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# THE USE OF ALGAL SUBSTITUTES AND THE REQUIREMENT FOR LIVE ALGAE IN THE HATCHERY AND NURSERY REARING OF BIVALVE MOLLUSCS: AN INTERNATIONAL SURVEY

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***ABSTRACT*** The mass-production of micro-algae has been recognized by several authors as the main bottle-neck for the culture of bivalve seed. This has prompted a search for alternatives to on-site algal production, such as dried heterotrophically-grown algae, preserved algal pastes, micro-encapsulated diets, and yeasts. However, the extent to which these products have been tried, and rejected or retained by hatchery operators is poorly documented. Also, the actual algal requirement and production cost of the bivalve seed industry is difficult to estimate.

The present inquiry allowed the collection of data concerning the requirement for live algae and its associated costs encountered in 50 commercial and experimental hatcheries from all over the world. Furthermore, the hatchery operators were questioned about their experience with alternatives for live algae, the quality and quantity of hatchery produced algae and bivalve seed, and the employment in this sector of aquaculture.

The capacity of the algal production facilities ranged between 1 $m^3$ for a few research laboratories to nearly 500 $m^3$ for one commercial hatchery. The total algal production capacity reported by 37 hatcheries amounted to about 500 $m^3$ algal culture $day^{-1}$, which is equivalent to about 50 kg of dry biomass. The total cost of algal production in 1990 reported by 20 hatcheries approximated U.S. $700,000 and averaged about 30% of the total seed production cost. The estimates for the algal production cost ranged from U.S. $50 to 400 per kg dry weight.

About a third of the questioned operators considered algal production as a limiting factor in the rearing of bivalve seed, whereas over 50% planned an expansion of the algal cultures and more than 90% was interested in the use of a suitable artificial diet.

The large interest for alternatives for on-site algal production was further demonstrated by the fact that more than 50% of the operators claimed to have experimented with artificial diets. Despite the extensive research efforts, artificial diets are rarely applied in the routine process of bivalve seed production and are mostly considered as a useful backup diet.

***KEY WORDS:*** micro-algae, bivalve, algal substitute/artificial, diet, hatchery, nursery

## INTRODUCTION

In the early stages of research in the field of intensive bivalve rearing, the mass culture of micro-algae was identified as the main constraint. An extreme illustration of this can be found in the earlier literature, where it was estimated that one oyster, during its growth from egg to market size, will consume approximately 1.28 $10^{12}$ cells of the alga *Thalassiosira pseudonana* (Pruder et al. 1976), which is equivalent to about 250 liter of dense algal culture. At present, the requirement for live algae in the intensive culture of bivalves is strongly reduced by the transfer of the small spat (1–2 mm) as soon as possible from the hatchery to the nursery (Claus 1981, Manzi 1985, Helm 1990). From the latter stage onwards they are fed partially, or in some cases exclusively, natural phytoplankton. Once the seed attains planting size (5–10 mm), they are transferred to grow-out areas, where they reach market size feeding solely on natural food. Nevertheless, several authors have recognized the production of large volumes of micro-algae, which is labor-intensive and requires specialized facilities, as the main bottle-neck for the culture of bivalve seed (Persoone and Claus 1980, Urban and Langdon 1984, De Pauw and Persoone 1988, Jones et al. 1991). This has resulted in the development of several alternatives to on-site algal production such as dried heterotrophically-grown algae (Laing et al. 1990, Gladue 1991, Laing and Verdugo 1991, Laing and Millican 1992), preserved algal pastes (Donaldson 1991, O'Connor and Nell 1991), microencapsulated diets (Jones et al. 1984, Langdon et al. 1985, Southgate et al. 1991), yeast-based diets (Epifanio 1979, Urban and Langdon 1984, Coutteau et al. 1990, 1991). Except for the sporadic reports at international meetings (Helm and Hancock 1990), the extent to which these products have been tried, and rejected or retained, by the hatchery operators is poorly documented. Furthermore, in order to direct future research efforts, it is essential to know the selection criteria of the farmer for an algal substitute which is eventually to be used in the daily practice of bivalve seed production. In this way, depending on the bivalve species and the applied production technology, either a cheap bulk feed or a more complete, high quality diet may be preferred.

The actual algal requirement and production cost of the bivalve seed industry is difficult to estimate due to the nearly complete lack of information concerning the quantity of seed or algae produced. Also, the requirement for live algae greatly varies between

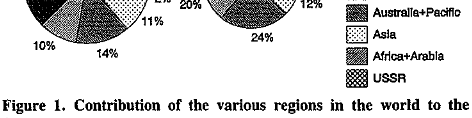


**Figure 1. Contribution of the various regions in the world to the distributed and received questionnaires.**

hatcheries, as it depends on the availability of natural phytoplankton, the size at which the spat leaves the hatchery, and the bivalve species cultured. The great diversity in the algal culture technology hinders the estimation of a standard algal production cost, since the latter varies with the yield and efficiency of the culture system. As a result, extrapolations based on a case study of one hatchery are of limited value. For this reason, the present survey aimed at the collection of data concerning the requirement for live algae and the associated costs encountered in several commercial as well as academic hatcheries. Furthermore, the hatchery operators were questioned about their knowledge of and experience with alternatives for live algae, and their intention and requirements to use artificial diets. Finally, this survey offered the opportunity to collect some unique data on the quality and quantity of hatchery-produced bivalve seed, and the employment in this relatively small sector of aquaculture.

