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A Brief Review of the Larval Rearing Techniques of Penaeid Prawns*

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Abstract As early as half a century ago, Hudinaga successfully spawned and attempted to rear the larvae of *Penaeus japonicus.* Publications in the 1960 s, 70's and 80's on breakthroughs in larval rearing of one penaeid species after another indicated that practical prawn farming had become a reality. At present, there are 24 *Penaeus* species and seven *Metapenaeus* species whose larval rearing techniques are partially or fully established. Among them, only nine species are propagated on a large commercial scale. The other species are now produced only on a small scale or experimentally.

There are many published papers dealing with larval rearing techniques of penaeid prawns. However, it is recognized that numerous details and problems remain unsolved pending further investigation and improvement. *P. japonicus* is the species which boasts the longest research history and the most successful larval rearing techniques. Nevertheless, there is little which scientists are able to do with the serious "white-turbid midgut gland disease" which has plagued the postlarvae of *P. japonicus* for the past several years. Similarly. *P. monodon* larval culture in the Philippines was once seriously affected by a fungus disease cause by *Lagenidium* sp., which resulted in poor survival rate.

Suitable larval rearing methods differ from one species to another, all showing varying degrees of modification from the major principles of larval rearing techniques of penaeid prawns. For example, a hatchery can easily obtain several hundred spawners of *P. japonicus,* but this is never the case with *P. monodon.* Therefore, the community culture method for rearing larvae in large tanks is preferred for the former species, while the separate tank method, also called the monoculture method, is best for the latter.

In general, larval rearing techniques of prawns is at its rapid growing stage. The status of larval rearing including rearing methods, feeding regimes and rearing systems, are herein summarized and introduced. The high priority problems to be solved, such as 1) selection of spawners, 2) improvement of rearing techniques, 3) larval diseases, 4) shipping methods, and 5) social impact are discussed and the prospects of larval rearing are described.

Introduction

As early as half a century ago, Hudinaga successfully spawned and reared larvae of *Penaeus japonicus* to the mysis stage (Hudinaga, 1935). In 1942, one of his famous papers entitled "Reproduction, development and rearing of *Penaeus japonicus* Bate" was published and became the primary foundation for prawn research. Unfortunately, World War II interrupted further development for more than 10 years. It was not until the late 1950's that several Americans became highly interested in penaeid hatchery work. In collaboration with Hudinaga, two species of American penaeids, white shrimp, *P. setiferus,* and brown shrimp, *P. aztecus,* were spawned and successfully reared in 1963 (Hanson and Goodwin, 1977).

However, two publications of Hudinaga and Kittaka, namely "Studies on food and growth of larval stages of a prawn, *Penaeus japonicus,* with reference to the application to practical mass culture" in 1966 and "The large scale production of the young kuruma prawn, *Penaeus japonicus* Bate" in 1967, contributed to the breakthrough in the mass production of penaeid prawns. It is on these two publications that the fundamentals of the prawn industry were based.

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Status

Twenty-four *Penaeus* species and seven *Metapenaeus* species can now be partially or fully artificially propagated (Table 1). Among these 31 species, *P. aztecus, P. duorarum, P. japonicus, P. monodon, P. orientalis, P. setiferus, P. stylirostris, P. vannamei* and *Metapenaeus ensis,* are the only nine species on which the practical commercialized propagation is carried out on a large scale.

Larval rearing methods

There are many different larval rearing methods in the world due in part to the wide variety of prawn species under culture. Other contributing factors are geography, climatic patterns, feeding regimes, and even personal preference (Hudinaga and Kittaka, 1966, 1975; Mock and Murphy, 1971; Salser and Mock, 1974; Shigueno, 1975; Heinen, 1976; Wickins, 1976; Aquacop, 1977; Liao, 1981). Hundreds of *P. japonicus, P. aztecus, P. duorarum* and *P. setiferus* spawners can be easily collected thus providing the hatchery with the necessary criterion to select the community culture method, whereby it is possible to rear a tremendous number of larvae in a hatchery tank of 100 tons or larger. In the community culture method, fertilizer is added directly to the tank for diatom growth, thus a food chain is formed in the larval rearing tank. The diatoms become the primary producer, providing food for prawn larvae and zooplankton. The larval prawn also consume these zooplankton. On the other hand, only a limited number of *P. monodon* spawners can be collected at any one time and, in addition, the larvae are slightly sensitive to direct application of fertilizer. Therefore, the community culture method is less suitable than the separate tank (monoculture) method for *P. monodon.* Comparisons between the community culture and separate tank (monoculture) methods are listed in Table 2.

Feeding regimes

Recent studies on the larval feed of penaeid prawns have made incredible progress (Furukawa et al., 1973; Griffith et al., 1973; Kittaka, 1976; Jones et al., 1979a, b; Liao et al., 1983). Today, even the application of manufactured microcapsules or the so-called microparticulate feed, is very promising (Jones, 1979a, b). Nevertheless, one should not forget the pioneer's hard work in the early history of the prawn industry. As early as 1934, Hudinaga succeeded in inducing the parent prawn of *P. japonicus* to spawn in the laboratory

Table 1. List of penaeid prawns partially or fully artificially propagated.

