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Perspectives in Maricultural Technologies

G. Persoone and P. Sorgeloos

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Perspectives in maricultural technologies

By G. Persoone† and P. Sorgeloos‡

† *Laboratory for Mariculture and* ‡ *Artemia Reference Center,*
State University of Ghent, J. Plateaustraat 22, 9000 *Ghent, Belgium*

Starting with the major issues of the recent World Conference on Aquaculture, organized in 1981 jointly by the European Mariculture Society and the World Mariculture Society, the paper indicates a number of new and appealing maricultural technologies in shellfish and fish farming.

It is postulated that several of the techniques described will have a far-reaching impact on maricultural production in the next decade.

Special attention is given to the potential of the mass production of brine shrimp *Artemia* in extensive and intensive operations, and in particular to its key role in vertically integrated aquaculture.

1. Introduction

The classic definition of mariculture, the marine branch of aquaculture, stresses the controlled production of food in the marine environment for human consumption; mariculture, however, also includes the culturing of marine organisms for other human needs, such as the extraction of interesting chemical and biochemical compounds (Grant, this symposium). Despite the promising future of this latter category of maricultural activities we shall restrict our present considerations to food production.

First of all, it should be emphasized that aquaculture, marine as well as freshwater, represents only a minor fraction of total food production on this planet. Despite the rapid increase predicted for the next decades, the farming of aquatic species will not influence to a very large extent the global food output at the world level. This statement, which may seem pessimistic at first, should be put in perspective, as we shall demonstrate below. According to forecasts, of the total annual food output from the aquatic environment, which is currently 75–80 Mt (65–70 from the sea and 10 from freshwater) nearly 90% originates from fishing activities and only 10% from culturing of aquatic species.

Aquaculture production, which amounted to 1 Mt per year in 1966–7 had increased to 6 Mt by 1975 and exceeded 8 Mt in 1978–9 (Pillay 1981). Although this figure represents close to 1 Mt of protein per year, this is still less than 1% of the annual worldwide protein production (figure 1).

It is interesting to note that in 1975 the output of freshwater aquaculture (4 Mt, almost exclusively finfish) was still nearly twice that of all maricultural production (dominated by molluscs and seaweed, approximately 1 Mt each).

Whereas the annual world fish catch is not likely to increase substantially during the next decades – unless some new important sources are tapped such as Antarctic krill – the production of aquaculture will probably increase by 10% per year and could yield 4 Mt of protein by the end of the century. This would then constitute approximately 2% of the global annual protein output (Kinne & Rosenthal 1977).

With regard to the future, Kinne (1980) states the following three general points.

1. 'Aquaculture opens up an important new avenue for making additional food available.' We may add that within the near future, the mariculture output will by far exceed the freshwater aquaculture production.

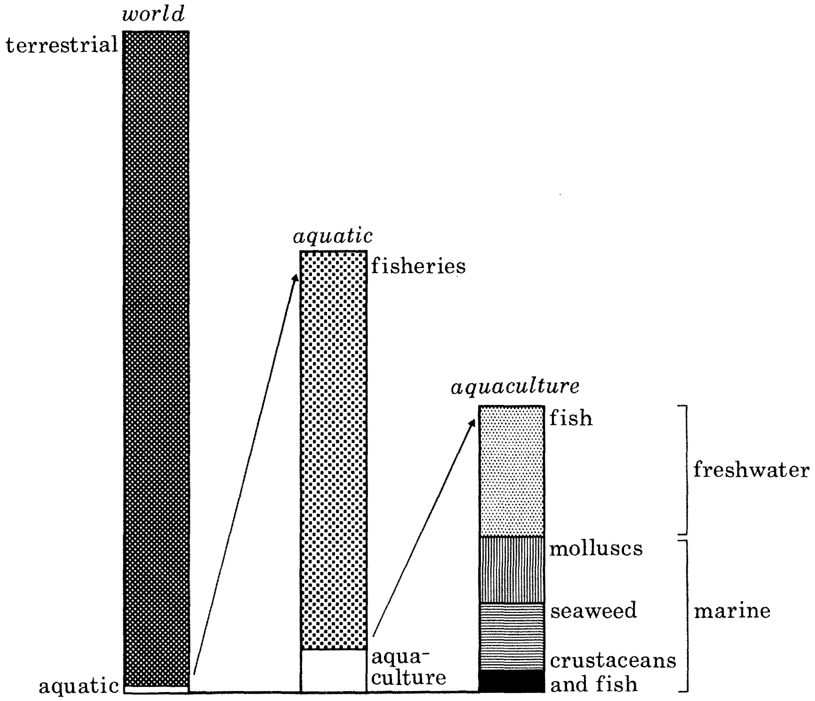

FIGURE 1. Schematic presentation of the food production at world level and the relative importance of the total food output in the aquatic environment compared with aquaculture.