## DESIGN, DISTRIBUTION, AND RETURN RATE OF THE QUESTIONNAIRE

The questionnaire consisted of six multiple questions. The first question offered the possibility to protect confidential data that

**TABLE 1.**

**Hatchery and nursery production of various bivalve species in 50 commercial and academic hatcheries in 1990.**

| | Hatchery (larvae + spat < 2 mm) | | | | Nursery (spat ≥ 2 mm) | | | |
|---|---|---|---|---|---|---|---|---|
| Species | Total Production ($10^6$ units) | % C | $n_C$ | $n_A$ | Total Production ($10^6$ units) | % C | $n_C$ | $n_A$ |
| **Oysters** | | | | | | | | |
| *Crassostrea gigas* | 29661.0 | 99 | 10 | 3 | 183.0 | 98 | 7 | 2 |
| *Crassostrea virginica* | 336.5 | 96 | 4 | 2 | 64.5 | 98 | 3 | 2 |
| *Saccostrea commercialis* | 6.0 | 50 | 1 | 2 | 6.3 | 79 | 1 | 2 |
| *Pinctata maxima* | 11.0 | 100 | 2 | 0 | 5.2 | 100 | 2 | 0 |
| *Crassostrea belcheri* | 20.3 | 0 | 0 | 3 | 2.4 | 0 | 0 | 3 |
| *Ostrea edulis* | 53.2 | 100 | 4 | 1 | 1.1 | 100 | 3 | 0 |
| *Crassostrea iredalei* | 0.5 | 0 | 0 | 1 | 0.5 | 0 | 0 | 1 |
| *Pinctada fucata* | 0.4 | 0 | 0 | 1 | 0.3 | 0 | 0 | 1 |
| *Crassostrea lugubris* | 0.5 | 0 | 0 | 1 | 0.050 | 0 | 0 | 1 |
| *Pinctada margaritifera* | 0.060 | 0 | 0 | 1 | 0.050 | 0 | 0 | 1 |
| *Tiostrea lutaria* | 0.017 | 0 | 0 | 1 | 0.007 | 0 | 0 | 1 |
| *Saccostrea echinata* | 2.0 | 100 | 1 | 0 | — | — | — | — |
| Number of species | 12 | | | | 11 | | | |
| Total production ($10^6$ units) | 30092 | | | | 263 | | | |
| **Clams, cockles, and arkshells** | | | | | | | | |
| *Tapes philippinarum* | 1982.0 | 85 | 7 | 2 | 155.0 | 96 | 6 | 2 |
| *Mercenaria mercenaria* | 211.0 | 74 | 4 | 3 | 63.4 | 84 | 4 | 3 |
| *Tapes decussata* | 103.8 | 100 | 4 | 1 | 25.7 | 100 | 4 | 1 |
| *Panopea abrupta* | 150.0 | 0 | 0 | 1 | 7.0 | 0 | 0 | 1 |
| *Tapes pullastra* | 1.6 | 100 | 1 | 0 | 7.0 | 100 | 1 | 0 |
| *Spisula solidissima* | 5.3 | 57 | 1 | 1 | 3.1 | 97 | 1 | 1 |
| *Mya arenaria* | 7.0 | 71 | 1 | 1 | 2.5 | 20 | 1 | 1 |
| *Mulinia lateralis* | 5.0 | 0 | 0 | 1 | 1.0 | 0 | 0 | 1 |
| *Tridacna gigas* | 59.1 | 0 | 1 | 2 | 0.3 | 7 | 1 | 2 |
| *Anomalocardia brasiliana* | 0.5 | 0 | 0 | 1 | 0.3 | 0 | 0 | 1 |
| *Anadara brouthtoni* | 0.4 | 0 | 0 | 1 | 0.3 | 0 | 0 | 1 |
| *Tridacna derasa* | 0.110 | 0 | 0 | 1 | 0.110 | 0 | 0 | 1 |
| *Hippopus hippopus* | 25.3 | 0 | 0 | 2 | 0.095 | 0 | 0 | 2 |
| *Tridacna maxima* | 15.0 | 0 | 0 | 1 | 0.040 | 0 | 0 | 1 |
| *Codakia orbicularis* | 3.0 | 0 | 0 | 1 | — | — | — | — |
| Number of species | 15 | | | | 14 | | | |
| Total production ($10^6$ units) | 2569 | | | | 266 | | | |
| **Scallops** | | | | | | | | |
| *Argopecten purpuratus* | 110.0 | 100 | 3 | 1 | 22.5 | 100 | 2 | 1 |
| *Patinopecten yessoensis* | 172.0 | 99 | 1 | 1 | 0.1 | 0 | 0 | 1 |
| *Argopecten irradians* | 14.0 | 71 | 1 | 1 | 5.5 | 27 | 1 | 1 |
| *Argopecten circularis* | 202.0 | 0 | 0 | 1 | 1.0 | 0 | 0 | 1 |
| *Pecten ziczac* | 1.0 | 0 | 0 | 1 | 0.5 | 0 | 0 | 1 |
| *Crassadoma gigantea* | 0.5 | 0 | 0 | 1 | 0.025 | 0 | 0 | 1 |
| Number of species | 6 | | | | 6 | | | |
| Total production ($10^6$ units) | 500 | | | | 30 | | | |

Species were ranked according to the nursery production. The percentage contribution of commercial operations in the production of each species (% C), and the number of commercial ($n_C$) and academic ($n_A$) hatcheries involved are indicated.

were possibly communicated in the questionnaire. The second question aimed at an evaluation of the profile of the hatchery on the basis of its productivity and the number of employees in 1990. The third and fourth question offered the possibility to detail, respectively, the knowledge of and experience with algal replacement diets. The capacity and nature of the algal production facilities of the hatchery were queried in question five. Finally, the last question consisted of various subquestions concerning the algal production cost, the extent to which the algal production capacity is a limiting factor for the hatchery and may be expanded in the future, the intention to use artificial diets and the most important characteristics these should comply with.

