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Chapter 12

SEMI-INTENSIVE CULTURING IN FERTILIZED PONDS

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TABLE OF CONTENTS

I. INTRODUCTION

Artemia biomass and cysts can be produced in intensive as well as semi-intensive and extensive conditions. Intensive production is performed in indoor tank systems under completely controlled conditions (see Chapter 12). Semi-intensive and extensive production refer to the culture of *Artemia* in outdoor conditions. The former is performed in small and managed salt pond systems (mostly seasonal solar saltponds); e.g. with some degree of control over salinity, water retention time, and feed availability. The latter (extensive production) consists of the harvesting of mostly natural *Artemia* populations from large biotopes with year-round high salinity conditions such as large solar salt operations or salt lakes.

Since *Artemia* is highly susceptible to predation, a major prerequisite to semi-intensive and extensive production is the availability of brine of sufficiently high salinity that is free from fish and invertebrates. In most saltpond locations/natural biotopes, this situation is reached at salinities from >80 to 100 g/l, although situations have been reported where fish and insects were still present at salinities of >100 to 130 ppt.[1]

Natural populations of *Artemia* are widely distributed over the five continents in a variety of isolated biotopes such as inland salt lakes, coastal lagoons and especially coastal salterns associated with commercial solar salt production.[2,3] A recent list of natural *Artemia* sites compiled by Vanhaecke et al.[3] extends to over 350 localities.

In most natural *Artemia* populations, densities are low, mainly as a result of food limitation due to a low nutrient content of the water. The few exceptions which have higher productivity are those biotopes (mostly large solar saltworks) which are located in highly eutrophic areas (e.g., near population centers, estuaries, or mangrove areas) such as the Leslie Saltworks in the San Francisco Bay, and the salinas of the Bohai Bay in China.[4] Production estimates for a few natural *Artemia* biotopes are given in Table 1. As a result of their generally low productivity, most of the natural biotopes offer opportunities for extensive harvesting of *Artemia* biomass only. Production of cysts in these biotopes, especially when the local ecological conditions are fairly stable, occurs only occasionally or is erratic. Moreover, since the quality of *Artemia* cysts differs from strain to strain and even from harvest to harvest[5,6] it is imperative to determine its nutritional value for specific application in aquaculture, prior to commercial development.

A schematic outline of a typical solar saltwork is given in Figure 1. Sea water flows over a series of successive ponds in which salinity gradually increases as sea water evaporates. During this process, salts with low solubility precipitate as carbonates and later as gypsum (see Figure 2). Finally, when the sea water has evaporated to approximately one tenth of its original volume, mother brine is transferred to the crystallizers where pure sodium chloride is deposited. *Artemia* is only found in the evaporation ponds of intermediate salinity, i.e., from approximately 90 g/l (≃ upper tolerance level of predators) to approximately 200 to 250 ppt. At elevated salinities *Artemia* die as a result of either starvation because of increased energy associated with hyperosmoregulatory physiology[7] and/or increased toxicity of the brine due to drastic changes in ionic composition caused by gradual precipitation and enrichment of different salts.

Very extended solar salt industries (i.e., highly mechanized operations of hundreds to thousands of hectares each with individual evaporation ponds of up to hundreds of hectares) are localized in climatic zones with high evaporation rates and restricted rainfall (e.g., various regions in Australia, South America, Mexico, United States, China, southern France, and southeast Italy) and are usually in production (though not necessarily harvesting) on a year-round basis. In contrast, numerous small cottage-scale units for artisanal solar salt production are in production in the tropical-subtropical belt only during a restricted period of the year; i.e., cycles of 3 to 6 months during the dry season when conditions are favorable for making salt. The large operations can only be managed with regard to *Artemia* presence,

TABLE 1
Production Estimates for Natural *Artemia* Populations

Site	Country	Maximum production	Period	Ref.
Lake Rezaiyeh	Iran	1.2 adults/l		68
Sivash Salt Lakes	U.S.S.R.	400/l		69
Slagbaai	Bonaire, Netherlands Antilles	200—360/l	Oct.—June	70
Mono Lake	California	4 adults/l		
		12 nauplii/l	June—Sept.	71
		400/l	Aug.—Sept.	72
Great Salt Lake	Utah	10/l		73
		100—200g dw/m^2	per year	74
Salin de Giraud	Camargue, France	10-100/l	March—Oct.	75
		0.02-0.2 g/l ww		
		16,000/m^2		76
Long Island Salina	Bahamas	25-100/l	May—Sept.	51
Alviso Salt Ponds	California	13 g/m^3 dw	summer	77
San Francisco Bay saltponds	California (harvest)	5 kg/ha ww	per week	78
Crimea Salt Lakes	U.S.S.R.	250 kg/ha	October	79
		3000 kg/ha	June	
Burgas-Pomorije saltworks	Bulgaria	2.75 g/l adults ww		
		0.93 g/l juveniles	June—Sept.	80
		0.5 g/l nauplii		
Lake Grassmere	New Zealand	4.2 g dw/m^3	Nov.—May	81,82
		4.9 g dw/m^3	Nov.—April	81,82

[a] Some data compiled from Persoone and Sorgeloos.[83]

especially to control the opportunistic dispersion of *Artemia*[3] when better hydrobiological conditions are required for solar salt production.[4,8-10] As a result, the big-pond systems can be tapped for extensive harvesting only. The small units are much more versatile and provide realistic possibilities for human-managed production of *Artemia* biomass and cysts through inoculation with selected strains, through salinity control, pond retention times, food availability, predator presence, etc. This chapter will cover the basic principles and strategies for semi-intensive production of *Artemia* in seasonal saltponds.

II. SEASONAL PRODUCTION OF *ARTEMIA* IN SMALL SOLAR SALTFARMS

A. TYPICAL CHARACTERISTICS OF SEASONAL SALTFARMS

Seasonal saltfarms generally have an area of less than a few hectares, while individual ponds can be as small as a few hundred m^2. The ponds are usually shallow with a water depth of <10 cm. Sea water of mangrove or estuarine origin is usually supplied by tidal inflow, although some farms use pumps, windmills, and/or manually operated waterscoopers to permit better manipulation of water levels.

During winter (e.g., in China, southern Spain, and Sicily) or monsoon season (e.g., in Central America and Southeast Asia) salt production is abandoned. In monsoon climates, salt evaporation ponds are eventually converted into paddy fields or shrimp/fish ponds (e.g., Southeast Asia). In some farms deep brine reservoirs (pickle ponds) are available for storage of the brine which remains available at the end of the dry season (e.g., Philippines and Indonesia); at the onset of the dry season, brine is pumped back into the evaporation ponds and allows a faster start-up of salt production.

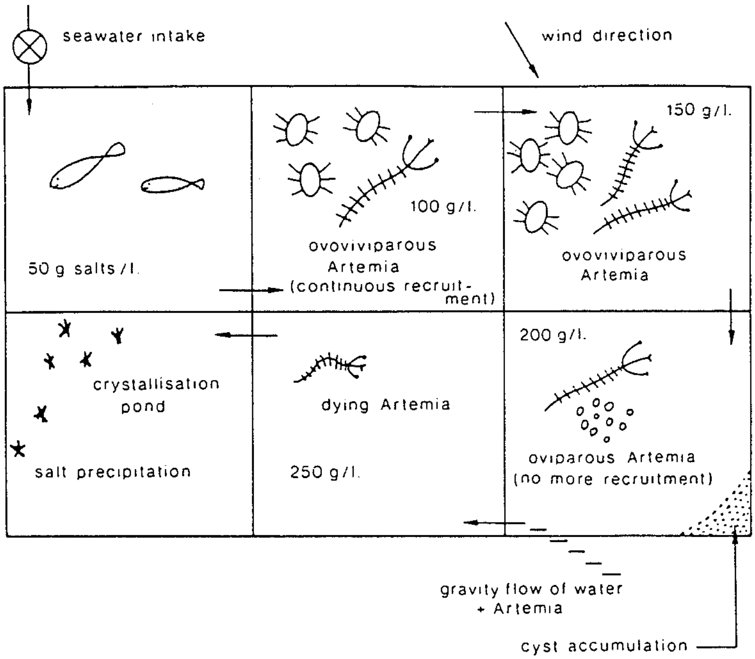


FIGURE 1. Schematic diagram of a solar salt operation with natural occurrence of *Artemia*. (From Sorgeloos, P., Léger, P., Lavens, P., and Tackaert, W., *Aquacult. Dév. Cahiers Ethologie Appliquée*, 7, 43, 1987. With permission.)

B. POND MODIFICATIONS

Successful production of *Artemia* in seasonal solar-salt fields involves minor pond modifications to increase the water depths in the future *Artemia* ponds (in the salinity range of 100 to 180 g/l) to a minimum level of about 40 to 50 cm (preferably 70 to 100 cm). High water depths are essential not only to prevent lethal high temperature conditions for *Artemia*, but also to promote the development of phytoplankton which through its shading effect inhibits the development of phytobenthos. In contrast to phytoplankton, the latter is undesirable because it is too large to be ingested by *Artemia*, and as it starts to float, it may further reduce evaporation and eventually contaminate the harvests of *Artemia* biomass and cysts as well as the salt. Since *Artemia* is a planktonic organism, deep ponds can also sustain a larger production per surface area than shallow ponds. High water depths and associated phytoplankton result in a dark coloration of the brine which is also beneficial for salt production since it enhances the evaporation efficiency through increased absorption of solar heat.[9] Higher water depths can easily be achieved by digging an inner perimeter ditch and using the soil from the ditches for heightening the dikes (Figure 3). However, the water levels in the *Artemia* ponds will than be higher than in the nonmodified upstream evaporation ponds, which implies that the brine has to be relifted (by pump or windmill) into the first *Artemia* pond from where it further gravitates into the following downstream ponds.

