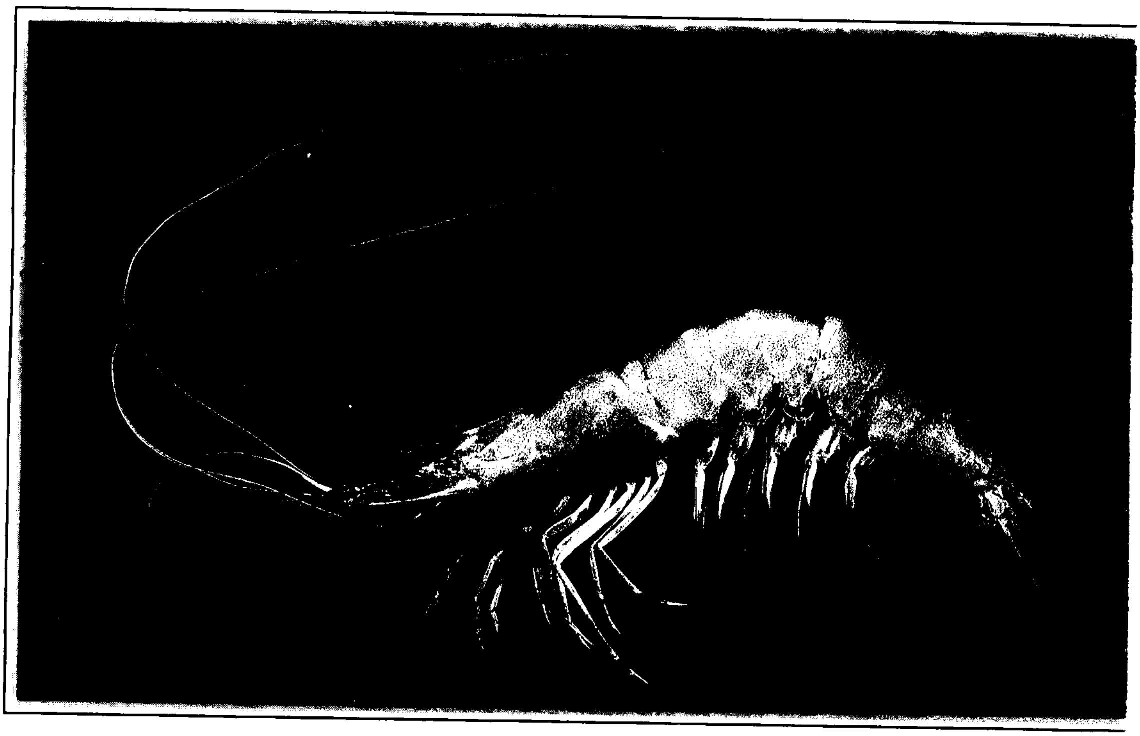
The Culture of Cold-Tolerant Shrimp:

Proceedings of an Asian-U.S. workshop on Shrimp Culture



Edited by
Kevan L. Main and Wendy Fulks

THE OCEANIC INSTITUTE

The Culture of Cold-Tolerant Shrimp: Proceedings of an Asian-U.S. Workshop on Shrimp Culture

Honolulu, Hawaii, U.S.A.
October 2-4, 1989

Edited by
Kevan L. Main and Wendy Fulks

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Cover photo of *Penaeus chinensis* by Shin Bok Lee, Doosan Industrial Co., Ltd., Republic of Korea

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PREFACE

The Asian Interchange Program (AIP) was established at The Oceanic Institute in 1989 (NOAA, U.S. Dept. of Commerce grant award no. NA85AA-D-SG082) to facilitate the exchange of aquaculture information between Asia and the United States.

Much of the shrimp consumed in the U.S. is imported. While culture facilities do exist, profits are generally low, and the U.S. shrimp culture industry is searching for ways to improve the situation. *P. vannamei* is the predominant shrimp culture species in the U.S., however, this tropical animal cannot tolerate low temperatures. *P. vannamei* is typically stocked in ponds after water temperatures are consistently above 20°C. Growth rates are not acceptable in most cases, until pond temperatures are above 23°C.

To increase production, many shrimp farmers in temperate areas are now culturing or exploring the possibility of producing exotic species which can grow in colder water. Due to this interest, cold-tolerant shrimp production was chosen as the topic for AIP's first year.

Not only have shrimp been cultured in Asia for centuries, but three species grown there are said to be "cold-tolerant": *Penaeus chinensis*, *P. japonicus* and *P. penicillatus*. These shrimp are reported to be able to survive or grow in water as cold as 15°C.

Only limited information about the culture of *P. chinensis* and *P. penicillatus* has been published, and much of the data has not been published in English. Much of the information on basic culture techniques for these two species is appearing in English for the first time. A great deal has been published about *P. japonicus*, however, up-to-date information has been included for comparative purposes because of the importance and interest in this cold-tolerant species.

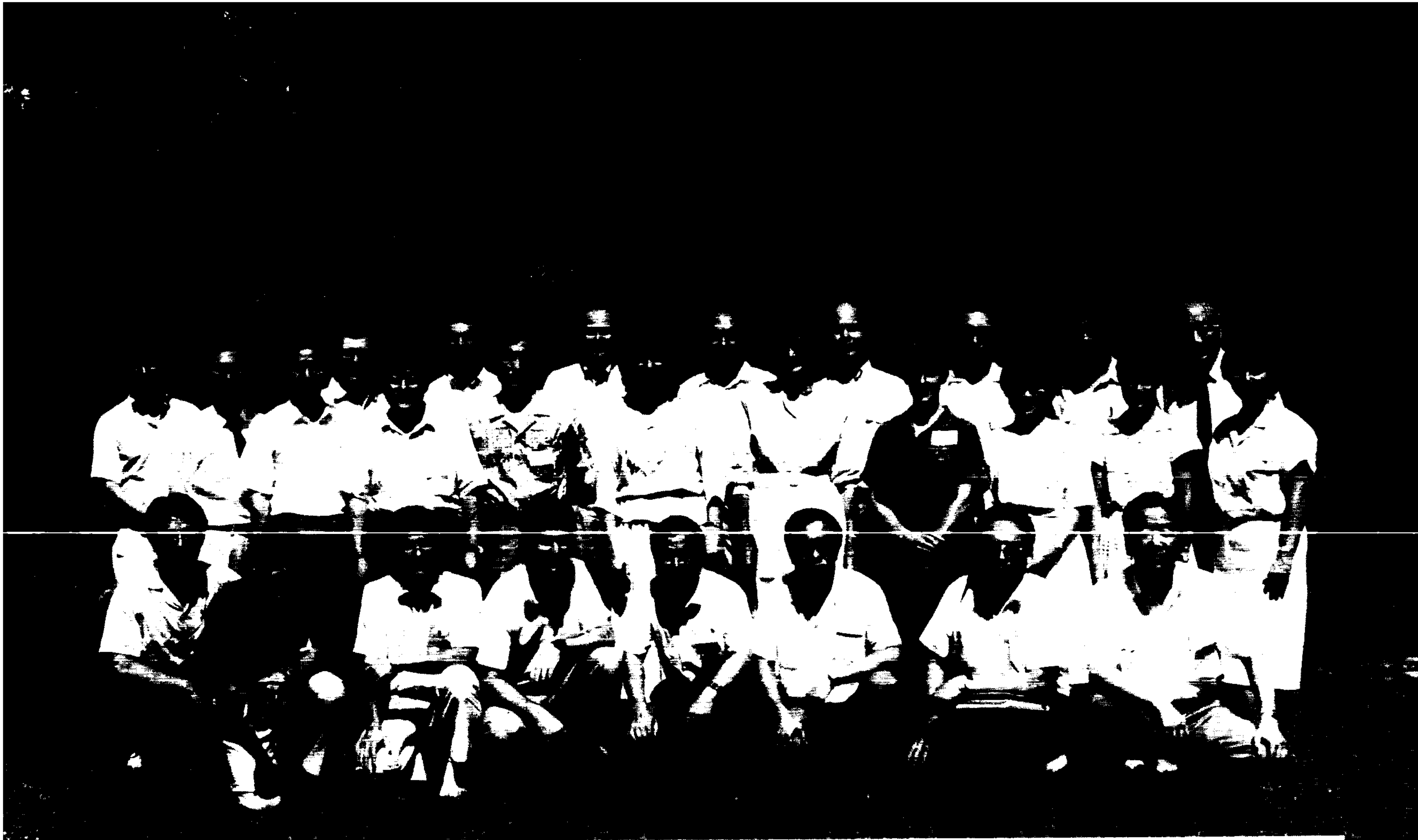
THE WORKSHOP

Following the completion of literature reviews and preliminary visits, we chose workshop participants from the People's Republic of China, the Republic of Korea, the Republic of China (Taiwan), and the United States. AIP brought these U.S. and Asian shrimp culture experts together for a workshop in Honolulu, Hawaii from October 2-4, 1989 (see Appendix I and Fig. 1; participants' names are listed "first name first"). Formal paper presentations and organized discussion group sessions were media through which information, ideas, and opinions were exchanged (see Appendix II). Chinese/English and Korean/English interpreters were present throughout the meetings to facilitate communication between all participants.

THE PROCEEDINGS

This volume is a compilation of the material discussed at the workshop. The Introduction, Discussion, and Discussion Group Summaries were written by the editors. Information about the biology, culture, and distributions of *P. chinensis*, *P. japonicus*, and *P. penicillatus* is summarized in the Introduction.

Section I contains the twelve papers prepared by the Asian participants for the workshop. Papers were edited mainly for scientific clarity, and have been published in the order in which they were presented. Byung-Ha Park begins with a general discussion of the state of shrimp culture in Korea. Ruiyu Liu brings us up to date on the past, present, and future of shrimp mariculture in China, including the following topics: maturation, larval rearing, growout, feeds, biotechnology, and disease. Yong Gil Rho has two papers on larval production in Korea: one for *P. chinensis*, the other for *P. japonicus*. In another paper on larval rearing, Kexing Wang and Shen Ma contribute a detailed summary of the techniques used to culture *P. chinensis* larvae in China. In their overview paper from Taiwan, I-Chiu Liao and Yew-Hu Chien compare the culture of all three cold-tolerant species. They have gathered information on



Workshop Participants. *Bottom* (left to right): Sanghee Alan Jo, Bob Rosenberry, Cheng-Sheng Lee, Craig Browdy, Cong-Hai Yang, Naiyu Zhang, Kexing Wang, and Byung-Ha Park; *Center*: Jim Wyban, Yew-Hu Chien, Yong Gil Rho, Jin Ho Kim, Shin Bok Lee, Kevan Main, Norma Stovall, Jane Lewis, Hongja Harrison, Shan Chen, and Xiaojing Shi; *Top*: Linden Burzell, George Chamberlain, Jack Whetstone, Jiaxin Chen, Wynn Pettibone, Yung Shang, Ping-Sun Leung, and Ruiyu Liu.

biology, larval rearing, and growout which they use to summarize the merits of *P. chinensis*, *P. japonicus*, and *P. penicillatus* as culture species.

Jin Ho Kim discusses Korean culture techniques for *P. chinensis* and *P. japonicus*, and also presents some comparative growth data for these species at different temperatures. Jiaxin Chen reviews *P. chinensis* culture in China, oftentimes presenting data on differing practices in the various coastal provinces. Although he was unable to attend the workshop, Qingbo Hu submitted a paper on *P. chinensis* and *P. penicillatus* culture in Southern China. In addition to discussing the practice of double-cropping these species, he presents research on the larval rearing of *P. penicillatus*, including tolerances to different feeds, salinities, pH, and concentrations of dissolved oxygen and inorganic nitrogen. Cong-Hai Yang summarizes research on juvenile *P. chinensis* growth at different temperatures, salinities, and concentrations of total ammonium-N. The growth of *P. chinensis* during growout is discussed by Naiyu Zhang. Finally, Deng-gong Cao and Jiang Yi were unable to attend the workshop, however, their research on choosing the best type of *P. chinensis* fry for culture, and the necessity of a nursery phase is presented in the final paper.

Discussion Groups covered the following topics: Growout (design, management practices, feeds, disease, predation, and growth rates); Nursery (design and management practices); Hatchery (design, management practices and growth rates); Maturation; Harvesting and Processing; and Marketing and Economics. Data from those sessions are summarized in the Discussion Group Summaries in Section II. Almost all of the information in those summaries was selected from 1) data templates created from tables made during discussions, 2) rapporteur's reports, and 3) tape recordings of the discussion sessions. The information on *P. japonicus* culture in Japan was generously contributed by Kunihiko Shigueno, who responded to our questions by mail.

The feasibility of culturing *P. chinensis* in the U.S. was analyzed with a bioeconomic model. The results of that study are presented in Section III. In Section IV, the pros and cons of culturing one or more of the cold-tolerant species in the U.S. are presented in the Discussion. Finally, comprehensive bibliographies were compiled for each species. They are found in Section V.

ACKNOWLEDGEMENTS

This book was prepared and published with financial support from NOAA, U.S. Department of Commerce grant number NA85AA-D-SG082, which was administered by the University of Hawaii Sea Grant College Program. The Oceanic Institute thanks the UH Sea Grant College Program for administrative program support throughout the project.

The editors would like to thank all the participants in the AIP workshop for contributing information and manuscripts on cold-tolerant shrimp culture. Ruiyu Liu in the PRC, Byung-Ha Park in Korea, and I-Chiu Liao in Taiwan provided invaluable assistance in organizing the presentations and travel arrangements for the workshop participants. We are deeply indebted to Jane E. Lewis and C.S. Lee for assisting in the planning, organization and implementation of the workshop. We thank Kunihiko Shigueno for his generous contribution of information on *Penaeus japonicus* by mail. We thank James Wyban, Gary Pruder, and Paul Bienfang for reviewing the Financial Analysis, and Norma Stovall, Tammy Rainville, Ellen Antill, Carolyn Rahman, and Ronnie Tiffany-Kinder for editing and administrative support. Finally, we thank the workshop interpreters: Weirong Cai, Shan Chen, Hongja Harrison, Sanghee Alan Jo, Xiaojing Shi and Shugiang Zhang.

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INTRODUCTION

The majority of U.S. shrimp farms culture *Penaeus vannamei*, a subtropical species native to South and Central America. Low temperatures during the late fall and early spring limit the production of this species to one crop per year. Commercial producers in the U.S. have expressed interest in identifying a shrimp that can be cultured during the periods when *P. vannamei* growth is temperature limited.

The Asian Interchange Program (AIP) workshop compared the biological characteristics and production parameters of three shrimp species which are cultured in Asia. *Penaeus chinensis*, *P. penicillatus*, and *P. japonicus* were selected for review because they are cultured in temperate areas and are frequently referred to as cold-tolerant species (see natural distributions in Figs. 1-3).

Growth has been reported in *P. chinensis* and *P. japonicus* at temperatures as low as 14 and 10°C, respectively (Sect. II, Disc. Group D). The lower limit for growth in *P. penicillatus*, however, is 20°C (Liao and Chien Chapter 6). The majority of *P. chinensis* culture is in China, although it is also commercially produced in Korea. *P. japonicus* is the primary culture species in Japan, and is also grown in Taiwan and Korea.

PENAEUS CHINENSIS

P. chinensis (Osbeck) is also known as *P. orientalis* Kishinouye, *Dui Xia*, Chinese Shrimp, Chinese Pair Shrimp, and Fleshy Prawn. This species is grown at higher latitudes than other cultured shrimp. *P. chinensis* is naturally distributed in water 90-180 m deep; much deeper than the areas in which other cultured species live. These observations suggest that *P. chinensis* can tolerate colder temperatures than other cultured shrimp. The natural distribution of *P. chinensis* is limited to the Asian coast from the mouth of the Pearl River in China (near Hong Kong) to Bohai Bay in the northern Yellow Sea (Figs. 1 and 4).

