated monthly by suspending nylon ropes (⌀28 mm) from the sea surface to the bottom. Ropes were examined 2 months after immersion, by sampling 10 cm per meter. All the young mussels were measured to the millimeter below.[1]

[1] "To measure the millimeter below" is the usual way to indicate the type of approximation used by us for measurements. It means for example, all the specimens of length between 3 mm and 3.9 mm are considered as if they are 3 mm long.

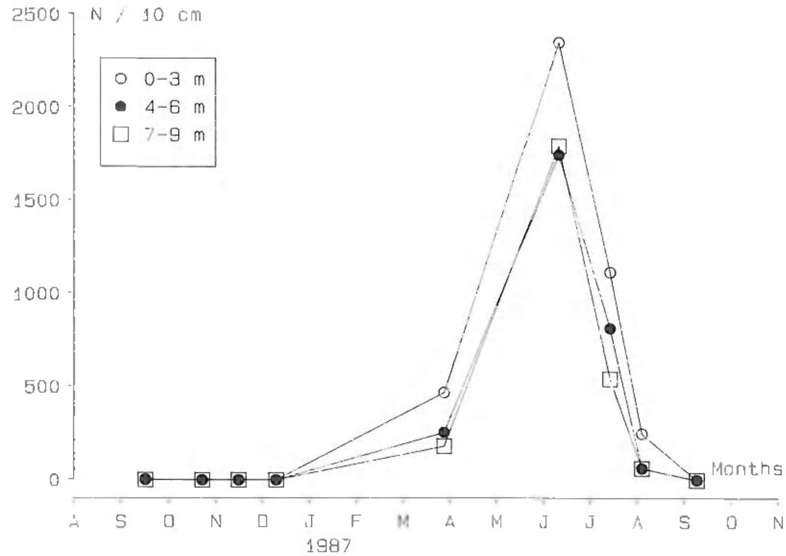

Figure 2. Density of mussels (number per 10 cm of rope, ⌀ 28 mm) settled on nylon ropes at three different depth ranges. Points refer to the dates of collector recovery.

Experimental mussel farming commenced in April 1983, when nylon ropes were immersed to obtain mussel seed. This was harvested in November of the same year and transferred into cylindrical nylon nets (44 mm mesh size). These nets were then suspended from the steel wires between pyramids, about 2–3 m from the bottom. During the first culture experiment only one "set" was immersed. Growth was followed from April 1983 until May 1985. These mussels were thinned out and transferred into cylindrical nylon nets with a larger mesh (68 mm) only once, in spring 1984. During the second culture experiment two mussel sets were followed (from May 1984 until January 1986) to test the influence of the number of thinning operations on mussel growth (Fabi et al., 1986). For each experiment, mussel samples were taken monthly and all the live mussels were weighed (TW: Total Weight) and measured to the millimeter below[1] (TL: Total Length). The size frequency distributions were analyzed by the NORMSEP Program (Abramson, 1971), to separate the "farmed" mussel population from the subsequent new settlements of seed. Thus all the reported values of mussel length and weight refer to growth of the farmed population. A seasonal Von Bertalanffy length-growth equation (Gaschutz et al., 1980) was computed for each culture.

In July 1986 experimental oyster culture was started with the immersion of special plastic collectors of the "Pleno multituiles" type (60·60·8 cm) each having a collecting surface of 1.4 m^2. They were fixed about 60 cm from the bottom, on two iron structures placed at the center of the reef. To study oyster growth under farming conditions, size frequency distributions and numbers of oyster seed settled on the collectors were recorded in September, October and November 1986. In November 1986 oyster seed was harvested from nine collectors and transferred into 66 plastic baskets (⌀30 cm) with 10 mm square-holes, which were suspended from the steel wires between the pyramids; 35 young oysters were put into each basket. From November 1986 until October 1987 several baskets were recovered about every 2 months: the total length, width, thickness and total fresh weight were measured for all the live specimens of *O. edulis* and *C. gigas*. In June 1987 it was necessary to change the immersed baskets because their square openings were obstructed by silt and young mussels. At the same time the number of oysters per basket was reduced to 23 specimens. The same operation was repeated in September 1987, when only 17 oysters were put into each basket. Finally, to investigate the time of settlement for the two farmed species, 10 oyster seed collectors were immersed monthly from May until October 1987 and recovered at 2 month intervals.

