Present status and prospects of the use of Artemia cysts and biomass in shrimp farming

Patrick Lavens and Patrick Sorgeloos

Laboratory of Aquaculture & Artemia Reference Center
University of Gent,
Rozier 44, 9000 Gent, Belgium
Fax: 32-9-2644193
e-mail: patrick.lavens@rug.ac.be


Key words: Artemia, cysts, biomass, hatchery, penaeids

Abstract

This paper gives an overview of the history of Artemia cyst provision worldwide since the 1950s. It allows to better assess the current situation characterised by poor yields from the main harvest site, the Great Salt Lake in Utah –USA, and to make prognoses about future supplies and demands.

The second part reviews the optimisation of the use of brine shrimp nauplii, decapsulated cysts and biomass in shrimp hatcheries and nurseries. It includes also the latest research developments with respect to the use of frozen Artemia biomass, possibly enriched with specific nutrients, as a supplement in broodstock diets to improve shrimp maturation.
Introduction

The number of penaeid hatcheries actually producing nauplii and/or post-larvae has steadily increased over the years. In 1997, over 5000 hatcheries were in operation worldwide, of which 90% are located in the Eastern Hemisphere (Rosenberry, 1997). This regional difference is due to the type of hatchery that is being operated. In SE-Asia, hatcheries are usually operated by a family on a small scale and adopting a green thumb, low-technical approach, whereas in the Americas large-scale multi-million dollar hatcheries are in operation. With the development of aquaculture, and especially shrimp production, the use of brine shrimp Artemia, although not a natural diet, became widespread, due to its convenience and its nutritional value for larval organisms (Léger and Sorgeloos, 1992). The fact that dormant cysts of Artemia can be stored for long periods in cans, then used as an off-the-shelf food requiring only 24h of incubation, makes them the most convenient and least labor-intensive live food available for the culture of larval penaeid species (Léger et al., 1986).

Artemia is offered as of the late zoea stages when the larvae can catch and ingest such big prey. As prey size is critical, even with the smallest brine shrimp strains, various techniques are applied: feeding pre-hatching stages, heat-killed freshly hatched nauplii or frozen nauplii of Artemia. Later in the mysis stage live freshly hatched nauplii can be used. Postlarval stages will readily take up brine shrimp metanauplii (>800μm). Dry formulated feeds are also popular from Zoea II onwards, but they don’t work on a 100% replacement basis for the live food.

2. Situation of Artemia cyst provision until 1997

Back in the early 1950s the initial commercial sources of cysts originated from the coastal saltworks in the San Francisco Bay (SFB), California-USA and an inland biotope, the Great Salt Lake (GSL) in Utah-USA. Artemia was marketed for the aquarium pet trade at a low price, i.e. less than 10$ per kg (Bengtson et al., 1991). Cyst prices increased considerably in the mid 1970s as the combined result of increased demands from the emerging hatchery activity, decreased harvests from the GSL and possibly simulated shortages by certain commercial companies. Based on research performed at the University of Gent in Belgium the idea was launched at the 1976 FAO Technical Conference on Aquaculture in Kyoto (Japan) that the cyst shortage was a temporary problem that could be overcome by the exploration and development of new Artemia resources and by the application of improved methods for cyst processing and use (Sorgeloos, 1979). By 1980 the situation had improved with several new commercial products from natural (e.g. Argentina, Australia, Canada, Colombia, France, PR China,) and man-managed (e.g. Brazil, Thailand) Artemia production sites. However, cyst quality in terms of hatching rate and nutritional composition proved to be highly variable, not only among the various strains and species of Artemia, but also among the various batches of the same location. During the 1980s new methods for evaluating and manipulating the hatchability of the cysts and the nutritional composition of the nauplii were adopted, mainly thanks to the efforts of the research group ‘International Study on Artemia’. At the same moment at GSL there was an important switch in the harvesting technology applied. Artemia was collected from the lake’s surface instead of from the shore and together with airplane spotting of the cyst streaks, it resulted in a tenfold increase in yield (> 200 tonnes/y of processed product) and an improved hatching quality. Consequently, there was a dominant presence of GSL cysts on the world market from the mid-eighties onwards. More than 90% of the world’s commercial harvest of brine shrimp cysts derived from GSL and sufficient high hatching product was available to fulfil the market needs. Bengtson et al. (1991) warned that this is a critical situation as a bad harvest year at GSL could have a major impact on provision and price of Artemia cysts for the larviculture industry at large.
In the meantime cyst consumption had increased exponentially as a result of the booming shrimp and fish hatchery industry. In 1997, some 6000 hatcheries required over 1500 metric tons of cysts annually. Approximately 80 to 85% of total *Artemia* cyst sales were for the shrimp hatcheries, the remaining part mainly went to the marine fish larviculture in Europe and East Asia, and the pet fish market. Again, GSL was able to fill that gap by increased harvesting efforts: more companies and more harvesting permits (Table 1), very efficient and cost-effective harvesting/processing techniques. The remaining part (10%) of the world's provision of cysts in the nineties derived from a number of locations with a limited production or harvesting/processing capacity, mainly natural sites in North & Central China and Siberia and semi-natural or managed sites in the San Francisco Bay area, S-Vietnam, Colombia and NE-Brasil.