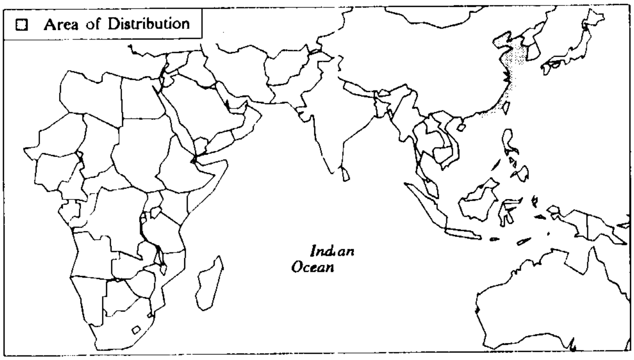

Fig. 1. The distribution of *Penaeus chinensis* (Adapted from Dore and Frimodt 1987).

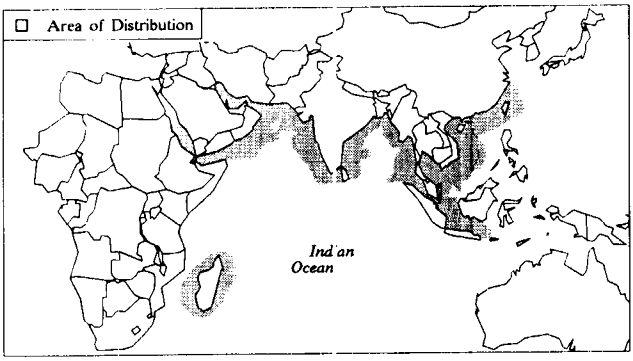

Fig. 2. The distribution of *Penaeus penicillatus*. (Adapted from Dore and Frimodt 1987).

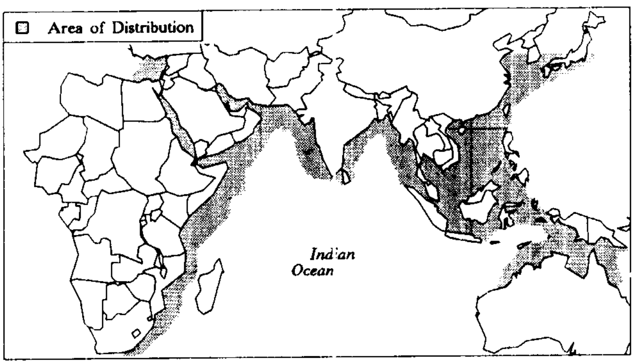

Fig. 3. The distribution of *Penaeus japonicus*. (Adapted from Dore and Frimodt 1987).

P. chinensis is cultured extensively and semi-intensively on the west coast of Korea (see Fig. 5) and in China, where it has been farmed for centuries. Production of cultured shrimp (primarily *P. chinensis*) was reported to have exceeded 153,000 metric tons in China in 1987 (Liu Chapter 2).

One of *P. chinensis*' greatest virtues is its ease of maturation in captivity. Large individuals will mature and mate in growout ponds in the absence of eyestalk ablation or other inducements (Sect. II, Disc. Group H). The majority of broodstock, however, is gravid females harvested from the Yellow Sea each

Figure 4. Coastal provinces of the People's Republic of China.

spring. Some captive broodstock are also used, especially in areas south of *P. chinensis* spawning grounds, but these animals are considered less fecund than wild stock. Discovering the optimal parameters for maturation of captive *P. chinensis* is a major focus of shrimp research in China.

P. chinensis reportedly has high growth rates under culture conditions, and tolerates very low salinities. In addition, its small egg size (half that of *P. japonicus*) enables nauplii to be reared at high densities (100,000-150,000 per ton, Chavez 1989).

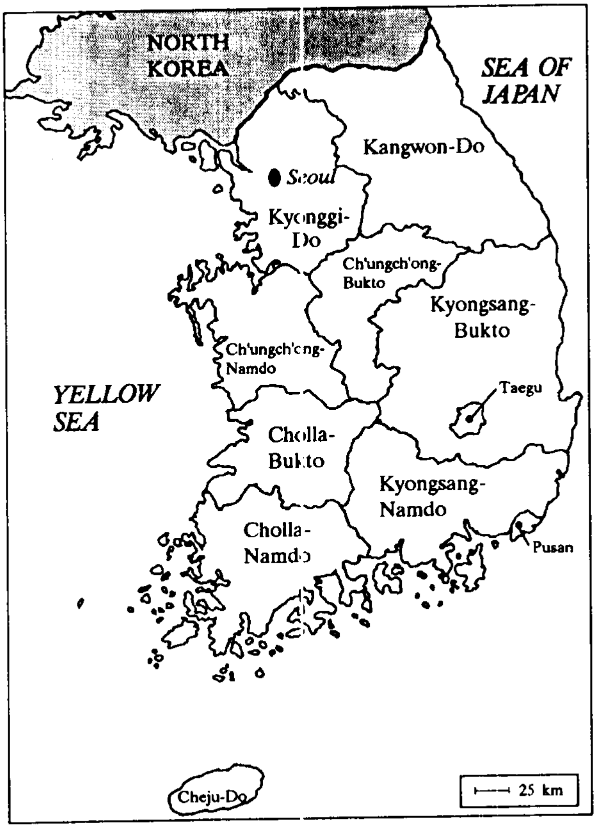

Figure 5. The Republic of Korea.

PENAEUS PENICILLATUS

Also known as the redtail prawn, this Indo-Pacific shrimp has a wider distribution than *P. chinensis*. Its range extends from Taiwan west to the Red Sea (see Fig. 3). *P. penicillatus* is cultured in China and Taiwan. In China, it is grown in the south, chiefly Guangdong, Fujian, and Guangxi provinces (Fig. 4). In some areas, the *P. penicillatus* crop follows a spring harvest of *P. chinensis*, which is imported from the north. *P. penicillatus* is also grown year-round on the southwest, west, and northeast coasts of Taiwan (see Fig. 6), where its average unit area of production rivals that of *P. monodon*. The culture techni-

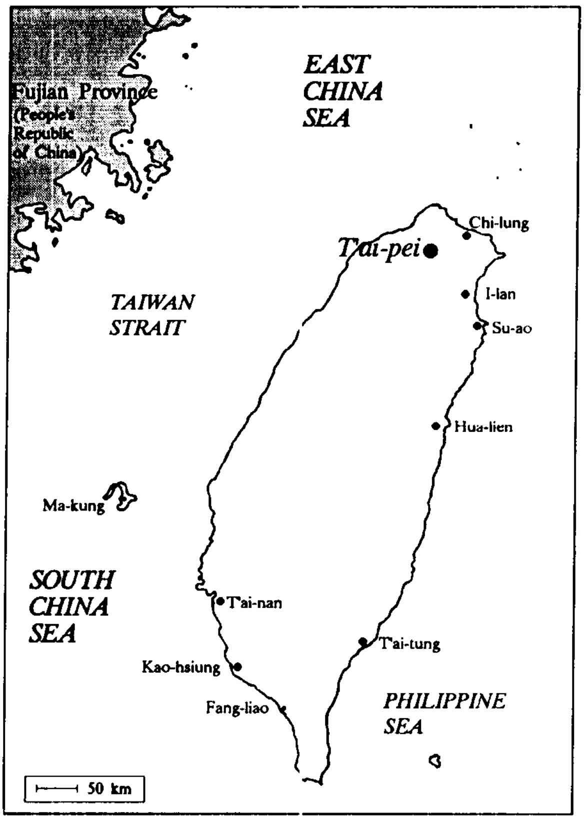

Figure 6. The Republic of China (Taiwan).

ques for this shrimp are very similar to those used for *P. chinensis* in China and for *P. monodon* in Taiwan.

Advantages to raising this species include its low protein requirement, high tail-to-head ratio, and good growth at high densities and at temperatures as low as 20°C (Liao and Chien Chapter 6). Liao and Chao (1987) reported that *P. penicillatus* had a higher growth rate in captivity than *P. semisulcatus* and *P. brasiliensis*, reaching 21 g in 120 days. Furthermore, spawning is easily induced with unilateral eyestalk ablation (Liao and Chien Chapter 6).

PENAEUS JAPONICUS

P. japonicus, the kuruma prawn, has the widest natural distribution of the three penaeids discussed here (Fig. 3). Its range extends north from South Africa to the Red Sea, west through the Malay Archipelago, north to Korea and Japan, and south to the Gulf of Carpentaria and North Queensland in Australia. *P. japonicus* is also cultured in numerous countries, both within and beyond its natural range. Liao and Chien (Chapter 6) list the following areas in which *P. japonicus* is cultured on a small scale: Hawaii, Brazil, Singapore, the Atlantic coast of France, and the Mediterranean coasts of Morocco, Portugal, Spain, Italy, Greece, Cyprus and Israel.

P. japonicus is an important species in Japan, Korea, and Taiwan. Its culture techniques were developed in Japan, where large-scale culture began in 1964 (Shigueno 1975). Stocking densities range from 15-60 per m^2, depending on PL (postlarvae) size and whether or not there will be successive harvesting (Sect. II, Disc. group B). This species requires a clean, sandy substrate in which to burrow, and a relatively high protein feed (52-60%, Deshimaru and Shigueno 1972). In Japan, *P. japonicus* reaches 20-25 g in five months.

P. japonicus is a colorful, striped species which brings a good price in Japan, where it is primarily sold live. Adults are hearty, and can survive shipping packed in moist sawdust.

SUMMARY

P. chinensis inhabits latitudes higher that those of any other cultured penaeids. It is a fast-growing, white shrimp which is very easy to mature in captivity. *P. penicillatus* requires warmer temperatures than *P. chinensis*, but has a low protein requirement and a high tail-to-head ratio. Its culture practices are similar to *P. chinensis*'. Finally, *P. japonicus* is a widely distributed, expensive, striped shrimp. It grows well in cold water, but has a high protein requirement and a limited market.

REFERENCES

See Appendices III-IV.

SECTION I

Contributed Papers

The Culture of Cold-Tolerant Shrimp: Proceedings of an Asian-U.S. Workshop on Shrimp Culture, Honolulu, HI, 1990.

THE STATUS OF SHRIMP CULTURE IN KOREA

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I. Marine environment of Korean waters
  A. Characteristics of the seas
    1. East Sea (Sea of Japan)
      a. Bottom of the sea
        i. This sea is part of the West Pacific Ocean, and it borders the Soviet Union, Japan and Korea.
        ii. Its area is 1,008,000 km^2. Most of the sea is deeper than 1,000 m with an average depth of 1,700 m, and a greatest depth of 4,049 m. The continental shelf is not wide.
      b. Currents
        i. Tsushima Current: this warm current enters the East Sea via the Korea Strait and flows northward (see Fig. 1).
        ii. Liman Current: this cold current flows southward and stretches to the mid-East Sea.
        iii. There are ten different current branches separated by sharp lines of demarcation.
      c. Water temperature (see Table 1)
        i. Water temperature of the sea surface fluctuates drastically by season. In the summer, it ranges from 27 to 29°C in the south and 20 to 24°C in the north. In the winter, the temperature ranges from 13 to 14°C in the south, and is 4°C in the north.
      d. Salinity
        i. It is 34.5 ppt in the winter and 33.0 ppt in the summer.
      e. Tide
        i. Average surface of the sea is lowest in February and highest in August. The seasonal difference is 0.3 m, the range is 0.2 to 0.6 m.
    2. South Sea
      a. Bottom of the sea

i. The area of the Korea strait is 75,000 km², and its capacity is 7,630 km³. Average depth is 101 m and the greatest depth is 227 m. The area of the East China Sea is 753,000 km² and its capacity is 263,000 km³. Its average depth is 349 m.

b. Current

i. The main Kuroshio Current that stretches southward from Jeju Island via Okinawa is divided into two branches. One flows to the northeast (the Warm Tsushima

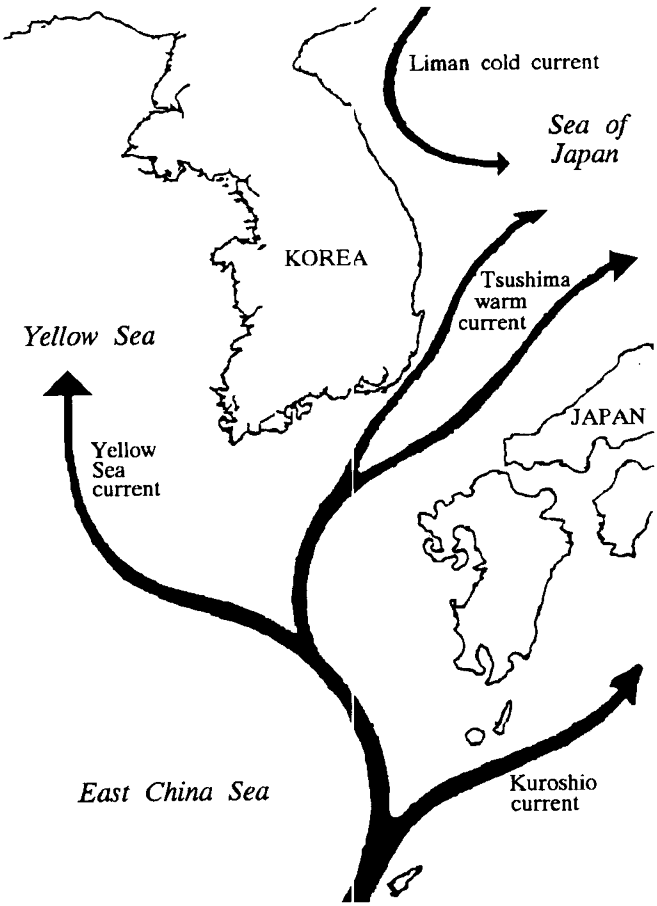

Fig. 1. The main water currents of Korean coastal waters.

Table 1. Water temperature of sea regions of Korea[1]

Sea Region		Month												
		1	2	3	4	5	6	7	8	9	10	11	12	Mean
East Sea	Jumunjin	9.09	8.06	8.48	9.95	12.86	19.14	22.40	23.32	21.55	18.02	14.97	12.66	15.04
			(3.9)[2]						(24.9)					
	Ch'ungmu	10.02	10.15	10.64	12.40	15.14	17.96	22.52	25.24	22.60	20.71	16.52	14.91	16.57
			(8.4)						(27.3)					
South Sea	Yeosu	6.53	5.55	8.09	12.77	17.18	20.53	23.04	25.42	23.19	20.79	15.97	10.54	15.80
			(7.8)							(27.3)				
	Puan	2.78	1.99	5.85	12.41	18.51	23.32	26.87	27.92	24.24	19.41	12.30	6.27	15.16
			(1.0)							(29.9)				
Yellow Sea	Poryung[3]	3.77	2.83	4.45	8.55	13.38	18.53	22.71	25.66	23.37	18.55	13.15	8.05	13.58
			(2.7)						(26.0)					
	Incheon[4]	2.68	1.55	3.77	8.40	13.97	18.92	22.65	24.29	21.30	18.54	12.89	6.28	12.94
			(1.2)						(26.2)					

[1]Monthly average data during fifty years (1932-1982)
[2]The figures in parentheses show the lowest and the highest data
[3]Poryung: 1983-1987 (monthly average data over five years)
[4]Incheon : 1969-1988 (monthly average data over 20 years)

Current) and the other flows to the northwest (the Warm Yellow Sea Current, see Fig. 1).

c. Water temperature (see Table 1)

i. In the winter, surface water temperature of the Warm Kuroshio Current is 22 to 23°C, that of the Warm Korea Current is 12 to 14°C, and the northwestern part of the sea is <10°C. In the summer, surface water temperature of the entire area ranges from 26 to 29°C.

d. Salinity

i. It is >34.5 ppt in the winter, <33.0 ppt in the summer.

e. Tide

i. Average surface of the sea is lowest in January and highest in August. The seasonal difference is about 0.3 m. The tidal range is 1.2 to 3.3 m, and increases from east to west. The tidal amplitude is greater than that of the East Sea, but less than that of the Yellow Sea.