The survey was announced in several aquaculture magazines and newsletters and through a poster presentation at two international aquaculture meetings (Coutteau and Sorgeloos 1991a,b). In total, 265 forms were distributed over 43 countries. Over 90 people responded to the survey and 50 questionnaires were retained for evaluation. The efficiency with which the distributed forms were returned ranged between 10% (Europe) and 38% (South and Central America). In this way, the contributions of the various regions in the world were well balanced in the survey, with the exception of the exclusion of the USSR, and Arabic and African countries (Fig. 1). For the analysis of the 50 completed forms, a distinction was made between 25 private hatcheries (further referred to as "commercial") and 25 facilities run by research institutes and governmental agencies ("academic").

## RESULTS

### 1. *Secrecy Clause*

Since about 50% of the commercial and 30% of the academic hatcheries demanded secrecy, all data were treated anonymously.

### 2. *Profile of the Farm*

#### 2.1 *Production Data for 1990*

In the present investigation, hatchery production included the rearing of eyed larvae (300–500 μm) for remote setting as well as small postset (1–2 mm; 1 cm for giant clams). Nursery production consisted of the rearing of juveniles from 2 mm to planting size (4–15 mm: clams; 5–30 mm: oysters and scallops; 15–20 cm: giant clams).

The total hatchery and nursery production reported for 33 different bivalve species, and the relative contribution of the academic and commercial hatcheries is presented in Table 1. The production figures and the number of hatcheries producing each species demonstrated that the commercial hatcheries focus on the production of a few species of oysters (*C. gigas, C. virginica, S. commercialis, O. edulis*), clams (*T. philippinarum, M. mercenaria, T. decussata*) and scallops (*A. purpuratus, P. yessoensis, A. irradians*), representing over 98% of the total seed production. The remaining bivalve species were primarily reared in research and state owned facilities in relatively low numbers. Furthermore, the hatchery production was dominated by the large amounts of eyed larvae and small postset (<1 mm) of *Crassostrea gigas*, produced primarily in hatcheries along the West Coast of the United States. As a result, oysters represented 90% of the recorded hatchery production. Interesting was that more than 70% of the larval production of the pacific oyster was due to the efforts of one company. The recorded production of larger clam and oyster seed was equally important, whereas scallops represented only 5% of the nursery production.

#### 2.2 *Number of Employees*

The total number of people employed in about 30 bivalve rearing facilities, including hatchery, nursery, and grow-out operations, was less than 500 (Table 2). Most of the private companies engaged two to four people in the hatchery and about the same number in the nursery, whereas a larger staff was involved in the more labor-intensive grow-out operations (Fig. 2).

### 3. *Inventory of Algal Substitutes*

The limited number of algal substitute diets reported in this study was classified either as dried algae, algal pastes, microencapsulated diets, yeast-based diets, or miscellanea (Table 3).

### 4. *Experience with Algal Substitutes for the Hatchery and Nursery Culture of Bivalves*

34 out of the 50 questioned people had knowledge of artificial diets for bivalves, while 28 (15 academic and 13 commercial) operators had experimented with at least one of them (Fig. 3). Nearly 60% of the interrogated people knew the dried *Tetraselmis suecica* product and more than half of the latter had evaluated its nutritional value experimentally. The other alternatives to live algae were relatively less well-known (Fig. 3).

It should be emphasized that the experimental results reported in this survey could not be verified concerning the dependability and profundity of the applied methodology, and should thus be regarded as preliminary. It was tried to reproduce the data as they were mentioned by the experimenters in the questionnaire. The experience recorded for the various bivalve species, culture phases and substitute diets is summarized in Table 4. The routine application of algal substitutes was reported by only three interviewees.

**TABLE 2.**

**Total number of employees in the various stages of bivalve culture operations.**

| | Hatchery | | Hatchery + Nursery | | Hatchery + Nursery + Grow-out | |
|---|---|---|---|---|---|---|
| | Total Employment | n† | Total Employment | n† | Total Employment | n† |
| Commercial hatcheries | 77 | 19 | 127 | 20 | 427 | 14 |
| Academic hatcheries | 30 | 12 | 95 | 16 | 61 | 14 |
| Total | 107 | 31 | 222 | 36 | 488 | 28 |

† Number of replies received from 50 returned forms.

Live algae were routinely replaced for up to 75% by algal paste (Coast oyster Co., USA) in the rearing of spat and broodstock of *C. gigas* and up to 25% by spray-dried *T. suecica* (Cell Systems Ltd., UK) in the culture of spat. Furthermore, algal culture was absent in five of the six hatcheries producing giant clam larvae, which were fed dried yeast, dried *T. suecica*, the Frippak micro-encapsulated diet, or a mixture of the latter two.