2. 'The importance of aquaculture is, to a considerable extent, a function of the area and the habits of the country concerned.' In this regard the most significant increases in maricultural production will, without any doubt, be realized in tropical and subtropical regions. Furthermore some countries will face an increasing shift in the ratio of fisheries to mariculture food production. This is already so in Japan where year after year marine aquaculture gains importance in comparison with fisheries: in 1979 there were 883 kt of farmed aquatic organisms compared with 2.8 Mt of fished products, a ratio of 1:3 (Nose 1981).

3. 'Improvements in biological and technological know-how can appreciably increase the efficiency of aquacultural food production.'

The aim of this paper is to point to some promising maricultural technologies which in the next decade may corroborate the latter statement.

2. BIOLOGICAL, TECHNICAL AND ECONOMIC ASPECTS OF AQUACULTURE

In a recent paper, 'Farming aquatic animals', Ackefors & Rosén (1979) gave an excellent outline of the basic factors involved in aquaculture and their complex interrelations (figure 2). From this figure it is obvious that biological and technological as well as socio-economic factors contribute both separately and in combination to the progress and the success or failure of

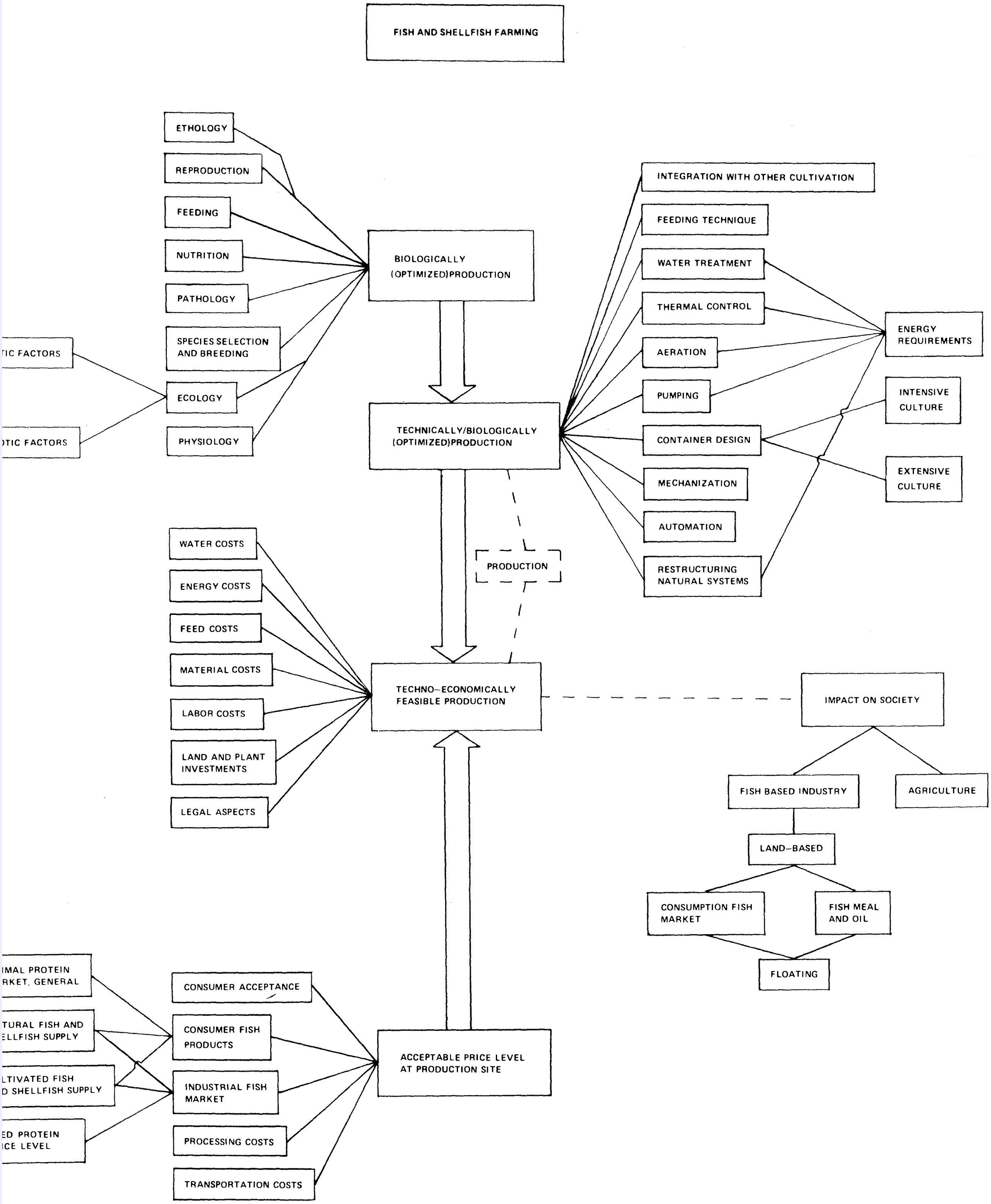

Figure 2. A scheme of important biological, technical and economical factors influencing the development of aquaculture (from Ackefors & Rosén 1979).

aquaculture ventures. Although this paper deals primarily with technological aspects of marine aquaculture, it is necessary to draw attention to the importance of the other variables as well.