Species	Common name	Status[a] E	S	c	Culture area	Distribution[b]	Reference
Penaeus aztecus Ives	Northern brown shrimp			+	USA	W.A.	Cook & Murphy, 1966
P. brasiliensis Latreille	Red-spotted shrimp		+		Taiwan	W.A.	Unknown[c]
P. californiensis Holmes	Yellow-leg shrimp	+			USA	E.P.	Unknown
P. canaliculatus (Olivier)		+			—	I.W.P.	Choy, 1984
P. duorarum Burkenroad	Northern pink shrimp			+	USA	W.A.	Ewald, 1965
P. esculentus Haswell	Brown tiger prawn	+			—	I.W.P.	Fielder et al., 1975
P. indicus Milne Edwards	Indian white prawn		+		S.E. Asia	I.W.P.	Muthu et al., 1974
P. japonicus Bate	Kuruma prawn			+	Brazil, Italy Japan, Korea, Taiwan	I.W.P.	Hudinaga, 1942
P. kerathurus (Forskal)	Caramote prawn	+			Italy	E.A.	Lumare et al., 1971
P. latisulcatus Kishinouye	Western king prawn	+			—	I.W.P.	Shokita, 1970
P. marginatus Randall	Aloha prawn	+			—	I.W.P.	Gopalakrishnan, 1976
P. merguiensis De Man	Banana prawn		+		Indonesia, Malaysia	I.W.P.	Unknown
P. monodon Fabricius	Giant tiger prawn			+	India, Indonesia, Philippines, Taiwan	I.W.P.	Liao et al., 1969
P. occidentalis Streets	Western white shrimp	+			Panama	E.P.	Ting et al., 1977
P. orientalis Kishinouye	Oriental shrimp			+	China, Korea	W.P.	Oka, 1967
P. paulensis Perez-Farfante	Sao Paulo shrimp	+			—	W.A.	Unknown
P. penicillatus Alcock	Red-tail prawn		+		Taiwan	I.W.P.	Liao, 1973
P. plebejus Hess	Eastern king prawn		+		Australia	S.W.P.	Kelemec & Smith, 1980
P. schmitti Burkenroad	Southern white shrimp	+			South America	W.A.	Unknown
P. semisulcatus De Haan	Green tiger prawn	+			Kuwait, Taiwan	I.W.P.	Liao, 1970
P. setiferus (Linnaeus)	Northern white shrimp			+	USA	W.A.	Heegaard, 1953
P. stylirostris Stimpson	Blue shrimp		+		Colombia, Ecuador, Panama	E.P.	Unknown
P. teraoi Kubo	White-beared shrimp	+			—	I.W.P.	Liao, 1970
P. vannamei Boone	White-leg shrimp			+	Colombia, Ecuador, Panama	E.P.	Unknown
Metapenaeus affinis (H. Milne Edwards)	Jinga shrimp	+			India	I.W.P.	Thomas et al., 1974
M. bennettae Racek and Dall	Greentail prawn	+			Australia	S.W.P.	Racek, 1972
M. brevicornis (H. Milne Edwards)	Yellow shrimp	+			India	I.W.P.	Sudhakaro, 1978
M. dobsoni (Miers)	Kadal shrimp	+			India	I.W.P.	Enomoto & Makino, 1970
M. ensis (De Haan)	Greasyback shrimp			+	S.E. Asia	I.W.P.	Unknown
M. joyneri (Miers)	Shiba shrimp	+			—	I.W.P.	Liao, & Huang, 1973
M. monoceros (Fabricius)	Speckled shrimp			+	S.E. Asia	I.W.P.	Funada, 1966
M. stebbingi Nobili	Peregrine shrimp	+			—	I.W.P.	Hasan & Haq, 1975

[a]Status (of development): E — Experimental; S — Small scale; C — Commercial scale.
[b]Distribution: W.A. — Western Atlantic; E.P. — Eastern Pacific; I.W.P. — Indo-West Pacific; E.A. — Eastern Atlantic: W.P. — Western Pacific; S.W.P. - South-Western Pacific.
[c]Unknown: Origins presently being verified but cannot be substantiated at this time.

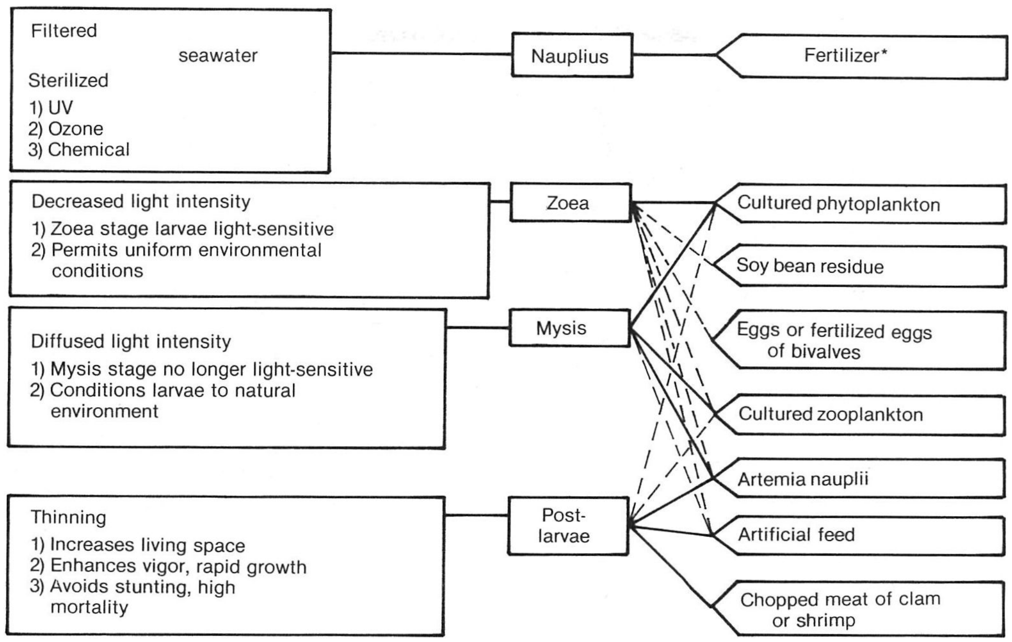

Fig. 1. Schematic representation of feeding regimes for developmental stages of penaeid prawn and related culture parameters. ____ most prominent feeding regime; – – occasional feeding regime. *Community culture method only.

for the first time, but it was not until 1940 that he was able to get a considerable number of larvae to metamorphose into mysis (Hudinaga, 1935, 1942). It was found that larvae in their nauplius stage were not difficult to keep alive, but upon reaching the zoea stage they became weak and died. Larvae in the mysis stage, however, were much stronger than in the zoea stage and could easily be kept alive for a long time. After the mysis stage, the postlarvae became even stronger, rendering their handling much easier and simpler. Therefore, in the culture of *P. japonicus,* and especially in order to raise the desired number of postlarvae, the most important matter is to rear them successfully through the zoea stage. The same was found to be true with many other penaeid prawn species through practical experience. One of the major factors that contributed to Hudinaga's breakthrough in successful rearing of zoea was the culture method of *Skeletonema* established by Matue. Hudinaga himself was greatly-indebted to Matue for valuable information with regards to the pure culture of *Skeletonema costatum* (Hudinaga, 1942, 1969).

As the zoea stage of penaeid prawns is the most difficult rearing period, it is believed that the smooth rearing means giving suitable feed in order to guarantee high survival of zoea and subsequent stages. In view of this, many research papers focused on the availability of a variety of feed for each larval stage (Table 3).

Larval sizes differ among species of penaeids and especially between those of the genera *Penaeus* and *Metapenaeus,* and therefore they feed on food particles of different sizes. In general, as shown in Fig. 1, zoea larvae prefer phytoplankton or tiny vegetable feed, but start to consume zooplankton when they reach the last substage of zoea. Mysis larvae prefer zooplankton, as do postlarvae (P_1-P_5). Postlarvae older than P_5 no longer pay attention to small food particles but actively start to search for larger food.