Results

Mussel Settlement.—The average density of mussel seed found on nylon rope collectors at three different depth ranges (0–3, 4–6 and 7–9 m) from August 1986

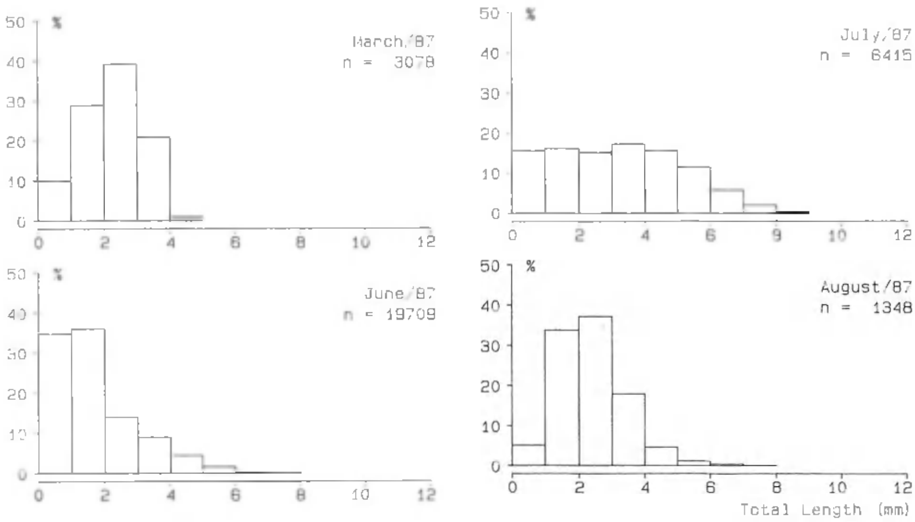

Figure 3. Length-frequency distributions of mussel seed settled on nylon ropes (mussel number refers to 10 cm of rope).

until September 1987, is shown in Figure 2. The main settlement season extended from April to July. The highest density of seed was recorded on the collectors immersed in April and recoverd in June, with a maximum of 2,833 specimens (per 10 cm of rope) at 1 m under the sea-surface and a minimum of 1,190 specimens at a depth of 9 m. No seed was observed on the collectors recovered in October, November and December 1986. On the collectors recovered in March 1986, after 3 months at sea, the seed was characterized by a higher abundance of individuals in the size range 1–4 mm, than in the size range <1 mm (Fig. 3), thus suggesting the existence of an early settlement of low intensity in winter months. These results are in agreement with the monthly Condition Index values estimated for mussels cultivated in the same area from December 1984 until Janury 1986 (Fabi et al., 1986) which showed that spawning started in early winter through late spring. Similar data were reported by several authors for the Adriatic (Poggiani, 1968; Hrs-Brenko, 1980; Valli, 1980; Ceccherelli and Barboni, 1983).