Indeed, Ackefors & Rosén (1979) pertinently emphasized that 'the success of aquaculture will be dependent on realistic and integrated planning of production, processing and marketing'.

3. REALISM IN AQUACULTURE: ACHIEVEMENTS, CONSTRAINTS, PERSPECTIVES

Five years after the Technical Conference on Aquaculture organized by FAO in Kyoto, Japan, the European Mariculture Society jointly with the World Mariculture Society convened a major aquaculture meeting in Venice, Italy, in September 1981 on the subject 'Realism in aquaculture: achievements, constraints, perspectives'. During this symposium – the largest of its kind ever organized in Europe (approximately 1100 people from 56 countries) – the three key factors biology, technology and economy from the scheme given in figure 2 were analysed and discussed in detail in 25 review papers, 160 poster papers, three panel sessions and five special meetings.

One of the major conclusions drawn at the end of this world encounter of specialists was that it was once again demonstrated that modern aquaculture in industrialized countries is, to a very large extent, of the intensive type: farming of aquatic species is more and more mechanized and dependent on sophisticated equipment and industrially produced live or inert feeds. As a result intensive aquaculture is almost always directed towards species commanding prices that are adequate to compensate for the high production costs (Bilio 1981).

A second general statement concerns the rapid development of extensive aquaculture farming in developing countries of the tropical and subtropical belt. In these countries the culturing of aquatic organisms traditionally relies on low-level technology using natural water bodies that can eventually be fertilized or enriched with nutrient salts or biodegradable waste products.

So far, however, highly sophisticated intensive aquaculture operations, financed with either local or foreign capital, are being installed at adequate sites in developing countries, at an ever-increasing pace. Since the products farmed in intensive systems are expensive, they consist mainly of luxury foods almost exclusively destinated for the foreign markets. It is an open question as to whom these financially expensive systems finally benefit.

4. PERSPECTIVES IN MARICULTURAL TECHNOLOGY

Entering the core of the subject, it would be presumptuous of us to try to predict the future of maricultural technologies, extensive or intensive, and this in different geographical locations. In the context of this meeting we shall limit our considerations to a few examples of new and appealing technologies for the farming of molluscs, crustaceans and finfish; we are convinced that some of them will make substantial breakthroughs during the next decade.

At present the techniques quoted below are either still in the design stage or in the R & D phase. Some, however, have already proved to be technologically and economically feasible; their practical implementation on a larger scale is only a matter of a few years away. Let it be said here that the examples given below only aim to demonstrate that commercial large-scale marine aquaculture is a recent human activity holding great promise. Its full expansion is still to come, just as in most other fields of exploitation of marine resources.

(*a*) *Mollusc farming*

Parallel to the traditional technique of capturing brood on collectors submerged in the natural environment, the success of which is subject to yearly fluctuations, man has achieved domestication of the reproductive cycle of several important species of edible molluscs, in particular oysters and clams. One can now with a small amount of broodstock produce tiny spat (seed) of oysters, clams and scallops by the millions all year round in so-called hatcheries.

The brood is kept indoors, under very special, almost sterile conditions, and is continuously fed with live algae; needless to say that this is a very costly procedure. The mollusc seed is, however, too fragile to be released immediately into the natural environment for grow-out to the commercial size. It is therefore cultured outdoors for a few months through the so-called nursery stage. During this period the spat grows from a few millimetres to 1–2 cm and is then sturdy enough to be transplanted to the natural environment.

We shall briefly outline three types of new mollusc-farming technologies with a promising future. The first is related to hatchery operations, the second to nursery and the third to the grow-out phase.

The current technique in hatchery culturing of oysters consists of giving the larvae that are ready to settle an appropriate substrate for fixation: the so-called cultch. A number of years ago it was discovered that, next to a variety of plastic 'collectors', sand grains are most suited for the settling of oyster larvae (which are only a few hundred micrometres in size); this has since led to the current technique of spat settlement 'one to one' on individual sand grains. Within a few months the spat grows to a size of a few millimetres and is called 'cultchless' because the original sand grain on which it settled is only barely visible. Recently, two alternative technologies for spat settlement have been developed by a Belgian company specializing in mariculture hardware, and show potential for further use in nurseries and even growing out in the natural environment.

The first consists of offering metal springs with a special coating as a substrate for the settling larvae. The advantages of this technique, which is currently in the R & D phase, are the following:

the animals are optimally exposed to the water currents containing the algal food;

the springs with the firmly attached spat can be moved very easily from one site to another;

by stretching the springs as the oysters grow, one can prevent the molluscs from hampering one another and at the same time continuously provide them optimal space for food availability and development.