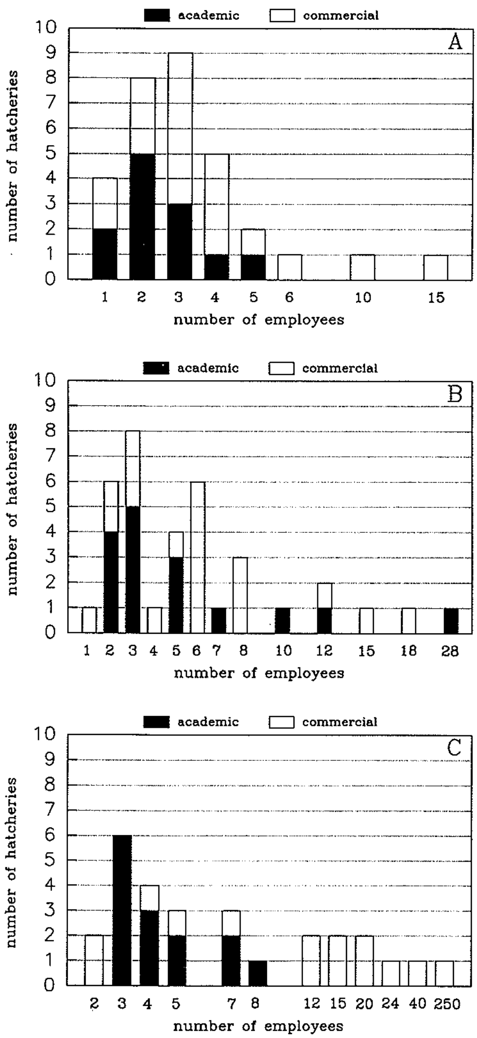


Figure 2. Employment per operation for hatchery (A, n = 31), hatchery + nursery (B, n = 36) and hatchery + nursery + grow-out (C, n = 28) rearing of bivalves.

**TABLE 3.**

**Substitute diets for live algae in bivalve culture.**

| Classification | Diet (C = commercially available, E = experimental) |
|---|---|
| Dried algae | —*Tetraselmis suecica* (C, Cell Systems Ltd., Cambridge, UK) |
| | —*Nitzschia* sp. (E, Martek Corp., Maryland, USA) |
| | —*Spirulina* (C, Earthrise Farms, California, USA) |
| Algal pastes | —Coast oyster diet 1 (C, Coast Oyster Co., Washington, USA) |
| | —algal paste (E, SeaAg Inc., Florida, USA) |
| | —algal paste (C, Innovative Aquaculture, British Columbia, Canada) |
| | —algal paste (refrigerated, centrifuged from excess production) |
| Microcapsules | —Frippak Booster (C, Frippak Feeds, Sanofi, Paris, F) |
| | —micro-encapsulated diet (E, James Cook University, Townsville, Australia) |
| Yeast-based diets | —Topal (C, Artemia Systems N.V.-S.A., Gent, Belgium) |
| | —manipulated yeast diets (E, University of Ghent, Gent, Belgium) |
| | —various brands of dried baker's yeast (*e.g.* Mauri, Nauplius) |
| Miscellanea | —cornflour (maizena) |
| | —corn starch (source not specified) |
| | —fry food (C, Biokyowa, Montana, USA) |

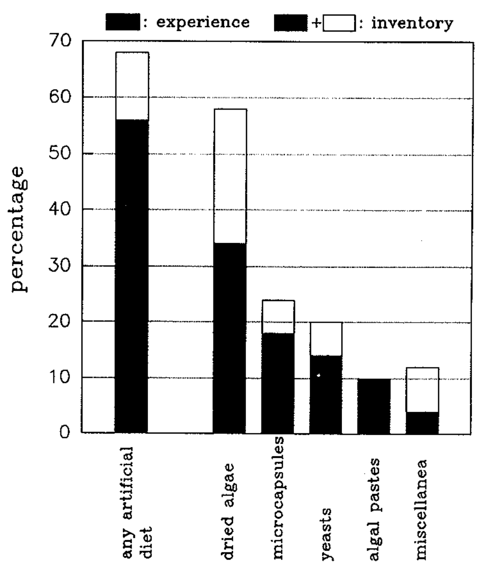


Figure 3. Percentage of hatchery operators that claimed to have knowledge of (total bar) and/or experience with (filled bar) various classes of artificial diets as reported in 50 questionnaires.

**TABLE 4.**

**Reported experience with the use of various algal substitutes in the culture of different species and stages of bivalves (B = broodstock, L = larvae, S = spat).**

| | Artificial Diets | | | | |
|---|---|---|---|---|---|
| **Bivalve Species** | **Dried Algae** | **Algal Pastes** | **Yeasts** | **Microcapsules** | **Miscellanea** |
| **Oysters** | | | | | |
| *Crassostrea gigas* | BS † ‡ | BS ‡ | S | LS | B |
| *Crassostrea virginica* | BS † | BS † | | | |
| *Ostrea edulis* | LS | | | | |
| *Saccostrea commercialis* | | | | L | |
| *Pinctada margaritifera* | | | | L | |
| **Clams** | | | | | |
| *Tapes philippinarum* | BLS † | | BS | S | |
| *Tapes decussata* | | | BS | | |
| *Mercenaria mercenaria* | BLS † | BS † | S | | |
| *Panopea abrupta* | S | | | | |
| *Dosinia dunkerii* | | | L | | |
| *Tridacna gigas* | LS | | LS | LS ‡ | |
| *Tridacna maxima* | LS ‡ | | LS ‡ | LS ‡ | |
| *Tridacna derasa* | L ‡ | | LS ‡ | LS ‡ | |
| *Tridacna squamosa* | L ‡ | | LS ‡ | LS ‡ | |
| *Hippopus hippopus* | LS | | | LS ‡ | |
| **Scallops** | | | | | |
| *Patinopecten yessoensis* | BS | | | | |

The results obtained with the various diets experimentally, as backup (†) or in routine culture (‡) are given in the text.

Several experiments indicated that substitute diets may be used to supplement insufficient rations of live algae. The spray-dried *T. suecica* and algal paste were found to be useful as a backup diet to replace 50% of the live algae in the diet of broodstock and spat of *C. virginica* and *M. mercenaria*. For spat of *T. philippinarum*, a replacement of 20–30% of the algae by dried *T. suecica* was applied in the absence of sufficient amounts of live algae. Dried *T. suecica* was found to be a satisfactory diet for feeding *O. edulis* in the size range of 2–10 cm during disease experiments, although growth was inferior to that in nature.