Table 1. Cumulative percentages of mussels settled on nylon ropes at different depths

Month	3/87	6/87	7/84	7/87	8/84	8/86	8/87
Depth (m)							
1	18.0	16.0	13.5	17.0	31.9	25.0	30.3
2	42.2	27.9	28.7	33.8	51.8	46.5	47.4
3	52.1	40.3	39.6	46.4	64.0	59.3	58.2
4	60.6	55.1	49.9	57.9	72.3	69.2	66.9
5	68.5	62.2	62.0	70.5	80.9	78.5	73.2
6	80.1	69.8	73.2	78.6	87.9	86.0	79.1
7	85.9	84.5	82.6	89.4	94.2	90.7	88.0
8	94.0	93.3	89.7	94.4	96.7	96.5	95.6
9	100.0	100.0	100.0	100.0	100.0	100.0	100.0

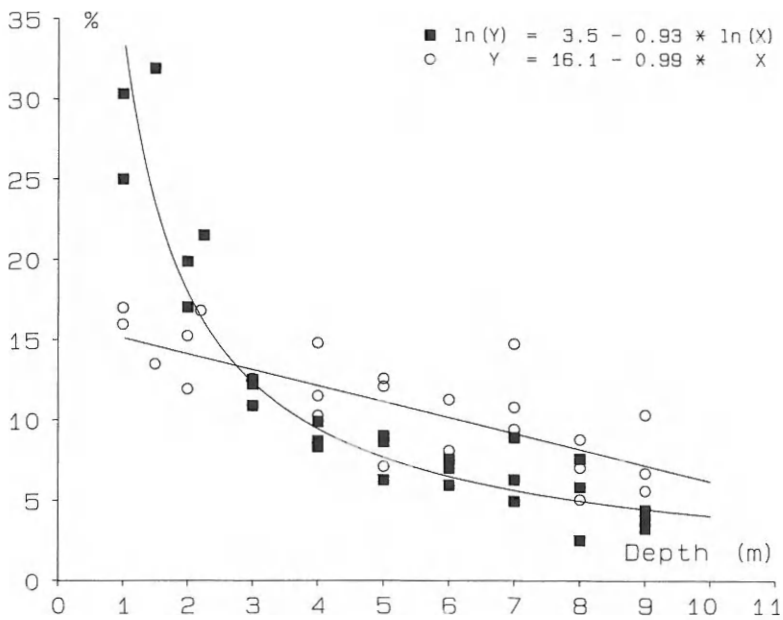

Figure 4. Percentages of mussels settled at different depths in high density months (circle) and low density months (square).

Our investigations also showed that mussel density generally decreased with depth and over 60% of specimens were always found in the first 5 m below sea level (Table 1). The regression analysis, applied to the percentages of the mussels settled on the collectors against depth, showed that, at time of maximum settlement (June–July), the density decreased gradually and a linear regression has proved to be the best function to fit the experimental data (Fig. 4). On the contrary, during the months of low settlement (for example August), the density of seed decreased with an exponential trend at depths of 2 or 3 m from the sea surface.

Mussel Growth.—Our previous investigations have shown that mussel growth was only slightly influenced by the different frequencies of thinning (Fabi et al., 1986), so that data from the two sets of the second culture experiment were pooled together. Figure 5A shows the seasonal Von Bertalanffy length growth curves for the two culture experiments. For the first culture experiment (April 1983–May 1985) the growth coefficients were: $L\infty$ (mm) = 86.66, K = 1.10, t_o = 0.40, C = 0.48 and t_s = 0.54. Values for the second culture experiment (May 1984–January 1986) were: $L\infty$ (mm) = 84.46, K = 1.30, t_o = 0.49, C = 0.50 and t_s = 0.52.

Growth rate as well as temperature showed a similar trend in the two investigated periods (Fig. 5): a comparable reduction in growth in length was observed during winter months as shown by the two coefficient values C and ts. A corresponding slackening was also observed in growth in weight.

Twelve months after transferring the seed from collectors into the cylindrical nylon nets, the shell length of the farmed population increased from 37 ± 3 mm (TL ± SD) to 71 ± 6 mm in the first culture (November 1983–November 1984), and from 42 ± 3 mm to 70 ± 6 mm in the second (November 1984–November 1985) for an average monthly increase of about 3 mm.