Larval rearing systems

Like larval rearing methods, the larval rearing systems differ according to species cultured and personal preference. The Japanese or Shigueno system is characterized by 100-ton or larger tanks, which are mainly used for larval rear-

Table 2. Comparison between community culture and separate tank (monoculture) methods.

	Community culture method	Separate tank (monoculture) method
1. Species	*Penaeus aztecus, P. duorarum, P. japonicus, P. setiferus*	*P. monodon*
2. Size of rearing tank for spawning and hatchery	Large tank (100-200 tons)	Small tank (0.5-20 tons)
3. Number of spawners	Many	Few
4. Fertilizer	Used	Not used
5. Light intensity	Normal sunlight	Subdued light
6. Production costs	Low	High
7. Risk	High	Low
8. Prospect for future development	Promising	Limited

ing of *P. japonicus* (Hudinaga and Kittaka, 1967; Shigueno, 1975). The Galveston system of 1- to 2-ton conical tanks is used for *P. stylirostris, P. vannamei* and *P. monodon* (Mock and Neal, 1974; Aquacop, 1975; Platon, 1978; Mock et al., 1980) and the Taiwanese system of 0.5- to 2-ton round tanks with flat bottom is used for *P. monodon* (Liao et al., 1969; Liao and Huang, 1973; Liao, 1981). There are both advantages and disadvantages of each system. For example, tanks of the Japanese system are very suitable for the community culture method, but there is a high risk of losing a great number of larvae if diseases occur. When the supply of spawners is unsteady, the larger size tanks are sometimes wasteful and inconvenient for rearing a limited number of larvae. They are also less flexible than smaller tanks for purposes of discarding larvae, cleaning tanks, and disinfecting equipment.

Two recently developed systems of larval rearing are shown in Fig. 2A and B. First, a ladder system hatchery is designed to take advantage of sloping ground and water level. Second, a hatchery of separate, medium-sized covered tanks with the advantage of being able to discard limited quantities of larvae is designed to suit warm tropical areas where prawns are easily exposed to epidemic disease and abandonment may be necessary. Additionally, three kinds of aeration set-up are shown for comparison (Fig. 2C).

Larval rearing practices

Among the penaeid prawns cultured today, *P. japonicus* is by far the most studied and therefore its larval rearing techniques are best established. It is the most important cultured prawn species in Japan where 500 million postlarvae are used each year for sea ranching and only 200 million postlarvae are used for aquaculture purposes. *P. japonicus* is also propagated in Brazil, Korea, Italy and Taiwan. The advantages of its hatchery work are (1) the availability of sufficient number of spawners at one time, (2) the established hatchery techniques, and (3) the strong tolerance of larvae to environmental factors.

The hatchery technique for *P. monodon* is more difficult than that of *P. japonicus*. However, *P. monodon* is the most treasured species in Southeast Asia and the most suitable species for culture worldwide (Forster and Beard, 1974; Liao, 1977, 1981; Motoh, 1981; Liao and Huang, 1982; Liao and Chao, 1983). It is now cultured mainly in Taiwan, Philippines, Indonesia, Thailand and India. In Taiwan, the total

Table 3. Food items and feeding regimes for various developmental stages of penaeid prawn.

Food item	Zoea	Mysis	Postlarvae (early: P_1-P_{10})	Postlarvae (later: P_{11}-P_{25})	References
Vegetable sources					
Skeletonema sp.	+ +	+ +			Hudinaga, 1942
Tetraselmis sp.	+	+			Beard et al., 1977
Isochrysis sp.	+	+			Beard & Wickins, 1980
Chaetoceros sp.	+	+			Hirata et al., 1975
Dunaliella sp.	—	—			SEAFDEC, 1981
Spirulina sp.	—	-			Tang, 1977
Chlamydomonas sp.	—	—			Hudinaga & Kittaka, 1975
Marine Chlorella	—	—			Hudinaga & Kittaka, 1975
Soy bean residue	+	+			Hirata et al., 1975
Animal sources					
Eggs or fertilized eggs of oyster	+ +	+ +			Liao, 1969
Eggs of *Mytilus*	+ +	+ +			Kittaka, 1975
Rotifer	+ +	+ +			Liao, 1969
Artemia salina	+ +	+ +			Hudinaga, 1969
Brine shrimp flakes	+ +	+ +			Unknown*
Moina sp.			—		Kittaka, 1975
Copepoda			+ +	+ +	Shigueno, 1968
Gammarus sp.			—	+ +	Kittaka, 1975
Balanus sp.			+ +	+ +	Kittaka, 1975
Nematoda			—	—	Liao, 1969
Annelida				+ +	Liao, 1969
Clam meat				+ +	Liao, 1969
Shrimp meat				+ +	Liao, 1970
Fish meat				+	Liao, 1969
Other sources					
Yeast					Furukawa et al., 1973
Milled feed		+	+	+	Shigueno, 1975
Sprayed dried feed		+	+	+	Shigueno, 1975
Microencapsulated diet		+	+	+	Jones et al., 1979a, b

Note: ++ Good; + Available; — Poor.
*Unknown: Origins presently being verified but cannot be substantiated at this time.