Despite the extensive efforts to evaluate various diets, the use of artificial diets appeared to be mostly restricted to the experimental stage. Contrary to the previous reports on the use of dried *T. suecica* as a partial algal substitute, various operators found it unsatisfactory either because of its high price (i.e. U.S. $170 per kg) or its poor performance (reported for larvae of *M. mercenaria, O. edulis;* spat of *T. philippinarum, C. gigas, P. yessoensis;* broodstock of *M. mercenaria*). The latter was mostly associated with difficulties to resuspend the dried algal cells without disintegrating them, and the fast settling of the food particles in the bivalve cultures. In this regard, dried *T. suecica* was found to be valuable in the culture of pedal feeders, such as *P. abrupta*, when it was introduced in the substrate.

Dried yeast (source not specified), was reported as being of low value as food for juvenile *C. gigas* at substitution levels ranging from 25 to 100%. Also, feeding Topal (Artemia Systems N.V.-S.A., Belgium) resulted in poor growth and high mortality for larvae of *Dosinia dunkerii* and yielded poor growth in spat of *C. gigas* and *T. philippinarum*. Manipulated yeasts (University of Ghent, Belgium) gave satisfactory results as an 80% algal substitute for spat of *M. mercenaria, T. philippinarum,* and *C. gigas*. Preliminary tests with broodstock of *T. decussata* and *T. philippinarum* indicated an acceptable conditioning index, but a retarded maturation in clams fed a 20/80% mixture of algae and manipulated yeasts.

The replacement of the algal diet fed to spat of *C. gigas* and *T. philippinarum* by microcapsules (Frippak Booster, Sanofi, France) yielded poor growth. However, the combined feeding of the experimental micro-encapsulated diet (James Cook University, Australia) with dissolved yeast extract resulted in a better growth of giant clam larvae (*T. gigas, H. hippopus*) than controls fed either *I. galbana* or *Pavlova salina*. Feeding these microcapsules to larvae of *S. commercialis* yielded up to 81% of the shell growth and similar ash free dry weight growth compared to algal-fed controls during a one-week experiment. By contrast, poor growth was re-

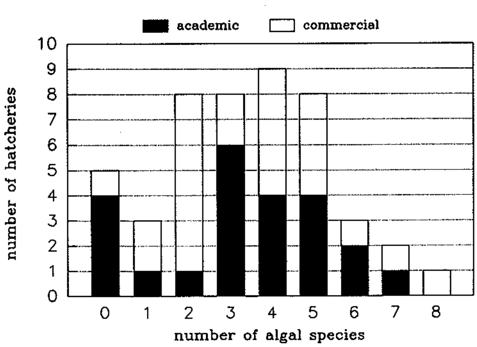


**Figure 4. Number of algal species cultured in 47 bivalve hatcheries.**

**TABLE 5.**

**Frequency of use and total daily production of various algal species.**

| Algal Species | Frequency of Use† | Total Daily Production | |
|---|---|---|---|
| | | n‡ | Volume ($m^3$) |
| *Isochrysis galbana,* clone T-Iso | 31 | 18 | 23.8 |
| *Chaetoceros gracilis* | 23 | 11 | 14.1 |
| *Chaetoceros calcitrans* | 16 | 10 | 6.0 |
| *Tetraselmis suecica* | 15 | 10 | 39.1 |
| *Thalassiosira pseudonana,* clone 3H | 14 | 9 | 112.0 |
| *Pavlova lutheri* | 11 | 7 | 11.7 |
| *Isochrysis galbana* | 8 | 5 | 9.1 |
| *Skeletonema costatum* | 6 | 3 | 58.8 |
| *Chroomonas salina* | 5 | 3 | 0.76 |
| *Dunaliella tertiolecta* | 4 | 2 | 2.2 |
| *Chaetoceros simplex* | 3 | 3 | 1.76 |
| *Chaetoceros muelleri* | 3 | 2 | 5.0 |
| *Nannochloropsis sp.* | 3 | 2 | 0.20 |
| *Cyclotella sp.* | 2 | 1 | 0.36 |
| *Phaeodactylum tricornutum* | 2 | 1 | 2.0 |
| *Tetraselmis chui* | 2 | 0 | — |
| *Pavlova salina* | 1 | 1 | 3.18 |
| *Dicruteria sp.* | 1 | 1 | 4.07 |
| *Tetraselmis levis* | 1 | 0 | — |
| *Dunaliella perva* | 1 | 1 | 0.012 |
| *Thalassiosira weissfloggii* | 1 | 1 | 0.12 |
| *Chlamydomonas sp.* | 1 | 1 | 0.52 |
| *Chlorella sp.* | 1 | 1 | 0.36 |
| TOTAL | 43 | 23 | 295 |

Species are ranked according to decreasing frequency of use.
† Number of hatcheries growing each algal species (from 43 completed forms).
‡ Number of hatcheries providing data which allowed to calculate daily production per algal species (from 23 completed forms).

ported when the same diet was fed to larvae of pearl oysters (*P. margaritifera*).

Cornflour may serve as a 20% algal supplement for broodstock of the pacific oyster, although increased bacterial growth was observed when fed to spat cultures.

### 5. *Total Algal Production in 1990*

Most hatcheries cultured between two and five different algal species (Fig. 4). Five of the six hatcheries in which giant clam larvae were reared did not maintain any algal culture. An inventory of the algal species recorded in this study is presented in Table 5. Eight algal species (*I. galbana,* clone T-Iso; *C. gracilis; C. calcitrans; T. suecica; T. pseudonana,* clone 3H; *P. lutheri; I. galbana; S. costatum*) were widely used and represented over 90% of the volume of algal culture produced in 23 facilities. The other species were used less frequently and about a third was reported only once.