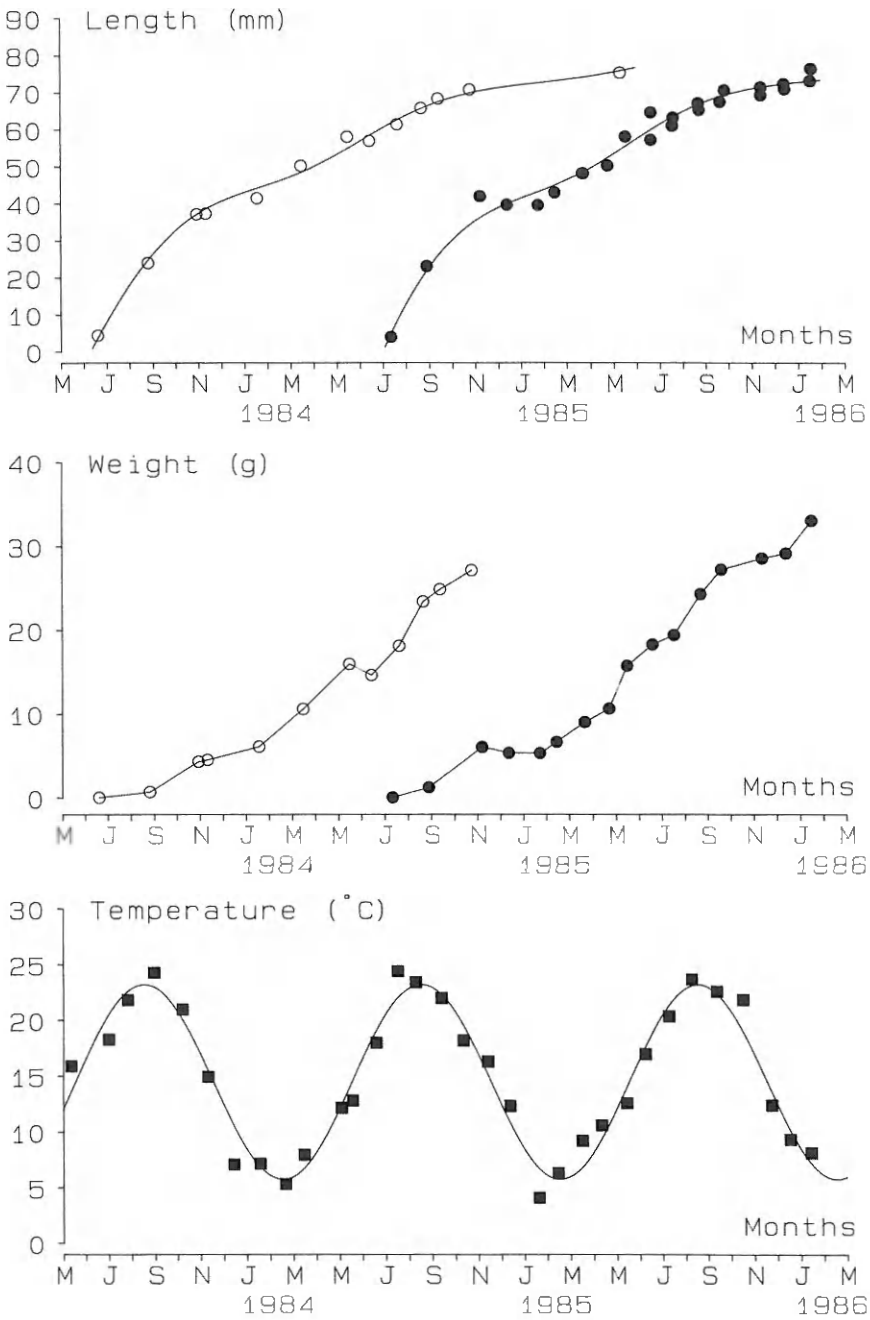

Figure 5. (A) Seasonal Von Bertalanffy length growth curves for mussels of the 1st culture experiment (empty circle) and of the 2nd culture experiment (solid circle). (B) Monthly average total weight. (C) Temperature trend on the bottom (Artegiani and Morbidoni, unpublished data).