It is thus not impossible that in the future, oyster spat will eventually be sold 'by the metre' instead of by weight or number.

The second type of new collector worth mentioning is the skri-collector which consists of a long plastic sheet supported by a metal wire net, rolled in a spiral. This substrate, which can also be used for spatfall in Nature, has a negligible mass in comparison to conventional collectors. Despite its compactness (height and diameter of 30–40 cm) each collector provides space for settling and growth of over 100000 oysters to a size of 1.0–1.5 cm. The spiral can be unrolled and cut into sheets of a convenient length at any time to provide optimal exposure to the growing spat.

Turning to nursery culturing it is well known that the major bottleneck at a certain stage of growth of the seed in hatcheries is the provision of algal food in sufficient quantity. Feeding millions of young oysters and clams implies a daily production of hundreds of cubic metres of algal cultures of suitable species; for economic reasons this cannot be performed by scaling up the monospecific indoor algal cultures of the hatchery. At the State University of Ghent in Belgium, our research team at the Laboratory for Mariculture is endeavouring to help solve this problem by studying the biological, technical and especially the economic aspects of nursery culturing of bivalve molluscs. For this purpose, a unique type of pilot-scale nursery has been built at the Belgian coast. It consists of large outdoor basins equipped with different systems to mix algal cultures and of an indoor nursery proper with flow through cylinders containing the mollusc spat. By studying the influence of a number of factors such as the ratio of the major inorganic nutrients, the intensity of mixing of the cultures, and the retention time in relation to the ambient illumination and temperature, we have succeeded in inducing and steering blooms of suitable microalgae in the basins (De Pauw 1981). All algal cultures are started from the natural phytoplankton present in the seawater, which is used as intake water after some degree of filtration.

In the nursery itself, the economic feasibility of year-round culturing of juvenile bivalves is studied by heating the water and the algal food in flow-through tanks to the optimal temperature for growth of the young molluscs (Claus 1981). Our model is a simulation of the use of thermal effluents from power plants built at the border of the sea, as a very suitable and continuous supply of free and readily available heat for year-round mariculture in temperate climates.

A third point studied in the pilot-scale nursery is the economic feasibility of harvesting the algal biomass during the summer and storing it to feed the bivalves during winter; the algal production in nature then decreases to a low level owing to decreasing photosynthesis in the limited sunlight. We are convinced that, if proved successful, this technique coupled with the use of thermal effluents could be a major breakthrough in the nursery culturing of bivalves at higher latitudes, which is currently impossible on a year-round basis.

Our colleagues from the Netherlands also have ambitious plans with regard to large-scale nursery farming of molluscs in western Europe. In the MARIOS project (Mariculture Eastern Scheldt) the Dutch plan to couple a hydro-gravity fed oyster nursery to the gigantic storm-surge barrier that will be constructed at the mouth of the eastern Scheldt (Drinkwaard 1981). This storm-surge barrier, which will cost many thousand million guilders, should be completed by 1985, and constitutes by itself one of the most daring challenges to Nature. The barrier consists of 66 concrete piers (the largest weighing 20 kt) to be placed in water exceeding 30 m in depth, over a length of more than 3 km. Steel sluices sliding between adjacent piers will reduce the tide by 25% even in the opened position. After the construction is finished in 1985, an enormous surface with harbours and docks will be available at the inner side of the dam, and space for new activities including several maricultural projects will be available. The nursery for 50 million young molluscs quoted above will consist of a 1 km long series of raceways with oyster trays, situated between a high-water and a low-water basin of 50 ha surface each. By the action of the tides, 25000 m^3 seawater per hour will flow through 100 raceways equipped with 100 upflow containers each; this should provide, without any costs for energy, the phytoplankton food for the growing molluscs.

A last example of human ingenuity in the field of mollusc farming has been extrapolated from the three-dimensional culturing of mussels on ropes suspended from rafts; the latter technology has proved extremely successful in the province of Galicia in Spain, and has brought that country to be the top mussel producer in the world. The new idea, put forward by a Belgian company specializing in harbour engineering, consists of redesigning conventional breakwaters that have to be built at certain coastal sites to reduce tidal currents and longshore drift. The traditional rock-filled breakwater is replaced by a pier supported by piles. Within the column framework, standard size caissons in several tiers can be installed. This mass structure guarantees the resistance to wave action, which of course is the first function of a breakwater. The caissons consist of frames provided with vertical rows of bars to which mussel spat is attached. The caissons are put into or taken out of the pier by a trolley equipped with a crane. The trolley brings the caissons to an onshore warehouse where the mussels are stripped from the bars mechanically.

This technique, originally conceived for mussel farming, can easily be adapted to farm other interesting marine species. The caissons can for example be stacked with trays containing oysters or clams; they can also be transformed into cages to rear crustaceans or fish, provided that an appropriate feeding technology is developed.

It has been calculated that a pier of 1 km in length provided with 3000 caissons could produce up to 5000 tons of mussels per year.