C. PREPARATION OF PONDS

Prior to *Artemia* production, it is recommended that ponds be completely emptied to expose bottom soil for a period of one to two weeks, followed by raking the upper layer of the soil to enhance mineralization of accumulated organic matter. Fish left in remaining mud holes may be killed by the use of rotenone or tea-seed cake or by application of lime in

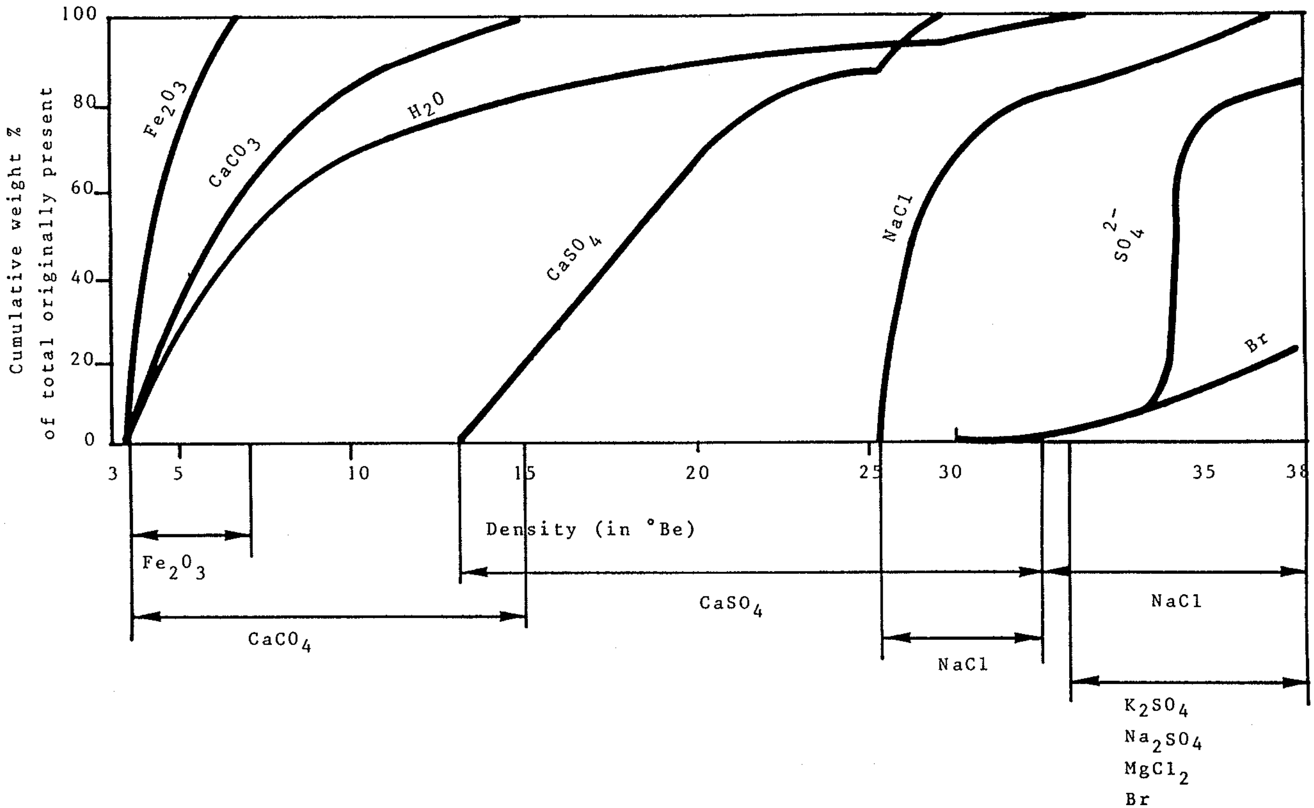


FIGURE 2. Deposition of salts during concentration of sea water (from Bradley, personal communication).[87]

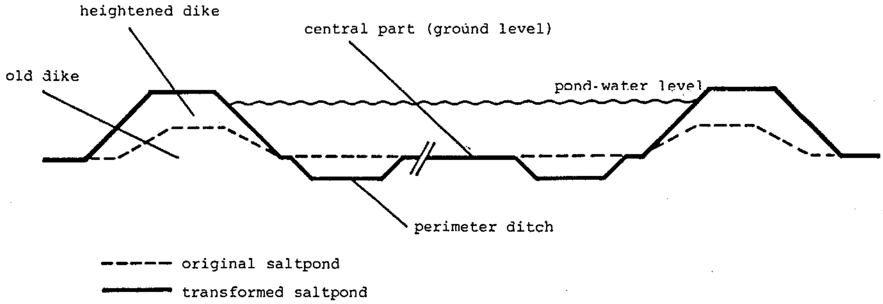


FIGURE 3. Longitudinal section through a modified *Artemia* pond. (Modified from Tackaert, W., Léger, P., Lavens, P., and Sorgeloos, P., *El cultivo del Camaron, Langostino y Congrejo en el Mundo: Bases y Tecnologias* (The Aquaculture of Shrimp, Prawn, and Crawfish in the World: Basics and Technologies), Chavez Justo, C. and Sosa Nishizaki, O., Eds., McGraw-Hill, Mexico, 1989. With permission.)

combination with ammonium sulphate.[11,12] Coastal saltfields may be located in mangrove areas associated with acid sulphate soils containing pyrite. Upon exposure to air, pyrite is oxidized to iron oxides and sulphuric acid, especially in newly excavated ponds. The release of the acid entails very low pH values, resulting in aluminium and iron leaching from the soil. The latter conditions are unfavorable for most aquatic organisms including *Artemia*; phytoplankton production is also inhibited through stripping of phosphorus from the water.[13] In a number of cases, soil acidity may be visually observed; i.e., air-exposed soils turn yellow to brownish-red. Addition of lime neutralizes the acid soil conditions, allowing for a better bioavailability of nutrients, which in turn enhances phytoplankton growth and production of *Artemia*. Lime, furthermore, aids in decomposition of pond muds, long term buffering of pH (which is essential in ponds where heavy organic fertilization is applied), and in the killing of undesirable fish eggs and pests through the toxic action of caustic components. There are several forms of lime: (1) calcium oxide, CaO, or quicklime has a neutralizing efficiency of 173% $CaCO_3$, and is used for fast action in ponds with very low pH, in the range of 3.5 to 5.0; (2) calcium hydroxide, $Ca(OH_2)$, or hydrated lime has a neutralizing efficiency of 135% $CaCO_3$ and also acts quickly to increase the soil pH; (3) calcium carbonate, $CaCO_3$, or agricultural lime (ground limestone) acts relatively slow and therefore may be used for long-term acidity control. CaO and $Ca(OH)_2$ may be used in newly excavated ponds while $CaCO_3$ is used in older, more stabilized ponds. To raise the pH by 0.1 unit, about 500 kg of $CaCO_3$ is applied per hectare.[13] Lime is applied to dry pond bottoms, although $CaCO_3$ at low rates not exceeding 400 kg/ha, may also be used in ponds filled with water. Best results are obtained by spreading lime over the entire bottom or surface. Dikes should also be limed to prevent acidic runoff in case of rainfall.

D. INTAKE OF SEA WATER AND INCREASE OF REQUIRED SALINITIES AND WATER DEPTHS

Most artisanal saltfarms are designed to permit intake of sea water by tide. Some are provided with sluices in order to obtain the maximum water level in the reservoir as close to the high-tide level as possible. Even then, and especially in the case where modified *Artemia* ponds are operated at higher water depths, it is rare that the brine can travel through the entire system by gravity alone. Pumps or windmills (see Figure 4) are required to supplement or take the place of the tidal gates. While water depths in the reservoir should always be as high as possible (to maximize supply of the brine to the downstream ponds), evaporators and *Artemia* ponds should initially only be filled to a level of 10 to 15 cm, in

FIGURE 4. Windmill used in seasonal solar salt farming in Thailand. (From Sorgeloos, P., Lavens, P., Léger, P., Tackaert, W., and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture,* Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

order to ensure maximum evaporation and to create high water temperatures harmful to predators. Predators should furthermore be avoided by screening the intake water upon filling the ponds. If the pH of the water in the modified *Artemia* ponds is still lower than 7.0, it is advisable to wash out the remaining acidity by repeated flushing of the pond with sea water. If the pH is higher than 7.0, low water levels in the *Artemia* ponds are allowed to evaporate until a salinity of about 100 g/l is reached; i.e., high salinity in combination with high temperatures obtained in thin waterlayers will eliminate copepods and other predators. At this point, gradual intake of sea water is restarted at a rate to maintain the salinity in the *Artemia* ponds around 100 g/l and be continued until the desired levels in the *Artemia* ponds (50 cm or more) are reached. While some predators (e.g., *Cyprinodon variegatus* and *Aphanius fasciatus*) are able to adapt to gradually increasing salinities, they will not resist the severe salinity shock created by the above practice of water intake. As soon as the *Artemia* ponds are filled to their maximum level, the rate of sea water intake is adjusted to maintain these depths. Consequently a density gradient typical for a normal salt operation

will be established in the successive *Artemia* ponds and evaporators. Between the *Artemia* ponds, the brine is preferentially bottom-drawn not only to prevent temperature and salinity stratification but also to enhance distribution and release of organic matter which accumulates on the bottom.

E. FERTILIZATION

1. General Requirements

Before introducing *Artemia* in the ponds, enough particulate food should be present in the water to guarantee high population productivity. Water with a green-brown color and a transparency of less than 20 cm mostly contains high concentrations of organic detritus particles and/or algae that can be used as food by the *Artemia*. This is generally the case in saltfarms associated with mangrove areas or eutrophic estuaries. The availability of the nutrients from mangrove or estuaries can be maximized by pumping at low tide.[14] In this situation of good food availability, fertilization is not required, at least not before the introduction of the *Artemia* nauplii. Water with only a slight coloration and a high transparency (>30 cm) is not productive enough and requires fertilization to increase the availability of natural food, 3 to 7 days prior to inoculation of *Artemia*.