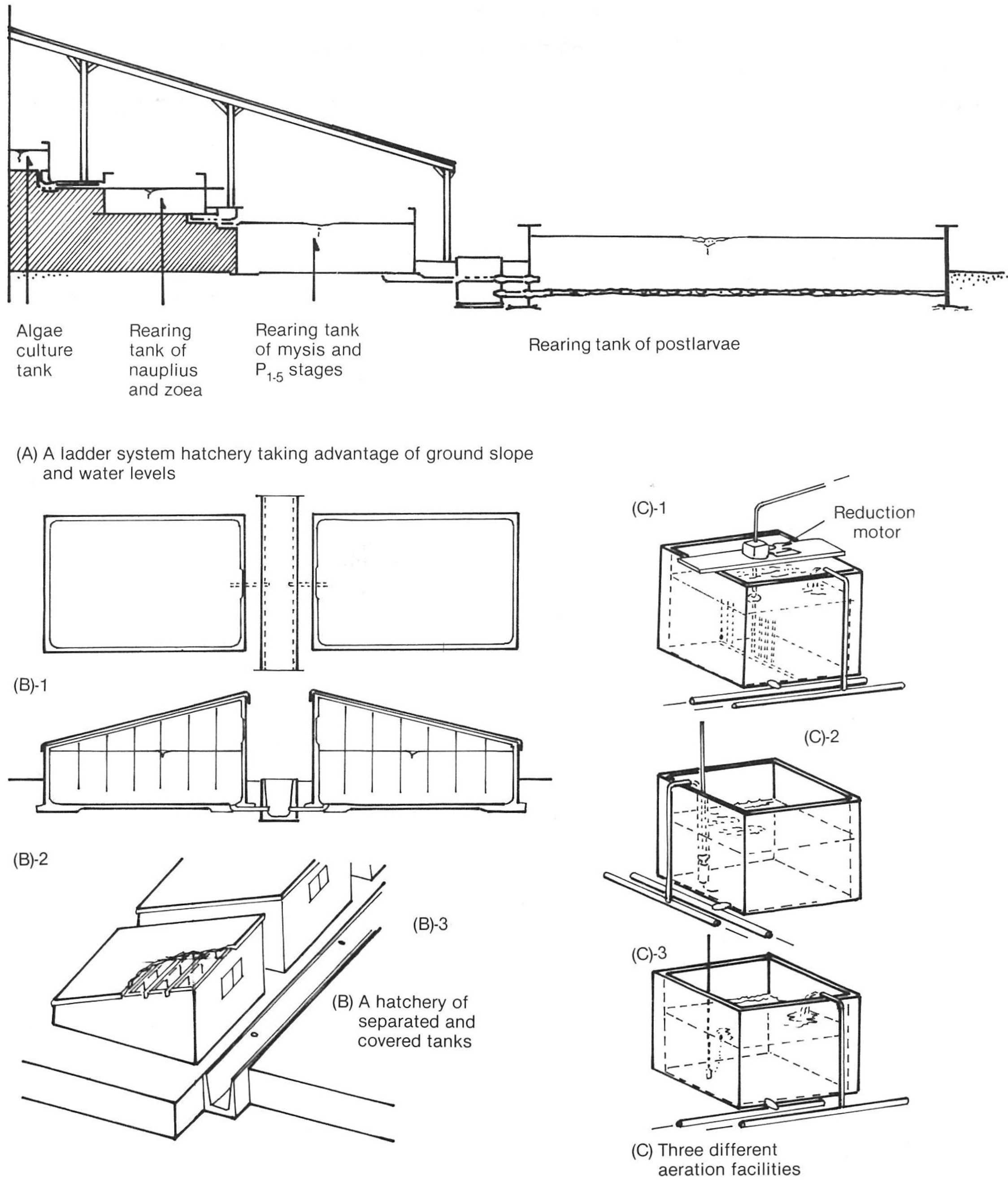

Fig. 2. Schematic diagram of penaeid prawn larval rearing system.

number of commercial hatcheries is more than 1,200 with an annual production of postlarvae as high as 600 million, more than enough to satisfy total domestic demand. The culture of *P. monodon* has great potential and bright prospects. The people in Malaysia, Sri Lanka, Japan, South Africa and Brazil are eager to try the culture of this prawn.

Penaeus stylirostris and *P. vannamei* are naturally abundant in Central and South America. The center of their culture is Ecuador. In 1976, there were only two farms with a total area of 63 ha. In 1984, the number of farms had increased to 465 and the total area to 59,350 ha. Before 1980, 100% of the prawn fry used for culture were collected from the wild. As a result of the rapid expansion of prawn culture and the destruction of the mangrove ecosystem, only one-third of the total fry demand could be met during the dry season of 1984. To further develop the prawn industry of Ecuador, artificially propagated larvae are absolutely needed. For the present, three recently established hatcheries are able to produce not more than 180 million P_{5-10} contributing only 5.5% of the estimated annual need of 3.3 billion fry. It is believed that five hatcheries under construction will soon be able to supply part of the remaining fry requirement by the end of 1985 (T.L. Huang, pers. comm., 1984).

Penaeus aztecus, P. duorarum and especially *P. setiferus* have comparatively easy larval rearing techniques (Kittaka, 1977). The small size of otherwise marketable adults and some lingering culture problems have kept the rearing of these three species at an early developmental stage. With mainland China as its culture center, probably 300-400 million postlarvae of *P. orientalis* are produced yearly, when estimated from the annual production of 3,000-4,000 tons. There is a possibility that *P. indicus, P. merguiensis, P. brasiliensis* and *P. schmitti* rank as potential aquaculture candidates for the near future.

Table 4 lists the distinctive characteristics of three major sizes of hatcheries i.e., large, medium and small hatcheries. Tables 5 and 6 list the number of postlarval prawns needed for desired harvest at various market sizes and survival rates and the number of postlarval prawns needed for various scales of grow-out ponds at different stocking densities for convenient reference.

Existing problems

Although research on prawns is far behind that of fishes, the development of the prawn industry is progressing well, even better than other aquaculture industries, mainly because prawns are a precious cosmopolitan food item. However, there are existing problems that need to be studied and solved before a truly successful prawn industry can be attained.

Table 4. Distinctive characteristics of three major sizes of hatcheries.

Size	Large	Medium	Small
Ownership	Company	Family or partner	Family
Personnel	Consultant, supervisor, technicians and workers	Owner and experienced workers	Owner and worker
Size (unit of pond)	600-800 m^2 plus accessory tanks (40-60 tons)	(1-20 tons)	(1-5 tons)
Electricity (generator power)	100 kw	50 kw	5 kw
Water storage	600 tons	200 tons	10-50 tons
Water treatment	Filtered at the source or UV light-treated	Filtered at the source or UV light-treated	Filtered at the hatchery
Number of spawners/yr	500 spawners	200-300 spawners	40-50 spawners
Sources of spawners	Private shrimp trawler or broker	Fishermen or broker	Fishermen or broker
Length of active operation (mo/yr)	11	10-11	6-8
Maximum capacity ($\times 10^6$ fry/yr)	10	5	1
Nursery	Necessary	Necessary	Not necessary
Shipping	Airplane, truck or exfarm	Truck or exfarm	Truck or exfarm

Selection of spawners

There is a close relationship between the physiological condition of a spawner and the quality of its eggs, survival of larvae and health during its subsequent culture period. The criteria for selecting the best spawners with good genetic makeup and perfect physical condition should be determined.

Many uncertain descriptions about unilaterally eyestalk-ablated spawners have been made, e.g. 1) there is a maximum of 2-3 or 4-5 spawnings after each ablation, 2) larvae obtained from the later spawnings are poorer in health than those from earlier ones, and 3) larvae obtained from eyestalk-ablated spawners are weaker and have lower survival rates than those of non-ablated spawners. There should be some scientific evidence to accept or reject each of the above mentioned statements.

Another observation that merits further investigation is that certain stimuli, such as transfer from one place to another or even from one tank to another, usually cause spawners to release their eggs during that same night. Based on this fact, spawning in captivity generally results in a premature release of eggs which is believed to be the cause of the poor survival rate of larvae. The problem is how to bring about a natural spawning when the eggs are ripe instead of stimulating a premature release of eggs to ensure optimum survival.