(*b*) *Farming of Crustacea*

In the years to come, substantial progress may be expected in the extensive as well as the intensive culture of several crustacean species (Sandifer 1981).

The industrial boom in the culturing of marine shrimp (*Penaeus* spp.), which started a few years ago, is now reaching the stage of a real 'shrimp fever', especially in tropical countries. In Ecuador, for example, several tens of thousands of hectares of coastal ponds are devoted to shrimp culture. Production has expanded from less than 200 t in 1974 to over 20 kt in 1980 (E. Arellano, personal communication). This type of farming simply consists of collecting post-larval shrimp in shallow coastal areas, transferring them to ponds filled with mangrove water (which is nutrient-rich) and harvesting them after a few months when they have reached commercial size. The major drawback of this simple method is that in the end the natural population of shrimp might well be depleted by overfishing (because of insufficient recruitment of the brood stock).

Scientists are, however, endeavouring to control the entire life cycle of crustaceans in captivity, exactly as they do with cultured commercial molluscs and finfish species. A first step, which has now become current practice, consists of capturing a limited number of gravid females and letting them spawn their abundant offspring under controlled conditions in the laboratory. As with molluscs, the crustacean larvae are completely dependent on a continuous supply of live food: algae or yeasts first, zooplankton next.

The capital role currently played by the brine shrimp *Artemia* in modern aquaculture of crustaceans and finfish, as well as the tremendous potential of this particular small crustacean in vertically integrated aquaculture and protein production, are treated in a separate section later in this paper.

Nowadays the maturation and reproduction of several commercially important crustacean species is completely mastered and their intensive culture has attracted many investments. A convincing example is a 400 ha high-technology industrial shrimp farm in Panama, which produces approximately 2 t of shrimp per hectare per year.

We cannot leave the field of crustacean culturing without mentioning the increasing importance of sea ranching. In 1979, for example, about 550 million post-larval shrimp were produced in Japan in federal and prefectural hatcheries. Half of the animals were released in the coastal waters to contribute to the maintenance of the natural stocks, which are under intensive fishing pressure (Hirata 1981). The fraction of the shrimp recovered by fishing varies widely but can amount to 30% in certain areas.

In several places in the world sea ranching experiments with juvenile lobsters are in progress, with encouraging results (Van Olst *et al.* 1980). One of the major handicaps of lobster ranching is the migration of the animals, resulting in low recoveries. In future this problem will be solved by the subsurface fencing-off of suitable coastal areas (small embayments) and by providing artificial shelters to reduce cannibalism among the animals and allowing high stocking densities.

(*c*) *Finfish farming*

After many years of research and struggle, the controlled intensive farming of several highly priced fish species such as seabass and seabream, sole and turbot will in the next few years reach the stage of commercial breakthrough in Europe. The reason for the slackening in the farming of these species in comparison with the highly successful culturing of salmon are, among others, the difficulties and the high cost of the production of live food necessary to feed the larval fish stages (Jones & Houde 1981). Before they can swallow *Artemia*, the larvae of many fish species need a smaller living prey. So far only a marine rotifer can be produced in sufficient amounts and its culture is in turn a factor in the mass production of a suitable live algal food. Although the biological and technical problems in mass-culturing these various successive links of the food chain leading to fish are now under control, the financial implications of the entire operation are considerable. Consequently one of the major research objectives in intensive culturing of crustaceans and finfish is the replacement – as soon as possible – of live foods by inert diets.

Rearing large numbers of growing finfish implies regular scaling-up not only of the size or numbers of enclosures in which the animals are held but also of the volume of water flowing through these enclosures. To solve these problems man is returning to the sea: the most up-to-date technique for fattening fish in intensive farming applications is indeed the offshore pen or cage culturing, which is now being practised at an increasing number of sites.

The most serious threat for offshore mariculture is stormy weather, which, whatever precautions are taken, can ruin a fish farmer in a few hours. A very promising technique for countering this problem consists of making submersible cages. Containers interconnected by a tubular collar are fixed around closed cages of metal mesh. When the containers are filled with water, the anchored cages sink to a certain depth below the zone of extreme turbulence. When the storm is over, compressed air blown into the containers lifts the cages again to the surface. This technology is also very useful in cases of temporary pollution of surface waters, the presence of toxic algal blooms or the decrease of salinity of the upper water layer in estuaries by extreme rainfall.

The above considerations only relate to the intensive culturing of finfish, of course. Considerable progress is, however, also to be expected in the extensive farming of fish, especially in the tropical and subtropical belt. Once the controlled maturation and spawning of highly appreciated species (such as milkfish) has become current practice the present production figures will no doubt increase substantially, exactly as for crustacean farming quoted above.