The total capacity of the algal culture showed a wide range from less than 1 $m^3$ for a few research laboratories up to nearly 500

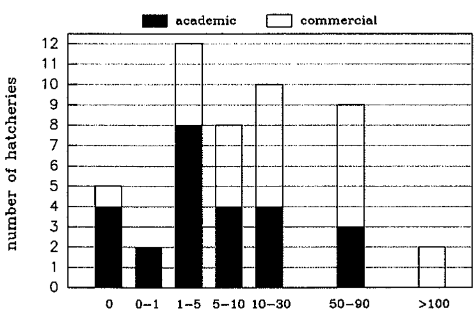


**Figure 5. Total container volume available for algal culture in 48 hatcheries.**

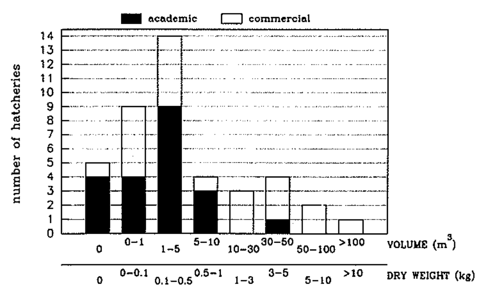


**Figure 6. Daily algal production in 42 hatcheries expressed either as volume of algal culture or as dry algal biomass.**

**TABLE 6.**

**Total production capacity and daily production of small and large scale algal culture systems in 21 hatcheries.**

| Scale Algal Culture | Average Yield (g/m$^3$)† | Daily Algal Production | | | |
|---|---|---|---|---|---|
| | | m$^3$ | % | kg DW§ | % |
| $<1$ m$^3$ | 248 | 31 | 12 | 7.7 | 28 |
| $\geq 1$ m$^3$ | 89 | 228 | 88 | 20.3 | 77 |
| TOTAL | | 259 | 100 | 28.0 | 100 |

† Derived from data on algal culture densities from 19 hatcheries and conversion to dry weight based on data from Brown (1991).
§ Estimated from average yield × daily production (m$^3$).

m$^3$ for one commercial hatchery (Fig. 5). Because the yield of the algal culture greatly varies according to the culture and climatological conditions, the volume available for algal culture is a poor estimate for the productivity. The latter was computed as the daily volume of algae produced and converted to dry weight assuming an average culture density of 100 g/m$^3$ (Gladue 1991). Apparently, about 50% and 60% of, respectively, the commercial and academic hatcheries produced daily less than 5 m$^3$ of algal culture, i.e. about 0.5 kg dry biomass (Fig. 6). A quarter of the commercial hatcheries produced between 10 and 50 m$^3$ algal culture per day, and six out of 21 companies reported a daily production between 30 and 110 m$^3$. The total volume of algal culture produced per day by 37 hatcheries amounted to 500 m$^3$, i.e. about 50 kg dry biomass.

Detailed data, obtained from 21 hatcheries, showed that most of the algae (i.e. 88% and 72% in terms of volume and dry weight, respectively) are produced in systems larger than 1 m$^3$ (Table 6). It is interesting to note that the average production yields of large and small scale cultures (respectively, 89 and 248 g/m$^3$; weighed average: 108 g/m$^3$) approximated the estimate of Gladue (1991). The majority of the hatcheries applied batch cultures (Table 7). Only 3 hatcheries, which were all located in Europe, grew algae solely in continuous cultures.

### 6. *Algal Production Cost in 1990 and Requirement for Artificial Diets*

The total cost of algal production in 1990 reported by 20 hatcheries amounted to nearly U.S. $700,000 (Table 8). The cost of live food production per hatchery greatly varied as could be expected from the large differences in production capacity, and averaged about U.S. $40,000 and 24,000 for commercial and academic hatcheries, respectively. The algal production cost averaged about 30% of the total seed production cost. Although few data were collected concerning the cost of live algae per unit dry weight, six out of nine estimates were in the range of U.S. $300–400.

Algal production was considered as a limiting factor by only a third of the interviewees (14 out of 43), whereas over 50% (24 out of 43) planned an enlargement of the algal culture units and nearly everybody (37 out of 40) considered the use of an artificial diet. The relative importance of the various characteristics of an artificial diet was estimated by summation of the quotations (between 1 and 5, 5 = most important) which were given to the features listed in each questionnaire. Food value, price, ease of use, and shelf-life were recognized as the most significant parameters that determine the value of an artificial diet (Fig. 7).

**TABLE 7.**

**Frequency of use of batch, semicontinuous, and continuous algal culture systems in 42 hatcheries.**

| Culture Method | Applied | Solely Applied |
|---|---|---|
| Batch | 38 | 27 |
| Semicontinuous | 5 | 1 |
| Continuous | 10 | 3 |

## DISCUSSION

The success of the questionnaire allowed the compilation of data from a significant number of companies, and research and demonstration centra involved in bivalve seed production. However, it is difficult to estimate the fraction which is represented by the latter in comparison with the total existing number of hatcheries. Also, the contributing hatcheries may not be a representative sample as a few important countries (e.g. France, China) did not participate in the survey. Therefore, the quantitative data concerning the production of algae and seed should not be used as a basis for straight extrapolation to production on a world scale, but rather indicate the order of magnitude. Also, because algal production is often varying according to the season, the data expressing the daily algal production estimated the maximal rather than the yearly average production.