In summary, the appropriate methods for obtaining healthy and non-ablated spawners with the guarantee of getting ripe eggs and thus, high larval survival need to be precisely and promptly studied.

Improvement of rearing techniques

There has been established no standard larval rearing method for each cultured species of penaeid prawn. Taking *P. monodon* as an example, some culturists in Taiwan have adopted the dark-room type hatchery, where the newly hatched eggs are successfully reared in darkness through all the larval stages, while others, making use of the common open type hatcheries for prawn larval rearing, cover the rearing tanks only during the light-sensitive zoea stage. These two methods are quite different as far as suitable light intensity for larvae is concerned, yet both produce postlarvae at comparable rates. It would be more logical if the ranges of tolerance to light intensity, water salinity and other parameters for each larval stage are well studied, so that a standard rearing method could be established. The advantageous community culture method is a common milestone for which the culturists should strive in the culture of various prawn species.

Generally speaking, a large majority of hatchery owners prefer to aim for high survival rates of larvae using a policy of overprotection i.e., an overdose of drugs is administered regardless of the state of health. It is suggested that hatcheries should not concentrate only on high survival rates but should try to follow the principle of natural selection. Unhealthy larvae, which in any case will die if no special treatment is undertaken, should preferably be removed. Such a wise decision will ensure good growth of the survivors

Table 5. Number of postlarvae (× 10^{n}*) needed to attain desired harvest levels at various market sizes and survival rates.

Harvest (× 10^{n}* mt)	Market size (g)	Survival rate (%)										
		5	10	20	30	40	50	60	70	80	90	95
1	20	1,000,000	500,000	250,000	166,667	125,000	100,000	83,333	71,429	62,500	55,556	52,632
	30	666,667	333,333	166,667	111,111	83,333	66,667	55,556	47,619	41,667	37,037	35,088
	40	500,000	250,000	125,000	83,333	62,500	50,000	41,667	35,714	31,250	27,778	26,316
1.5	20	1,500,000	750,000	375,000	250,000	187,500	150,000	125,000	107,143	93,750	83,333	78,947
	30	1,000,000	500,000	250,000	166,667	125,000	100,000	83,333	71,429	62,500	55,556	52,632
	40	750,000	375,000	187,500	125,000	93,750	75,000	62,500	53,571	46,875	41,667	39,474
2	20	2,000,000	1,000,000	500,000	333,333	250,000	200,000	166,667	142,857	125,000	111,111	105,263
	30	1,333,330	666,667	333,333	222,222	166,667	133,333	111,111	95,238	83,333	74,074	70,175
	40	1,000,000	500,000	250,000	166,667	125,000	100,000	83,333	71,429	62,500	55,556	52,632
2.5	20	2,500,000	1,250,000	625,000	416,667	312,500	250,000	208,333	178,571	156,250	138,889	131,579
	30	1,666,670	833,333	416,667	277,778	208,333	166,667	138,889	119,048	104,167	92,593	87,719
	40	1,250,000	625,000	312,500	208,333	156,250	125,000	104,167	89,286	78,125	69,444	65,790
3	20	3,000,000	1,500,000	750,000	500,000	375,000	300,000	250,000	214,286	187,500	166,667	157,895
	30	2,000,000	1,000,000	500,000	333,333	250,000	200,000	166,667	142,857	125,000	111,111	105,263
	40	1,500,000	750,000	375,000	250,000	187,500	150,000	125,000	107,143	93,750	83,333	78,947
3.5	20	3,500,000	1,750,000	875,000	583,333	437,500	350,000	291,667	250,000	218,750	194,444	184,211
	30	2,333,330	1,166,670	583,333	388,889	291,667	233,333	194,444	166,667	145,833	129,630	122,807
	40	1,750,000	875,000	437,500	291,667	218,750	175,000	145,833	125,000	109,375	97,222	92,105
4	20	4,000,000	2,000,000	1,000,000	666,667	500,000	400,000	333,333	285,714	250,000	222,222	210,526
	30	2,666,670	1,333,330	666,667	444,444	333,333	266,667	222,222	190,476	166,667	148,148	140,351
	40	2,000,000	1,000,000	500,000	333,333	250,000	200,000	166,667	142,857	125,000	111,111	105,263
4.5	20	4,500,000	2,250,000	1,125,000	750,000	562,500	450,000	375,000	321,429	281,250	250,000	236,842
	30	3,000,000	1,500,000	750,000	500,000	375,000	300,000	250,000	214,286	187,500	166,667	157,895
	40	2,250,000	1,125,000	562,500	375,000	281,250	225,000	187,500	160,714	140,625	125,000	118,421
5	20	5,000,000	2,500,000	1,250,000	833,333	625,000	500,000	416,667	357,143	312,500	277,778	263,158
	30	3,333,330	1,666,670	833,333	555,556	416,667	333,333	277,778	238,095	208,333	185,185	175,439
	40	2,500,000	1,250,000	625,000	416,667	312,500	250,000	208,333	178,571	156,250	138,889	131,579
5.5	20	5,500,000	2,750,000	1,375,000	916,667	687,500	550,000	458,333	392,857	343,750	305,556	289,474
	30	3,666,670	1,833,330	916,667	611,111	458,333	366,667	305,556	261,905	229,167	203,704	192,982
	40	2,750,000	1,375,000	687,500	458,333	343,750	275,000	229,167	196,429	171,875	152,778	144,737
6	20	6,000,000	3,000,000	1,500,000	1,000,000	750,000	600,000	500,000	428,571	375,000	333,333	315,790
	30	4,000,000	2,000,000	1,000,000	666,667	500,000	400,000	333,333	285,714	250,000	222,222	210,526
	40	3,000,000	1,500,000	750,000	500,000	375,000	300,000	250,000	214,286	187,500	166,667	157,895
6.5	20	6,500,000	3,250,000	1,625,000	1,083,330	812,500	650,000	541,667	464,286	406,250	361,111	342,105
	30	4,333,330	2,166,670	1,083,330	722,222	541,667	433,333	361,111	309,524	270,833	240,741	228,070
	40	3,250,000	1,625,000	812,500	541,667	406,250	325,000	270,833	232,143	203,125	180,556	171,053
7	20	7,000,000	3,500,000	1,750,000	1,166,670	875,000	700,000	583,333	500,000	437,500	388,889	368,421
	30	4,666,670	2,333,330	1,166,670	777,778	583,333	466,667	388,889	333,333	291,667	259,259	245,614
	40	3,500,000	1,750,000	875,000	583,333	437,500	350,000	291,667	250,000	218,750	194,444	184,211
7.5	20	7,500,000	3,750,000	1,875,000	1,250,000	937,500	750,000	625,000	535,714	468,750	416,667	394,737
	30	5,000,000	2,500,000	1,250,000	833,333	625,000	500,000	416,667	357,143	312,500	277,778	263,158
	40	3,750,000	1,875,000	937,500	625,000	468,750	375,000	312,500	267,857	234,375	208,333	197,368
8	20	8,000,000	4,000,000	2,000,000	1,333,330	1,000,000	800,000	666,667	571,429	500,000	444,444	421,053
	30	5,333,330	2,666,670	1,333,330	888,889	666,6667	533,333	444,444	380,952	333,333	296,296	280,702
	40	4,000,000	2,000,000	1,000,000	666,667	500,000	400,000	333,333	285,714	250,000	222,222	210,526
8.5	20	8,500,000	4,250,000	2,125,000	1,416,670	1,062,500	850,000	708,333	607,143	531,250	472,222	447,368
	30	5,666,670	2,833,330	1,416,670	944,444	708,333	566,667	472,222	404,762	354,167	314,815	298,246
	40	4,250,000	2,125,000	1,062,500	708,333	531,250	425,000	354,167	303,571	265,625	236,111	223,684
9	20	9,000,000	4,500,000	2,250,000	1,500,000	1,125,000	900,000	750,000	642,857	562,500	500,000	473,684
	30	6,000,000	3,000,000	1,500,000	1,000,000	750,000	600,000	500,000	428,571	375,000	333,333	315,790
	40	4,500,000	2,250,000	1,125,000	750,000	562,500	450,000	375,000	321,429	281,250	250,000	236,842
9.5	20	9,500,000	4,750,000	2,375,000	1,583,330	1,187,500	950,000	791,667	678,571	593,750	527,778	500,000
	30	6,333,330	3,166,670	1.583,330	1,055,560	791,667	633,333	527,778	452,381	395,833	351,852	333,333
	40	4,750,000	2,375,000	1,187,500	791,667	593,750	475,000	395,833	339,286	296,875	263,889	250,000