This resulted in a new vulnerable situation of dependence on virtually one resource. In an average year the Great Salt Lake produces about 4000 tonnes of raw, wet cyst material. Processing reduces this raw harvest to approximately 1200 tonnes of processed, commercial product of good hatching quality. However, since the lake is a large (South Arm today is 2900 km² and North Arm is 1750 km²) natural ecosystem, climatic and other environmental changes may interfere which make that large, often unpredictable, fluctuations in harvest occur from year to year (Table 1). E.g.,

- low number of cysts produced as a consequence of a slow build up of the *Artemia* population, low food availability (fluctuations in primary production), no switch from ovoviviparous towards oviparous reproduction
- potential harvest period (fishing season runs from October to January) reduced because of bad weather (storm, fog) which does not allow boats to reach the cyst streaks, early cyst breaking, or because of restrictions issued by the Utah Division of Wildlife Resources
- potential harvest quantities reduced because of cyst streaks contaminated with dying biomass or because cysts have buoyancy problems.

The environmental changes may furthermore influence the dormancy capacity and thus final hatchability of the cysts produced (see review of Lavens and Sorgeloos, 1987).

As a consequence, the poor yield from the Great Salt Lake during the 1994-95 cyst harvesting seasons (Table 1) resulted in a temporary but severe cyst shortage in 1995 (Sorgeloos and Van Stappen, 1995). With increasing cyst prices and awareness of the critical situation for the aquaculture industry, several *Artemia* resources were revisited and/or explored with respect to their commercial potential. These resources were situated mainly in Central Asia: i.e. Lake Urmiya in Iran, Abi Lake in P.R China, Bolshoye Yarovoje in Siberia, several lakes in Kazakstan, Lake Kara Bogaz Gol in Turkenistan, salt lakes in Argentina.