3. Yellow Sea

a. Bottom of the sea

i. The sea is located in the Northwest Pacific and surrounds Korea and China. The sea measures 1,000 km from north to south and 700 km from east to west.

ii. Its area is 404,000 km^2, the capacity is 17,620 km^3, and the depth is 60 to 80 m (average: 44 m, deepest: 103 m).

b. Current

i. A branch of the Kuroshio current which is divided south of Jeju Island flows into the Yellow Sea (see Fig. 1).

c. Water temperature (see Table 1)

i. It fluctuates greatly according to the season. In the winter, surface water temperature ranges from 2 to 8°C and is 24 to 28°C in the summer.

d. Salinity

i. In the winter, it is 31 to 32 ppt in the north, 32 to 33 ppt in the middle, and 33 to 34 ppt in the southern section of the sea. In the summer, salinity ranges from 31.2 to 31.8 ppt.

e. Tide

i. Average surface of the sea is lowest in January and highest in August. The seasonal difference is about 0.5 m. The tidal amplitude is large, 3.7 to 8.6 m.

ii. In some areas, the current velocity is 5 to 6 km.

II. Trends of Aquaculture in Korea. In Korea, the main aquaculture projects during the 1950's and 1960's were seaweed culture. Shellfish culture was developed in the 1970's. In the 1980's, the trend changed to the culture of marine fish. We are moving toward developing crustacean culture, such as shrimp and crabs, in the 1990's.

A. 1988 Seafarming production statistics (provisional): Tables 2-10.

III. Major species and their distribution in Korea (see Table 11)

IV. History of shrimp culture in Korea

A. Shrimp culture research (Fisheries Research & Development Agency and Fisheries Universities)

1969: Artificial seed production of *Penaeus japonicus*, *P. chinensis*.
1970: Research on spring spawning population of *P. japonicus*.
1973: Investigation of distribution and migration of *P. chinensis*.
1983: First release of *P. japonicus* artificial seed.
1987: First release of *P. chinensis* artificial seed.
1989: Research on energy metabolism of *P. japonicus*.

B. Shrimp culture in private companies

1941: Pilot culture of *P. chinensis*.
1958: Experimental culture of *P. chinensis*.

Table 2. The number of fishfarmer households and areas under production in Korea, 1988.

Population (x 1,000)	Per capita fish consumption	GNP	Number of households	Number of fish farmers	Areas under production (ha)	Areas available for expansion (ha)	Length of coastline (km)
41,975	7.5 kg	$4,040	56,932	130,251	112,432	95,258	15,000

Table 3. Fish landings by source of production, 1988. Value: US $ x 1,000.

Marine Sector						Brackishwater Sector			Freshwater Sector					
Capture Fisheries			Culture Fisheries			Culture Fisheries			Capture Fisheries			Culture Fisheries		
Volume (tons)	Value	% of total landings	Volume (tons)	Value	% of total landings	Volume (tons)	Value	% of total landings	Volume (tons)	Value	% of total landings	Volume (tons)	Value	% of total landings
2,286,721	2,623,809	71.3	886,605	572,066	27.6	NA	NA	NA	24,681	51,168	0.8	11,128	63,061	0.3

Total Capture		Total Culture		Total (Capt. + Cult.)	
Volume (tons)	Value	Volume (tons)	Value	Volume (tons)	Value
2,311,402	2,674,977	897,733	635,127	3,209,135	3,310,104

Table 4. Total production of marine culture, 1988 (unit: MT).

Division	Fish	Crustacea	Shellfish	Seaweed	Others	Total
Production	1,290	181	420,687	441,569	22,878	886,605
Percentage of total	0.15	0.02	47.45	49.80	2.58	100.00

Table 5. Total production of marine fish farming, 1988 (unit: MT).

Yellow tail	Bastard halibut	Rock fish	Sea breams	Others	Total
1,258	16	5	2	9	1,290

Table 6. Total production of marine crustacea farming, 1988 (unit: MT).

Fleshy prawn	Kuruma prawn	Total
102	79	181

Table 7. Total production of marine shellfish farming, 1988 (unit: MT).

Oyster	Short-necked clam	Cockles	Arkshell	Sea mussel	Other	Total
284,472	51,245	14,502	49,013	15,693	5,762	420,687

Table 8. Total productioon of marine seaweed farming, 1988 (unit: MT).

Laver	Sea mustard	Fusiforme	Kelp	Others	Total
115,749	281,657	23,871	11,612	8,680	441,569

Table 9. Total production of marine miscellaneous species farming, 1988 (unit: MT).

Sea squirt (*Halocynthia roretzi*)	Sea squirt (*Stylela clava*)	Lug worm	Total
14,014	8,859	5	22,878

Table 10. Production statistics of seafarming in Korea (estimated, unit: thousand head).

Year	*Haliotis discus hannai* (abalone)	*Halocynthis roretzi* (sea squirt)	*Penaeus japonicus* (Kuruma shrimp)	*Paralichthys olivaceus* (Flounder)	No. of eggs fertilized *Paralichthys olivaceus*	*Chrysophrys major* (Porgy)
1988	2,200	10,200	4,500	260	1,000	400
1989	2,200	10,000	5,000	260	5,000	450

Year	No. of eggs fertilized *Chrysophrys major*	*Sebastes schlegeli*	*Limando herzenstein* (Flatfish)	*Penaeus chinensis* (Fleshy shrimp)	*Portunus trituberculatus* (Blue crab)	*Anonthocidaris crassispina* (sea urchin)	Total No.
1988	---	80	10	1,650	300	50	20,650
1989	1,000	90	---	.3,320	600	100	28,020

Table 11. Major species and their distributions in Korea.

Family	Scientific name	Common name	Korean name	Distribution
Penaeidae	*Penaeus japonicus* BATE	Kuruma prawn	Bori Saewoo	South of East Sea, South Sea, south of mid-Yellow Sea
	Penaeus chinensis (OSBECK)	Fleshy prawn	Dae Ha	South Sea, Yellow Sea
	Penaeus monodon FABRICIUS	Giant tiger prawn	Hongdari Olluk Saewoo	South of Jeju province
	Metapenaeus joyneri MIERS	Shiba shrimp	Chung Ha	South Sea, Yellow Sea, East China Sea
	Trachypenaeus curvirostris STIMPSON	Southern rough shrimp	Kkot Saewoo	South of East Sea, Yellow Sea, South Sea, East China Sea
Sergestidae	*Acetes japonicus* KISHINOUYE	Akiami paste shrimp	Jot Saewoo	West of South Sea, Yellow Sea
	Acetes chinensis HANSEN	Northern mauxia shrimp	Chungkuk Jot Saewoo	North of mid-Yellow Sea
Palaemonidae	*Macrobrachium nipponese* DE HAAN	Oriental river prawn	Jinggomi Saewoo	Kyonggi, Chungnam, Kangwon, and Kyongnam province
Pandalidae	*Pandalus hypsinotus* BRANDT	Coonstripe shrimp	Dohwa Saewoo	East Sea
	Pandalus borealis KROYER	Northern shrimp	Pukjok Punhong Saewoo	East Sea
Palinuridae	*Panulirus japonicus* VON SIEBOLD	-	Dak Saewoo	South Sea, Jeju province
	Linuparus frigonus VON SIEBOLD	-	Poldak Saewoo	Jeju province

1963: Artificial seed production and culture of *P. chinensis* in Shinheung Co.
1968: First culturing of *P. chinensis* by Doosan Industrial Inc.
1970: Research on artificial feed development using the by-product from beer production at Doosan Industrial Inc.
1972: First release of *P. chinensis* artificial seed by Doosan Industrial Inc.
1973: Experimental culture of *P. japonicus* by Doosan Industrial Inc.
1975: Development of artificial hatching technique for *P. japonicus* at Doosan Industrial Inc.
1980: Establishment of mass production system for *P. japonicus* at Doosan Industrial Inc. (Namhae 20 ha)
1982: Establishment of mass production system for *P. chinensis* at Doosan Industrial Inc. (Dangjin 14 ha)
1986: Shrimp production of 250 MT by Doosan Industrial Inc.
- a. *P. japonicus* : 100 MT
- b. *P. chinensis* : 150 MT
- c. Seed of *P. japonicus* : 16 million heads
- d. Seed of *P. chinensis* : 65 million heads
- e. Result of seed release in the sea as of 1985: 263 million heads

1988: Result of shrimp culture production as of 1988: 522 MT

V. Status of shrimp culture
- A. Research on shrimp culture (government institutes)
  - 1. Result of artificial seed production (see Table 12)
- B. Shrimp culture in private companies
  - 1. Results of artificial seed production (see Table 13)
  - 2. Production and area of shrimp culture (as of the end of 1988, see Table 14)

VI. Results of release of artificial seed production of *P. chinensis* (see Table 15)

VII. Status of shrimp production (see Tables 16-18)

Table 12. Artificial seed production in government institutes (unit: thousand head).

	P. japonicus	*P. chinensis*		
Year	Koje hatchery	Poryong hatchery	Puan hatchery	Total
1983	325	---	---	325
1984	1,540	---	---	1,540
1985	2,200	---	---	2,200
1986	3,700	---	---	3,700
1987	4,800	1,070	---	5,870
1988	4,500	1,600	50	6,150
1989	5,000	3,200	120	8,320
Total	22,065	5,870	170	28,105

Table 13. Artificial seed production in private companies (unit: million head).

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Total
P. japonicus	10	10	10	10	10	15	18	18	25	22	148
P. chinensis	5	4	47	29	64	60	65	50	60	48	432
Total	15	14	57	39	74	75	83	68	85	70	580

Table 14. Production and area of shrimp culture (as of the end of 1988).

Region	No. of Farms	Licensed area (ha) Exploited	Unexploited	Total	Production (MT)	Species	Remarks
Chungnam	20	468.1216	350.3653	818.4869		*P. japonicus* and *P. chinensis*	banking culture method
Chonnam	2	0	8.5	8.5			
Kyongnam	1	21.36	0	21.36			
Total	23	489.4816	358.8653	848.3469	521.88		

Table 15. Results of the government sponsored release of artificially produced *P. chinensis* seed (unit: thousand head).

Year	Release site	No. released (inds)	Body length	Remarks
1988	Chungnam Taean Anmyun	7,245	1.5	
	Chonnam Muan Haeje	4,000	"	
	Subtotal	11,245		
1989	Chungnam Taean Anmyun	4,238	1.5	Price: 5.3 Won/ind. (670 Won - $1 US)
	Chonnam Haenam Songji	4,000	"	
	Subtotal	8,238		
	Total	19,483		

Table 16. Shrimp production in Korea (unit: MT, thousand $US).

	1983			1984			1985			1986			1987		
	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT
CULTURE FISHERY															
P. japonicus	-	-	-	18	346	19.2	44	779	17.7	51	1,269	24.9	71	1,327	18.7
P. chinensis	50	975	19.5	75	670	8.9	39	295	7.6	82	981	12.0	113	1,832	16.2
Acetes japonicus	-	-	-	-	-	-	-	-	-	-	-	-	17	7	0.4
Others	-	-	-	-	-	-	1	1	1.0	-	-	-	-		
Subtotal	50	975	19.5	93	1,016	10.9	84	1,075	12.8	133	2,250	16.9	201	3,166	15.8
CAPTURE FISHERY															
P. japonicus	1,336	1,349	1.0	1,236	1,332	1.1	1,844	1,266	0.7	864	982	1.1	2,322	2,892	1.2
P. chinensis	396	4,605	11.6	773	4,904	6.3	667	4,231	6.3	1,503	8,750	5.8	683	6,148	9.0
Metapenaeus joyner	1,386	2,382	1.7	2,293	4,082	1.8	2,729	4,343	1.6	3,911	6,209	1.6	3,032	5,770	1.9
Acetes japonicus	16,994	13,088	0.8	9,791	10,769	1.1	13,488	13,939	1.0	15,029	15,317	1.0	16,640	18,325	1.1
Panulirus japonicus	97	99	1.0	149	344	2.3	248	250	1.0	193	210	1.1	347	218	0.6
Others	14,015	11,516	0.8	15,007	12,062	0.8	19,248	15,118	0.8	20,480	18,198	0.9	21,524	24,223	1.1
Subtotal	34,224	33,039	1.0	29,249	33,493	1.1	38,224	39,147	1.0	41,980	49,666	1.2	44,548	57,576	1.3
Total	34,274	34,014	1.0	29,342	34,509	1.2	38,308	40,222	1.0	42,113	51,916	1.2	44,749	60,742	1.4

Table 17. Korean shrimp exports (unit: MT, thousand $US).

	1983			1984			1985			1986			1987		
	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT
Shrimp (live)	124	906	7.3	67	851	12.7	106	1,300	12.3	216	3,277	15.2	310	4,308	13.9
Shrimp (fresh, cold storage)	60	227	3.8	55	254	4.6	419	559	1.3	538	1,706	3.2	972	2,324	2.4
Shrimp meat (frozen)	175	877	5.0	306	1,111	3.6	188	730	3.9	265	1,246	4.7	165	1,391	8.4
Shrimp (frozen except meat)	4,336	22,915	5.3	4,428	25,861	5.8	2,560	18,817	7.4	3,839	21,910	5.7	3,271	19,128	5.8
Fleshy prawn (fresh frozen)	-	-	-	2	18	9.0	-	-	-	4	4	1.0	1	3	3.0
Lobster (live)	2	11	5.5	-	-	-	7	20	2.9	2	7	3.5	-	-	-
Lobster (fresh, cold storage)	2	19	9.5	1	4	4.0	1	8	8.0	4	76	19.0	4	37	9.3
Pickled shrimp	425	894	2.1	296	653	2.2	390	865	2.2	307	579	1.9	437	873	2.0
Shrimp (smoked)	32	244	7.6	10	69	6.9	30	82	2.7	10	51	5.1	7	48	6.9
Shrimp (canned)	4	11	2.8	-	-	-	-	-	-	40	113	2.8	16	68	4.3
Dried shrimp meat	6	58	9.7	3	17	5.7	14	77	5.5	1	6	6.0	17	104	6.1
Shrimp (dried except meat)	5	52	10.4	12	96	8.0	6	84	14.0	17	136	8.0	4	51	12.8
Total	5,171	26,214	5.1	5,180	28,934	5.6	3,721	22,542	6.1	5,243	29,111	5.6	5,204	28,335	5.4

Table 18. Shrimp imports to Korea (unit: MT, thousand $US).

	1983			1984			1985			1986			1987		
	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT	Quant.	Value	Price /MT
Shrimp (live)	-	-	-	1	8	8.0	1	10	10.0	6	30	5.0	1	64	64.0
Shrimp (fresh, cold storage)	-	-	-	-	-	-	-	-	-	-	-	-	35	302	8.6
Shrimp meat (frozen)	5	3	0.6	-	-	-	-	-	-	-	-	-	1	7	7.0
Shrimp (frozen except meat)	18	242	13.4	268	690	2.6	-	-	-	80	289	3.6	150	1,316	8.8
Lobster (fresh, frozen)	1	1	1.0	2	36	18.0	4	74	18.5	8	144	18.0	4	74	18.5
Lobster (fresh, cold storage)	-	-	-	1	14	14.0	-	-	-	-	-	-	-	-	-
Pickled shrimp	124	68	0.5	809	438	0.5	529	299	0.6	590	349	0.6	1,304	986	0.8
Total	148	314	2.1	1,081	1,186	1.1	534	383	0.7	684	812	1.2	1,495	2,749	1.8

The Culture of Cold-Tolerant Shrimp: Proceedings of an Asian-U.S. Workshop on Shrimp Culture, Honolulu, HI, 1990.

PRESENT STATUS AND FUTURE PROSPECTS FOR SHRIMP MARICULTURE IN CHINA[1]

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INTRODUCTION

Mariculture production in China developed rapidly after the founding of the People's Republic. 1987 production was 1.1 million metric tons (MT), about 20% of total marine fishery production. This represents a hundred fold increase from 1950 production (Table 1).