Although the total catches of the various commercially important bivalve species are well documented (FAO Yearbook of Fisheries Statistics), literature data estimating seed production are completely lacking. The reported total production for 1990 of *Crassostrea gigas* seed of planting size (i.e. 183 million oysters) is comparable with about 3% of the total world catches for this species in 1987 (i.e. 620,000 metric ton, FAO Yearbook of Fisheries Statistics, assuming a market size of 100 g). The pacific oyster harvest on the West Coast of North America amounted to 25,000 mt in 1989 (Chew 1990), i.e. approximately 250 million oysters. The production of over 25 billion eyed larvae of *C. gigas* for remote setting, reported by the hatcheries along the Pacific coast of the United States, confirms that this technique is providing the main part of the seed to the farmers in this region (Chew 1990) and is in agreement with the value of 27 billion recently reported by Le Borgne and Bodoy (1992).

Walne (cited in Persoone and Claus 1980) composed in 1978 a preference list of algal species suitable for hatchery rearing of bivalves on the basis of a survey held among ten institutes active in intensive bivalve culture in Europe and North America (Table 9). It is clear that the relative importance of several algal species has significantly changed over the last decade, in particular with

**TABLE 8.**

**Algal production cost in bivalve hatcheries. Replies obtained from n hatcheries.**

| | ALGAL PRODUCTION COST (C = commercial, A = academic hatchery) | | | | | |
|---|---|---|---|---|---|---|
| | Total Per Hatchery (US $) | | Fraction of Total Seed Cost (%) | | Cost Per Unit Weight (US $ (kg DW)$^{-1}$) | |
| | C | A | C | A | C | A |
| total | 442,000 | 212,000 | | | | |
| n | 11 | 9 | 8 | 15 | 4 | 5 |
| average | 40,000 | 24,000 | 33 | 27 | 400/338/150/ 50–100 | 365/322/318/ 300/75 |
| min | 5,000 | 4,000 | 5 | 6 | | |
| max | 160,000 | 74,000 | 60 | 60 | | |

the recognition of *I. galbana*, clone T-Iso (Helm and Laing 1987) and *C. gracilis* (Enright et al. 1986) as valuable species.

The algal production capacity recorded for the various hatcheries, varying from 1 to over 100 $m^3$ day$^{-1}$, can be related to the estimates of Helm (1990) for the quantities of algae required in a hatchery operation. The latter author calculated that one million juvenile clams or oysters of 3 mm shell length will consume about 1.4 $m^3$ of dense algal culture each day at the optimum rearing temperature of 24°C, while one million of larvae require only 15 liter of algal culture.

The algal production cost per unit dry weight appeared to be known (or released) by few hatchery operators. The few values, reported by hatcheries producing less than 5 $m^3$ algal culture per day mostly exceeded U.S. $300 (kg DW)$^{-1}$, which is higher than most data in the literature (Table 10). Lower estimates, ranging between U.S. $50 and 100, were reported by hatcheries producing relatively large quantities of algae (Fig. 8). Obviously, large scale culture systems, which provide the bulk of the algal biomass grown in bivalve hatcheries, yield lower production costs per unit of dry weight.

The survey revealed that more than half of the questioned operators had experimented with algal substitutes in their hatchery. Despite these efforts, artificial diets are included in the routine production process of only a few hatcheries and more often considered as a useful backup diet. In either case, the live algae could only be partially replaced by dried *Tetraselmis suecica* (up to 25–50%) or a preserved algal paste (up to 75%). The hatcheries rearing giant clams appeared to be an exceptional case as they mostly lack algal culture facilities, and the feeding regime of the larvae and early postset consists solely of artificial diets. This may be ascribed to the lower food requirements of giant clams compared to other bivalves due to the establishment of a symbiosis with dinoflagellates shortly after metamorphosis (Fitt et al. 1984) and to the relatively high costs associated with maintaining algal cultures on the often remote sites where giant clam farms are located (Munro, pers. comm. 1991).

It is interesting to note that the results obtained with the same artificial diet greatly vary between experimenters and are often inferior to those reported in scientific papers. In this way, the unsatisfactory results, reported for the micro-encapsulated Frippak diet fed to spat of the Manila clam and the Pacific oyster, conflict with the successful experiments performed by Laing (1987). The

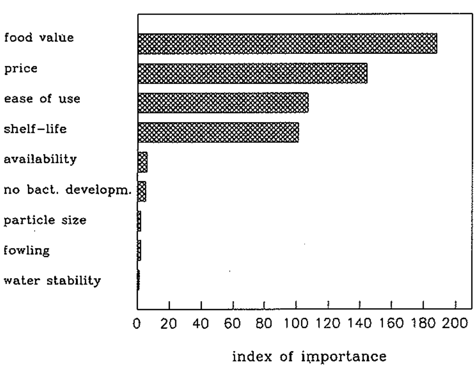


**Figure 7. Index of importance of various parameters of an artificial diet for bivalve rearing, based on 50 completed questionnaires. The index was calculated by summation of the quotations given to each parameter (between 1 and 5, 5 = most important, maximal index = 250).**

**TABLE 9.**

**Relative importance of various algal species in bivalve hatcheries as reported in the survey of Walne (1978, in Persoone & Claus, 1980) and in the present study.**

| | Frequency of Use | |
|---|---|---|
| Algal Species | Walne (out of 10) | Present Study (out of 43) |
| *Isochrysis galbana* | 8 | 8 |
| *Pavlova lutheri* | 7 | 11 |
| *Tetraselmis suecica* | 6 | 15 |
| *Phaeodactylum tricornutum* | 5 | 2 |
| *Pseudoisochrysis paradoxa* | 5 | — |
| *Thalassiosira pseudonana* | 4 | 14 |
| *Chaetoceros calcitrans* | 4 | 16 |
| *Skeletonema costatum* | 2 | 6 |
| *Isochryis galbana*, clone T-Iso | 2 | 31 |
| *Chlamydomonas* sp. | 1 | 1 |
| *Pyramimonas obovata* | 1 | — |
| *Tetraselmis chui* | 1 | 2 |
| *Rhodomonas* sp. | 1 | — |