3. Actual situation & future prospects of *Artemia* cyst availability

The last harvesting season at the Great Salt Lake (1997/98) was again bad, resulting in a total yield of only one third of that of the previous two seasons. Also the quality of the harvested product was low, resulting in processed cysts of a medium-hatching rate (70%). Moreover, it is expected that this situation will not improve much during the next season(s) since biotope conditions have become rather unfavourable for brine shrimp production. Over the last decade, there has been a continuous decrease in salinity in the Southern arm. Furthermore, during the past 18 months and most likely as a consequence of the 'El Nino' climatic phenomenon, a torrent of fresh water has entered the lake and reduced salinity in most areas below the level favoured by *Artemia*. Such low salinity (i.e. <90ppt) allows the entrance of predators (e.g. Corixidae beetles, fish), has a negative impact on primary production composition and mode of reproduction of the brine shrimp, and reduces the floating capacity of the fewer cysts produced. An analogous situation happened during the previous big 'El Nino' of 1983, but then the North Arm of GSL took over as cyst-producing site. This because culverts and openings through the railroad causeway that is dividing the
lake allowed the influx of large bodies of low salinity water from the South arm, and reduced
the salt concentrations in this high-saline biotope to levels acceptable for brine shrimp
production. Since years, however, these connections have not been maintained. They are
partially blocked and this has led to an almost saturated brine situation (240ppt) in most parts
of the North Lake. Although the government is undertaking actions to restore the water flow,
it is not likely that brine concentrations for optimal Artemia production will be installed in the
next years.

This situation supports a further intensification of the exploitation of promising natural
sites as listed above, and the exploration of new locations in semi-arid areas (Vanhaecke et
al., 1987; Triantaphyllidis et al., 1996). Several of these sources may have a production
potential equal to GSL, as a lot of Asian product is available on the market now. However, it
remains difficult to give good estimations for the future since little information is available on
the ecology of these Artemia habitats. This means that no stable cyst provisions can be
guaranteed, but the diversification of sources will limit the risks of sudden shortages due to
environmental changes.

In addition, smaller quantities (1-20 tonnes each) of mostly good hatching quality are
expected to be provided on a more continuous basis from man-managed ponds and
saltworks worldwide (CA-USA: Schmidt, pers. comm.; NE-Brasil: Camara, 1996; Vietnam:
Baert et al., 1997; Java-Indonesia: Kontara, pers. comm.; Chili, Colombia, Peru, Eritrea,
Madagascar, India, Pakistan, Thailand: Triantaphyllidis et al., 1998; pers. communications).
These small-scale cyst productions, although technically very successful in several countries
in SE-Asia and Latin America (Sorgeloos, 1987), are not expected to contribute significantly
to the world’s cyst supplies. Nevertheless, they provide interesting opportunities for local
commercial developments, especially in developing countries with importation restrictions.
Local cyst availability is here an important asset in the development of a viable hatchery
industry (Vu Do Quynh, 1987).

The latter developments, if well followed-up, may provide in total several thousands of
tonnes of harvestable cysts. Their operation, however, will be cost/market driven and high
productions at GSL will automatically result in a drop of interest and profitability. Also, there
are often differences with the ‘classic’ GSL product that require attention when applying them
in penaeid shrimp hatcheries. A few examples may illustrate this:
- deactivation of the dormancy status of Central Asian cysts seems to be difficult,
  which limits the hatching performance of the product
- the classical techniques for cyst decapsulation are not applicable as such with
cysts from central Asia without losing their viability
- most of the parthenogenetic strains from Asia have a large cyst size
- little information is available on the nutritional quality of these sources

Therefore, we strongly recommend that Artemia companies provide exact information on the
origin and characteristics of the cyst products they market, and that no blends of different
sources would be processed as has happened in the past. It will anyhow be possible in the
very near future to identify the origin of commercial cyst products by means of a DNA-
fingerprinting technique recently developed in Belgium (Bossier et al., in preparation).

Remains then the question what will be the future demand of cysts. Again it is difficult
to assess yearly requirements as a number of factors may interfere. First, it remains hard to
predict the increase in numbers of fry produced by the fish and shrimp hatcheries. Generally,
it is expected that larviculture outputs of marine fish worldwide will further increase
(Sorgeloos and Léger, 1992), implying a higher need of cysts. However, today the biggest
demand is for the shrimp hatcheries (>80%). The operation of these hatcheries depends in
the first place on the needs for juveniles by the grow-out farms. Although the high market
prices for shrimp induce a keen interest for expansion of the shrimp business, production
increases might not be at the same pace as in the past. They may be limited because of a
new policy for responsible aquaculture, involving lower stocking densities and less land converted into new ponds. Also disease outbreaks may limit farm operation in certain areas (e.g., Thailand, 1996). In the second place, hatcheries may remain temporarily out of operation when there is an abundant supply of wild seed, which is unpredictable (e.g., during the 1997 ‘El Nino’ year in Ecuador).