Since the goal is to stimulate phytoplankton and not phytobenthos, it is essential to apply the fertilizer only to ponds already filled to maximum water levels. In flow-through systems, it is best to fertilize the low salinity ponds as we have often experienced difficulties in initiating a phytoplankton bloom when fertilizing high salinity ponds; i.e., chemical interactions limit the nutrient availability for a restricted number of algal species. In the latter systems, phytoplankton-rich water is ultimately drained into the high salinity ponds. Two kinds of fertilizers or a combination of both can be used: (1) organic fertilizers, such as dried chicken manure, and (2) inorganic fertilizers (commercial products used in local agriculture) with a high nitrogen and phosphorus content. Generally inorganic fertilizers stimulate phytoplankton growth more rapidly, while organic fertilizers act more slowly but provide a long-range effect since they first have to be degraded by bacterial action to release plant nutrients. In addition, some organic fertilizers such as dried and ground chicken manure will easily disperse into the water column. Since they still contain up to 20% protein, they may also act as a direct food source for *Artemia*. Organic products are cheaper than inorganic fertilizers but much more bulky, and therefore involve more labor in their use. Moreover, organic fertilizers, especially when not properly distributed, may accumulate and decay at the pond bottom and create anaerobic zones resulting in oxygen deficiency, acidity, and toxicity through production of hydrogen sulphides.

Optimal rates of application are difficult to predict since they will vary from location to location due to climatic differences and quantitative/qualitative fertility of the local soil and water. Morales[86] reported that minimum concentrations of nitrogen and phosphorus in the water in order to obtain blooming of phytoplankton should be 1 to 2 mg/l and 0.1 mg/l, respectively. Different fertilization programs also favor different types of food in the ponds; e.g., plankton is favored by a high ratio of nitrogen to phosphorus whereas organic manures, which are usually high in phosphorus, enhance the growth of undesirable filamentous algae. The fertilization program in *Artemia* ponds needs to be adjusted to optimize the availability of phytoplankton. The following doses can be recommended as a guideline. These concentrations have proven to be effective but other application rates and combinations of both organic and inorganic fertilizers are not excluded.

2. Organic Fertilizers

Best results to date have been obtained with chicken manure. Although cow and goat dung have been successfully used in some cases, chicken manure, in contrast to some other manures, such as from cattle (low nitrogen to phosphorus ratio: 1.5; high contents of

undigested insoluble material) is more effective in inducing a phytoplankton bloom since it has a relatively high N/P ratio (3.5) and good dispersibility, providing a larger surface for bacterial breakdown. In addition, it does not accumulate on the pond bottom since it is highly soluble. Van der Zanden[15] reported a significant increase in the development of phytobenthos or "lab-lab" whenever cow dung was used.

Chicken manure needs to be dried and sieved for removal of debris, bran, feathers, etc., and it is preferable to grind it to increase its availability as a direct food source for *Artemia*. Nonetheless, good results have been reported by Jumalon et al.[11] when using chicken manure suspension (1:1 ratio of manure to sea water).

Dry chicken manure is applied at rates of 0.5 to 1.25 ton/ha at the start with dressings of 100 to 200 kg every 2 to 3 days.

3. Inorganic Fertilizers

- Combination of 100 kg/ha mono-ammonium-phosphate (N:P:K ratio expressed in weight percentage of 16:20:0) and 50 kg/ha ammonium-nitrate (33:0:0); weekly dressings of 50 and 25 kg/ha, respectively.
- Combination of 50 kg/ha di-ammonium-phosphate (18:46:0) and 50 kg/ha urea (44:0:0); weekly dressings of 25 and 20 kg/ha, respectively.
- 100 kg/ha urea (44:0:0); weekly dressings of 40 kg/ha (e.g., in ponds where natural levels of phosphorus are high).

Recently a by-product from the industrial production of monosodium glutamate derived from cassava or sugar cane molasses has been succesfully used as a cheap fertilizer for *Artemia* ponds. Application rates of up to 2500 l/ha have been found very effective in inducing dense phytoplankton blooms. In view of its acidity the effluents of the monosodium glutamate fermentation should be applied in small quantities but on a frequent basis.

Both organic and inorganic fertilizers should be very evenly spread over the pond surface. Slow dissolving pelleted fertilizers (e.g., 16:20:0) are first made into concentrated solutions (prepared overnight) or are placed on a platform in areas of active water flow (e.g., near the brine intake), 15 to 20 cm below the water surface in order to ensure a more even release and mixing and prevent any trapping of nutrients into the soil.

Although the fertilizer is generally applied directly to the *Artemia* ponds, several farmers are now working with separate "food production ponds" from which they feed the *Artemia* ponds; these may be low salinity ponds, 50 to 80 g/l, which are not necessarily integrated in the brine circuit. Availability/production of phytoplankton in these ponds is maximized through intake of "green water" from fish/shrimp ponds or through supplemental fertilization with fecal droppings from a vertically integrated poultry farm.[11,12]

F. *ARTEMIA* STRAIN SELECTION

In view of the high degree of genetic variation[16] associated with the diversity of biochemical, biometrical, and physiological characteristics[5,17] found among strains of *Artemia* the selection of the strain best adapted to the particular ecological conditions (especially temperature regimes) of the saltfarm and/or most suitable to its later application in aquaculture farms, is very important. Strain selection can be based on the available data of growth and production performance,[18,19] reproductive characteristics,[20] anion concentration tolerance,[21] and especially temperature/salinity tolerance.[22] In addition, whenever possible, a comparative bioassay culture test should be performed in closely simulated conditions using the untreated brines of the habitat as culture medium. Strain selection might also be restricted by the intended application of the produced *Artemia* in local aquaculture; e.g., if small nauplii are needed for the production of the early larval stages of fish and shrimps, a strain producing small cysts and nauplii is to be preferred.[23] On the other hand, if local aquaculture is primarily

interested in *Artemia* biomass as a nursery/weaning or shrimp maturation diet, then a strain showing good growth and survival, as well as dominant ovoviviparous reproduction characteristics will be the most interesting.

G. INOCULATION PROCEDURES

Inoculation of *Artemia* should be performed as early as possible in the brine circuit where no predators are found (i.e., usually at salinity levels of around 100 g/l). In flow-through systems with short pond-retention times, downstream ponds at higher salinity need not be inoculated since they will be gradually stocked with *Artemia* drained from the inoculated pond. Although Jumalon and Robles[24] reported an optimum *Artemia* production at an inoculation density of 50 nauplii per l, Vu Do Quynh and Nguyen Ngoc Lam[25] reported faster growth and maturation as well as higher fecundity at densities <20 nauplii per l. From our observations it is clear that small inocula (10 to 20 nauplii per l) are generally as effective (at least under normal temperature conditions) and more economical than large inocula since they exhibit a faster population increase when compared to the latter.

The quantity of cysts needed to obtain the number of nauplii needed for inoculation (and taking into account a 30% mortality at stocking) is calculated from the pond volume and the hatching efficiency of the selected cyst batch.[26] Cysts are preferably hatched close to the ponds. Optimal hatching conditions[26] are often difficult to achieve under field situations; nonetheless, the following aspects should be taken into consideration:

- Shaded or roof-covered area should be used to prevent excessive heating of the hatching containers by direct sunlight.
- Transparent, preferably funnel-shaped hatching containers, should be used. If flat-bottomed containers have to be used, they should be equipped with several aeration lines on their bottom so as to provide good mixing and aeration of the water.
- Hatching containers should be illuminated during the night to provide the essential light stimulus,[27] especially when cysts are incubated in late afternoon or evening.
- Air should be supplied from a blower, compressor, or several aquarium pumps powered by the net current, a generator, or batteries.
- Clean 20 to 35 ppt sea water should be used, filtered through a fine filter cloth (100 μm).
- Sodium bicarbonate should be added at a rate of 1 g/l hatching medium so as to buffer the sea water.
- Cyst densities should not exceed >1 g/l, especially under suboptimal hatching conditions.

It is essential to harvest the nauplii in the first instar stage. This is determined from subsamples taken at regular intervals or from hatching rate and synchrony data for the given strain or batch.[28] Older instar stages will not survive the salinity shock when transferred from natural sea water into 100 g/l of salt water. After hatching, the nauplii should be screened over a 125 μm filter, thoroughly washed and transferred to clean sea water or pond water at half their hatching density. They are now ready for inoculation into the pond. If the pond is not within walking distance from the hatching site, aeration should be provided during transport (battery-operated pump or oxygen tank) to prevent mortality. If transport takes several hours, it is best to cool the nauplii container to 0—5°C using cooled sea water or adding ice bags. At these low temperatures the naupliar metabolism and motoric activity are strongly reduced without affecting their viability.[29] Moderate aeration, e.g., with a battery-operated aquarium pump, has to be provided to keep the motionless animals in suspension. In this way about 100 million nauplii can be successfully transported for a period of several hours in a 20 liter plastic bag packed in a cooled styrofoam box. The best time

of the day to inoculate a pond is during late evening when the water temperature is low and will continue to drop until early morning. When the nauplii have been transported at low temperature it is essential to allow the temperature in the containers to rise so that the animals can resume their motoric activity before they are introduced in the pond. Under heavy wind conditions it is important to siphon the nauplii on the leeward side of the pond to avoid having them driven on shore by heavy wave action.