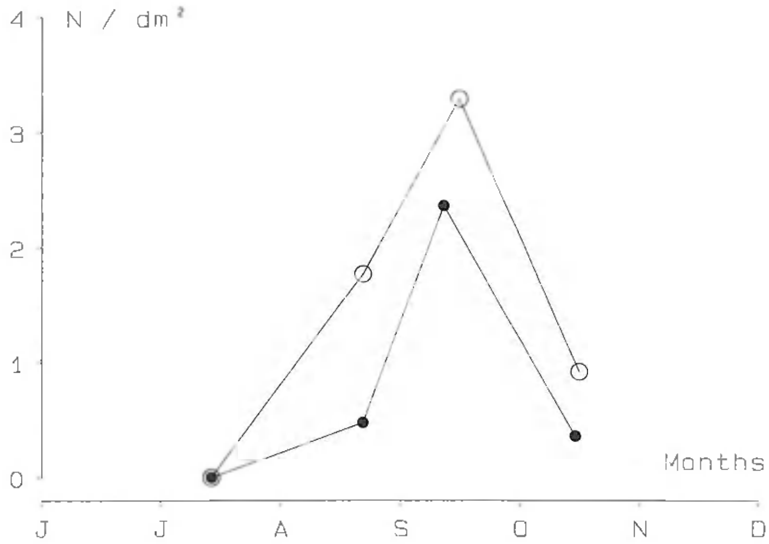

Figure 6. Density (number of specimens per dm^2) of *O. edulis* (empty circle) and *C. gigas* (solid circle) settled on the collectors. Points refer to the dates of collector recovery.

Mussel Mortality and Production.—Large differences in survival rate (ratio of the number of mussels recovered each month to the initial average number used) were observed through the experimental periods. But average losses were 25%. These survival fluctuations seemed independent from the immersion time. After 5 months of farming the total production was about 4 kg of which commercial specimens were 2.4 kg. After 12 months a total production of about 7 kg was obtained. No significant production increase was obtained from each culture after the second winter of farming, because of slackened winter growth and spawning.

Oyster Settlement.—For both species a short period of recruitment was recorded from July to October 1987, with the highest number of specimens from the collectors immersed in July and recovered in September of the same year (Fig. 6). In 1987 spat of *O. edulis* outnumbered *C. gigas* in all samples (Table 2), whereas the abundance of the two species was practically the same on the collectors immersed in 1986. For both species there was less settlement in 1986 than in 1987. But the two species reached a greater average length in 1986 than in 1987. Large differences of settlement density over the years have also been reported for *O. edulis* in the Gulf of Lion (west Mediterranean Sea) and along the French Atlantic coasts (Paquotte and Moriceau, 1986).

The influence of the position of collectors on oyster settlement was shown, both in 1986 and 1987, by the higher number of specimens that settled on the more external collectors (1st–2nd and 9th–10th) of each pile rather than the central ones. This trend might be partially explained by the reduced water circulation among the central collectors. More oysters settled on the lower than on the upper surfaces of the collectors. The material of collectors was highly selective. In fact, among bivalves, only oysters and some specimens of the Anomidae family had settled on them; mussel settlement was very rare.

Oyster Growth.—Oysters have an irregular shell with high variability in length, width and thickness. Analysis of the measurement data, taken on our samples, proved shell length to be a good parameter to follow to determine the growth of

Table 2. Density (number of oysters per dm^2), percentages of abundance and average TL of *O. edulis* (O) and *C. gigas* (C) settled on the collectors in different months