Table 2 shows the 1986 production for the primary species cultured. The rapid development of shrimp farming during the past decade is of particular significance. The total production of cultured shrimp was 153,000 MT in 1987, compared to 450 MT in 1978 (Table 3). The total yield of shrimp fry was approximately 66 billion. Since 1986, China has led the world in both the total production of farmed shrimp and the production of artificially-reared shrimp fry. This indicates that China has achieved great success in shrimp mariculture. The support of marine biologists and fishery researchers played an important role in this fast development.

[1]Contribution number 1760 of the Academia Sinica Institute of Oceanology

Table 1. Total marine fisheries and mariculture production in China, 1950-87 (in 10^3 metric tons).

Year	Marine fishery production	Mariculture production	Mariculture/fishery ratio (%)
1950	546	10	1.83
1955	1,656	107	6.46
1960	1,870	121	6.47
1965	2,014	104	5.16
1970	2,281	184	8.07
1975	3,349	279	8.33
1980	3,257	444	13.63
1983	3,617	545	15.07
1986	4,754	858	18.05
1987	5,480	1,100	20.07

Table 2. Production of main species of cultured organisms, 1986 (in 10^3 metric tons).

Organisms	Production	Percent
Japanese kelp		
(*Laminaria japonica*)	203.4	23.7
Mussels		
(*Mytilus galloprovincialis*, etc.)	210.7	24.6
Razor clam		
(*Sinonvacula constrica*)	126.2	14.5
Pair shrimps		
(*Penaeus chinensis*, etc.)	82.8	9.7
Oysters		
(*Ostrea rivularis*, etc.)	55.0	6.4
Clams		
(*Ruditapes philippinarum*, etc.)	41.6	4.8
Cockles		
(*Anadara granosa*)	24.2	2.8
Scallops		
(*Clamys farreri*, *Argopecten irradians*)	23.7	2.8
Purple laver		
(*Porphyra jezoensis*, *P. haitanensis*)	12.6	1.6
Total	780.2	90.9

This article is a brief review of the history, present status and future prospects of China's shrimp farming.

HISTORICAL REVIEW

Although shrimp mariculture in China is hundreds of years old, modern shrimp farming techniques were developed only in the last two decades, particularly in the 1980's. Before the 1950's, shrimp farming was based mainly on the traditional method of extensive polyculture of shrimp and fish. The Chinese pair shrimp[1] and the local mullet, *Liza so-iuy* were grown together in Northern China. In Southern China, the white shrimps, *P. merguiensis* and/or *P. penicillatus* and the grey mullet, *Mugil cephalus* and its congeners were stocked in ponds (named "Yugang" in Northern China or "Yu-wen" in South China). The juveniles and postlarvae were collected and stocked naturally with inflowing water during high tides. During growout, the food supply

[1] Its common name in North China along the Bohai coast: The shrimp were sold by pairs in the market before the founding of the People's Republic.

Table 3. Annual production of cultured shrimp in China, 1978-1987.

Year	Production (10^3 MT)	Total area (10^3 ha)	Average production (kg/ha)
1978	0.45	1.3	35
1979	1.3	7.3	178
1980	2.6	9.3	279
1981	3.6	13.7	263
1982	7.0	16.5	424
1983	8.9	20.3	438
1984	19.3	33.4	578
1985	40.7	59.7	682
1986	82.8	85.2	972
1987	153.3	131.1	1,169

consisted of what was present in the inflow water. Hence, yield was very low and unstable, usually less than 5-10 kg/mu (75 kg/ha, 15 mu = 1 ha). There was almost no basic or applied mariculture research.

Projects focusing on the biology, life history and artificial breeding of *P. chinensis* under controlled conditions started in the early 1950's in laboratories of marine biological and fisheries institutes (Liu et al. 1959). Success was first achieved in 1960 by Professor Shang-chin Wu at the Institute of Oceanology, Academia Sinica (IOAS) in Qingdao. A workshop to exchange information about shrimp fry rearing was held at IOAS, organized by the Ministry of Fisheries. Despite these efforts, shrimp farming developed slowly before the middle 1970's because of little support and low profit. Only a small number of shrimp fry were produced by "semi-artificial methods of shrimp larval rearing." The spawned eggs hatched and the shrimp larvae were reared in earthen growout ponds; larval stages fed on natural microalgae living in the pond. Unfortunately, survival rate was low.

To better promote shrimp culture in China, the States Fisheries Administration organized a joint research project on shrimp fry rearing in the late 1970's. Optimal conditions for temperature and water quality management and hatchery feed supply were intensively studied (Liu 1983; W. Zhang et al. 1980a,b; N. Zhang et al. 1983; N. Zhang and Sun 1984). Techniques for industrial production of shrimp fry were developed in the early 1980's. Some 10 million shrimp fry (mostly PL5) were produced, and about 450 MT of cultivated shrimp were harvested in 1978 (Table 3). Many shrimp hatcheries and shrimp ponds have been established in Northern and Eastern China, as the techniques for hatchery operation were improved (Table 4). In contrast, shrimp mariculture study and production along the South China Sea coast developed quite slowly until the last three to five years.

The total production in China in 1982 was about 2 billion shrimp fry and 7,000 MT of cultivated shrimp. Annual production of cultivated shrimp has doubled every year since 1983. China became the largest producer of cultured shrimp in 1986, producing a total of 82,827 MT. Production further increased to about 66 billion shrimp fry and 153,273 MT of cultured shrimp in 1987, leading the world's production (Table 5).

The rapid development of shrimp fry production was made possible in large part by the contributions of China's marine and fishery scientists and technical workers to seed and growout production. It was the group of scientists from the Academia Sinica

Table 4. Production of artificially-reared shrimp fry in coastal provinces of China, 1986.

Province or city	Production ($x 10^6$ ind)	Hatchery capacity ($10^3 x m^3$)	Production per unit area (10^3 ind/ m^3)	Geographic location
Liaoning	10,024	44	227.8	Yellow Sea and Bohai Sea
Hebei	3,704	21	176.4	
Tianjin	608	7.5	81.1	
Shandong	8,334	56	148.8	
Jiangsu	4,008	25	160.3	
Zhejiang	2,277	15	151.8	East China Sea
Fujian	2,140	29	73.8	
Guangdong	1,167	13	89.8	South China Sea
Guangxi	121	2.5	48.4	
Total	32,383	213	152.0	

Institute of Oceanology, not shrimp culturists from Hong Kong or Hawaii, who first succeeded in the production operation of the Binhai Shrimp Farm Hatchery (a joint venture of Tianjin City and an enterprise in Hong Kong) in 1980. Application of advanced techniques to hatchery production produced a total of 14 million shrimp fry and an average yield of 46,900 pieces/m^3 in the hatchery with a 300 m^3 capacity (Liu 1983).

The most important species cultured in China is *Penaeus chinensis* (Osbeck) (=*P. orientalis* Kishinouye), which comprises about 80% of the total yield of cultured

Table 5. Production of cultured shrimp in the coastal provinces of China, 1986-1987.

Province	Production (MT)		Total area of shrimp ponds (ha)		Yield per unit area (kg/ha)		Geographic location
	1986	1987	1986	1987	1986	1987	
Liaoning	24,666	43,504	21,320	27,727	1,157	1,569	Yellow Sea and Bohai Sea
Hebei	11,971	24,937	9,693	14,087	1,235	1,770	
Beijing	148	237	180	320	822	746	
Tianjin	2,365	4,390	2,827	3,540	837	1,240	
Shandong	17,379	33,919	23,393	35,720	743	950	
Jiangsu	8,468	11,777	8,713	10,873	972	1,083	
Subtotal	64,997	118,764	66,127	92,267	983	1,287	
Shanghai	1,384	2,018	927	1,293	1,493	1,630	East China Sea
Zhejiang	5,755	7,228	5,440	7,106	1,058	1,017	
Fujian	6,189	13,338	7,020	14,067	882	948	
Subtotal	13,328	22,584	13,387	22,466	996	1,005	
Guangdong	4,424	11,577	5,087	16,120	870	718	South China Sea
Guangxi	78	348	667	1,200	117	290	
Subtotal	4,502	11,925	5,735	17,320	783	689	
Total	82,827	153,273	85,267	131,387	971	1,167	

shrimp. It is mainly produced in the northern provinces down to Zhejiang (Table 4). Next in importance are *P. penicillatus* (Fujian and Guangdong), *P. merguiensis* (Guangdong and Guangxi), and *P. monodon* (Fujian, Guangdong and Hainan provinces). *Metapenaeus ensis* is also cultured in low salinity and brackish water ponds in the southern and southeastern provinces. In addition, very few hatcheries and culture ponds have been developed for *P. japonicus* and *P. semisulcatus*. The former is the most important species cultured in Japan and some European countries. The latter is cultured in high salinity waters in Mid-Eastern countries.

PRESENT STATUS

Maturation and Larval Rearing

Wild broodstock are caught in the late spring from fishing grounds and used for larval rearing in most shrimp hatcheries along the Yellow Sea coast and the Bohai Gulf. Pond-cultured shrimp, however, have also been used since the early 1970's for maturation and spawning in some hatcheries in Zhejiang and Fujian provinces, where wild stocks are very rare and difficult to obtain.

One of the most favorable biological characteristics of *P. chinensis* is that the cultured shrimp can mature in captivity without eyestalk ablation or other special operations. Eyestalk ablation has been used (with the cauterization method) only when spawning time must be manipulated.

Gravid female shrimp are usually stocked in earthen ponds at 10-15/m^2. The spawned eggs are collected and hatched in fry-rearing tanks (most of which are cement). The operation is quite different from that for *P. monodon*. Most hatchery tanks are equipped with heating and aeration systems. Two batches of *P. chinensis* fry can be produced in North China from April to June. In the eastern and southern provinces, *P. chinensis* hatchery production usually starts in February, and production of *P. penicillatus* and *P. merguiensis* follows. Maturation of pond-cultured female *P. penicillatus* is difficult in Fujian Province. The local hatcheries use wild broodstock for spawning. However, Hu has succeeded in the induced maturation of *P. penicillatus* by using the eyestalk ablation method.

A new government regulation prohibits fishing for wild *P. chinensis* broodstock during their spawning migration (see Fig. 1). Experimental studies on the maturation of cultured shrimp have proven successful, although spawning and hatching rates are still low and unstable. Pond-cultured broodstock should be available to all hatcheries in the country in two years.

One problem is the low copulation rate of captive shrimp. Artificial insemination has been adopted to obtain fertilized eggs from pond-cultured overwintering shrimps. Of 811 insemination operations performed by Yang in 1986, 88% were successful; the fertilization rate averaged 48%. The number of such operations rose to 12,792 in 1987, and a total of 12 million postlarvae were obtained.

Water quality management and feed supply are the most important parameters in

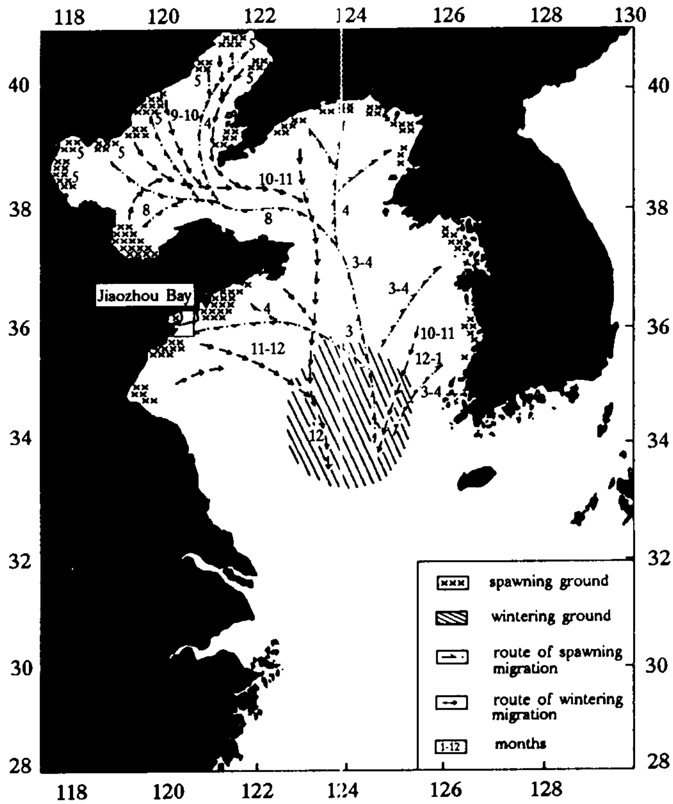

Fig. 1. Migration of *Penaeus chinensis*.

shrimp fry production. Experiments carried out by Wu et al. in the 1960's were the first to provide information on temperature, salinity, dissolved oxygen content, pH, NH_3-N, and heavy metal ions (Zn^{++}, Cu^{++}, Fe^{+++}, K^{+}, Ca^{++}, etc.). Improvement of hatchery water management techniques, including adding EDTA-Na or its substitutes to the hatchery tank water, enhanced the efficiency of industrialized mass production of shrimp fry in the 1980's (W. Zhang et al. 1980a, b).

At the same time, the isolation and culture of monocellular algae have also been greatly improved. In addition to *Phaeodactylum* and *Chaetoceros* which are commonly used to feed shrimp larvae, *Isochrysis galbana* and *Nitzschia closterium* were recently cultured and used successfully in fry-rearing production. Microparticulate and microencapsulated formulated feeds development has also brought about improvements. Difficulties were encountered when different substitutes of live feeds such as egg yolk or soy-milk etc., were used in fry production. The shrimp larvae could not obtain enough nutrition, resulting in low survival and growth rates. Unhealthy postlarvae were usually obtained. As a result, studies on nutritional requirements (necessary vitamins, amino acids, fatty acids and heavy metal ions) of shrimp during different developmental stages were increased.

Another problem is that the damage caused by different types of diseases during fry production has increased. *Vibrio*, fungal and viral diseases and parasitic protozoan infestations have all been reported recently (Meng and Yu 1980, 1982, 1983). Some chemicals have been effectively used to control them, but the best method is to keep the tank water clean and the larvae healthy and strong.

Growout

Commercial shrimp farming has been developed mainly in Northern China. The growout ponds of most shrimp farms are earthen, typically about 2 to 10 ha (mostly 3-5 ha) and 1.5 to 2.0 m deep. Most of them in Hebei and Liaoning provinces were smaller (2-3 ha), constructed in the 1980's and equipped with pumping systems for water exchange. The growout ponds are bigger than those commonly found in Southeast Asian countries, and the operation is mainly semi-intensive. Most of the shrimp ponds in Shandong and Jiangsu provinces (constructed in the 1970's and 1980's) are larger, generally about 4-7, or 10 ha, and usually not over 1 m deep. Most are equipped with pumping systems and rarely with aerators. A few extensive culture ponds are very big, larger than 20 ha.

Before the mid 1980's smaller shrimp fry (7 mm long, mainly PL5-7) were stocked directly into the shrimp pond for growout in most shrimp farms. But recent production practices have indicated that to stock larger fry (PL25+) reared for approximately 3 weeks in nursery ponds is more convenient. This is because we can estimate the exact number of shrimp fry to be stocked in the growout pond and accurately calculate the amount of feed to be given, minimizing feed wasting and avoiding contamination of the bottom. This practice also allows for more time to kill predators and to propagate natural food organisms in the pond. At least one-third of the shrimp farms in China perform nursery culture and stock PL25+'s for their growout production.

Initial stocking density of juvenile shrimp (mostly PL4-5) in a growout pond is usually 150,000-300,000/ha. However, the yield is usually low, and the harvested shrimp small. Comparison of the results obtained from experiments with lower and higher stocking densities has shown that the quantity of harvested shrimp from ponds of the same size depends upon the feed supply and pond management. Under the present conditions of China's shrimp farming production (including the feed quality) a lower stocking density (no more than 75,000-150,000 fry/ha), is preferable.

Data indicate that there has been a steady increase in the average yield per unit area of culture ponds. The average production per unit area was quite low before the 1980's, only 176 kg/ha (25.4 kg/mu) in 1979. It increased steadily in the 1980's, from 971 kg/ha in 1986 to 1,167 kg/ha in 1987 (Table 5).