On the other hand, cyst shortages encourage the application of modified feeding strategies during the hatchery cycle, reducing the quantities of Artemia required. Artificial diets will certainly gain in popularity in the near future as they reduce problems and risks involved in the production of live food. Furthermore, they could better meet the food size requirements of the predator and be more energetically effective (Léger & Sorgeloos, 1992). Quite a number of products are already commercially available, but their nutritional composition, digestibility and physical performance, especially regarding suspension in the water column and leaching, need to be further optimised before they can completely replace live food. Their application may also depend on the goal the hatchery wants to achieve, i.e. production of high numbers of postlarvae (high densities and survival rates) or production of high-quality fry (strong, resistant to stress and diseases). The use of formulated diets will be easier in the first case. Anyhow, it is the cost-effectiveness of the different feeding strategies that will determine the preferential application of compound diets or live food organisms. It is likely that this may differ much from region to region, and between industrial and backyard hatcheries.

4. Optimisation on the use of Artemia in shrimp hatcheries

Although using Artemia cysts appears to be simple, several factors are critical for hatching the large quantities needed in larval crustacean production. These include cyst disinfection or decapsulation prior to incubation and hatching under the following optimal conditions: constant temperature of 25 to 28 °C, 15 to 35 ppt salinity, minimum pH of 8.0, near saturated oxygen levels, maximum cyst densities of 2 g/L, and strong illumination of 2,000 Lux (Sorgeloos et al., 1986). All these factors will affect the hatching rate and maximum output, and hence the production cost of the harvested Artemia nauplii. Attention should be paid to select specific Artemia cyst lots with good hatching synchrony (less than 7 h between hatching of first and last nauplii) and high hatching efficiency (more than 200,000 nauplii per gram product). After hatching Artemia nauplii should be separated from the hatching wastes prior to their feeding to the shrimp. After switching off the aeration in the hatching tank, cyst shells will float and nauplii will concentrate at the tank’s bottom. They should be siphoned off within 5 to 10 min, and thoroughly rinsed with seawater or freshwater, preferentially using submerged filters (Sorgeloos and Léger, 1992) to prevent physical damage to the nauplii.

At the high water temperatures that are applied during cyst incubation, freshly-hatched Artemia (instar I) develop into the second larval stage (instar II) within 6 - 8 h and while consuming their yolk reserves. It is important to feed instar I nauplii rather than starved instar II metanauplii that are transparent, less visible and less digestible, and contain 25% lower individual dry weights and energy content (Vanhaecke et al., 1983). Instar II are also about 50% larger in length and swim faster than first instars. As a result they are less acceptable as prey and reduce the energy uptake by the predator per unit of hunting effort (Léger et al., 1986). All this will be reflected in reduced larval growth or an increased (20 to 30%) Artemia cyst consumption to feed the same weight of starved metanauplii to the penaeid larvae. Storing freshly-hatched nauplii up to 24 h at temperatures near 4°C, in densities of up to 8x10⁷/L, will greatly reduce their metabolic rate, and thus yolk consumption, and preclude molting to the second instar stage (Léger et al., 1983). This 24-h cold storage economizes the Artemia cyst hatching effort in the hatchery (i.e. fewer tanks, larger volumes,
a maximum of one hatching and harvest per day) and allows not only a constant supply of a high-quality product but also the possibility of more frequent food distributions.

As the size of Artemia cysts and consequently their nauplii can vary significantly (Vanhaecke and Sorgeloos, 1980), it is critical to choose a strain with small cysts (diameter < 230 μm) in case the Artemia feeding is started at the zoa III stage.