*n = -2, -1, 0, 1 2, 3, . . . n. For example, if the harvest level is 15,000 mt, that is 1.5 × 10^{4} rat (n = 4), market size of 30 g and survival rate 80%, then the number of postlarvae needed is 62,500 × 10^{4}, that is 625 million.

in subsequent culture periods (Liao, 1981). Besides, now that many crops are desired in each pond per year, one should stock the pond with postlarvae of a larger size than is currently used, to shorten the cropping time. Of course, there are additional advantages in shortening each cropping time, such as avoiding poor pond bottom conditions and increasing annual production. The existing problem is to improve nursery techniques for juvenile prawns on a large production scale.

As mentioned previously, many breakthroughs in larval feeding, including the accurate establishment of mass culture of phytoplankton, progressive development of mass culture of zooplankton, and primary development of microencapsulated feed, have been achieved. However, they all need further studies before ideal feeding regimes can be declared. Furthermore, the use of modern equipment in the hatchery facility should be encouraged. Aquaculture engineers should design functional, labor- and energy-saving devices to further improve hatchery production.

Larval diseases

In the initial period of the development of the prawn industry, unsuitable and insufficient food, resulting in substandard nutrition and starvation, were major causes of larval mortality. Occasionally, non-lethal or low mortality diseases caused by protozoan infections occurred, but no serious larval diseases or high mortalities were encountered, hence no papers were written on the subject. In contrast, with increasing popularity and profitability of prawn culture in recent years, hatcheries are often overcrowded with larvae, and this is generally accompanied by the occurrence of diseases. White-turbid midgut gland disease has been reported in *P. japonicus* (Shigueno, 1975), as well as *Lagenidium* infection in all penaeid prawns (Couch, 1942; Cook, 1971; Lightner and Fontaine, 1973; Lightner, 1977; Lightner and Redman, 1981; Lightner, 1983), *Baculovirus penaei* (BP) disease in *P. aztecus, P. duorarum, P. setiferus, P. stylirostris* and *P. vannamei* (Laramore, 1977; Couch, 1978; Overstreet, 1978), and recently also baculoviral midgut gland necrosis (BMN) in *P. japonicus* (Sano et al., 1981), Monodon baculovirus (MBV) disease in *P. monodon* (Lightner and Redman, 1981; Lightner, 1983), and finally infectious hypodermal and hematopoietic necrosis (IHHN) in *P. stylirostris* and *P. monodon* (Lightner, 1983). All of these have proven to be a serious threat to hatchery business, with possibly one exception — it is not yet known if MBV is an important disease. Table 7 summarizes the major diseases in the larval and postlarval stages of penaeid prawns and the corresponding treatments.

It is commonly believed that diseases may increase in variety and occurrence with time, especially with respect to the virus-caused diseases. For the present, only four viral diseases have been identified in prawn larvae, but it is likely that more will be found. The ultimate concern is obviously how to prevent diseases and reduce their devastating effects on larvae so that great losses can be avoided. MBV disease shows its lethal effect only when combined with the serious symptoms of other diseases. It is true that by providing MBV-infected larvae with a suitable environment and food they are better protected from other diseases and hence can

Table 6. Number of postlarvae ($\times 10^{n*}$) needed for various sizes of grow-out ponds at different stocking densities per crop.

Pond area ($\times 10^{n*}$ ha)	Stocking density (postlarvae/m²)										
	3	5	10	15	20	25	30	40	50	60	70
1	30	50	100	150	200	250	300	400	500	600	700
1.5	45	75	150	225	300	375	450	600	750	900	1,050
2	60	100	200	300	400	500	600	800	1,000	1,200	1,400
2.5	75	125	250	375	500	625	750	1,000	1,250	1,500	1,750
3	90	150	300	450	600	750	900	1,200	1,500	1,800	2,100
3.5	105	175	350	525	700	875	1,050	1,400	1,750	2,100	2,450
4	120	200	400	600	800	1,000	1,200	1,600	2,000	2,400	2,800
4.5	135	225	450	675	900	1,125	1,350	1,800	2,250	2,700	3,150
5	150	250	500	750	1,000	1,250	1,500	2,000	2,500	3,000	3,500
5.5	165	275	550	825	1,100	1,375	1,650	2,200	2,750	3,300	3,850
6	180	300	600	900	1,200	1,500	1,800	2,400	3,000	3,600	4,200
6.5	195	325	650	975	1,300	1,625	1,950	2.600	3,250	3.900	4,550
7	210	350	700	1,050	1,400	1,750	2,100	2,800	3,500	4,200	4,900
7.5	225	375	750	1,125	1,500	1,875	2,250	3,000	3,750	4,500	5,250
8	240	400	800	1,200	1,600	2,400	2,400	3,200	4,000	4,800	5,600
8.5	255	425	850	1,275	1,700	2,125	2,550	3,400	4,250	5,100	5,950
9	270	450	900	1,350	1,800	2,250	2,700	3,600	4,500	5,400	6,300
9.5	285	475	950	1,425	1,900	2,375	2,850	3,800	4,750	5,700	6,650