	Month							
	9/86		8/87		9/87		10/87	
Species	O	C	O	C	O	C	O	C
Coll.								
1°	2.49	2.19	—	—	—	—	—	—
2°	0.91	1.22	2.03	0.66	4.00	2.54	0.78	0.16
5°	0.76	0.96	1.70	0.38	2.91	2.19	0.76	0.18
6°	0.68	1.00	—	—	—	—	—	—
9°	1.08	1.09	1.59	0.39	2.96	2.36	1.23	0.76
10°	1.59	2.04	—	—	—	—	—	—
%	47	53	79	21	58	42	72	28
TL (mm)	18.00	18.47	10.04	9.57	9.28	8.45	10.44	9.86

both species. Therefore the average lengths derived from the monthly size-frequency distributions of *O. edulis* and *C. gigas*, obtained in the period June 1986–October 1987, were used to compute the parameters of the seasonal Von Bertalanffy growth equation for each species. Growth values for *O. edulis* were: $L\infty$ (mm) = 76.85, K = 1.53, t_o = 0.68, C = 1.02 and t_s = 0.55. For *C. gigas* they were: $L\infty$ (mm) = 86.00, K = 1.63, t_o = 0.72, C = 1.13 and t_s = 0.56.

After 2 months of growth on the collectors, the two species did not present any important difference, but, in the subsequent months, *C. gigas* showed a faster growth rate (Fig. 7). In 11 months of growth in the suspended baskets, *O. edulis* grew from an average length of 31 ± 9 mm (November 1986) to 67 ± 8 mm (October 1987). During the same time *C. gigas* grew from 34 ± 11 mm to 75 ± 7 mm.

Both species showed an identical remarkable reduction in growth in length and weight during winter months. This fact was reflected in the C coefficients of the Von Bertalanffy length growth equations which reached very high values (≥ 1), much higher than in mussels.

Oyster Mortality and Production.—In November 1986, after 4 months of growing on collectors, a mortality of 12% was estimated for *O. edulis* and *C. gigas*. A further 20% was lost because of manipulation during the transfer from collectors to farming baskets, so that a total average number of 257 specimens for the two species was obtained per collector.

After 7 months of suspended growth (November 1986–June 1987) an average mortality of 3% was estimated for the whole period. As this mortality was observed in all the recovered baskets, it might be due to any possible damage suffered by specimens during the transferring operation. An additional mortality (up to 6%) was observed during summer months, probably due to a reduction of water flow within the baskets because of fouling and siltation. No differences of mortality have been evidenced between *O. edulis* and *C. angulata*. Production from oyster farming excluding these mortality values was estimated as 4 kg of *O. edulis* and 7 kg of *C. gigas* per collector for 11 months of growth.

Conclusions

The experiments carried out on the Portonovo artificial reef showed that settlement of mussel seed occurred from early winter until late summer, reaching