Also the biochemical composition of the brine shrimp nauplii may be insufficient to meet the nutritional requirements of the shrimp larvae. Léger et al. (1985, 1987a) concluded that the main factor affecting the nutritional value of Artemia for marine shrimp larvae was the content of the highly unsaturated fatty acid (HUFA) eicosapentaenoic acid 20:5n-3 (EPA). In the nineties it was demonstrated that another HUFA, docosahexaenoic acid 22:6n-3 (DHA), which is virtually lacking in Artemia, is an essential nutrient for most marine organisms (Watanabe, 1993). However, it is possible to enrich HUFA-deficient Artemia, e.g. the GSL strain, by use of a simple method (bioencapsulation, Léger et al., 1987b) which allows the incorporation of different kinds of products and nutrients into the Artemia prior to feeding to predator larvae. The highest enrichment levels are obtained using emulsified concentrates. Freshly-hatched Artemia are immediately transferred to the enrichment tank at a density of 100 to 300/mL (for enrichment periods > 24 h or < 24 h, respectively). The enrichment medium consists of hypochlorite-disinfected and neutralized seawater maintained at 25 °C. The enrichment emulsion is added in doses of 0.3 g/L every 12 h. Strong aeration using air stones or pure oxygen is required to maintain dissolved oxygen levels above 4 ppm. Enriched nauplii are harvested after 24 or 48 h, thoroughly rinsed and stored at temperatures below 10°C in order to assure that HUFA are not metabolized during storage. Enrichment levels up to 60 mg/g DW n-3 HUFA can be obtained after 24-h enrichment with the emulsified concentrates, but the size of e.g. GSL Artemia after 24-h enrichment will also increase from 550 μm to about 660 μm. Other important nutrients, and even therapeutics, can be successfully incorporated in the same way, e.g. vitamin C levels can be boosted from 500 up to 2500 μg/g DW (Merchie et al., 1997).

Feeding n-3 HUFA-enriched Artemia nauplii results in increased larval survival and growth in several Penaeus spp. (Bengtson et al., 1991). In addition, Léger and Sorgeloos (1992) showed that the effect of hatchery diet composition, especially with regard to n-3 HUFA content, might only become evident in later stages. Negative effects on survival and growth when feeding n-3 HUFA-poor Artemia were aggravated when the animals had previously been fed a n-3 HUFA-poor diet as opposed to an n-3 HUFA-rich food during the zoae stages. When postlarvae that had been fed with enriched GSL Artemia were subsequently fed an artificial diet, better food acceptance, growth and survival were recorded than in postlarvae previously fed n-3 HUFA-poor Artemia. Also the physiological condition of postlarvae, expressed as the resistance to a salinity stress, is significantly improved when feeding HUFA-boosted Artemia (Tackaert et al., 1992), which may have important implications on the quality of the postlarvae for stocking. Although the cited studies provided convincing evidence of the importance of the n-3 HUFA in Artemia when used as food for shrimp larvae, quantitative dietary requirements as well as the relative importance of selected HUFA (e.g. DHA) remains to be explored. Results obtained by Rees et al. (1994) and Kontara et al. (1995) with postlarval P. monodon confirmed the earlier suggestion of Kanazawa (in D’Abramo, 1991) that 1% n-3 HUFA in the diet is a minimal value for postlarval penaeids. Apparently there is no specific requirement for DHA over EPA in larval shrimp. Culture tests feeding Brachionus and Artemia, enriched with various DHA/EPA ratios, to larval (Z-1 to PL-11) P. vannamei (Wouters et al., 1997) and postlarval (PL-5 to PL-25) P. monodon (Kontara et al., 1995) revealed no significant differences in survival, growth and metamorphosis rate.

Vitamin C, more specifically ascorbic acid (AA), is generally considered to be an essential dietary component for larval stages of aquaculture organisms, affecting several
biological (e.g. growth, survival) as well as physiological functions (e.g. resistance to toxicants and stress, immunocompetence) (Dabrowski, 1992; Merchie et al., 1997). The effect of vitamin C enrichment in Artemia nauplii on larviculture outputs of penaeid shrimp, however, remains to be verified.