The average yields differ markedly between the various coastal provinces (see Table 5). In 1987 Hebei province had the highest yield, averaging 1,770 kg/ha. Second in yield was Liaoning province which produced 1,569 kg/ha. Tanghai County of Hebei Province produced a total of 6,500 MT of cultured shrimp in 1987, yielding 2,782 kg/ha. All harvested shrimp attained marketable size (body length = 12 cm), yielding a profit of about 19,200 Yuan (ca. USA $5,000) per hectare. Yields of other provinces are comparatively low, particularly Guangxi and Guangdong, because most shrimp farms are extensive.

Intensive culture experiments in China have just begun. Dr. Naiyu Zhang harvested 618.9 kg of shrimp in a 227.7 m^2 tank (averaging 2.75 kg/m^2, Zhang and Li 1988). The feed conversion ratio was 3.05. Almost no large-scale intensive culture is presently practiced in China. However, it has been reported that an experimental pond (0.17 ha) in Yantai City, Shandong province, yielded an average of 15,750 kg/ha.

Since the growth period for cultured shrimp in most farms in China is short (about 4 months), and only one crop per year is possible, experiments aimed at harvesting two crops a year have been performed recently in Fujian and Guangdong provinces. Good results have been achieved by culturing *P. chinensis* and *P. penicillatus* or *P. merguiensis* alternately in one year. With 2-crop culture, a total of 2,531 kg/ha (1,627 kg/ha for *P. chinensis* and 904 kg/ha for *P. penicillatus*) was harvested in a year in Fujian province (Hu et al. 1988).

Nutrition and Formulated Feeds

In different coastal areas of China, particularly in North China, pond-cultured shrimp are mainly fed living marine or brackish-water invertebrates, such as thin-shelled small bivalve molluscs, *Aloides laevis*, *Musculus senhousie*, *Laternula navicula*; small gastropods, *Umbonium* spp.; the clam, *Ruditapes philippinarum*; the blue mussel, *Mytilus galloprovincialis*; the razor clam, *Sinonvacula constricta*; small crustaceans, *Corophium* spp.; and polychaetes, *Nereis* spp., *Perinereis* spp., etc. (Liu 1983). These animals are abundantly distributed in the intertidal zone and shallow coastal waters (the blue mussels are artificially cultured).

The rapidly expanding shrimp farming industry needs large quantities of formulated feeds for shrimp farms in different geographical areas. Studies on comparative physiology have been conducted on the nutritional needs of shrimp (mainly *P. chinensis*, *P. penicillatus* and *P. merguiensis*) at various developmental stages. Requirements for amino acids, fatty acids, trace metals, vitamins and other elements have been investigated (He 1988, Liu and Zhu 1984). Results of biochemical studies on digestive enzyme activity have also been published. Based on the results obtained in various experiments, many kinds of formulated shrimp feeds have been developed by scientists and manufactured in many factories around the country (Liang et al. 1978, Lou 1983, Xu 1988, Xu et al. 1988).

In 1986 the Shandong province Ocean Developing Center tested the effectiveness of different formulated shrimp feeds in Qingdao City. One of the four feeds formulated by the Institute of Oceanology, Academia Sinica, proved to be the best. Four shrimp feed factories were established in 1987. A total of 4,950 MT of formulated feeds were manufactured to supply farms in Shandong province. Part of the production has also been supplied to shrimp farms in Tianjin, Hebei and Liaoning provinces in Northern China. An average production of 1,290 kg/ha of cultured shrimp with an average body length of 15 cm was achieved on a 30 ha farm in 1987. They produced more than 10,000 MT of formulated feeds in 1988. An average yield of 12,205 kg/ha has been obtained, with all harvested shrimps larger than 12 cm in body length (Wu et al. 1986, unpublished report). Higher stability in pond water (2-3 hrs) is one of this feed's main characteristics. Nevertheless, the feed conversion rate is still low, only about 3 to 3.4. Formulated pellets were estimated to be two thirds of the feed used in shrimp mariculture in China in 1988.

Biotechnology Studies and Breeding of New Varieties

Although *P. chinensis* is a very good species for farming in most coastal provinces in China, many shrimp farms have requested that scientists provide them with new varieties of culture species which have high growth rates, high disease resistance, high adaptability to various environmental conditions and feeds, etc. Experiments on breeding new varieties by hybridization or sex control (all female shrimp breeding) by polyploid induction and breeding, are now being conducted.

To identify shrimp varieties which can be cultured at high densities with high growth rates, scientists are conducting artificial breeding experiments. *P. chinensis* has been crossed with *P. monodon* via the artificial insemination technique of transplanting spermatophores (obtained by the electro-stimulation method) into the thelycum of pond-cultured female shrimp (Yang et al. 1988). Chromosome and karyotypical studies on *P. chinensis* and *P. monodon* have been performed, and others on *P. semisulcatus* and *P. penicillatus* are presently being conducted. The chromosome numbers of the two former species are the same, 2n=88 (n=44, Xiang 1988, Xiang et al. in press), although they belong to different sub-genera. Furthermore, the chromosome number differs from *P. japonicus* (2n=86) and *P. setiferus* (2n=90). These are the first steps toward further studies on polyploid induction and other experiments aimed at finding methods for obtaining all-female shrimp, or better strains of hybrid shrimp, which may be cultured in different areas of China.

Pathology Studies and Disease Control

Little attention was paid to diseases of cultured shrimp before the 1980's because losses were limited to certain areas and were not very serious. Shrimp disease surveys have been conducted recently in most coastal provinces, particularly in Southeastern and Southern China. Black-gill disease, *Vibrio* red-leg disease and other diseases were reported to afflict pond-cultured *P. chinensis*, *P. penicillatus* and *P. merguiensis*. Idiopathic muscle necrosis (IMN) was reported in *Penaeus* spp. and *Metapenaeus ensis*; gas bubble disease and *Vibrio* diseases in hatchery-reared shrimp larvae were reported from different areas along the coast of China (Meng and Yu 1980, 1982, 1983, Wu et al. in press). Losses are now serious in southern areas of China where water temperatures are higher. Microbiological and pathogenic studies have been carried out and methods for disease control have been developed. Copper sulfate has been successfully used to control *Vibrio* diseases in shrimp hatcheries (Chen, Du et al. in press). Studies on viral and fungal diseases are now beginning.

FUTURE PROSPECTS

P. chinensis is the most important and best species of cultured shrimp in China. To raise the production per unit area is of vital importance for the steady development of China's shrimp farming industry. It can be reached only by improving culturing techniques. Research on larval biology, nutritional physiology and biochemistry; feeds development, diseases and pathology; and biotechnology related to new strain breeding are important subjects to be studied and will certainly be strengthened. Our ability to control the development and growth of organisms and their living conditions should be improved, and high efficiency formulated feeds for juvenile stages developed.

(1) According to a new government regulation, fishing for wild broodstock of *P. chinensis* during their spawning migration will be entirely prohibited as of 1990. Experimental studies on overwintering and maturation, and copulation in captivity will be accelerated. More research will be conducted on spawning, hatching rates, and survival of larval stages. Pond-cultured broodstock for shrimp rearing should be available to all hatcheries in the country in two years. The number of broodstock used in hatcheries will be decreased. The method of stocking many gravid females in one tank for spawning and egg collection will be changed or improved. Our ability to control the reproduction and growth of organisms and their living environments will be enhanced in the next decades. Mathematical models of larval rearing tank ecosystems and computer manipulation techniques will be developed.

Methods for the prevention of larval diseases will be developed. Fiberglass, round hatching tanks will be used.

Furthermore, the trend toward increasing culture area will be slowed down.

(2) In the next decade, our ability to manipulate the quality of hatchery tank and growout pond water will be enhanced, espe-

cially with regard to H_2S and pH. Depth of growout ponds will be changed to not less than 1.5 m, and most shrimp ponds will be equipped with aeration systems. The structure of microecosystems in shrimp ponds will be studied and better manipulated.

(3) More attention will be paid to formulated feeds for the growout and larval rearing of shrimp, including improved techniques, and studies on feed efficiency and conversion ratio. Studies on the effect of amino acids, fatty acids and vitamins will also be extended. Different kinds of microparticulate and microencapsulated formulated feeds for larval stages will be developed and manufactured.

(4) We have learned that the loss of about 50% of the 1988 harvest in Taiwan was the result of the Monodon baculovirus (MBV) and other viral and bacterial diseases. The importance of studying shrimp diseases is being given more attention by most shrimp farmers and mariculture scientists. Intensive studies will be conducted by groups of experts, including ecologists, microbiologists, pathologists and pharmacologists, and various methods will be developed to control and prevent diseases. Research should be strengthened immediately to avoid the serious damage which can be caused by diseases. However, we believe that the most important and effective method is to maintain an ideal environment, and that prevention is more important than cure or control.

(5) Research topics in which biotechnology will be applied to sea farming include: microstructure of gametes, maturation and fertilization processes, structure and manipulation of chromosomes, induction of hyploidy and polyploidy, etc., and all-female shrimp induction breeding. Many more young scientists will be trained to participate in these studies.

(6) High quality processing and product storage techniques will be developed and improved.

(7) Techniques for intensive culture in cement or fiberglass tanks or in earthen ponds will be developed. The practice of producing two (or three) crops of *P. chinensis* and *P. penicillatus* or *P. merguiensis* will be examined.

In general, nutrition and feeds, disease prevention, and the application of biotechnology to shrimp production should be enhanced in the future years. We hope to see China's fishery production increased to 20 million MT in the year 2000, and the percentage of aquaculture yield increased from its present 30% to 60-70% by the end of the century.

We believe that with the support and encouragement of the government, and through the hard work of marine and fishery scientists, and mariculture workers, we will develop and improve our mariculture techniques and produce more high quality cultured shrimp for the people of China and the world. We will also have more high quality shrimp species for culture, and the shrimp *P. chinensis* will be used by more countries in their shrimp production.

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PRESENT STATUS OF FLESHY PRAWN (*PENAEUS CHINENSIS*) SEED IN KOREA

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I. Spawner
- A. Spawning season
  1. From early April to early June (mainly early to mid-May) on the western coast of the Korean peninsula
  2. Water temperature: 14-18°C
- B. Fishing ground
  1. Fishing area: Sandy bottom, 10-20 m deep in mid-western coast of Popsongpo, Yonggwang-gun, and Chonlanamdo-province to Anmyondo island Taean-gun Chungchongnamdo-province (see Fig. 1)
  2. Fishing method: gill-net
- C. Landing
  1. 50 to 1,000 gravid females a day at Popsongpo-port, Gunghang-port and Moonpori-port in Chonlanamdo-province and at Changgi-port Taean-gun Chungchongnamdo-province
- D. Selection of spawners
  1. Well-matured females: active with a wide, elongated shape and a blue-green colored ovary
  2. Individuals captured early in the spawning season
- E. Transportation
  1. Transport in a 400 liter aquarium, holding 100 fry in oxygenated 14-16°C seawater.
  2. *P. chinensis* are more active and nervous than kuruma shrimp, so transport with saw-dust seems to be unsuitable.
- F. Stock
  1. Density: approximately 100 gravid females per 2 ton circular aquarium
  2. Water quality control: running water at 16-18°C during the day, and during the night, stable with aeration.
  3. Duration: induce spawning immediately after a two to three day acclimation period.

Table 1. Lengths and weights of captured spawners.

Total length (cm)		Body weight (g)		Number of eggs
Range	Average	Range	Average	
16.0-21.6	18.2	47.0-123.0	75.9	3×10^5-10×10^5

4. Feeding: not necessary

G. Size of spawners: Table 1

II. Artificial maturation and reproduction

A. Collection of spawners

1. Late April to early May for early seed production

B. Stocking of spawners

1. Spawning tanks

a. 2-5 ton circular tank in the Puan Hatchery

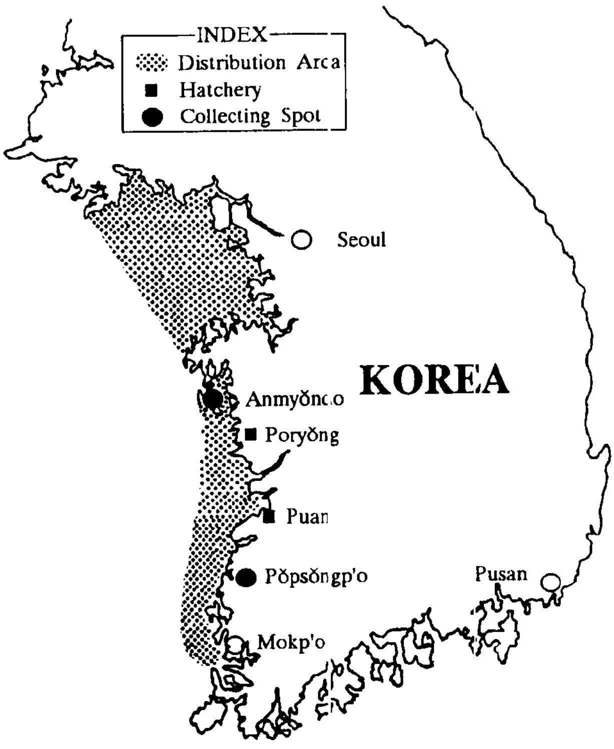

Fig. 1. The distribution of *P. chinensis* in Korea.

b. 75-150 ton circular tank in the Poryong Hatchery
2. Stocking density
a. Three to four spawners per ton for smaller tanks (8-10 spawners per 2-5 ton tank)
b. One spawner per ton for larger tanks (80-100 spawners per 75-150 ton tank)
3. Seawater
a. Natural seawater passed through 3-5 μm mesh. Fill both the small (2-5 ton) and the large (75-150 ton) tanks with 60 cm of seawater.

C. Induction of spawning
1. Stimulation: heat shock. Ultraviolet light is used to increase water temperature 2-3°C higher than the stocking water temperature of 16-18°C.
2. Treatment time: 1800 to 1900 hrs. in dark room
3. Spawning: from 2100 to 2400 hrs., with the peak at 2200 hrs. If the amount of eggs spawned is insufficient, the spawner will be maintained in the tank for one to two more days.
4. Expected number of eggs
a. 4,500-165,000 eggs per spawner
b. Peak spawning time varies by area, for instance, it is in early May on the southwestern coast and in late May on the mid-western coast.
5. Rate of spawning
a. About 80-90% of spawners are induced to spawn within 2-3 days.

D. Management of fertilized eggs
1. Remove spawners just after spawning.
2. Keep eggs in water at 18-19°C or 20-22°C.
3. In the smaller tank (2-5 ton), stop the aeration and exchange half of the seawater after the eggs sink down.
4. In the larger tank (75-150 ton), aerate to scatter eggs and prevent them from settling.

E. Hatching
1. Hatching tank: same as the spawning tank
2. Hatch out: hatch out occurs after 48 hours in 18-19°C water, and after 36 hours at 20-22°C.
3. Hatching rate
a. Above 80-90%
b. Approximately 150,000 nauplii from each spawner

III. Management of larval stage

A. Collection of nauplii
1. 2-5 ton tank: isolate with light and transfer to rearing tank
2. 75-150 ton tank: continue rearing

B. Stocking density
1. Usually 50,000 to 70,000 individuals per ton

Table 2. Larval rearing tanks at Puan and Poryong Hatcheries.

Puan Hatchery		Poryong Hatchery	
Capacity	Number	Capacity	Number
2 tons	6	75 tons	3
5 tons	1	150 tons	1

C. Water quality control
1. Water temperature: 20-22°C
2. Optimum water pH: 8.0-8.7
3. Specific gravity: 1.0210-1.0216
4. Water exchange:
   a. 2-5 ton: exchange 30% of the total water volume with filtered fresh water every day.
   b. 75-150 ton: supply 10-15 cm additional water daily for 8-10 days.