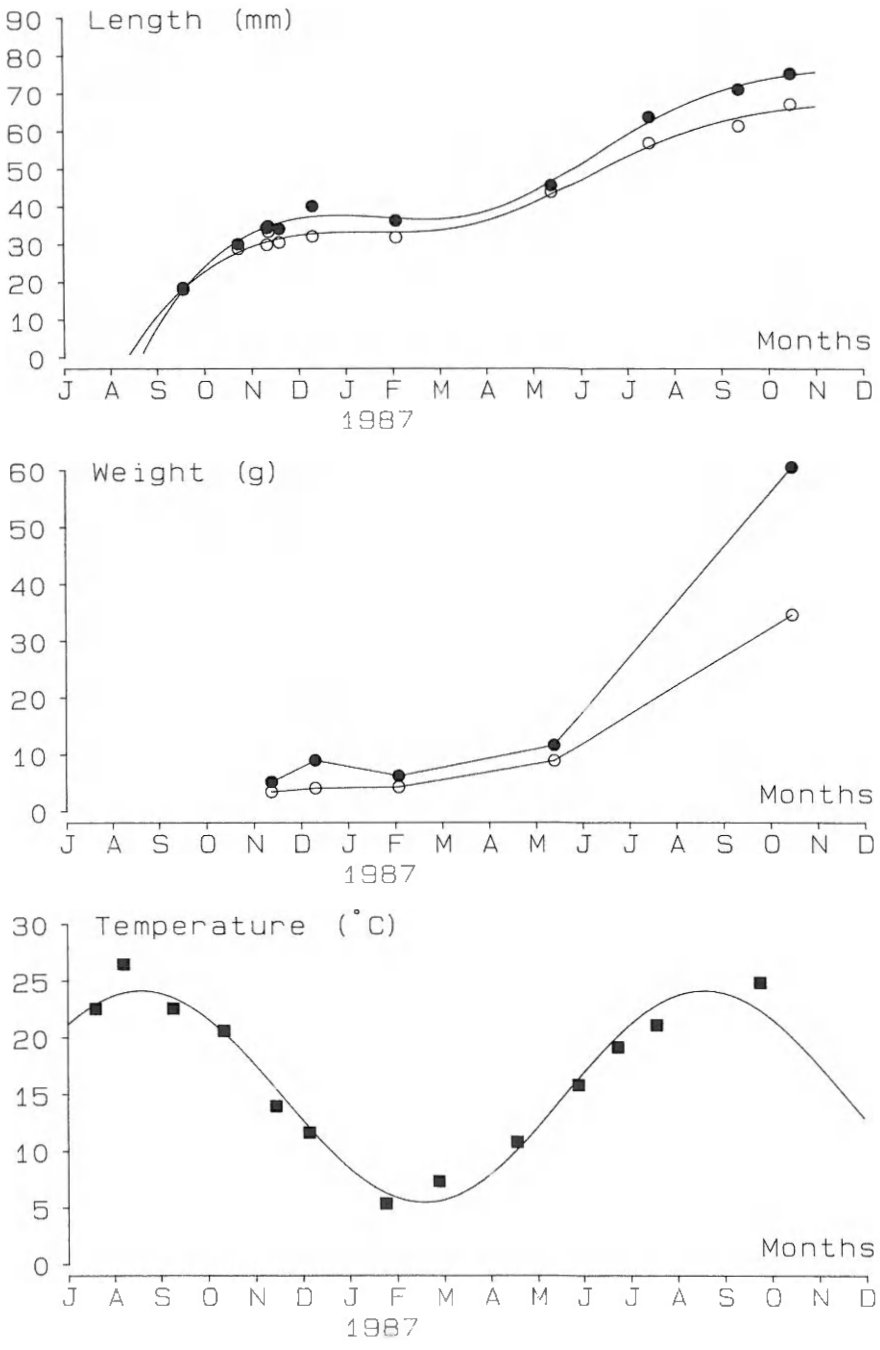

Figure 7. (A) Seasonal Von Bertalanffy length growth curves for *O. edulis* (empty circle) and *C. gigas* (solid circle). (B) Monthly average total weight for the two oyster species. (C) Temperature trend on the bottom (Artegiani and Morbidoni, unpublished data).

the highest intensity in late spring–early summer. From a commercial point of view, this period appears to be the best for the immersion of collectors which should be placed at depths of 1 to 5 m, where the highest settlement density was obtained. Thus seed collected in summer could be harvested at the beginning of autumn and transferred into the nylon nets for the subsequent growing period. Mussels harvested during the subsequent autumn (average TL = 70 mm), after 1 year of growth, would produce the best yield for the farmer. Beyond 1 year winter reduction in growth rate and emission of gametes will result in an insignificant weight increase. Moreover the possibility of losing a part of the potential production due to winter storms must be considered.

The first attempts to collect oyster seed on artificial collectors and to farm it in suspended baskets gave satisfactory results. Oysters showed a shorter period of settlement than mussels, extending from late summer until early autumn. The possibility of later settlement was not investigated. Oyster seed attached to the collectors should be harvested within 3–4 months to avoid shell deformation and an eventual mortality caused by crowding. This period could vary from year to year according to the total length reached by the oysters. The harvesting of young oysters from collectors caused some damage and high mortality, despite this, overall production from each collector was high (more than 250 oysters$\cdot$collector^{-1}).