*n = -2, -1, 0, 1, 2, 3,. . . n. For example, if the total area of grow-out ponds is 15 ha (1.5×10^n ha) (n = 1) and the stocking rate is 25 postlarvae/m², then the number of postlarvae needed is 375×10^1 thousand, that is 3.75 million.

attain normal growth. For the present, MBV is known to exist in Taiwan and the Philippines, but the extent of its range in other areas is unknown. Being an enzootic virus, MBV should be eradicated. To avoid further contamination, strict quarantine and burning of the infected larvae should be carried out (Lightner et al., 1983).

In summary, the concept that prevention is more important and effective than cure in controlling a disease is absolutely accurate. Reducing stress due to crowding and application of quarantine measures are as necessary as the continuing research on viruses and determination of the etiology of other diseases.

Shipping methods

Even if the three above-mentioned problems of rearing, spawners and diseases are solved, the large quantities of prawn larvae produced in a hatchery still face the problems of shipping before they can be stocked in culture ponds. Transport may be international which usually takes more than 30 hours and also entails expensive shipping costs. The lack of basic biological knowledge and related transport information makes this procedure difficult and a waste of resources. The failure of live transport is not fair to the billions of tiny creatures, each with the dignity of life for which it has struggled seriously and successfully in the hatcheries. Since the relevant research is weak in both quantity and quality, only limited transport data are summarized in Table 8.

It is known from available data that the nauplius stage is ideal for shipping. Nevertheless, there are two limiting factors. First, great quantities of nauplii are requested within a short time frame, often within as short as one to two days. Second, shipping is limited to as short a time as possible i.e., before the larvae molt into zoea, in order to avoid mortality owing to absence of food for zoea and high consumption of oxygen during metamorphosis.

In general, a polyethylene or PVC bag inflated with oxygen and placed in a styrofoam box, has been adapted for convenient and functional shipping. Additional studies on the proper ratio of larvae, water and oxygen; suitable temperature; proper use of substrate; chemical and live diet organisms; etc. during shipping have to be done one by one in order to determine their practical applications to the prawn industry.

Social impact

As the prawn industry continues to progress, more and more hatcheries are being established. In Taiwan for example, there was only one hatchery in 1968 and then a rapid development occurred over the last 15 years. By 1983, there were more than 1,200 hatcheries. The supply of postlarvae is now greater than the demand, causing the price of postlarvae to plummet making it now far below the break-even point with some hatchery owners losing their capital investment. Although low price of postlarvae is advantageous to the culturist, imbalance of supply and demand has a social impact because of the waste of manpower and resources.

This is a warning for people in Southeast Asia, and Central and South America not to repeat the overproduction model, but to maintain a steady and well coordinated industry.

Prospects

Judging from the above-mentioned status and existing problems, the science of larval rearing techniques for penaeid prawns, although still a "state-of-the-art," is in a stage of rapid development. Nevertheless, there are optimistic and promising prospects for penaeid prawns in most of the countries currently undertaking prawn culture as well as in some countries with great potential. It is believed that this industry will continue to grow at a fast rate for the reasons discussed below.

High requirement for technologies

Since the natural resources of prawns are diminishing, there is a genuine demand for cultured prawns. In turn, the supply of wild postlarvae is insufficient for culture purposes because of the destruction and pollution of their environment, as accurately and vividly exemplified by the Ecuadorian prawn industry. Steady development in the past had totally relied on wild prawn larvae for seed supply but it is becoming more and more dependent on hatcheries, the most reliable source for the future. There is no doubt that hatchery production is the best model for fry supply in many other countries where people realize that natural resources can not be relied upon forever.

The penaeid prawn is an ideal animal for sea ranching. A much greater number of larvae is needed for ranching purposes than for culture. Hereafter, as sea farming fisheries or resource managing fisheries develop, there will be an increasing need for postlarvae and thus a high requirement for larval rearing techniques.

Diversification of cultured species

Food for human consumption will require more variety as the standard of living increases in the world. Although prawns were considered a luxury food item when they first appeared on the table, species diversification is far below that of fish. There are three possible ways towards diversification. First, more indigenous species should be explored and studied to determine the feasibility and advantages of their propagation and culture. Second, selected exotic species should be introduced. For example, the introduction of *P. japonicus* and *P. monodon* to Brazil and *P. brasiliensis* to Taiwan is proving to be very promising. Lastly, trials in producing hybrids by cross-breeding or use of genetic alteration should be considered. People are now looking forward to pioneering trials in this significant area. The more the variety of cultured prawn species, the brighter the prospects.

Specialization of propagation procedure

Hatchery business is complex and complicated. Specialization of each propagation procedure for an ideal cooperative model is suggested. For example in Taiwan, the hatchery business has been divided into six specialized sub-businesses; 1) suppliers of locally harvested or imported spawners; 2) suppliers of hatchery-produced nauplii; 3) brokers for buying and selling nauplii; 4) suppliers of early postlarvae ($P_{11\text{-}13}$); 5) suppliers of late postlarvae ($P_{20\text{-}30}$ and

Table 7. Diseases found in the developmental stages of penaeid prawn larvae and their control methods.