IV. Rearing of larvae and fry until release or sale

A. Larval rearing tank: Table 2

B. Larval rearing density: Table 3

C. Water quality control
1. Water temperature: 22-24°C at mysis, and 19-20°C for the postlarval stage
2. pH: 8.0-8.7 (or lower than 9.0)
3. Specific gravity: 1.0200-1.0240
4. Water exchange:
   a. Through the mysis stage, exchange 30-50% total water volume every day in the smaller tank and supply 10-15 cm additional water daily to the larger tank.
   b. During the postlarval stage, exchange 30% of rearing water twice daily for both tank sizes.

D. Feeding
1. Starting feed: usually from Zoea I stage
2. Feed type: Diatoms such as *Skeletonema costatum*, *Chaetoceros gracilis*, *Navicula* sp. and *Nitzschia* sp.; also rotifers, *Artemia*, formula feed and chopped short-necked clam meat (see Table 4)

Table 3. Densities used during the rearing of *P. chinensis* larvae in small and large tanks.

Smaller tank (100,000 larvae/ton rearing water)		Larger tank (50,000-70,000 larvae/ton of rearing water)	
Volume	No. larvae	Volume	No. larvae (x 10^3)
2 tons	200,000	75 tons	3,500-4,000
5 tons	500,000	150 tons	6,000-9,000

Table 4. Feed types and amounts for the different stages of *P. chinensis*.

Stage	Food items	Daily amount	Frequency	Remarks
Zoea	Diatoms	$3x10^5$-$5x10^5$ cells/ml		Diatom propagation by fertilization
	Rotifers	5 inds/larva	4-5	
	Formula feed (50-150 μm)	20-60 g	"	
Mysis	Diatoms	Brownish color		"
	Artemia	10 inds/larva	4-5	
	Formula feed (150-250 μm)	70-100 g	"	
Postlarva	Formula feed (250-450 μm)	100-200 g	4-5	
	Short-necked clam	300% of body weight	"	Adjust amount fed by amount consumed

E. Growth and survival rate: Table 5

V. Diatom cultivation

A. Species: *Skeletonema costatum*, *Chaetoceros gracilis*, *Navicula* sp., *Nitzschia* sp., etc.

B. Culture method

1. Inoculation of the rearing tank
2. If the diatoms are insufficient, inoculate with additional cultured diatoms.
3. Fertilizer: KNO_3 (1.00 g), Na_2HPO_4 (0.50 g), and Na_2SiO_3 (0.05 g); per ton of sea water

VI. Others

A. Facilities and their capacities for *P. chinensis* seed: Table 6

B. Annual seed production: Tables 7 and 8

C. Survival statistics of *P. chinensis* in hatcheries by year: Tables 9 and 10

Table 5. Survival and growth rates at 22-24°C for *P. chinensis* during different developmental stages (as of 1989).

Stage	Size (mm)	Days after hatched out	Survival rate Range	Survival rate Mean
Nauplius	0.16	1	75.3-93.6	87.6
Zoea	0.5	5	71.3-86.0	76.4
Mysis	1.5	12	37.5-76.1	46.4
Postlarva	2.3	20	22.1-55.0	41.1
PL20	15-20	40	2.6-12.2	6.2

Table 6. Production statistics for *P. chinensis* (as of 1989).

Hatchery	Tank Volume	Tank Number	Annual production	Maximum capacity (individuals)
Puan	2 tons	6	120,000 inds	200,000
	5 tons	2	(8,000 inds/ton)	
Poryong	75 tons	3	3,200,000 inds	5,000,000
	150 tons	1	(10,000 inds/ton)	

Table 7. Annual *P. chinensis* seed production at the Puan hatchery for 1988 and 1989.

Year	Production ($x10^3$)	Sale Number ($x10^3$)	Sale Date	Remarks
1988	50	50	6/10-15	Price: 4 Won/ind
1989	120	120	6/7-8	(670 Won = 1 $US)

Table 8. Annual *P. chinensis* production at the Poryong Hatchery for 1987-1989.

Year	Production ($x\ 10^3$)	Release* Number ($x\ 10^3$)	Release* Date	Sale Number ($x\ 10^3$)	Sale Date	Remarks
1987	1,070	500	July	500	June	Price: 4 Won/ind
1988	1,600	750	July	850	June	(670 Won = 1 $US)
1989	3,200	1,500	June 2	1,700	late May	

*Environmental conditions of the release ground:
-Location: shallow water of Kwandang-ri, Chungchongnamdo-province
-Bottom type: fine sand
-Water depth: 5 m
-Water temperature: 23-27°C

Table 9. 1988 and 1989 survival statistics for the Puan Hatchery.

Year	No. of spawners	Hatched out nauplii	Postlarvae (20th stage)	Size at sale (length in cm)
1988	30	1,000,000	50,000	1.8-2.0
1989	200	1,700,000	120,000	1.5-2.5

Table 10. 1987-1989 survival statistics for the Poryong Hatchery.

Year	No. of spawners	Hatched out nauplii	Postlarvae (20th stage)	Size at sale (cm) Range	Average
1987	1,106	21,640,000	1,070,000	1.3-1.8	1.5
1988	690	24,200,000	1,600,000	1.5-2.1	1.8
1989	380	35,250,000	3,200,000	1.4-1.9	1.6

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PRESENT STATUS OF KURUMA PRAWN (*PENAEUS JAPONICUS*) SEED, IN KOREA

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I. Spawner
- A. Spawning season
  1. June-October (mainly July-August)
  2. Water temperature: 17-25°C (mainly 22-23°C)
- B. Fishing area: Sandy clay bottom 5-7 m deep in the middle of the southern coast (Eastern north coast of Kojedo island, Kyongsangnamdo-province, see Fig. 1.)
- C. Landing: 30-50 gravid females daily for four to five days, at neap tide, between early August and early September
- D. Selection of spawners
  1. Well-matured individuals, i.e., with a very large and distinct diamond-shaped, dark green mass of ovary below the dorsal shell
  2. Complete appendages
- E. Transport
  1. Transport with sawdust more convenient than transport in container of seawater
  2. 10-15°C cold room for storage
  3. For shipping shrimp alive, keep at 15°C in cartons.
  4. The shrimp and sawdust are alternately layered from the bottom to the top.
- F. Size of spawners
  1. Total length: 17-20 cm
  2. Carapace width: 2 cm
  3. Body weight: 68-117 g (average is 89 g)
  4. Body weight diminishes 10-20 g after spawning.
  5. Number of eggs averages 20×10^4 - 30×10^4. Maximum is 100×10^4.
- G. Stock
  1. Aquarium: 1 ton FRP circular tank
  2. Density: about 100 individuals/m^2 bottom area
  3. Water quality control

a. Keep water temperature at 15-18°C to inhibit spawning
b. No running water or aeration
c. Total water exchange every two to three days

II. Artificial maturation and spawning
A. Holding of spawners
1. Aquarium: 60 ton tank, 200 ton tank (circular)
2. Stocking rate of spawners: 1-2 individuals per ton (average 1.5). 60 ton tank: 80-100 individuals; 200 ton tank: 150-200 individuals
B. Water management
1. Water temperature: 25-30°C (average 27-28°C)
2. Water volume: 30 cm until spawning
3. Seawater: filtered seawater passed through filtration tank

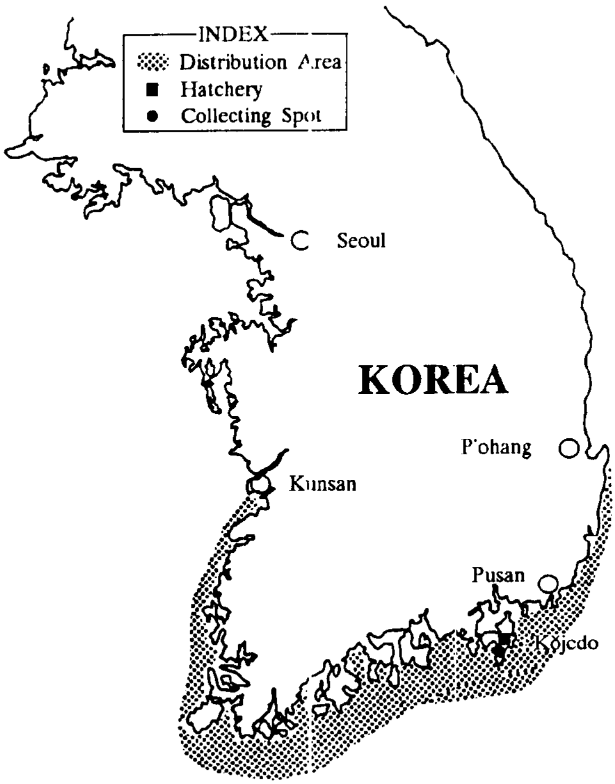

Fig. 1. Distribution of *P. japonicus* in Korea.

4. Water exchange: twice daily, 20-25% of total volume
C. Spawning induction
1. Spawning tank: after adaptation to 15-18°C water for 2-3 days, transfer spawners to 27-28°C spawning tank.
2. Treatment time
a. Stocking time: 1800 to 2000 hrs.
b. Strong aeration to prevent eggs from settling (air diffusers are scattered on the tank bottom, one for every 0.25 - 1 m^2 of bottom area).
3. Spawning time: between 2000 and 0400 hrs. (usually 2400 to 0200 hrs.)
a. Spawners can be stored in spawning tanks for 2-3 days
b. Spawning is continued for 2-3 days
4. Spawning rate: 60% of the spawners stocked
D. Hatching
1. Hatching tank: hatch out in spawning tank
2. Hatch out: within 10-13 hours at 27-28°C
3. Amount of larvae
a. 60 ton tank: 2×10^6 - 3×10^6 nauplii
b. 200 ton tank: 4×10^6 - 5×10^6 nauplii
III. Larval management
A. Stocking density: 50,000 - 60,000 larvae per ton (from nauplius to zoea)
B. Water management
1. Water temperature: 27-28°C
2. Water control: new seawater is added, approximately 10-20 cm daily, after the spawners are removed.
3. Other: pH 8.5; specific gravity 1.018-1.022
IV. Rearing of larvae and fry (until release or sale)
A. Rearing of larvae
1. Larval rearing tank
a. 60 ton tank: 9 tanks
b. 200 ton tank: 4 tanks, the same as the spawning and hatching tank
2. Stocking density: 50,000-60,000 larvae per ton (from nauplius to zoea)
a. 60 ton tank: 2×10^6 - 3×10^6 larvae
b. 200 ton tank: 6×10^6 - 7×10^6 larvae
B. Larval feed: Tables 1 and 2
C. Water management
1. No water exchange until zoea stage, and subsequently add 10-20 cm additional water daily.

Table 1. Types of larval feeds and feeding regimes for different developmental stages of *P. japonicus*.

Stage[1]	Type of food	Daily amount of food[2]	Feeding frequency (feeds/day)	Remarks
Zoea[3]	Formula feed B.P	30-60 g	4-5	Promote proper population growth of diatoms by fertilizing
Mysis	Formula feed B.P	65-100 g	"	
	Brine shrimp	5-10/larva	2	
Postlarvae				
PL1-5	Formula feed A.S	120-150 g	4-5	
	Brine shrimp	15-20/larva	2	
PL6-10	Formula feed C_1	160-170 g	4-5	
	Brine shrimp	10-20/larva	2	
PL11-20	Formula feed C_2	180-200 g	4-5	Discontinue brine shrimp. Only formula feed.

[1]The stage of postlarvae is elapsed days after metamorphosis of postlarvae
[2]Reduce total feed quantity 5% as water temperature decreases (about 24-25°C)
[3]Feeding begins at Zoea I stage.

2. From mysis stage (four to five days after spawning), water exchange is 20-25% daily (twice a day: 0800 to 0900 hrs., 1400 to 1600 hrs.).
3. During postlarval stage exchange 30% of water twice daily.
4. Water temperature: 27-28°C
5. pH: 8.5-9.0. Control water circulation to prevent the pH from going above 9.0.
6. Specific gravity: 1.018-1.022, euryhaline.

D. Survival rates: Table 3.

V. Diatom cultivation

A. Species: *Skeletonema costatum*, *Chaetoceros gracilis*, *Navicula* sp., *Nitzschia* sp., etc.

B. Culture method

1. Fill 200 ton tank with 30-50 cm of seawater (using 10 μm cartridge filter) and aerate.

Table 2. Formula feed (NIPPAI, Shrimp Feed).

Formula feed	Particle size	Larval stage
B.P	50-100 μm	Zoea-Mysis
A.S	100-200 μm	PL1-5
C_1	200-300 μm	PL6-10
C_2	300-500 μm	PL11-20
C_3	500-700 μm	PL20-35
C_4	0.8-1.5 mm	Juvenile shrimp
C_5	1.5-2.0 mm	"

Table 3. Survival rates of *P. japonicus* at different developmental stages.

Stage	Number of larvae ($x10^3$)	Survival rate (%)	Size	Remarks
Nauplius	2,000	100	300-330 μm	
Zoea	800	40	0.91-2.24 mm	
Mysis	560	28	2.90-4.8 mm	
PL1	380	19	4.6-5.6 mm	
PL10	280	14	6.5-11.2 mm	
PL30	22	11	200-300 mm	Releasing

2. When nauplii are found in the water, add chemical fertilizers as follows:
   KNO_3 - 1.00g
   Na_2HPO_4 - 0.50g
   Na_2SiO_3 - 0.05g
   (per 1 ton of seawater)
3. Concentration of diatoms will attain 10^5 cells/ml within 5-6 days.
4. If diatom bloom is insufficient, inoculate with additional cultured diatoms
5. Reduce the amount of fertilizers when the diatom growth reaches its maximum level.

VI. Other information: Tables 4-6

Table 4. Hatchery facilities and production capacity.

Tank		Annual	Maximum
Volume	Number	production	production capacity
60 tons	9		$5,000 \times 10^3$
200 tons	4	$5,000 \times 10^3$	$6,000 \times 10^3$

Table 5. Annual productioon of seed (unit: thousand).

Year	Amount of production	Number released	Releasing[1] Size	Season	
1983	325	325	2-3 cm	September	Eastern coast of Koje island
1984	1,540	1,540		"	
1985	2,200	2,200		"	
1986	3,700	3,700		"	
1987	4,800	4,800		"	
1988	4,500	4,500		late Sept.-early Oct.	
1989	5,000	5,000		Aug. 22-Sept. 10	

[1]Environment of releasing site:
-Bottom soil: sand clay
-Water depth: 5 m
-Water temperature: 23-24°C

Table 6. Annual fluctuations in survival number.

Year	Number of spawners	Hatched out nauplii	Postlarvae (30th stage)	Survival rate (%)	Size at release (mm)
1983	63	4,114,000	325,000	7.9	20-25
1984	340	22,000,000	1,540,000	7.0	20-26
1985	318	25,882,000	2,200,000	8.5	20-30
1986	570	38,144,000	3,700,000	9.7	"
1987	550	47,525,000	4,800,000	10.1	"
1988	490	46,875,000	4,500,000	9.6	"
1989	535	44,643,000	5,000,000	11.2	"

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ADVANCES IN LARVAL REARING TECHNIQUES FOR *PENAEUS CHINENSIS* IN CHINA

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INTRODUCTION

Penaeus chinensis is a commercially valuable species distributed in Chinese waters (Liu 1955). In the mid-1960's, Oka (1964, 1970) published a series of papers on *P. chinensis* culture. In China, research on its breeding biology and larval rearing began in the 1950's. Scientists of the Institute of Oceanology of Academia Sinica (IOAS) and the Yellow Sea Fisheries Research Institute (YSFRI) developed larval rearing techniques in the early 1960's. Postlarvae were reared either in net cages made of bolting silk or directly in earthen ponds. These techniques made possible the provision of small numbers of shrimp fry to farms during the late 1960's and early 1970's.

Cooperating with scientists from the IOAS and YSFRI, we developed the techniques for commercialized production of *P. chinensis* fry by the end of the 1970's (Wang et al. 1982). Since then, shrimp fry have been reared successfully on a large scale, meeting the demands of a rapidly expanding shrimp farming industry. In addition, during the last few years, billions of juvenile shrimp have been released annually to increase the natural population.