Ostrea edulis showed a slower growth in length and in weight than *C. gigas* reaching the commercial size (in Italy it is 60 mm TL) 2 months later than *C. gigas,* which already in July 1987 had an average TL of 64 mm. During winter months both species showed an identical decrease in growth rate, more so than the mussels. Obstruction of the holes of baskets as a consequence of mussel settlement and siltation may increase the mortality, especially in late summer months. Thus it would be necessary to clean or change the baskets more than once during the same season. This inconvience might be reduced by putting the oysters into baskets with larger holes.

These experiments have confirmed the possibility of utilizing this type of artificial reef not only for fish attraction and for protection against illegal trawling, but to recycle the large amount of energy present in eutrophic water such as that of the Adriatic Sea, where, in the absence of solid substrates, this would be lost. The artificial reefs provide these substrates, making it possible to develop a great biomass of bivalves. The realization of suitable structures for farming inside these reefs and the introduction of rational breeding methods allow better exploitation of these resources to obtain a more select product. Currently the farming techniques described in this paper seem to be the most reliable for the realization of shell farms in open sea along the Italian coasts.

From a commercial point of view, large-scale realization of these farms could satisfy the high shellfish demand of the Italian market and, at the same time, it would represent a different way of managing the coastal area and of employing part of the fishing effort more rationally. In fact several associations of fishermen have recently applied for the new artificial reefs. Some of these (in particular four in the Adriatic Sea) are already under construction with European Economic Community and Italian Government funds.

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Literature Cited

Abramson, N. J. 1971. Computer programs for fish stock assessment. FAO Fish. Tech. Pap. 101. 148 pp.

Ardizzone, G. D. and G. Bombace. 1983. La barriera artificiale di Fregene. Report to the Ministry of Merchant Marine. 30 pp.

Bombace, G. 1981. Note on experiments in artificial reefs in Italy. Stud. Rev. GFCM 58: 309–324.

Ceccherelli, V. U. and A. Barboni. 1983. Growth, survival and yield of *Mytilus galloprovincialis* Lamk. on fixed suspended culture in a bay of the Po River Delta. Aquaculture 34: 101–114.

Fabi, G., L. Fiorentini and S. Giannini. 1985. Osservazioni sull'insediamento e sull'accrescimento di *Mytilus galloprovincialis* Lamk. su di un modulo sperimentale per mitilicoltura immerso nella baia di Portonovo (Promontorio del Conero, Medio Adriatico). Oebalia N.S. 11: 681–692.

———, ——— and ———. 1986. Growth of *Mytilus galloprovincialis* Lamk. on a suspended and immersed culture in the Bay of Portonovo (Central Adriatic Sea). FAO Fish. Rep. 357: 144–154.

Gaschutz, G., D. Pauly and N. David. 1980. A versatile BASIC Program for fitting weight and seasonally oscillating length growth data. ICES CM D:6. 23 pp.

Hrs-Brenko, M. 1980. The settlement of mussels and oysters in the Northern Adriatic Sea. Nova Thalassia 4, Suppl.: 67–85.

Paquotte, P. and J. Moriceau. 1986. Bilan operation de captage d'huitres plates en Mediterranee 1985. Intern report, IFREMER Sete/Palavas. 24 pp.

Poggiani, L. 1968. Note sulle larve planctoniche di alcuni Molluschi dell'Adriatico Medio-Occidentale e sviluppo post-larvale di alcuni di essi. Note Lab. Biol. Mar. Fano 1: 139–179.

Valli, G. 1980. Riproduzione ed accrescimento di alcune specie di Molluschi eduli nelle lagune di Grado e di Marano. Nova Thalassia 4, Suppl.: 49–65.

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