**TABLE 10.**

**Production cost of marine micro-algae.**

| Production Cost (US $/kg dry weight) | Remarks | Source |
|---|---|---|
| 300 | *Tetraselmis suecica*, 200 l batch culture | Calculated from Helm et al. (1979) |
| 77 | | Pruder (1981; in Urban & Langdon, 1984) |
| 167 | Various diatoms, continuous flow cultures (240 $m^3$)† | Calculated from Walsh et al. (1987) |
| 4–20 | Outdoor culture | De Pauw & Persoone (1988) |
| 160–200 | Indoor culture | |
| 23–115 | Summer-winter production, continuous flow cultures in bags (8 $m^3$) and tanks (150 $m^3$)† | Dravers (pers. comm., 1990) |
| 50 | Tank culture (450 $m^3$)† | Donaldson (1991) |

† Total volume available for algal production.

latter author obtained for the same bivalve species a similar growth as the algal-fed controls when substituting up to 60–85% of the algal diet by microcapsules. Also, the limited replacement of live algae by dried *T. suecica* is in contrast with reports of successful substitution of up to 75% and 90% of the live algae in the spat rearing of, respectively, *Crassostrea virginica* (Helm and Hancock 1990) and *Tapes philippinarum* (Laing & Millican 1992). Although various authors have demonstrated through laboratory experiments that live algae could be substituted for up to 50% by dried yeast (*Candida utilis*) in the juvenile rearing of several bivalve species (Epifanio 1979, Alatalo 1980, Urban and Langdon 1984), no confirmation of this was revealed in the survey. The inconsistent performance of artificial diets may have several explanations. Certain products, such as the dried algae, appeared to be difficult to use and may not always have been presented in the optimal form to the animals. Alternatively, the experimental conditions, including quality and quantity of the algal control diet,

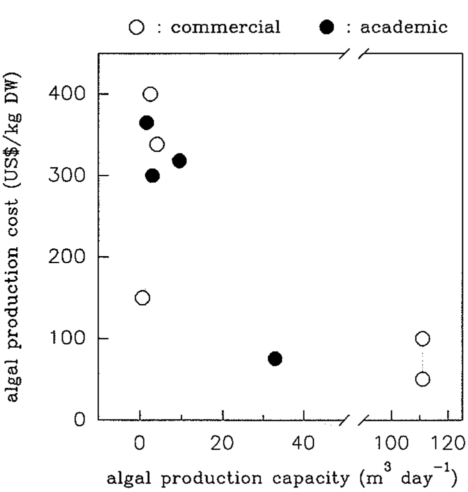


**Figure 8. Algal production cost as a function of the production capacity for 8 bivalve hatcheries. Dotted line connects estimates from one company.**

stocking density, water quality, and scale of the experiment, may affect the performance of the artificial diet. In this regard, the specific conditions of laboratory experiments can be expected to differ from those encountered in a hatchery.

## ACKNOWLEDGMENTS

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# THE USE OF ARTIFICIAL DIETS IN THE HATCHERY REARING OF BIVALVE MOLLUSKS

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ABSTRACT

Hatchery rearing of bivalve mollusks depends on the production of live micro-algae, which is costly and often unpredictable. Therefore, the development of a cost-effective artificial diet would greatly reduce the operating costs and improve the efficiency of bivalve seed production. This paper reviews the results reported so far in literature on the use of the various alternatives to on-site algal production. Furthermore, an overview is presented of the results obtained by the authors using manipulated yeasts as algal substitute in feeding trials with juveniles of various commercially important bivalve species. Literature data and experimental findings were compared with experience "from the field" through an international inquiry among the operators of 50 commercial and research hatcheries. Despite the extensive research efforts, artificial diets are rarely applied in the routine process of bivalve seed production and are mostly considered as a useful backup diet.

## INTRODUCTION

Intensive rearing of bivalves has so far relied on the production of live algae, which generally accounts for about 30% of the total seed production cost. Unicellular algae are an indispensable food source for the conditioning of the broodstock, the rearing of the larvae till settlement and the subsequent growing of the postset until they reach a size of 1 to 2 mm. From the latter stage onwards they are fed partially, or in some cases exclusively, natural phytoplankton. Once the seed attains planting size (5-10 mm), they are transferred to grow-out areas, where they reach market size feeding solely on natural food (Claus, 1981; Manzi, 1985; Helm, 1990).

The variable quality and availability of natural phytoplankton has prompted most bivalve hatchery operators to use monospecific algal cultures. The relative algal requirements of the various culture phases in the hatchery depend on whether the operation aims at the mass-production of larvae for remote setting or growing millions of seed till planting size (Fig. 1). In either case, the juveniles, representing the largest biomass in the hatchery and demanding the highest weight-specific rations, consume the largest volumes of algal culture.

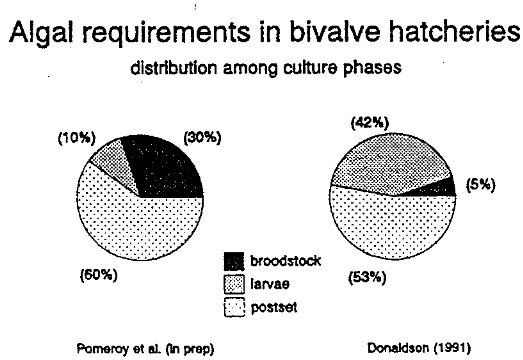


Fig. 1: The relative requirements for cultured algae of the broodstock, the larvae and the postset stages in a bivalve hatchery.