Last but not least, microbial control over the Artemia is important. Over the last few years studies in Europe and elsewhere have indicated that the microbial diseases that affect commercial hatcheries are mostly related to the important bacterial inputs via the live food (Verdonck et al., 1994). Quantitative data of the microflora in sea bass and sea bream hatcheries revealed the presence of several thousand bacteria per brine shrimp nauplius and specific measures need to be considered to reduce these bacterial loads. Recently, new practices have been introduced with disinfected Artemia cysts that offer remarkable improvements in the hatchery operations (Merchie et al., 1997).

5. Direct use of decapsulated Artemia cysts in hatcheries

Aside from the most common regime of feeding freshly-hatched and/or 24-h enriched nauplii, dry decapsulated cysts (also called de-shelled or shell-free cysts) can be used in start-feeding shrimp larvae. However, the rapid settling of the cysts in seawater can make them unavailable for planktonic larvae unless they can be kept in suspension by using conical-shaped culture tanks and strong aeration. Best results are obtained when feeding decapsulated cysts to postlarval shrimp as a partial or complete substitute for live nauplii (Staels et al., 1995). The major advantage here might be, aside from being a directly available off-the-shelf product, that cysts with poor hatching quality can still be used as a food source.

6. Use of Artemia biomass in nursery feeding

The high food value in nursery culturing of shrimp of Artemia biomass harvested from outdoor ponds or intensive indoor culture systems is well documented. The most spectacular example is the use of thousands of tons of fresh brine shrimp biomass harvested from coastal and inland saltworks as a supplementary natural food in the pond culture of P. chinensis in the Bohai Bay, People’s Republic of China (Tackaert and Sorgeloos, 1991). Dhert et al. (1993) developed a simple culture system for juvenile and adult Artemia as food for postlarval P. monodon. The growth performance of shrimp reared from PL-4 to PL-25 on live juvenile Artemia was identical to the growth obtained when feeding newly-hatched brine shrimp. Furthermore, the PL-25 reared with juvenile Artemia displayed significantly better resistance in salinity stress tests; i.e. the stress sensitivity index dropped from 138 with freshly-hatched nauplii to 36 when feeding juvenile Artemia. Besides nutritional and energetic advantages, the use of Artemia biomass for feeding postlarval shrimp also results in improved economics as expenses for cysts and weaning diets can be reduced. Although the fresh-live form has the highest nutritive value, harvested Artemia can also be frozen, freeze-dried or acid-preserved (Abelin et al., 1991; Naessens et al., 1995) for later use, or made into a flakes or other forms of formulated feed.

7. Use of Artemia biomass in maturation facilities

In penaeid shrimp, nutritional factors play an important role in the stimulation of sexual maturation and mating, fertilisation success and the quality of eggs and nauplii (Harrison, 1990). Broodstock animals are typically fed a combination of natural diets and an artificial pellet. The inclusion of marine polychaetes (bloodworms) in the natural fraction is considered as essential for good reproductive performance (Gomez and Arrellano, 1987; Browdy, 1992). However, the provision of bloodworms is unpredictable and their nutritional composition may vary according to location and season of collection (Lytle et al., 1990).
Therefore, there has been a search for alternatives and Browdy et al. (1989) detected an enhanced reproductive performance when using frozen *Artemia* biomass as a dietary component for *Penaeus* semisulcatus. Our laboratory, in collaboration with CENAIM Ecuador, further investigated the potential of adult *Artemia* (whether or not bio-encapsulated with maturation enhancing components) as a replacement for marine polychaetes in the maturation diet of *P. vannamei* (Naessens et al., 1997; Wouters et al., 1998).