H. FACTORS AFFECTING POPULATION GROWTH

During the first days after inoculation it is very difficult to see the nauplii since they have lost their distinct orange color and tend to concentrate in the deeper parts of the pond. It is only when the nauplii have grown into adults that one may evaluate if the inoculation has been successful. In fertilized ponds, operated under optimal conditions (i.e., temperatures within the tolerance range for the selected strain; pH between 7.5 and 8.5; intermediate salinity levels of 100 to 150 g/l; and presence of sufficient quantities of particulate feed, especially phytoplankton) sexual maturity may already be attained 7 to 10 days after inoculation.[25,30] Under these conditions the parental and the first generations will generally reproduce by ovoviviparity, resulting in a fast increase of the population. The size to which the population will grow is determined by the carrying capacity of the pond. The principal factors which affect this carrying capacity are pond depth, food availability (determined by the concentration of nutrients in the water), and the frequency of water intake which will improve the water quality and result in an extra nutrient influx and better mixing of the nutrients which accumulate on the pond bottom. Aside from quantity, quality of the planktonic algal population may also affect the population growth of *Artemia*. Green algae (e.g., *Tetraselmis* and *Dunaliella*) and diatoms (e.g., *Chaetoceros, Navicula,* and *Pleurosigma*) are a much better food for *Artemia* than planktonic filamentous blue-green algae (e.g., *Lyngbya* and *Oscillatoria*). The latter are too big for *Artemia* to be ingested and clog their thoracopods resulting in starvation of the *Artemia*. Filamentous blue-green algae might predominate in stagnant waters (since green algae and diatoms settle) and in conditions of high concentrations of organic matter, high pH, and low CO_2 levels.[31-33] In this regard, Jumalon and Ogburn[33] found a high correlation between the arrest of water intake rich in CO_2, the collapse of green algal populations, and the development of planktonic filamentous cyanophytes. This implies that regular water intake is important in pond management; i.e., aside from affecting the amount of food, continuous flow also stimulates blooming of particular phytoplankton species more suitable for *Artemia* development.

I. FACTORS CONTROLLING CYST PRODUCTION

Although the factors controlling the mode of reproduction are not fully understood, oviparity in *Artemia* is generally considered to be induced by environmental stress.[34,35] In pond systems, cyst production is often observed when the population is exposed to high salinities (e.g., when the *Artemia* reach the high salinity ponds). Salinity shocks have also been found effective in switching the population toward cyst production[36,37] i.e., abrupt lowering or raising of the salinity through rapid intake of brine of a very different density or at heavy rainfall. In addition, low oxygen concentrations or considerable fluctuations in dissolved oxygen levels reportedly induce oviparous reproduction in *Artemia*.[34,38] This condition stimulates the synthesis of hemoglobin and the consecutive excretion by the brown shell gland of its metabolic end product, hematin, which is the main constituent of the cyst shell of *Artemia*.[39-41] Oxygen stress in pond conditions may be accomplished by raising the salinity and/or by increasing the rate of fertilization to induce blooms of phytoplankton, creating extensive diurnal fluctuations in dissolved oxygen.

Several authors postulated that the frequency of oviparity in *Artemia* is not only correlated with environmental stress, but is also influenced by the geographical strain of *Artemia* which

has been used for inoculation.[20,42,43] In this regard, Gajardo and Beardmore[44] suggested that encystment in *A. franciscana* is under genetic control and is associated at least in part with the levels of heterozygosity found in the females. In view of the considerable interstrain differences in the distribution of heterozygosity,[16] care must be taken in selecting a strain showing high heterozygosity levels; e.g., a strain inhabiting a variable and stressful environment, if cyst production is preferred. Even then, pond management should be directed toward creation of stress conditions to retain the genetic variability in the population and consequently prevent a decline in the cyst production.

It has been observed on several occasions in tropical habitats that newly introduced populations initially exhibit a high rate of oviparous reproduction, followed, however, by a drastic decrease in cyst production as soon as the population has become fully established (adapted to the new environment?) and/or the biotope has become completely stabilized, e.g., in Brazil,[45] Thailand,[12] and Vietnam.[46] This phenomenon was recently observed for the second time in Macau, Brazil: reappearance of cyst production at the end of 1987 and beginning of 1988 was associated with transformation of the local shrimp farm into evaporation ponds for salt production presenting a "new biotope" for *Artemia*. Berthélémy-Okazaki and Hedgecock[47] presumed that this decline in cyst production may be due to harvesting of the cysts leading to a removal of the genotypes predisposed towards oviparity from the population. They suggested that cyst production could possibly be revived by reinoculation with a highly oviparous strain.

J. MONITORING OF ENVIRONMENTAL CONDITIONS AND FOOD PRODUCTION IN PONDS

A basic prerequisite for correct pond management implies regular evaluation of the environmental conditions of the ponds. The physico-chemical parameters to be monitored include (1) dissolved oxygen, readily measured with an oxygen electrode or by Winkler titration;[48] (2) brine densities at the water surface and the pond bottom measured with a refractometer or with Baumé scale hydrometers (see conversion tables for brine density and degrees Beaumé, as well as corrections for temperature in Tables 2 and 3); (3) pH-values using a pH meter; (4) air and water temperatures at water surface and pond bottom with a minimum-maximum thermometer; and (5) water depth, read from a depth gauge.

Since maintenance of a healthy phytoplankton population is considered to be one of the most important keys for a successful *Artemia* production, regular monitoring of nutrient levels and associated standing crops of phytoplankton are important for proper pond management, i.e., rate of water intake, fertilization dressings, and biomass harvesting. The concentration of the major nutrients should be regularly controlled to ensure that no deficiency causing inhibition of algal growth is developing and/or that the ratio of N/P is not becoming too low. This involves analysis of reactive inorganic phosphate (the major form of phosphorus required for algal cells), reactive nitrate, nitrite, and ammonia, preferably by standard colorimetric procedures.[48,49] The phytoplankton population should be analyzed at least once a week. Phytoplankton densities may be determined from a representative sample by direct microscopic counting using a counting chamber. Whenever possible, species composition and cell size of the algal population should be determined, as the first may directly affect the nutritional value of the *Artemia* produced,[5] and the latter determines whether the algal cells (especially when forming chains or colonies) are small enough ($\leq$50 μm) for ingestion by *Artemia*.[50] Records of phytoplankton species commonly found in nutrient enriched salinas were published by Davis[51] and Wongrat.[52] Other parameters to follow in respect to phytoplankton densities are water turbidity, the concentration of chlorophyl, phytoplankton dry weight, and primary productivity. Turbidity may be measured using a colorimeter or a Secchi disk. Procedures for measuring dry weight, chlorophyl, and primary productivity are described in Vonshack,[53] Strickland and Parsons,[48] and Boyd.[54] In situations where the water

TABLE 2
Conversion Table for Various Units of Salinity

Density (g/ml)	Degree Beaumé (°Be)	Salinity (g/l)	Density	Degree Beaumé	Salinity	Density	Degree Beaumé	Salinity	Density	Degree Beaumé	Salinity
1.020	2.8	28.6	1.061	8.4		1.102	13.4		1.141	17.8	
1.021	3.0		1.062	8.5		1.103	13.5		1.142	17.9	
1.022	3.1		1.063	8.7		1.104	13.6		1.143	18.0	
1.023	3.3		1.064	8.8		1.105	13.7		1.144	18.1	
1.024	3.4		1.065	8.9		1.106	13.8		1.145	18.2	
1.025	3.6		1.066	9.0		1.107	14.0		1.146	18.3	
1.026	3.7		1.067	9.2		1.108	14.2		1.147	18.5	
1.027	3.8		1.068	9.3		1.109	14.3		1.148	18.6	
1.028	4.0		1.069	9.4		1.110	14.4	159.5	1.149	18.7	
1.029	4.1		1.070	9.5	99.4	1.111	14.5		1.150	18.8	222.1
1.030	4.2	42.4	1.071	9.6		1.112	14.6		1.151	19.0	
1.031	4.4		1.072	9.7		1.113	14.7		1.152	19.1	
1.032	4.5		1.073	9.9		1.114	14.9		1.153	19.2	
1.033	4.7		1.074	10.0		1.115	15.0		1.154	19.3	
1.034	4.8		1.075	10.1		1.116	15.1		1.155	19.4	
1.035	4.9		1.076	10.2		1.117	15.2		1.156	19.5	
1.036	5.0		1.077	10.3		1.118	15.3		1.157	19.6	
1.037	5.1		1.078	10.5		1.119	15.4		1.158	19.7	
1.038	5.3		1.079	10.6		1.120	15.5	175.1	1.159	19.8	
1.039	5.4		1.080	10.7	114.1	1.121	15.6		1.160	19.9	237.8
1.040	5.5	56.4	1.081	10.8		1.122	15.7		1.161	20.0	
1.041	5.7		1.082	11.0		1.123	15.8		1.162	20.2	
1.042	5.8		1.083	11.1		1.124	15.9		1.163	20.3	
1.043	6.0		1.084	11.2		1.125	16.0		1.164	20.4	
1.044	6.1		1.085	11.3		1.126	16.2		1.165	20.5	
1.045	6.2		1.086	11.5		1.127	16.3		1.166	20.6	
1.046	6.4		1.087	11.6		1.128	16.4		1.167	20.7	
1.047	6.5		1.088	11.7		1.129	16.5		1.168	20.8	
1.048	6.6		1.089	11.8		1.130	16.6	190.6	1.169	20.9	
1.049	6.7		1.090	11.9	128.6	1.131	16.7		1.170	21.0	253.7
1.050	6.8	70.6	1.091	12.0		1.132	16.8		1.171	21.1	
1.051	7.0		1.092	12.1		1.133	16.9		1.172	21.2	
1.052	7.2		1.093	12.3		1.134	17.0		1.173	21.3	
1.053	7.3		1.094	12.4		1.135	17.1		1.174	21.4	
1.054	7.5		1.095	12.5		1.136	17.3		1.175	21.5	
1.055	7.6		1.096	12.6		1.137	17.4		1.176	21.6	
1.056	7.7		1.097	12.7		1.138	17.5		1.177	21.7	
1.057	7.9		1.098	12.8		1.139	17.6		1.178	21.8	
1.058	8.0		1.099	13.0		1.140	17.7	206.3			
1.059	8.1		1.100	13.1	144.0						
1.060	8.2	84.9	1.101	13.2							

TABLE 3
Temperature Corrections (to 20°C) For Density Readings of Concentrated Sea Water

Temp. (°C)		Density range (g/ml at 20°C) from 1.00 to 1.05	1.05 1.10	1.10 1.15	1.15 1.20	1.20 1.25	1.25 1.30
10	Subtract	.002	.002	.003	.003	.003	.003
11	correction	.002	.002	.003	.003	.003	.003
12	from	.001	.002	.002	.003	.003	.002
13	measured	.001	.002	.002	.003	.002	.002
14	density	.001	.001	.002	.002	.002	.002
15		.001	.001	.002	.002	.002	.002
16		.001	.001	.001	.002	.002	.001
17		.001	.001	.001	.001	.001	.001
18		—	.001	.001	.001	.001	.001
19		—	—	.001	.001	—	—
20		—	—	—	—	—	—
21		—	—	.001	.001	.001	—
22	Add	.001	.001	.001	.001	.001	.001
23	correction	.001	.001	.001	.002	.002	.001
24	to measured	.001	.002	.002	.002	.002	.002
25	density	.002	.002	.003	.003	.003	.002
26		.002	.002	.003	.003	.003	.003
27		.003	.003	.004	.004	.004	.004
28		.003	.003	.004	.005	.005	.004
29		.004	.004	.005	.005	.005	.005
30		.004	.004	.005	.006	.006	.006
31		.004	.005	.006	.006	.006	.006
32		.005	.006	.006	.007	.007	.007
33		.005	.007	.007	.007	.007	.007
34		.006	.007	.007	.008	.008	.008
35		.006	.007	.008	.008	.008	.008

contains little or no silt, a good correlation is found between the latter parameters and the water turbidity, the measure of which still is the easiest and most rapid way to determine changes in phytoplankton densities.