Disease	Affected parts	Symptoms	Treatment		Life stages affected*	References
Bacteria						
Bacterial necrosis	Appendages	Appearing as localized necrosis or discoloration on any appendage, causing high mortality of zoea and mysis stages, affects postlarva to a lesser extent.	Furanace Erythromycin Achromycin	1.1 ppm 1.5 ppm 1.2 ppm	Z, M, PL	Tareen, 1982 Lightner, 1983
Vibrio infection	Hemolymph, midgut gland	In initial stages of one form, some larvae will show yellow-vermilion and red color permeating entire nervous system. Another form exhibits "White-turbid liver," where the midgut gland of the larvae becomes generally white-turbid. Turbidity becomes more apparent and well-defined as the disease progresses.	Furazolidone Terramycin Furanace	2.0 ppm 450 mg/kg biomass 1.3 ppm	PL	Nickelson and Vanderzant, 1971 Lewis, 1973 Shigueno, 1975 Lightner, 1977 Johnson, 1978 Cirpiani et al., 1980 Tareen, 1982 Lightner, 1983
Filamentous bacteria	Gills, pleopods	Commonly found attached to the gill filaments and the pleopods, turning blackish when bacteria mix with dirt. If severely affected, the respiratory function of the gill suffers damage.	Cutrine plus malachite green Potassium permanganate Cuprous chloride	0.5 ppm 10 ppm 8.5 ppm 1.0 ppm	PL	Delves-Broughton and Poupard, 1976 Streenbergen and Schapiro, 1976 Johnson, 1978 Solangi et al., 1979 Lightner et al., 1980 Tareen, 1982 Lightner, 1983
Shell disease	Exoskeleton, muscles	If infected by chitinoverous bacteria, the exoskeleton will display eroded blackened areas. The edges or tips of the exoskeleton parts are typically attacked. Also bacteria can rapidly enter the body through surface breaks to cause internal damage.	Malachite green and formalin combined	0.9 ppm 22 ppm	PL	Cook and Lofton, 1973 Delves-Broughton and Poupard, 1976 Johnson, 1978 Tareen, 1982 Lightner, 1983
Black gill disease	Gills	In initial stages, gill color turns dull orange-yellow or light brown. When advanced, the area darkens until it is finally black.	Malachite green Methylene blue	3.0 ppm 8-10 ppm	PL	Shigueno, 1975 Tareen, 1982
Fungi						
Lagenidium infection	Body cavity, appendages	Only thin-cuticled prawns can be infected, thus larval prawns are highly sensitive. The hyphae appear inside the body of zoea and continue into mysis stage, resulting in massive muscle destruction, and heavy mortality of zoea and mysis.	Treflan[R] Malachite green	0.1 ppm 0.01 ppm	Z, M	Hubschaman and Schmitt, 1969 Lightner and Fontaine, 1973 Lightner, 1977 Johnson, 1978 Gopalan et al., 1980 Tareen, 1982 Lightner, 1983
Ectocommensal protozoa						
Ciliate infection (*Zoothamnium* sp., *Epistylis* sp.)	Gills, eyes, exoskeleton	Heavy infestation by *Zoothamnium* sp. of gills and eyes of larval prawn results in high mortality. *Epistylis* sp. seems to prefer exoskeleton as attachment site and is less harmful. When abundant on gill surface, both can cause hypoxia and death. Additionally, their abundant presence on general body surface of larvae may interfere with locomotion, feeding, molting, etc. Parasite burden increases until ecdysis provides relief.	Malachite green and formalin combined Quinacrine hydrochloride Chloramine-T Methylene blue Saponin 10%	1.0 ppm 25 ppm 0.8 ppm 5.5 ppm 8.0 ppm 5.0 ppm	Z, M, PL	Johnson et al., 1973 Overstreet, 1973 Johnson, 1974 Delves-Broughton and Poupard, 1976 Lightner, 1977 Liao et al., 1977 Johnson, 1978 Lightner et al., 1980 Tareen, 1982 Lightner, 1983

Table 7. (continued)

Disease	Affected parts	Symptoms	Treatment	Life stages affected*	References
Viruses					
Penaeid baculoviruses (BP, MBV, BMN)	Hepatopancreas, anterior midgut	Penaeid baculoviruses infect epithelial cells of the hepatopancreas and, less commonly, anterior midgut, causing high mortality in the postlarval stage.		PL	Johnson. 1978 Sano et al., 1981 Lightner, 1983 Lightner et al., 1983 Couch, 1974
Infectious hypodermal and hematopoietic necrosis (IHHN)	Hypodermis, hematopoietic organs	Prawns dying from acute IHHN show massive destruction of cuticular hypodermis and often of the hematopoietic organs, of glial cells in the nerve cord, and of loose connective tissues such as the subcutis and gut serosa. Only prawns within a size range of 0.05-1.0 g have been observed to have these epizootics, resulting in massive mortalities (often 80 to 90% within 2 weeks of onset).		PL	Lightner, 1983
Miscellaneous diseases					
Abnormal nauplii	Appendages	Occur as a result of poor quality of spawner.		N	Tareen, 1982
Amoebiasis of larvae	Subcutis, muscles	Invasion of muscles and subcuticular tissues located in the abdomen, cephalothorax, antenna, and eyestalks, by unclassified amoeba.		Z	Laramore and Barkate, 1979 Lightner, 1983
Larval encrustation	Exoskeleton	Brown to black encrusted deposits which contain iron salts affect larval penaeids.		Z, M, PL	Lightner, 1983

*N — nauplius, Z — zoea, M — mysis, PL — postlarva.

Table 8. Shipping record of penaeid prawn larvae.

Species	Larval stage shipped	Origin	Destination	Duration (hr)	Container	Aeration	Water (ℓ)	Number (larvae/bag)	Survival rate (%)	Remarks
Penaeus stylirostris	Nauplius	Panama	Tungkang	35	Plastic bag in polystyrene foam box	O_2	10	125×10^3	100	Totalled 500,000 in 4 bags
P. monodon	$P_{20\text{-}30}$	Tungkang	Rio de Janeiro	30	Portable plastic tank	Air from battery pump	20	4×10^3	20	Stopped at Tokyo 2 days
P. monodon	P_{15}	Tungkang	Salvador (Brazil)	85	Plastic bag	O_2	10	$15\text{-}25 \times 10^2$	20-30	
P. penicillatus	$P_{6\text{-}8}$	Tungkang	Salvador (Brazil)	85	Plastic bag	O_2	10	$15\text{-}25 \times 10^2$	60-70	

6) brokers for buying and selling either $P_{11\text{-}13}$ or $P_{20\text{-}40}$. Joint ventures and linkages among these six sub-businesses are very functional.

The more detailed the breakdown of a business, the more progressive it becomes. Not only in Taiwan, but also in the world, there seems to be an increasing number of subsidiary businesses surrounding the prawn larval rearing operation. Due to high specialization, there are more job opportunities and a better chance of improving techniques. All these factors combined point towards a very bright future for larval rearing techniques.

Modernization of facilities and international exchange of knowledge

There is a great need for experts in zoology, botany, biochemistry, mechanics, engineering, electronics, veterinary medicine, pharmaceutics, marketing, etc. to start joining the prawn industry and contributing their specialized knowledge. The goal is to modernize facilities and hence larval rearing techniques. Recently, the gradual popularity of related journals, handbooks, proceedings and digests, and the increasing frequency of workshops, colloquia, symposia and conferences act as a functional tool for international collection and exchange of knowledge and techniques. Therefore, it is deeply believed that there are very promising prospects for larval rearing techniques and the prawn farming industry.

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