Sofar we could clearly demonstrate that co-feeding frozen brine shrimp biomass (enriched or non-enriched) instead of frozen bloodworm resulted in an equal maturation performance of the broodstock shrimp (Table 2, Naessens et al., 1997). The fraction of the female population that produced at least one spawn is even larger in the *Artemia* feeding regime than for the bloodworm-supplemented diet. Also the number of spawns per female and the spawning frequency are higher in the *Artemia* treatment. When combining mating success, spawn size and egg hatching percentage as the average number of nauplii produced per night and per female, again a significant increase could be demonstrated for the *Artemia* treatment compared to the bloodworm treatment (4127 versus 1582).

Similar observations were made by Wouters et al. (1998). A dietary regime consisting of squid, oyster, clam and mussel only (treatment squid, fig.1A) gave poor results for most reproductive parameters. Supplementation with *Artemia* biomass resulted in higher survival, improved maturation and reproduction, and better offspring quality. Considering that adult *Artemia* containing reproductive stages were used in this study, its effect on ovarian maturation and reproductive activity might not only be attributed to specific nutrients, but also to hormones or sexual steroids. It is indeed likely that the reproductive hormones within crustaceans are of the same nature and therefore could be effective in other species. Supplementing the feeding regime with HUFA-enriched *Artemia* as compared to regular brine shrimp biomass promoted mating and spawning (fig. 1A). These results may indicate that through the enrichment of *Artemia* more adequate lipid levels are supplied that can sustain optimal reproductive performance in *P. vannamei*.

The second part of the experiment (fig. 1B) further confirms that the role of the enrichment product is not only energetic but also nutritional (as all treatments were isocaloric). Best results were obtained with the treatment that received a supplement of *Artemia* biomass enriched with lipids (n-3 HUFA, cholesterol), vitamins (C, E) and astaxanthin. However, by reducing the concentration of PUFA and cholesterol in the enriched *Artemia*, a decline in egg fertilisation, a lower incidence of repeated spawns and a lower egg production per female is observed, which clearly demonstrates the importance of PUFA and cholesterol. Vitamins and astaxanthin appear to play a positive role on shrimp reproductive performance if they are provided together with high PUFA and cholesterol levels: the best performing treatment in most aspects is the one that received the PV enriched *Artemia*. We assume that the positive role of high vitamin levels can be attributed by their antioxidant properties.

Finally, the broodstock diet composition may also have an effect on the egg and larval quality of the offspring produced. Table 3 shows that inclusion of *Artemia* enhanced significantly hatching percentage and larval survival at Zoa-1 and Mysis-2 stages (Wouters et al., 1998). Boosting the brine shrimp biomass with specific components, however, did not affect the quality parameters.

In view of the overall good performance of *Artemia* biomass when supplemented in broodstock diets, its lower cost and the more stable supply (Lavens and Sorgeloos, 1996) compared to bloodworm, (enriched) frozen adult brine shrimp appears to be a valid commercial alternative for marine polychaetes in *P. vannamei* maturation diets.

Acknowledgements
Over the past two decades our studies with the brine shrimp *Artemia* have been supported by research contracts from the Belgian National Science Foundation, the Belgian Administration for Development Cooperation, and the Belgian Ministry of Science Policy.
References


Léger, P.; Bieber, G.F. and Sorgeloos, P. 1985. International Study on Artemia. XXXIII. Promising results in larval rearing of Penaeus stylirostris using a prepared diet as


Table 1. Harvests of *Artemia* cysts from the Great Salt Lake, Utah-USA during the past decade. (In metric tonnes of raw wet weight cysts)