K. MONITORING OF *ARTEMIA* PRODUCTION PERFORMANCE

Precise estimates of *Artemia* densities are difficult to make because of the heterogenous distribution in ponds which is influenced by wind, water temperature, light, pond depth, etc.[55,56,57] Nevertheless, rough estimates of *Artemia* densities, among other field data, may provide a valuable tool to assess the rate of biomass harvesting. Water samples should be taken at weekly intervals from fixed stations scattered throughout the pond, in the ditch as well as in the central part or along fixed transects. Sampling is preferentially done as early as possible in the morning when *Artemia* are more uniformly distributed.[24,25] Samples may be taken with a specific sampler[24] or with a variety of containers such as beakers, buckets, etc. When using the latter sampling procedure, it is advisable to thoroughly mix the water column so as to stir up bottom-dwelling *Artemia*.[58] The number of samples to be taken from a pond depends on the distribution of the *Artemia* as well as on the volume of the sample and the abundance of *Artemia*. This may be estimated by calculating the coefficient of variance (CV, variance/mean density), i.e., the lower the CV value, the more precise the sampling.

Of essential importance in pond management (e.g., rate of biomass harvesting, fertilizer

TABLE 4
Examples of Population Composition in *Artemia* Pond at Various Time Intervals (A through H)

Sampling time	Nauplii	Juveniles	Preadults	Adults	Cysts
A	+ +	–	–	–	–
B	–	–	+	+ +	–
C	+ +	–	–	+	–
D	+	+	+	+	–
E	+	–	–	+ +	–
F	–	–	–	+ +	–
G	–	–	–	+ +	+
H	+	+	+	+	+

addition, pond retention time, etc.) is the population composition, which provides valuable information on the population dynamics of *Artemia* in the ponds. The population composition should be analyzed from representative samples taken at weekly intervals from several places in the pond (e.g., combined with the density sampling). Samples containing large numbers of animals may be subsampled until they contain 200 to 300 animals. The *Artemia* are categorized into five classes: cysts and/or nauplii (Instar I—IV), juveniles (Instar V—VII, larvae with developing thoracopods), preadults (adult size but not yet reproductively active), and adults. These classes may be distinguished under a dissection microscope or by pouring the *Artemia* over three successive filter screens with mesh sizes of about 500, 375, and 125 μm which respectively retain adults and preadults; juveniles; and nauplii and cysts. The adults and preadults can easily be separated by eye. The (relative) presence of each *Artemia* class is expressed as percentage of the total number of *Artemia* counted in the plankton sample or is evaluated as follows: – absent; + present; + + dominant presence. Of further interest is the evaluation of the reproductive activity of the females; i.e., empty or full broodsacs and nauplii or cysts bearing. Table 4 shows a typical example of the population composition in an *Artemia* pond at various time intervals. The population changes over one-week intervals, from A through D, reveal a very healthy population; e.g., inoculation (A), growth up to preadult and adult stage (B), first generation of nauplii released (C), and continuous reproduction and good growth conditions (D). However, a population composition remaining for consecutive weeks (E) eventually evolves into a situation which reveals food-limiting conditions (F); e.g., initial algal concentrations are still sufficient for the adults to ensure reproductive activity but too limited for the nauplii which have a lower feeding efficiency than adults; subsequently (F) food becomes too scarce even for the adults. When oviparity is the dominant mode of reproduction no population recruitment is observed (G); in heavily fertilized ponds a mixed reproductive activity is often observed (H).

L. STRATEGIES FOR CULTURE MAINTENANCE

The information collected from the monitoring programs is used to make appropriate decision about pond management. Optimal conditions for biomass production are at the lower salinity levels (100 to 150 g/l) and under conditions of very regular food availability. When transparency levels are high (>30 cm), and pond nutrient levels become undetectable or fall below levels found in the intake water, fertilizer dressing or intake of nutrient-rich water (e.g., from a feed production pond) should be considered. During temperature/salinity stratification (which causes lethal high temperatures for *Artemia*) or when planktonic blue-green algae become dominant, the bottom flow of water from pond to pond should be maximized. Selection of desirable phytoplankton species and/or the prevention of the development of undesirable cyanophytes which have the ability to fix atmospheric nitrogen may also be aided by supplemental fertilization with specific nutrients; e.g., through ap-

plication of nitrogen fertilizer during conditions where nitrogen is limiting but phosphorus is abundant, or through application of silicate in low salinity ponds to enhance the growth of diatoms, which are rich in the desired highly unsaturated fatty acids.

Sustained population growth also entails regular harvesting of the biomass so as not to exceed the carrying capacity of the pond. Insufficient harvesting may lead to a complete removal of the food (even in ponds with high nutrient levels) due to the high grazing pressure of increasing numbers of *Artemia*, eventually leading to a collapse of the population. Similarly, over-harvesting may reduce the grazing pressure on planktonic algal blooms which may deleteriously affect the salt production.[4,9] Ideally, the rate of biomass harvesting should approach the maximum sustainable yields. Since a precise estimation of the latter is impossible, the rate of biomass harvesting should be assessed from estimation of density, population composition, fertility parameters, and phytoplanktonic standing crop (e.g., estimated by water turbidity levels). In situations where densities increase over time with a population composition showing all *Artemia* classes represented, combined with a dominant ovoviviparous reproduction, biomass is being renewed at a high rate. In this case and when transparency levels increase, indicating that the primary production rate cannot sustain the grazing pressure of the *Artemia* population, frequent harvesting of biomass is recommended. If on the other hand, densities are decreasing and/or the population consists mostly of preadults and adults showing low fecundity and/or dominant oviparous reproduction, harvesting should cease.

In Section II.I. of this chapter we described the factors which induce cyst production. Production of cysts may naturally occur in the high salinity ponds. It may also be induced, even at low salinity levels, by increasing the rates of fertilization or by applying through salinity shocks of 10 to 20 g/l rapid intake of low salinity brines. Oviparity, however, should only be induced when the population density is sufficiently high since during conditions of dominant cyst production, recruitment will be inhibited, eventually resulting in a gradual decrease of the population due to constant mortality.

M. HARVESTING AND QUALITY CONTROL

Produced cysts float at the surface and accumulate along the windward side of the pond. They can be easily collected from the water surface with a double-screen dip net (Figure 5). Cysts should be harvested as soon as possible after production (accumulation) in order to ensure maximum recovery and hatching quality because:

- Cysts washed ashore are difficult to harvest as well as to clean; in addition they will dry and may eventually become airborne.
- Cysts may be exposed to temperatures >40°C which are lethal for hydrated cysts.[26]
- Cysts may be exposed to repeated hydration/dehydration cycles (rainfall, high humidity) and lose part of their energy reserves[59] resulting in a decreased hatchability.[26]

In order to prevent the cysts from being washed ashore and to facilitate harvesting, the windward pond corner or side should be steepened or lined with a cyst barrier, e.g., corrugated plastic. When winds develop heavy waves, foam is built up in which cysts are trapped and then blown away. In this case wave breakers should be installed in two or more rows parallel to the cyst barrier (Figure 6).

Harvested cysts may undergo an on-site cleaning by washing the harvested product with saturated brine or water from the pond over screens with different mesh widths (e.g., 1000, 500, 125 μm) in order to remove debris larger and smaller than the cysts. This wet-dry product stored in brine or mixed with crude salt (for proper dehydration) may be an acceptable product for local use, provided it is consumed within a few weeks. For the production of high quality cysts with optimal hatchability, maximum purity, and storability, the following

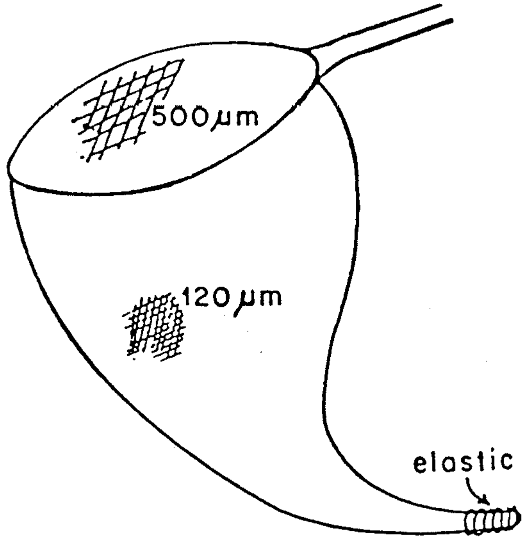


FIGURE 5. Double screen dip net for cyst harvesting. (From Sorgeloos, P., Lavens, P., Léger, P., Tackaert, W., and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture*, Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