Last but not least, sea-ranching of fish will without doubt become one of the major mariculture assets for the future. Salmon ranching, for example, has expanded to 3×10^9 juveniles released from hatcheries in 1980 (McNeil 1981). In the USSR over 100 million fingerlings of sturgeon have been stocked in the Caspian and Azov seas, resulting in a 1–3 % recovery of mature fish by fisheries (Doroshov 1981).

5. POTENTIAL OF THE MASS PRODUCTION OF BRINE SHRIMP, *ARTEMIA*

One of the major differences between mariculture and cattle breeding is that the larvae of most aquatic animal species of commercial interest, which are grown in intensive hatchery systems, have to be offered a live food whereas cattle accept inert diets throughout their lives (Kinne & Rosenthal 1977). In this regard the early pioneers in controlled farming of fishes and crustaceans were hampered by the technical difficulties of collecting the necessary small zooplankton organisms from Nature or producing them under controlled conditions (Shelbourne 1968).

The finding in the 1930s that the 0.4 mm nauplius larva of *Artemia*, a small crustacean, constitutes an excellent food for newborn fish larvae resulted in a significant breakthrough in hatchery aquaculture. Technically speaking the advantage of using *Artemia* is that one starts from an apparently inert product, namely the dry cysts. These cysts, which are in fact dormant embryos, are commercially available and can be stored for years. They only have to be incubated for 24 h in seawater to produce free-swimming larvae (Sorgeloos 1980*a*, *b*). During recent years, the worldwide availability and the practical use of this *Artemia* food have been greatly improved as a result of more than a decade of intensive research on the brine shrimp *Artemia* (Sorgeloos 1979, 1982*a*; Sorgeloos *et al.* 1982).

Through fundamental and applied studies on *Artemia*, there is now a better knowledge of the biology of this very primitive crustacean whose first scientific description dates back to 1755 (Kuenen & Baas-Becking 1938). As a result of its unique characteristics, *Artemia* offers great potential for mass production (Sorgeloos 1980*b*):

in optimal culturing conditions brine shrimp grows from larva to adult in less than 2 weeks, increasing in length by a factor 20 and in biomass by a factor 500;

neither abiotic nor biotic requirements change throughout the animal's development;

Artemia has a high fecundity (more than 100 offspring every 4 days) and a long lifespan (exceeding 6 months);

since this animal is a non-selective particulate filter-feeder, a wide range of very cheap foodstuffs can be employed to culture *Artemia*, e.g. organic manures (chicken dung) and agricultural by-products (rice bran, whey, brewers' yeast);

Artemia can be successfully grown in very high densities (i.e. more than 10000 animals per litre) in salt water, and is not very demanding as to the qualitative and quantitative composition of this water;

the adult brine shrimp has a very high nutritional value: i.e. its exoskeleton is very thin (less than 1 μm); 60 % of its dry mass consists of proteins rich in essential amino acids;

Artemia furthermore contains significant concentrations of vitamins, hormones, carotenoids, etc.;

in fish farming and crustacean farming, adult brine shrimp is considered to be the best reference diet for the postlarval stages;

direct consumption of sun-dried *Artemia* by man has been, and is still, practised by primitive tribes in America and Africa.

Recent developments in the mass production of brine shrimp, some of which are still in the R & D phase and others are already in the pilot-scale stage, provide sufficient evidence that several types of *Artemia* bio-industries will reach commercial status in the 1990s.

(*a*) *Artemia as indirect by-product of solar-salt operations*

For many decades solar salt making was considered as a purely physical–chemical process; i.e. as a result of evaporation, salinity concentrations build up progressively, until the saturation level is reached and salt crystals precipitate. Recently it has been proved, however, that the hydrobiological activity in a solar salt operation largely determines the quality and quantity of the salt produced (Davis 1980). Algal blooms, which prevent early precipitation of gypsum and in extreme situations may even hamper salt crystallization, are kept under control by the grazing *Artemia*. Brine shrimp metabolites also provide a suitable substrate for *Halobacterium*, the presence of which assures a red coloration of the crystallizer and thus promotes salt production (Jones *et al.* 1981). In this regard it is obvious that a better knowledge of the biology of *Artemia* and of its population dynamics now provide better opportunities to control the salt operation's output through proper *Artemia* management, for example by the cyclic introduction of *Artemia* under the form of nauplius larvae hatched from cysts (Persoone & Sorgeloos 1980; Sorgeloos 1982*a*).

Aside from its beneficial impact on the solar salt operation, *Artemia* can be exploited in the form of cysts or adult biomass or both as a most valuable by-product (Sorgeloos 1980*b*, 1982*a*). Considering the several hundreds of thousands of hectares of salt ponds in the world, it is no exaggeration to say that in the tropical and sub-tropical belt, the production of salt combined with *Artemia* will yield hundreds of tonnes of *Artemia* cysts and thousands of tonnes of adult biomass.