Larval rearing techniques are being improved to match the rapid development of shrimp culture. Yield of shrimp seed has increased markedly. The average yield is 150,000/m^3. In some hatcheries in Northern China, yield is as high as 200,000-300,000/m^3.

BROODSTOCK CULTURE TECHNIQUES

Female broodstock are usually captured from wild populations. Overfishing before the spawning season, however, may destroy natural shrimp resources, since so many broodstock are removed. To avoid this, scientists have researched the over-wintering of pond cultured shrimp and achieved significant results. In some districts, shrimp have been farmed and propagated successfully for several generations. Cost of fry production is thus reduced, and broodstock can be provided to those provinces lacking natural populations of gravid female shrimp.

Chinese shrimp are multiple spawners. Under optimum conditions, mature females can breed three or four times in one spawning season (seven times is the maximum). The interval between spawnings is five to 20 days (Xu 1983). Only the eggs from the first two or three spawnings, however, are selected for hatching.

Because captive shrimp have a lower mating rate, Cong-Hai Yang (1989) has developed techniques for artificial insemination (transplantation of spermatophores) of *P. chinensis*.

SPAWNING

In the 1960's and early 1970's, gravid female shrimp were placed in net cages for spawning. Overcrowding usually resulted in a lower spawning and fertilization rate, however, and produced large numbers of deformed embryos. The spawning method has been improved in recent years, and gravid females are now placed in separate spawning tanks. Eggs are collected the following morning and transferred to rearing tanks.

The new method allows the gravid females to swim freely and maintains better water quality. This technique not only utilizes the broodstock more efficiently but also prevents contamination of the rearing tank. Since stocking density influences the quality of spawned eggs, overcrowding in the spawning tanks must be avoided. Densities of 10-15/m^2 are recommended.

DENSITY OF EGGS AND LARVAE

In the past, eggs collected from spawning tanks were hatched at densities of 200,000-250,000/m^3, nauplii were reared at densities of 150,000-200,000/m^3, and the yield of postlarvae was approximately 50,000-100,000/m^3. In recent years, the densities for hatching and rearing have been increased to 500,000/m^3 for eggs (even up to 1,000,000/m^3 in some hatcheries) and 300,000/m^3 for nauplii. Yields of 200,000-300,000 fry per unit rearing water are quite common.

Although many scientists are concerned about those high densities, experience has shown that high densities are feasible if the rearing conditions are optimum and kept constant.

REARING MEASURES

Aeration

Aeration is one of the most significant factors in shrimp larval rearing. It improves water quality and evenly distributes larvae and feed in the rearing tanks. Moreover, use of aeration reduces the amount of energy larvae expend in swimming, and thus hastens growth. In this manner, aeration may increase larval survival as well. In the Japanese method, aeration is conducted at the rate of 0.5-1% per volume per minute. To improve water quality and oxygen supply for high density larval rearing, aeration has been increased to 1.5-2% of water volume per minute in our larval rearing tanks.

Water Exchange

In the 1960's and 70's, rearing tanks were filled to a third to half tank volume before spawning. After larvae hatched, treated seawater was added to rearing tanks every day until the mysis stage. Water replacement began when the tank was full. The new method is to completely fill the tanks with treated seawater when shrimp eggs are transferred. Water replacement begins at the Z2 stage, usually twice a day. The replacement rate is 30-50% per day, more if necessary. During the postlarval stage, the rate is increased to 100% or more every day.

Temperature

Although *P. chinensis* is mainly distributed in the Yellow Sea, it originated in the subtropical South China Sea. Its temperature tolerance range is quite wide. *P. chinensis* can adapt to both warmer and colder temperatures. Once their temperature acclimation is determined, water temperature in rearing tanks can be adjusted to enhance larval development and survival. Oka (1964) indicated that the optimum temperature for larval rearing is approximately 25°C. In our hatcheries, temperatures are now maintained at 27-28°C for late larval rearing; this shortens the rearing period.

Nutrition and Food

Using the C^{14}-S^{35} labelling technique, Huiming Luo (1981) performed an experiment on the feeding habits of *P. penicillatus*. He concluded that Z1-3 are chiefly filter feeders, and larvae become predatory at Mysis 1. According to our observations, Z1 of *P. chinensis* can prey on rotifers, and Z2 can grasp coarse particles of egg yolk. In addition, the mysis can filter microalgae, especially *Platmymonus* sp. Hence, we believe that both zoea and mysis of *P. chinensis* can prey upon and filter food. The size of food particles and their speed should correspond to the feeding ability of larvae at various stages.

Luo also studied the relationship between feeding efficiency, absorption rate, filtering rate and microalgal densities, thus providing a theoretical foundation for determining quantity and type of food to be used in larval rearing.

The quantity and quality of food are very important in high density larval rearing. Shrimp larvae will develop successfully only if they are given proper nutrition. The principal vegetable feed used in the zoeal stage is microalgae. Widely used species of microalgae are *Phaeodactylum tricornutum*, *Nitzschia closterium*, *Chaetoceros muelleri* and *Platymonus* sp. *C. muelleri* is considered to be the best.

The rotifer, *Brachionus plicatilis*, and *Artemia* nauplii are often used in shrimp hatcheries as a source of animal protein. The high demand for and high cost of these live feeds means we must find other natural or artificial diets with which to replace them. Many types of food are now available for marine particle feeders, including a number of micro-encapsulated and micro-granulated feeds produced in China. These have partially or completely replaced living *Artemia* nauplii in some shrimp hatcheries. Besides those formulated commercial diets, some others such as soybean powder, hen's eggs, clam flesh, and shrimp flesh, have been used to feed shrimp larvae at different stages. The use of various kinds of diets in reasonable proportions may prevent the nutritional deficiencies which may result from using a single artificial feed.

DISEASE

There are many kinds of diseases which infect larvae and often cause heavy losses in nurseries. The most common diseases are:

Fungal Disease

Fungi infecting shrimp larvae belong to the genera *Lagennidium* and *Siropidium* in the class Phycomycetes. Both infect eggs and larvae in various stages. They do very serious damage and can destroy all the shrimp fry produced during the breeding season. To prevent fungal disease, female broodstock should be carefully disinfected and the water in rearing tanks regularly treated with 6-10 ppb of malachite green. Treating the infected larvae with nystatin is often a fairly effective cure.

Bacterial Disease

Two species in the genera *Leucothrix* and *Thiothrix* adhere to the surface of shrimp eggs and larvae. Infected eggs stop developing and diseased larvae become less active, swim with difficulty, gradually sink to the bottom of the tank, and die. Keeping the culture water fresh and clean can prevent this disease.

Infection by *Vibrio* spp. seriously affects larval mortality during the rearing operation. Infected larvae appear pale and turbid, swim weakly and stop feeding. Large numbers of living *Vibrio* may be seen in the body and organs of moribund larvae. Sometimes *Vibrio* is mixed with *Pseudomonas* sp. There is high mortality of infected larvae, often 100% mortality in diseased rearing tanks. Treating with 1-2 ppm of chloromycetin is effective to some degree.

Viral Disease

A disease similar to midgut-gland necrosis disease which occurs in *P. japonicus* has been found in *P. chinensis*. Infected mysis and postlarvae stop feeding and swim in circles on the surface with head and tail bent backward. The gut and midgut-gland appear milky and necrotic. Mortality is quite high. The virology test for this disease has not been performed.

Parasitic Ciliate Disease

The pathogen of this disease is a type of endoparasitic ciliate, a new geographical form of *Paranophrys carcini*. It often occurs at different larval stages and in over-wintering adults. The infection rate is very high, and often results in 100% mortality in the infected tanks. The ciliate is also found in the water, so water may be the medium for spreading the disease. Disinfecting culture water in tanks with 25 ppm of formalin has proven effective in preventing infection from ciliates. No effective treatment has been found for the ciliate-infected adults and larvae.

Ectocommensal Ciliate Disease

This kind of ciliate adheres to the surface of larval shells. So far, 38 species, belonging to nine genera, and four families have been found in *P. chinensis* larvae (Song 1986). *Zoothamnium, Carchesium, Vorticella* and *Epistylis* are common genera. By adhering to the larvae's body, they hinder its swimming and feeding. They also slow down development and metamorphosis and can cause death. Ciliates usually adhere when larvae are weak from lack of food and when they cannot molt regularly due to infection by some other pathogen. Therefore, the best prevention is to keep tank water in good condition and supply a sufficient diet to the culture tanks in order to hasten normal molting. In addition to the diseases mentioned above, some other diseases also are found during fry production. These include bubble disease, deformity disease, flagellate adhesive disease and others whose pathogenicity is still unclear. Simply put, diseases cause very serious problems in shrimp fry production, and further research is urgently needed.

FACILITIES

The current practice is to grow larvae in rearing tanks from nauplii to postlarvae 7-10 mm long. Larval transfer is unnecessary until harvest. If larvae are overcrowded, some of them should be transferred at an early postlarval stage to other tanks or to outdoor tanks.

Rearing Tank

Tanks used for large scale larval production are concrete and 1.5-1.8 m deep. Volume typically ranges from 30-100 m^3, some even reaching 200 m^3. Of the various tank shapes, rectangular is more convenient. Tank corners are usually rounded. Indoor rearing tanks are built in a greenhouse covered with a translucent roof made of fiberglass-reinforced plastic.

Water Supply System

The water supply system varies by location. In hatcheries located in clear areas, seawater is treated by sedimentation and subsequent filtration through 150-200 mesh bolting silk netting before being used in the rearing tanks. In areas of poor water quality, seawater needs to be treated by sedimentation twice in different settling tanks, for at least 24 h before it is filtered with bolting silk and placed into rearing tanks. High level tank and sand filter beds are included in some water treatment systems. The various water treatment systems used in our hatcheries are as follows:

(1) Seawater ⇒ pump ⇒ high level settling tank ⇒ bolting silk netting ⇒ rearing tank

(2) Seawater ⇒ settling tank ⇒ pump ⇒ high level tank ⇒ bolting silk netting ⇒ rearing tank

(3) Seawater ⇒ settling tank ⇒ pump ⇒ pressurized sand filter bed ⇒ high level tank ⇒ rearing tank

(4) Seawater ⇒ settling tank ⇒ sand filter well ⇒ pump ⇒ high level tank ⇒ rearing tank

(5) Seawater ⇒ settling tank ⇒ sand filter well ⇒ pump ⇒ high level preheating tank ⇒ rearing tank

Aeration Installations

Aeration is essential to a larval rearing operation. In large hatcheries, it is provided by Root's blowers. These have the advantage of being oilless, and maintaining steady pressures and a large air supply. The blowers should have an air pressure of 0.35-0.5 Bar and supply air at a rate of 1-2% of volume of culture water per minute. At least two of them are needed in any hatchery for alternate use. Airstones are scattered over the bottom of the rearing tanks, one per m^2. They are connected to PVC tubes by polyethylene branch hoses, and the PVC tubes lead to the blowers. Another aeration method is to use PVC tubes with tiny holes spaced 10-15 cm apart instead of airstones and branch hoses. The PVC tubes are laid in rows on the bottom of the tank 1-1.5 m apart. Airstones are more efficient at supplying oxygen and the PVC tubes are better for stirring water.

Heating System

Heating is needed in cold regions like Northern China. Depending upon the ambient water temperature needed and where the hatchery is located, a boiler is chosen for 1,000 m^3 of culture water. Boilers have the capacity to provide 300,000-600,000 kcal of heat per hour. Electric heaters are used in some small hatcheries and terrestrial heat and surplus heat from factories are utilized in some hatcheries as well.

Installations for Microalgal and Rotifer Culture

There are two methods of microalgal culture. Closed culture is usually used in small-scale microalgal culture while open culture is used for mass production. Invented by Rucai Wang (unpubl.), a patented method of closed column culture for microalgae is now available. With this method, the microalgae are cultured continuously in a closed column, in which temperature, light, aeration and water quality are all controlled. Open culture takes place in indoor concrete tanks or in fiberglass-reinforced plastic tanks 0.5 m deep, varying in area from a few m^2 to 10-20 m^2. Temperature is adjusted by electric heaters installed in the room or tanks. Aeration and light control are also possible. Seawater used is sterilized chemically with 20-50 ppm of chlorine or hydrochloric acid. For the mass production of microalgae, water is treated by sand filter bed.

Indoor rotifer culture is for maintaining culture stocks and small-scale culture, while outdoor culture is for large-scale production. Indoor rotifer culture is usually carried out in flasks, fiberglass-reinforced plastic tanks and concrete tanks which are 1 m deep and several m^3 in volume.

Although culturing in earthen ponds has the advantage of lower cost and high production, rotifer production often does not meet the feed demands of shrimp larval rearing since outdoor water temperature cannot be controlled. The earthen pond is a long rectangle 0.5-1.0 m deep and 200-2,000 m^2 in area. Concrete tanks and earthen ponds are used in outdoor rotifer culture. A sluice gate is built at one end of the pond or at opposite ends if two are needed.

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EVALUATION AND COMPARISON OF CULTURE PRACTICES FOR *PENAEUS JAPONICUS*, *P. PENICILLATUS* AND *P. CHINENSIS* IN TAIWAN

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Abstract

The temperate penaeids, most notably the kuruma prawn, *Penaeus japonicus*; the redtail prawn, *P. penicillatus*; and the fleshy prawn, *P. chinensis*, have been gaining attention from those interested in diversifying culture species in Taiwan, especially since the recent *P. monodon* production crash. In this paper, the culture practices for these three penaeids are evaluated and compared with respect to biological characteristics, larval rearing, growout, and marketing. Polyculture techniques and crop rotation are also discussed.

INTRODUCTION

World production of cultured prawns in 1988 was estimated to be 450,000 metric tons (MT) (Rosenberry 1989). This production was mainly *P. monodon*, the grass prawn (33%); *P. chinensis*, the fleshy prawn (22%); and *P. vannamei*, the white-leg shrimp (18%). The balance of production was from *P. penicillatus*, the redtail prawn (8%); *P. merguiensis*, the banana prawn (4%); *P. japonicus*, the kuruma prawn (3%); *P. stylirostris*, the blue shrimp (2%); and others (10%). The tropical and subtropical species *P. monodon* and *P. vannamei* dominated prawn culture until successful development of *P. chinensis* culture was achieved in mainland China in 1982. Total cultured prawn production in China was 2, 7 and 22,000 MT in 1980, 1982 and 1984, respectively, and the increase was mainly due to *P. chinensis* culture. *P. chinensis* production in 1986 was over 60,000 MT (Liu and Zhong 1986).

Recently, *P. chinensis* has also received attention in many other parts of the world, along with two other temperate penaeid species, *P. japonicus* and *P. penicillatus*. Besides being commercially cultured in Bohai Bay in mainland China, *P. chinensis* has been experimentally cultured in Japan (Oka 1967), Hong Kong (Tseng and Chang 1980), New Zealand (Anonymous 1986), and France (Quincy 1987).

Among these three species, *P. japonicus* is the most widely cultured. It is already produced on a large commercial scale in Japan. It is also commercially or experimentally cultured on a small scale in Hawaii, Brazil, Singapore, on the Atlantic coast of France, and on the Mediterranean coast in Morocco, Portugal, Spain, Italy, Greece, Cyprus and Israel. Many countries are interested in this species because it is expensive, tasty, and colorful in appearance. In Taiwan, the culture of these three penaeid species has also been considered. In fact, as early as 1969, the possibility of culturing *P. japonicus* was being explored (Liao and Huang 1972). Interestingly, what were then merely candidate species are now under large-scale commercial culture in Taiwan. After the 1988 *P. monodon* production crash, culture trials with *P. chinensis* were begun to provide more alternatives to the prawn culture industry.