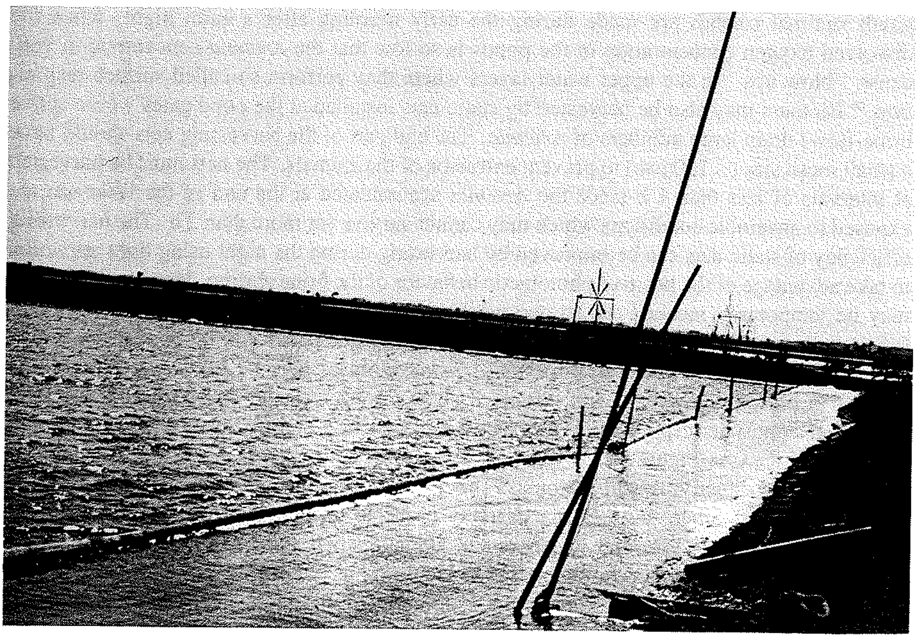


FIGURE 6. Floating bamboo poles used as a wave breaker for the harvesting of *Artemia* cysts. (From Sorgeloos, P., Lavens, P., Léger, P., Tackaert, W., and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture*, Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

additional processing steps are however required: (1) density separation in brine to remove heavy debris in the same size range of the cysts; (2) rapid washing in fresh water to remove salt; (3) density separation in fresh water to separate full cysts from empty cysts and other small light debris — this step should not take longer than 15 minutes in order to prevent elevated hydration levels which may initiate cysts metabolism; (4) removal of excess water by squeezing or centrifuging the cysts; and (5) drying in order to reduce the water level in the cysts below the critical level of 10% (preferably between 2 and 5%) in order to arrest the metabolic activity in the cysts. Optimal cyst quality in terms of hatching efficiency, hatching rate, and energy content is obtained by fast and homogeneous drying of all cysts at temperatures just below 40°C.[84] Among the different drying techniques, optimal results are obtained when the cysts are kept in continuous movement in the drying air; i.e., each cyst is dried individually at the same time. This may be accomplished in a fluidized bed dryer (Figure 7) or a rotary dryer (Figure 8). If the latter equipment is not available, cysts may also be dried on drying racks on which the cysts are spread in thin layers of uniform thickness (few mm only). The drying racks are placed in the open air, protected from the sun to avoid temperatures higher than 40°C, or in a temperature-controlled room or oven at 35 to 38°C provided with good air exchange. Homogeneous drying is enhanced by granulating the cysts upon distribution on the drying racks through a 3 mm screen and by regular brushing (initially every h) of the cysts. Table 5 shows the effect of drying conditions on the hatching efficiency of cysts in Lavalduc, France. For more details with regard to cyst processing and drying, we refer to Sorgeloos et al.[26]

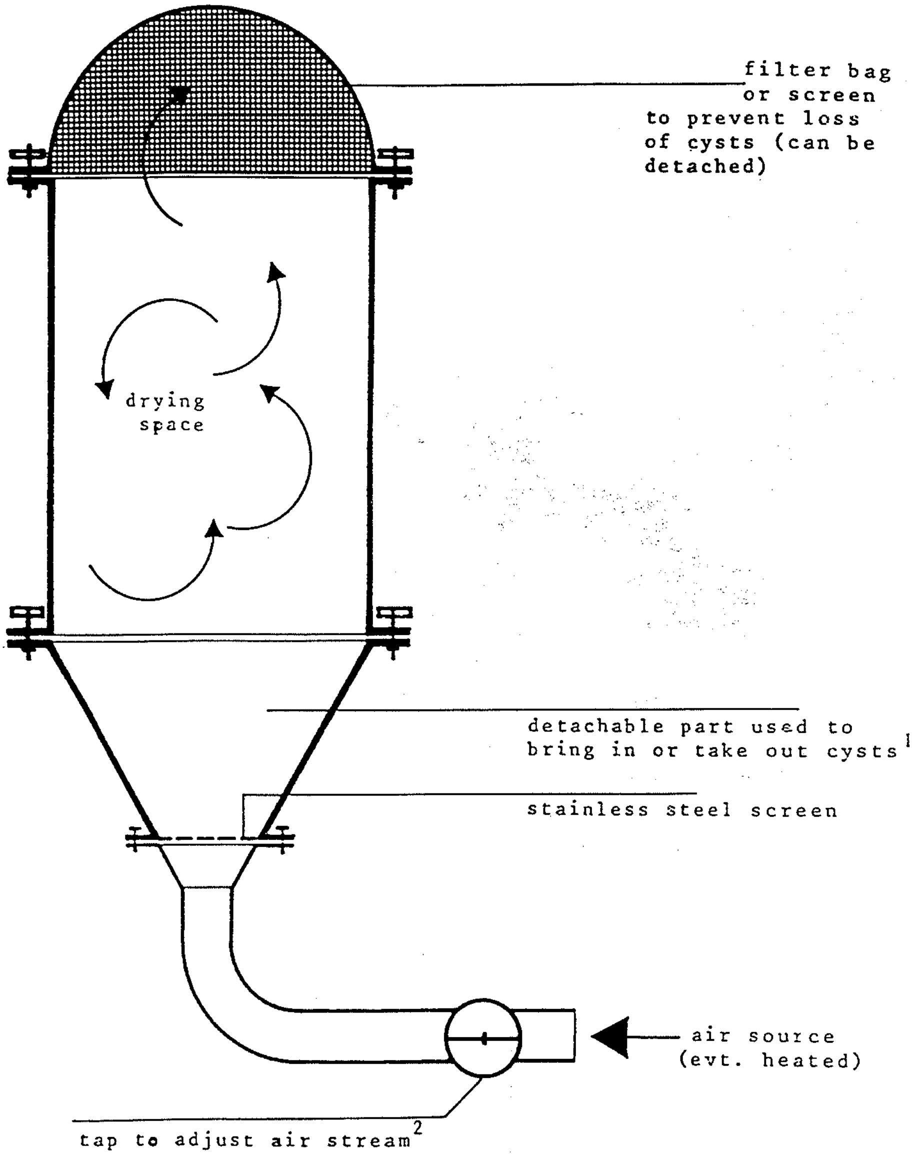
For long-term storage, cysts should be packed in air tight containers (cans) under vacuum or nitrogen.

Adult biomass may be harvested manually with a dip net (in small ponds) or with a conical net (see Figure 9) which can be towed over the entire pond. In highly eutrophic ponds optimal catches are made during the early morning after a calm night, when the dissolved oxygen concentration in the ponds is so low that the *Artemia* concentrate in very dense "blow-ups" in the upper water layers where they perform so-called surface respiration.[26] Biomass may also be harvested by static nets installed at the pond gates where active brine-flows drain large numbers of *Artemia*. The end part of the harvesting nets should have a small mesh size (<100 μm) to prevent extrusion of the animals. The nets must be harvested at intervals of less than 1 h since the *Artemia* accumulated at the end of the filter sac are exposed to anaerobic conditions which they cannot survive for more than 2 h. The harvesting efficiency of static nets can be improved by harvesting during the night using light attraction to take advantage of the positive phototactic behavior of the brine shrimp. Harvested biomass may be temporarily stocked (up to one week) in nylon screen cages (e.g., 1.5 × 2.0 × 0.5m) with a mesh width of 800 μm, which are suspended in the culture ponds (see Figure 10). For long distance live transport, the *Artemia* biomass may be packed at densities of 100 g/l in plastic bags filled with one-third cooled pond water (5 to 10°C) and two-third oxygen at atmospheric pressure. The bags are placed in a styrofoam box together with a few bags of ice (see Figure 11).

If not used directly, *Artemia* biomass should be frozen or dried after thorough washing with fresh water. Since *Artemia* is extremely prone to decomposition (due to proteolytic enzyme activity) it is essential to freeze the animals when still alive. In order to ensure optimal quality, the biomass should be frozen as quickly as possible in a blast or plate freezer (−25°C or lower) in thin layers (maximum 1 cm thick) or in small ice cube trays. A properly frozen product when thawed in water, yields only intact animals and does not pollute the water by leaching of body fluids (see Figure 12 for quality control).

N. SPECIFIC MODIFICATIONS FOR FURTHER OPTIMIZATION OF *ARTEMIA* PRODUCTION

Since pond production of *Artemia* requires the availability of high salinities to exclude



[1]conical shape results in differences in air pressure and assures better mixing of the cysts

[2]more pressure is needed at the start (heavy cysts containing much water before dehydration) than at the end (light cysts with low water content) to keep the cysts suspended in the drying chamber.