<table>
<thead>
<tr>
<th>Season</th>
<th>Firms</th>
<th>Licenses</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988/89</td>
<td>7</td>
<td>-</td>
<td>2170</td>
</tr>
<tr>
<td>1989/90</td>
<td>12</td>
<td>-</td>
<td>5020</td>
</tr>
<tr>
<td>1990/91</td>
<td>19</td>
<td>24</td>
<td>4860</td>
</tr>
<tr>
<td>1991/92</td>
<td>11</td>
<td>26</td>
<td>5870</td>
</tr>
<tr>
<td>1992/93</td>
<td>12</td>
<td>20</td>
<td>4900</td>
</tr>
<tr>
<td>1993/94</td>
<td>12</td>
<td>18</td>
<td>4030</td>
</tr>
<tr>
<td>1994/95</td>
<td>14</td>
<td>29</td>
<td>2680</td>
</tr>
<tr>
<td>1995/96</td>
<td>21</td>
<td>63</td>
<td>6640</td>
</tr>
<tr>
<td>1996/97</td>
<td>32</td>
<td>79*</td>
<td>6600</td>
</tr>
<tr>
<td>1997/98</td>
<td>32</td>
<td>79*</td>
<td>2020</td>
</tr>
</tbody>
</table>

*: Moratorium installed by Utah Division of Wildlife Resources

Table 2. Maturation of *Penaeus vannamei* broodstock fed a mixture of marine organisms supplemented with Panama bloodworm (control) or non-enriched *Artemia* biomass (Art). (Modified from Naessens et al., 1997)

<table>
<thead>
<tr>
<th>Dietary supplement</th>
<th>Bloodworm</th>
<th><em>Artemia</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturation efficiency</td>
<td>25.7*</td>
<td>24.9*</td>
</tr>
<tr>
<td>Spawns (cumulated)</td>
<td>20</td>
<td>62</td>
</tr>
<tr>
<td>Surviving females spawned (%)</td>
<td>73.7</td>
<td>88.5</td>
</tr>
<tr>
<td>Number of spawns per surviving female</td>
<td>1.05</td>
<td>2.38</td>
</tr>
<tr>
<td>Spawning frequency per surviving female</td>
<td>2.9</td>
<td>0.94</td>
</tr>
<tr>
<td>Eggs per spawn (x 1000)</td>
<td>227.8*</td>
<td>247.1*</td>
</tr>
<tr>
<td>Hatching percentage</td>
<td>43.1*</td>
<td>40.5*</td>
</tr>
<tr>
<td>Nauplii per spawn (x 1000)</td>
<td>107.4*</td>
<td>105.7*</td>
</tr>
<tr>
<td>Nauplii per night per female</td>
<td>1582*</td>
<td>4127*</td>
</tr>
</tbody>
</table>

*Numbers with similar superscripts within rows are not significantly different (p>0.05).*
Table 3. Effect of different broodstock dietary supplements on egg and larval quality parameters in *Penaeus vannamei*. (Modified from Wouters *et al.* 1998).

<table>
<thead>
<tr>
<th>Dietary supplements</th>
<th>control</th>
<th>Artemia</th>
<th>Enriched Artemia</th>
<th>Artemia enriched with lipids+vit</th>
<th>lipids</th>
<th>vitamins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hatch (%)</td>
<td>31.6±36.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60.8±27.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>61.6±30.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50.9±33.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>44.4±29.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>32.2±24.6&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Larval survival N2-Z1(%)</td>
<td>41.1±32.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>71.8±22.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>69.4±21.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>62±24&lt;sup&gt;a&lt;/sup&gt;</td>
<td>54±30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>47±27&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Zoeal / spawn (x 10&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>42.8±56.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>93.4±60.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94.0±60.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>87.2±84.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>69.2±75.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>40.6±42.2&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Zoea I length (μm)</td>
<td>804.7±116.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>900.5±36.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>884.4±36.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>897.7±116.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>862.6±193.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>799.4±264.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Larval survival Z1-M2 (%)</td>
<td>8.3±4.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43.9±23.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48.4±19.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> diet containing squid, mussel, oyster and clam
Figure caption:

Figure 1. Maturation and spawning frequencies in *Penaeus vannamei* broodstock fed different supplements to a natural diet consisting of squid, clam, oyster and mussel. 1A: first experiment; 1B: second experiment.