As a result of the commercial expansion of crustacean and fish aquaculture, future demands for cysts are expected to increase exponentially. The present annual consumption is about 60 t commanding an average price of U.S. $30.00 kg^{-1} (Sorgeloos 1982*b*). Except for the limited market of aquarium pet shops, the use of adult *Artemia* is still in the development phase (Webber & Sorgeloos 1980). Solar saltworks, however, provide unique opportunities for so-called vertically integrated aquaculture projects (Sorgeloos 1982*a*). The various *Artemia* products can be successfully used, as has been recently demonstrated in a *Penaeus* shrimp farm at a large salt plant in northeast Brazil. The nauplii are hatched from cysts and used in the shrimp hatchery; adult *Artemia* are collected from the evaporation ponds and are directly fed to the post-larval shrimp in the nursery and to the adult shrimp in the maturation facility. Compared with the traditional aquaculture farm where only nauplii are used for food, the feeding of adult brine shrimp to shrimp or fishes in the nursery stages results in the production of healthier shrimps or fish juveniles. Consequently performances in the grow-out ponds can be significantly increased. In crustaceans, a diet of adult *Artemia*, known to be rich in reproductive hormones, is also a much more efficient maturation trigger than the classical techniques of eyestalk ablation and exposure of the animals to a specific photoperiod régime. At the Brazilian plant, experiments are now in progress to use dried *Artemia* as a cheap substitute for fish meal in the formulation of pellets to feed shrimp in grow-out ponds.

This successful example will no doubt soon be followed by others. Within another decade improved biological management will allow solar saltworks to integrate with major aquacultural bio-industries.

(*b*) *Extensive production of Artemia*

Artemia production in the natural environment is not limited to man-managed solar saltworks. The preliminary knowledge acquired during recent years in southeast Asian *Artemia* projects sufficiently proves the large potential of brine shrimp cultivation in extensive pond systems.

Provided that salinities in the culture ponds can be kept within the range of 100 to 150 g l^{-1}, yields of more than 10 g live mass brine shrimp per square metre per day can easily be maintained by weekly fertilizations with chicken dung or manure and commercial inorganic fertilizer (Sorgeloos 1982*a*). Converted to a hectare this means yearly productions of more than 30 t of *Artemia* biomass, corresponding with approximately 1.8 t of animal protein (dry mass). It is also possible to direct the salinity management towards cyst production, resulting in harvests of up to 15 kg processed cysts per hectare per month. This type of extensive *Artemia* production, which is limited to warm climates and dry seasons, offers unique opportunities of increased food production in the third world countries. *Artemia* production can be integrated in local aquaculture developments (see §*a*) as is now being tested in pilot-scale operations in Thailand and the Philippines, or be considered as a new type of complementary agriculture. The latter approach is expected to find wide applications in the 1990s. Indeed, throughout the tropical belt millions of hectares of agricultural lands have to be abandoned or are unsuited for classical agriculture as a result of salinity problems (International Soil Science Society 1980), e.g. salt-affected soils, high salinity or limited availability of irrigation waters. Many of these sites, however, offer favourable conditions for the production of *Artemia* in brine waters. Provided that cheap organic fertilizers are available, vast areas in Africa and South America could be developed for brine shrimp farming. *Artemia* meal, a new source of high-quality animal protein, could be used in poultry and cattle feeds. Live or frozen preparations of brine shrimp could eventually be considered as a direct or indirect food for man. In the Peruvian coastal zone for example, several hundreds of thousands of hectares of alluvial land areas are suited to culture brine shrimp in ponds. With the aid of the Belgian Administration for Development Cooperation, the local government is considering setting up demonstration farms, to be expanded into an integrated system of cooperatives. This initiative should not only lead to an expansion of the present cultivable area, but will result in a very beneficial development for these extremely poor Peruvian coastal rural areas suffering from the deteriorating anchovy fisheries and fishmeal industry.

(*c*) *Intensive production of Artemia*

A decade of research on the culturing biology of the brine shrimp has finally resulted in reliable production techniques for the controlled high-density culturing of *Artemia* (Sorgeloos 1982*a*). Whereas, in outdoor pond systems, brine shrimp densities of up to 100 animals per litre are considered very high, intensive cultures can be operated at more than 15000 animals per litre.

Although still in the R & D pilot-scale stage, the system of flow-through culturing on inert diets (Brisset *et al.* 1982) offers unique opportunities for industrial application in the 1990s. Production results are very high, i.e. over a culturing period of only 2 weeks, 25 kg live mass of brine shrimp can be produced in a 1 m^3 tank. Critical costs for a suitable culture medium and for food can be considerably reduced. Thanks to its tolerance for qualitative as well as quantitative water composition, *Artemia* can be cultured in a wide variety of thermal effluents, e.g.

from power stations, desalination plants or geothermal projects. Because *Artemia* thrives on various kinds of particulate wastes of organic nature, such as rice bran, whey powder, milk substitutes or brewer's yeast, it is highly likely that further selection studies might allow recycling of local waste products in an *Artemia* production plant. It is clear, however, that further research is needed to evaluate the quality of the end-product and to study engineering aspects related to the scaling-up of culture techniques.