FIGURE 7. Schematic drawing of fluidized bed dryer for *Artemia* cysts. (From Sorgeloos, P., Lavens, P., Léger, P., Tackaert, W., and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture*, Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

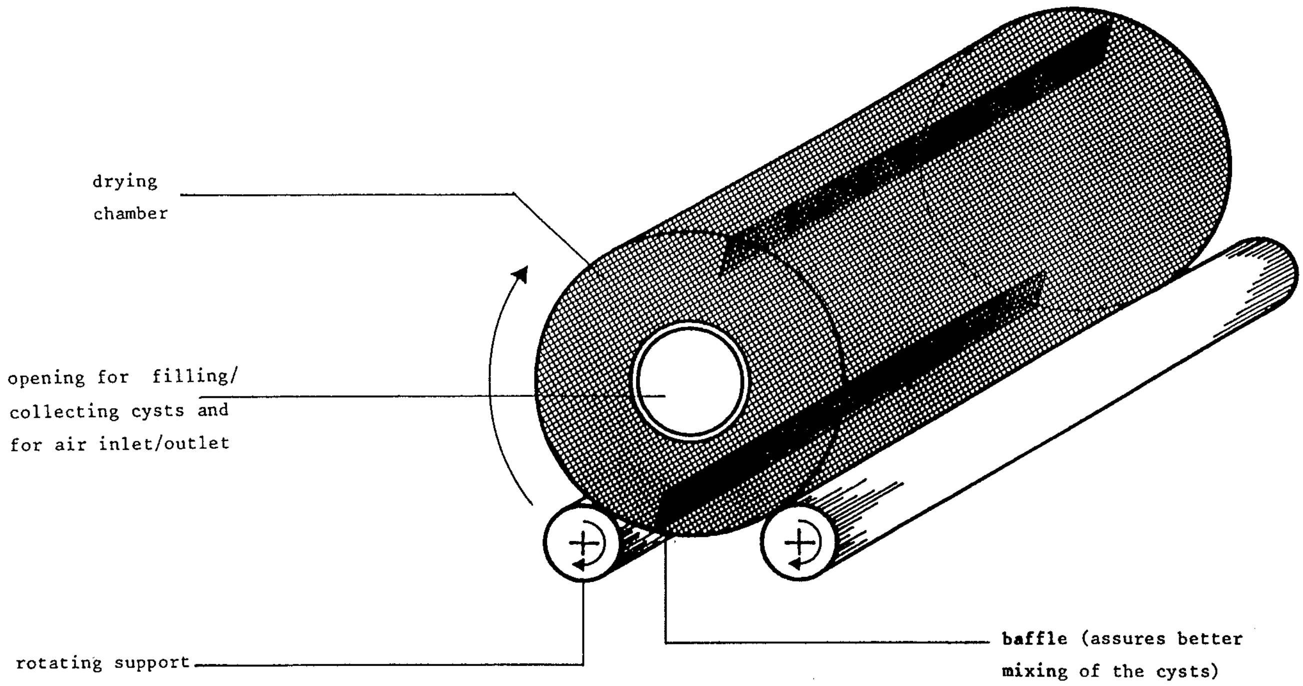


FIGURE 8. Schematic drawing of rotary dryer for Artemia cysts. (From Sorgeloos, P., Lavens, P., Léger, P., Tackaert, W. and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture*, Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

TABLE 5
The Effects of Drying Conditions on the Hatching Efficiency of Cysts from Lavalduc, France[a]

Drying conditions			Hatching efficiency (nauplii/g cysts)	
Method	Temp. (°C)	Thickness of cysts layer (cm)	X[b]	SD[b]
Oven dryer				
	30	1.5	69,120	9,760
	30	0.5	149,600	10,240
			(154,120)	(7,600)
	38	1.5	150,880	7,200
	38	0.5	181,360	9,600
			(179,200)	(10,100)
Fluidized-bed dryer	35		182,400	6,400
			(181,960)	(6,920)
Control (unprocessed cysts)			178,640	(8,840)

[a] Data compiled from Sorgeloos et al.[26]
[b] In parentheses, data for same cysts but after 1-month storage under vacuum.

predators, the production season in monsoon climates is basically limited to the dry season only. Nevertheless, a significant extension of the production season may be realized by the installation of overflow devices (e.g., PVC turndown pipes and level controlled gates) in order to allow decanting of stratifying layers of rain water, combined by rigorous control of predators (e.g., through screening of intake water by means of a bag screen or semicircular screen mounted to or surrounding the gate/pump). Year round production of biomass has been successfully applied in both the Philippines[11] and Thailand[12] at salinities of 60 to 80 and 70 to 90 g/l, respectively.

In farms having brine reservoirs, salinity control during the rainy season may further be facilitated by the recirculation of surplus brine from these reservoirs into the *Artemia* ponds. In addition, this practice allows for maximal water exchange (essential for good phytoplankton production) and salinity manipulation (e.g., salinity shocks for the induction of cyst production). Another specific modification beneficial for *Artemia* production under high temperature conditions involves the installation of shading platforms (e.g., made of coconut fronds). De los Santos et al.[60] reported that *Artemia* tend to concentrate under this shade to escape lethally high temperatures occurring on sunny days.

III. PRODUCTION FIGURES OF *ARTEMIA* IN FERTILIZED PONDS

Table 6 shows production figures of *Artemia* cysts and biomass in different man-managed saltfarms. Although the most successful farms yield 10 to 20 kg dry weight (dw) cysts and/or 100 to 375 kg wet weight (ww) biomass/ha/month, there is considerable variation from farm to farm, mainly as a result of differences in farm management. A survey of salt *cum Artemia* farms in Thailand in 1983,[61] revealed that poor production in the Samut Sakorn and Phetburi area (see Table 6) were correlated with low pond water depths, inappropriate local conditions such as acidity of the soil, and insufficient fertilization. Poor farm management including lack of pumping and application of cow dung instead of the previously

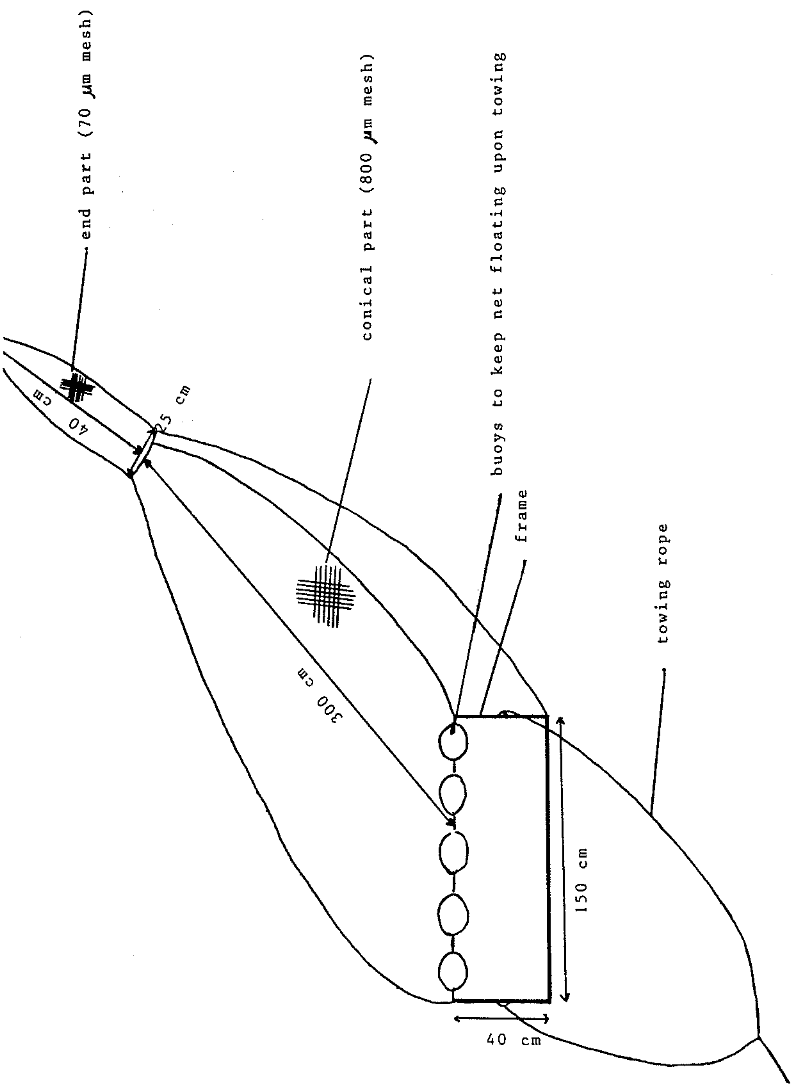


FIGURE 9. Conical harvesting net for *Artemia* biomass.

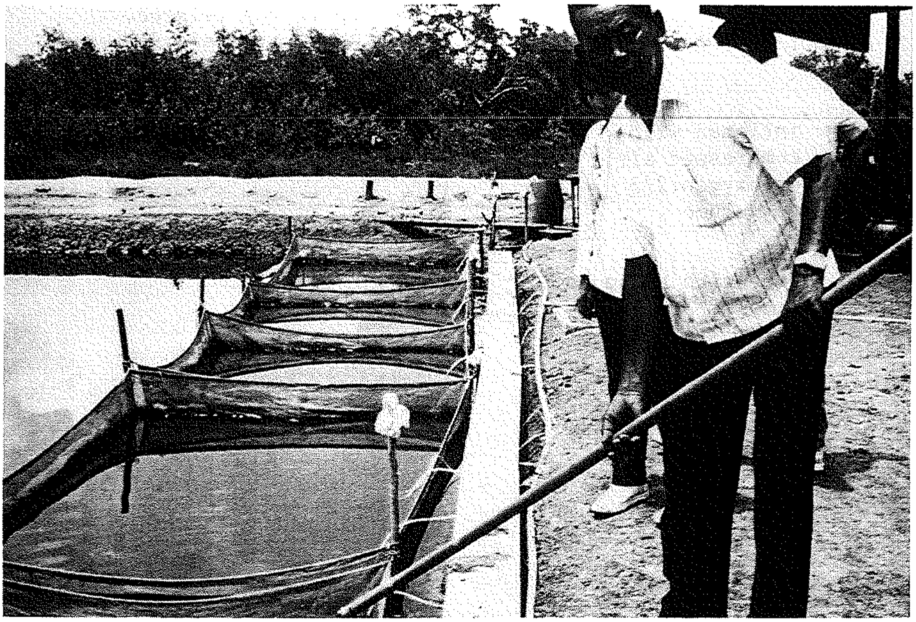


FIGURE 10. Storage net for *Artemia* biomass produced in seasonal salt ponds in S. E. Asia. (from Sorgeloos, P., Lavens, P., Léger, P., Tackaert, W., and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture*, Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

used chicken manure resulted in the development of lab-lab and overall food-limiting conditions. These were also responsible for the sharp decrease in cyst productions in Vinh Chau, Vietnam (area not specified) in 1988 (29.1 kg ww) as compared to 1987 (120 kg ww).[15] On the other hand, Vu Do Quynh and Nguyen Ngoc Lam[25] found that the introduction of a flow-through type management in Cam Ranh Bay, Vietnam improved the cyst yield from 1.4 — 6.8 to 8.6 kg of dw cysts/ha/month.