With the present culture techniques, it has been estimated that for a production unit of 10 kt per year, the cost of 1 kg live mass of *Artemia* will be under U.S. $0.40 kg^{-1} (Solvay et Cie, personal communication). Based on these figures, industrial applications can now be considered in relation to the market demand, for example as food for aquaculture industries, *Artemia* as source for extraction of pharmaceutical products, and the use of brine shrimp in protein-rich food products.

P.S. is a research associate at the National Fund for Scientific Research (N.F.W.O., Belgium).

REFERENCES

Ackefors, H. & Rosén, C. G. 1979 *Ambio* **8** (4), 132–143.

Bilio, M. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Brisset, P., Versichele, D., Bossuyt, E., De Ruyck, L. & Sorgeloos, P. 1982 *Aquacultural Engng* **1** (2), 115–119.

Claus, C. 1981 In *Nursery culturing of bivalve molluscs* (ed. C. Claus, N. De Pauw & E. Jaspers), pp. 1–33. European Mariculture Society, Bredene, Belgium, Special Publication no. 7.

Davis, J. S. 1980 In *The brine shrimp Artemia* (ed. G. Persoone, P. Sorgeloos, O. Roels & E. Jaspers), vol. 3 (*Ecology, culturing, use in aquaculture*), pp. 51–55. Wetteren: Universa Press.

De Pauw, N. 1981 In *Nursery culturing of bivalve molluscs* (ed. C. Claus, N. De Pauw & E. Jaspers), pp. 35–69. European Mariculture Society, Bredene, Belgium, Special Publication no. 7.

Doroshov, S. I. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Drinkwaard, A. C. 1981 In *Nursery culturing of bivalve molluscs* (ed. C. Claus, N. De Pauw & E. Jaspers) pp. 93–116. European Mariculture Society, Bredene, Belgium, Special Publication no. 7.

Hirata, H. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

International Soil Science Society 1980 *Proceedings of the International Symposium on Salt-Affected Soils, 18–21 February* 1980 (569 pages). Kamal.

Jones, A. & Houde, E. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Jones, A. G., Ewing, C. M. & Melvin, M. V. 1981 *Hydrobiologia* **81**, 391–406.

Kinne, O. & Rosenthal, H. 1977 In *Marine ecology* (ed. O. Kinne), vol. 3, pp. 1321–1398. Chichester: Wiley.

Kinne, O. 1980 *Interdisc. Sci. Rev.* **5**, 24–32.

Kuenen, D. J. & Baas-Becking, L. G. M. 1938 *Zool. Meded.* **20**, 222–230.

McNeil, W. J. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Nose, T. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Persoone, G. & Sorgeloos, P. 1980 In *The brine shrimp Artemia* (ed. G. Persoone, P. Sorgeloos, O. Roels & E. Jaspers), vol. 3 (*Ecology, culturing, use in aquaculture*), pp. 3–24. Wetteren: Universa Press.

Pillay, T. V. R. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Sandifer, P. A. 1981 In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Shelbourne, J. E. 1968 Ph.D. thesis, London University. (143 pages.)

Sorgeloos, P. 1979 In *Advances in aquaculture* (ed. T. V. R. Pillay & Wm. A. Dill), pp. 321–324. Farnham: Fishing News Books Ltd.

Sorgeloos, P. 1980*a* In *The brine shrimp Artemia* (ed. G. Persoone, P. Sorgeloos, O. Roels & E. Jaspers), vols 1, 2 and 3, pp. xix–xxiii. Wetteren: Universa Press.

Sorgeloos, P. 1980*b* In *The brine shrimp Artemia* (ed. G. Persoone, P. Sorgeloos, O. Roels & E. Jaspers), vol. 3 (*Ecology, culturing, use in aquaculture*), pp. 25–46. Wetteren: Universa Press.

Sorgeloos, P. 1982*a* In *Realism in aquaculture: achievements, constraints, perspectives* (ed. M. Bilio, H. Rosenthal & C. Sindermann). (In the press.)

Sorgeloos, P. 1982*b* *Eur. Mariculture Soc. Spec. Publ.* (In the press.)

Sorgeloos, P., Bossuyt, E., Lavens, P., Léger, P., Vanhaecke, P. & Versichele, D. 1982 In *Mariculture* (ed. J. P. McVey) (*CRC Handbook in Marine Science*). (In the press.)

Van Olst, J., Carlberg, J. & Hughes, J. T. 1980 In *The biology and management of lobsters* (ed. J. S. Cobb & B. Phillips), vol. 2 (*Ecology and management*), pp. 333–384. Academic Press.

Webber, H. H. & Sorgeloos, P. 1980 In *The brine shrimp Artemia* (ed. G. Persoone, P. Sorgeloos, O. Roels & E. Jaspers), vol. 3 (*Ecology, culturing, use in aquaculture*), p. 413. Wetteren: Universa Press.