Recently, biomass has been the product of preference (especially in Thailand) largely because it is easier to master than cyst production, which in most farms has remained inconsistent. Biomass production furthermore offers new local marketing opportunities; e.g., during the dry season in Thailand more than 3000 kg of locally produced biomass is being harvested and consumed on a daily basis as a starter feed in shrimp nursing.[85]

IV. SOCIO-ECONOMIC ASPECTS AND BENEFITS OF SALT *CUM ARTEMIA* PRODUCTION

Seasonal solar-salt production as practiced in Southeast Asia, Central America, East Africa, etc. is a labor-intensive activity generating employment for thousands of families. Its profitability, however, is usually limited, largely because of the low yields and the poor quality of the salt produced, owing to the small scale and artisanal manufacturing practices of this type of salt operation. In Viet Nam, for example, the mean annual income/worker in 1987/1988 was equivalent to 30 kg of rice.[15] In Thailand, the revenue of solar salt production has drastically decreased due to competition from rock-salt mining.[12] In fact, in many countries (e.g., Thailand, Panama, and Costa Rica) hundreds of those family-operated saltfarms are being abandoned for socio-economic reasons.

The profitability of these seasonal saltfarms can be considerably improved by integrating

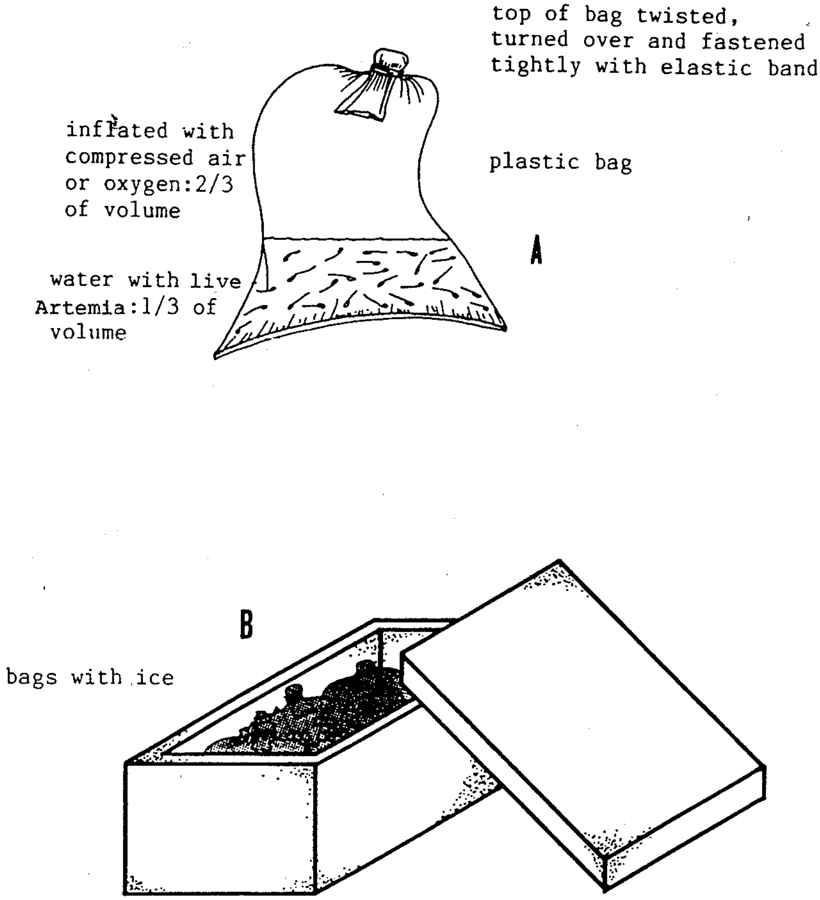


FIGURE 11. Live transport of *Artemia*—transport bag (A) and styrofoam box (B). (From Sorgeloos, P., Lavens, P., Léger, Ph., Tackaert, W. and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture,* Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

Artemia production with solar-salt production. Based on a survey of five salt *cum Artemia* farms in Thailand, Vanhaecke[61] estimated that the total cost required for pond modification and operation of one ha *Artemia* pond was about 2040 U.S. dollars. Assuming a production of 180 kg ww cysts and 500 kg ww biomass/ha (extrapolated from average production figures of farms that adopted proper pond modification and good biological management) at average market prices of $16 and $4.4/kg respectively, the average benefits from *Artemia* production amounted to $3040 and $3870 in the first year and $3870 in the following years of operation. This represents an additional income almost triple of that derived from salt.[12]

During recent years salt *cum Artemia* production has become a profitable business. The latest data for Thailand[62] reveal annual revenues from *Artemia* biomass production of over $14,000 (for average production yields of 260 to 375 kg/ha/month on a year round basis and wholesale prices of about $4/kg). Integrated *Artemia* production is not only attractive from a socio-economic point of view, it also stimulates the development of local aquaculture (especially in those countries which do not have hard currency for importing *Artemia* cysts, e.g., Vietnam, Bangladesh, etc.) through the local availability of cheap *Artemia* products.

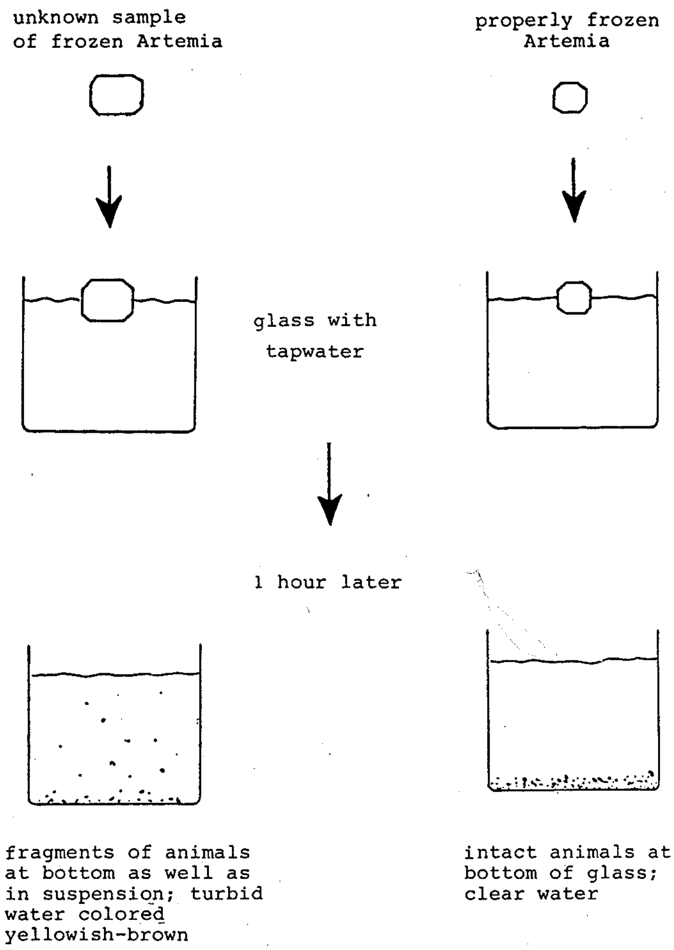


FIGURE 12. Quality control of *Artemia* biomass. (From Sorgeloos, P., Lavens, P., Léger, P., Tackaert, W., and Versichele, D., *Manual for the Culture and Use of Brine Shrimp Artemia in Aquaculture*, Artemia Reference Center, State University of Ghent, Belgium, 1986. With permission.)

TABLE 6
Production of *Artemia* Cysts and Biomass in Man-Managed Saltfarms

Country	Location	*Artemia* production (kg) Cysts	Biomass	Ref.
Thailand	Chonburi	23.1 (dw/ha/month)	52.5 (ww/ha/month)	61
Thailand	Samut Sakorn	5.2 (dw/ha/month)	61.7 (ww/ha/month)	61
Thailand	Phetburi	3.0 (dw/ha/month)	27.2 (ww/ha/month)	61
Thailand	Cha-Choengsao	17.5 (dw/ha/month)	14.4 (ww/ha/month)	61
Thailand	Samut Songkram	15.3 (dw/ha/month)	51.5 (ww/ha/month)	61
Thailand		25.0 (ww/ha/month)	—	12
Thailand	Tambon Klong Tamru, Chonburi	—	260—375 (ww/ha/month)	62
Thailand	Cha-Choengsao	5.0 (ww/ha/month)	—	58
Philippines	Barotac Nuevo	5.0—18.6 (dw/ha/month)	29.4 (ww/ha/month)	60
Philippines	Negros Oriental	20.0 (dw/ha/month)	2000—7000 (standing crop/ha)	11
Viet Nam	Cam Ranh Bay	1.4-6.8-8.6 (dw/ha/month)	—	25
Viet Nam	Vinh Chau	3.2-3.4 (dw/ha/month)	—	15
Viet Nam	Vung Tau	5.0 (dw/ha/month)	—	63
China	Xuwen County	74.6 (dw/ha/year)	—	64
Peru	Virrilla	35.0 (ww/ha/month)	0.06 (standing crop/m^3)	65
Indonesia	Madura Island	38.0 (dw/ha/month)	—	66
Jamaica	Portland Cottage	8.2 (dw/ha/month)	—	67

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EXTENDED ABSTRACTS

COLLOQUIUM

MARINE RESEARCH IN FLANDERS

- 20 YEARS IZWO -

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