Production of *P. japonicus* in Taiwan has steadily increased from 100 MT in 1981 to 4,000 MT in 1988, and was second only to *P. monodon* in 1988 (Table 1). The increase in production volume between 1987 and 1988 can be attributed to the decision of some prawn farmers to switch from *P. monodon* to *P. japonicus*, since the latter is immune to MBV (Monodon Baculovirus) (Fukuda et al. 1988). *P. penicillatus*, on the other hand, has been cultured on a large scale in Taiwan since 1986, when production was 3,000 MT. A production jump to 7,000 MT in 1987 made it the second most important prawn cultured in Taiwan. Parallel to the decline of *P. monodon* production in 1988, *P. penicillatus* production decreased to 3,500 MT, but was still only slightly lower than production of *P.*

Table 1. Production volume (metric tons) of the main shrimp cultured in Taiwan from 1981 through 1988. The percentage of total production is in parentheses.

Year	*Penaeus monodon*		*Penaeus japonicus*		*Penaeus penicillatus*		*Metapenaeus ensis*		Others	Total
1981	6,000	(72.3)	100	(1.2)	----	----	1,200	(14.5)	1,000	8,300
1982	8,000	(73.1)	50	(0.5)	----	----	1,600	(14.6)	1,300	10,950
1983	15,000	(89.3)	50	(0.3)	----	----	850	(5.4)	900	16,800
1984	18,000	(89.0)	200	(1.0)	----	----	900	(4.3)	1,600	20,700
1985	30,000	(91.7)	500	(1.5)	----	----	1,200	(3.7)	1,000	32,700
1986	60,000	(85.7)	800	(1.1)	3,000	(4.3)	1,200	(1.7)	5,000	70,000
1987	95,000	(83.0)	1,500	(1.3)	7,000	(6.1)	1,000	(0.9)	10,000	114,500
1988	30,000	(68.7)	4,000	(9.2)	3,500	(8.0)	1,200	(2.7)	5,000	43,700

japonicus. It is possible that MBV and some of the common diseases of *P. monodon* also affected this species. *P. penicillatus* is not immune to MBV.

This paper compares these three temperate penaeids with regard to biological characteristics, larval rearing, growout, and marketing, and evaluates the suitability and potential of their culture practices.

BIOLOGICAL CHARACTERISTICS

The biological characteristics of these three penaeids are summarized in Table 2. *P. japonicus* has the widest distribution, *P. chinensis*, the narrowest (Holthuis 1980, Yu and Chen 1986). *P. chinensis* is distributed only in nearshore and offshore areas of mainland China, particularly in the Bohai Bay and Yellow Sea. The southernmost extent of its distribution is the mouth of the Pearl River (Liu and Zhong 1986). The minimal spawning temperatures in nature are 13, 20 and 23°C for *P. chinensis*, *P. japonicus* and *P. penicillatus*, respectively. From the geographical distribution and minimal spawning temperature in nature, it appears that *P. chinensis* is more cold-resistant than the other two prawns. The optimal temperature, as ascertained by culture experience and consistent with geographical distribution, indicates that *P. japonicus* has the widest temperature range, while *P. chinensis* is the least adaptable to high temperatures.

Both records of maximum size and regular size in the fishing grounds indicate that *P. japonicus* is the largest of these three species of prawn, *P. chinensis*, the smallest. The well-being (fatness) index, B, of the weight-length relationship ($W = A \times L^B$) indicates that *P. penicillatus* is the most slender in form. The larger the B value, the fatter the prawn. The ratio of carapace length to total length of the maximum size prawn demonstrates that the head of *P. penicillatus* is relatively small compared with the other two prawns (Table 2).

P. penicillatus and *P. chinensis* are both classified in the subgenus *Fenneropenaeus*. They have a similar appearance and behavior when compared with *P. japonicus* (subgenus *Marsupenaeus*). *P. chinensis* usually stay on or in the sediment during the day. At night, they are more active and swim slowly in the bottom layer or in the midlayer (Liu and Zhong 1986). *P. penicillatus* are less benthic than *P. chinensis*. The prawns move around on the bottom or swim in the water column day and night. *P. japonicus* seldom swim in the water column. During the day, the prawns bury themselves in the sediment with only eyes and antennules exposed. They feed mostly when it is dark.

LARVAL REARING

The minimum size at sexual maturity is smaller in *P. japonicus* than in the other two prawns (Table 3). For all three, ovarian maturation in captivity can be achieved without eyestalk ablation.

In Taiwan, the hatchery techniques and facilities for *P. japonicus* and *P. penicillatus* are generally the same as those for *P. monodon*. The hatchery techniques for *P.*

Table 2. Comparison of biological characteristics of *Penaeus japonicus*, *P. penicillatus*, and *P. chinensis*.

	P. japonicus (kuruma prawn)	*P. penicillatus* (redtail prawn)	*P. chinensis* (fleshy prawn)
Distribution[a,b]	Indo-West Pacific, Eastern Atlantic, Mediterranean	Indo-West Pacific	Yellow Sea, East China Sea, Korean Bight
Optimal temp. (°C)[c]	18-28	25-30	18-25
Habitat depth range (m)[a]	0-90	2-90	90-180
Main habitat depth (m)[b]	10-40	<30	20
Main spawning months	2-4[d] (South China Sea)	4-5[e] (South China Sea)	5[e] (Yellow Sea)
Min. spawn temp. (°C)	>20	>23	>13[d]
Weight vs. length relationship ($W = A \times L^B$, B=fatness index)			
Ax10-6, B Male	9.9, 3.030	21.1, 2.881	11.3, 2.999
Ax10-6, B Female	6.4, 3.116[e]	65.6, 2.643[e]	11.0, 3.001[d]
Max tail length (mm) M[a]	190	163	154
Max. tail length (mm) F	225	212	183
Max. carapace length (mm) M[a]	53	31	42
Max. carapace length (mm) F	66	33	55
Max. CL/TL (%) M	27.89	19.02	27.27
Max CL/TL (%) F	29.33	15.57	30.05
Regular size in fishing ground (g)[b]	15-20	13-16	10-15
Appearance	striped	white	white
Diurnal activity	night	day and night	day and night
Burying behavior	yes	no	no
Sediment preference	sand	mud	mud
Schooling behavior	no	yes	yes
Water clearance	clear	turbid	turbid
Endurance in air	strong	weak	weak

[a]Holthuis 1980; [b]Yu and Chen 1986; [c]Wang 1983; [d]Changcheng 1984; [e]Liu and Zhong 1986

monodon have been extensively described by Liao (1985).

Rearing *P. japonicus* and *P. penicillatus* larvae is relatively easy compared to *P. monodon*, because the former species have higher survival rates. In one experiment, the survival rate of *P. japonicus* from egg to PL5 (22.57%) was higher than that of *P. monodon* (10.92%) (Lim 1982). In an experiment on mass production of *P. penicillatus* larvae, the survival rate was 22.94% from egg to PL9 (Liu and Huang 1986). On several occasions, *P. penicillatus* larvae spawned naturally in outdoor ponds have shown good survival. The larvae survived on natural food present in the pond without supplementary feeding (Liao 1988a).

Among these three prawns, *P. chinensis* have the longest duration of hatching and larval development because their hatchery temperature is the coldest (Table 3). The optimal temperature ranges for embryonic development are lowest for *P. chinensis* (Table 4), which reflects the minimal spawning temperature in nature (Table 2). The optimal salinity ranges for embryonic and larval development are lower for *P. penicillatus* than for the other two prawns (Table 4). For *P. penicillatus*, the lower limit of salinity for hatching was 20-25 ppt; for rearing nauplii to zoea, 20-25 ppt; and for mysis, 25 ppt (Chang 1986). The suitable temperature for hatching and for rearing nauplii to zoea was 23-29°C, and from zoea to mysis, 26-29°C (Chang 1986).

According to Wang (1983), *P. chinensis* larvae have the strongest resistance to ammonia toxicity among the penaeids. TL50, 19 hours of total ammonia are 29.1, 12.7, 12.7, 34.4, and 34.6 mg/l for nauplius, zoea, mysis, PL10-14, and PL30-34, respectively. No ammonia toxicity data for the other two species are available.

It appears that *P. penicillatus* postlarvae can withstand shipping better than *P. monodon* postlarvae. For the same shipping duration of 85 hours, the survival rate of *P. penicillatus* (PL6-8, 60-70%) was higher than that of *P. monodon* (PL15, 20-30%) (Liao 1985). No data are available on the tolerance of larvae or postlarvae of the three prawns when subjected to shipping.

Table 3. Comparison of hatchery temperature, duration of hatching, and larval development of *Penaeus japonicus*, *P. penicillatus*, and *P. chinensis*.

	P. japonicus	*P. penicillatus*		*P. chinensis*
Sexual maturity size				
Length (cm) M	11-14[a]	12-16[b]	12-14[a]	15-20[b]
Length (cm) F	13-16	15-20	14-16	18-23
Weight (g) M	15-31	30-40	22-35	20-40
Weight (g) F	25-47	40-60	35-56	60-80
Hatchery temp. (°C)	27-29[c]	25-26[d]	29[e]	19-20[f]
Hatching (hours)	13-14	13.5	12-14	34.5
Protozoea (days)	5-6	4.5	2	8
Mysis (days)	5	3.5	3.5	7

[a]Liu and Zhong 1986; [b]Mao et al. 1987; [c]Hudinaga 1942; [d]Pan and Yu 1989; [e]Chang 1986; [f]Oka 1967

An experiment on artificial propagation of *P. chinensis* was conducted at the Tainan Branch of the Taiwan Fisheries Research Institute (TFRI) in February, 1989 (Y.Y. Ting, pers comm.). Temperature manipulation and HCG injection were used to induce ovarian maturation. Three brooders spawned 12 times and produced 3.8 million eggs. Average hatching rate was 87.95%. A total of 420,000 PL5 were produced and the survival rate from egg to PL5 was 11.05%.

GROWOUT PRACTICES

P. japonicus

Kuruma prawns are cultured mainly on the west coast (Changhwa), northeast coast (Ilan), southwest coast (Pingtung and Kaohsiung) and on the island of Penghu. The normal stocking time is fall (mid-September to November), but stocking can be done as early as August and mid-September in Ilan and Changhwa, respectively, right after the *P. monodon* crop. Stocking takes place earlier so that various sizes of prawns can be harvested from December to March, during which time the fisheries and culture production of this species in Japan is low and prices are favorable. The stocking densities vary from 30-50 PL/m^2. In Pingtung, the southernmost county, where *P. monodon* is cultured in intensive systems, *P. japonicus* is stocked at a high density (200 PL25/m^2) in August. Some of the young prawns (5-8 g) are harvested and sold locally, like sand shrimp, *Metapenaeus ensis*, during October or November. This is not only to get cash returns in the middle of the cropping cycle, but to decrease prawn density.

During the past two years, culturing *P. japonicus* in the summer has become popular,

Table 4. The optimal water quality parameters for the development of embryos and larvae of *Penaeus japonicus*, *P. penicillatus* and *P. chinensis*.

	P. japonicus		*P. penicillatus*		*P. chinensis*
Optimal temperature range (°C)					
Embryo	25-30[a]		26-29[a]	23-29[b]	18-20[a]
Nauplius	28		26-29	26-32	20-22
Zoea	28		26-29	26-29	22-24
Mysis	28		26-29	26-29	23-25
PL 1-7	28		25-30		25-26
Optimal salinity range (ppt)					
Embryo	30-35[a]	25-47[c]	23-30[a]	25-32[b]	24-35[a]
Nauplius	27-29	20-40	22-30	25-32	27-38
Zoea	27-35	29-45	22-31	25-32	25-37
Mysis	23-44	22-43	20-30	25-30	27-39
PL 1-7	23-47	20-43	18-30		16-39

[a]Wang 1983; [b]Chang 1986; [c]Lim 1982

possibly to replace some *P. monodon* culture. The reasons for this substitution are as follows:

(1) Further land depression, which results from *P. monodon* culture, can be lessened. *P. japonicus* culture requires less freshwater than *P. monodon* culture, and regulations against exhausting the underground freshwater supply are being enforced.

(2) The price of small *P. japonicus* is as good as *M. ensis*, and the price of market-size *P. japonicus* is high in the Japanese market.

(3) Locally produced *P. japonicus* feed is available and much less expensive than imported feed.

(4) Fry price is low and fry quality problems are fewer than those of *P. monodon*.

(5) *P. japonicus* is immune to MBV.

The summer culture practices for *P. japonicus* are as follows: Stocking takes place from April to May and is 90-150 PL/m^2. After the one-month nursery stage, the juveniles are collected and restocked to lower the density by about a third.

The bottom preparation of ponds before stocking is similar to that of *P. monodon* ponds, except that 3-5 cm of fresh sand is spread on the bottom. This is to accommodate the burrowing behavior of this species. Sometimes the center (1/9 of the total bottom area) is left uncovered with sand to reduce costs, since the sediment at the middle of the pond deteriorates the fastest and would not be inhabited by the prawns. The sandy bottom also helps the sediment to remain in a higher reduction-oxidation (redox) state.

Comparing the sediment chemistry of *P. monodon*, *P. japonicus*, and *P. penicillatus* ponds, Chien (1989) attributed the significantly higher average redox potential of *P. japonicus* ponds (-85 mV, at a 5 mm depth) compared to *P. monodon* ponds (-142 mV), to the easy diffusion of DO into the sandy sediment and the burrowing activity of *P. japonicus*. However, no statistically significant difference was found in redox potential between *P. japonicus* ponds and *P. penicillatus* ponds (-111 mV).

Since *P. japonicus* is sensitive to sediment quality, keeping the sediment in a favorable oxidation state is important. Therefore, aeration in *P. japonicus* ponds is more intensive than in other prawn ponds. Bottom aeration is sometimes employed by using an air compressor which channels air to a network of pipes installed beneath the sand layer.

Water depth is 1.0-1.5 m. Salinity during stocking is the same as in the hatchery, 25-30 ppt. Salinity is lowered as the prawns grow, and is then maintained at 20-25 ppt. Instead of pond-side feeding as with *P. monodon*, *P. japonicus* feeding covers most of the pond since the prawns are more evenly distributed. Either two feedings, at dusk and 1-2 hours before dawn, or three feedings with one more feeding added around midnight, are conducted daily. Being carnivorous, *P. japonicus* requires relatively more animal protein and total protein in its diet. The optimum dietary protein level for *P. japonicus* ranges from 52 to 60% (Deshimaru and Shigueno 1972; Deshimaru and Kuroki 1974; Deshimaru and

Table 5. The average unit area production (kg/ha/year) of the primary shrimp species cultured in Taiwan from 1986 to 1988.

Year	*Penaeus japonicus*	*Penaeus penicillatus*	*Penaeus monodon*
1986	1,649	5,160	5,563
1987	2,427	11,203	5,578
1988	3,170	6,424	2,109

Yone 1978). Local *P. japonicus* feed has a protein content of at least 50%. No data are available on the relationships among growth, survival, and stocking density. There is an increasing trend in unit area production (kg/ha). The average unit area production was 1,649, 2,427, and 3,170 kg/ha for 1986, 1987 and 1988, respectively (Table 5).

Imported *P. japonicus* feed from Japan is much more expensive (US$3.85/kg) than the local feed, so importation has now stopped. The current (1989) prices for local *P. japonicus* feed are US$1.67 and $1.60/kg for juvenile and subadult feed, respectively. Although *P. japonicus* feed for all stages is locally available, some farmers still use the less expensive *P. monodon* feed and supplement this with ground trash fish and sea snails once every two to three days, or with fish oil during the juvenile stage (5-6 g). The prices of *P. monodon* feed are US$1.37 and $1.31/kg for juveniles and subadults, respectively.

Food conversion ratio (FCR) of local *P. japonicus* feed is 1.4-2.0, which is lower than that reported for the Japanese brands. It is possible that the difference is due to the style of water management. Taiwanese use the "green-water" method, unlike the Japanese, who use the "clear-water" method. Natural productivity may have helped produce a lower FCR.

Color of *P. japonicus* can be enhanced by feed pigmentation. A study has shown that synthesized astaxanthin is more effective in color enhancement than algal meal (*Dunaliella salina*) and synthesized β-carotene. If *P. japonicus* is given feed containing 100 mg astaxanthin/100 g feed for two months, there is no discernable color difference between the cultured prawn and the wild one (Cheng 1989). To produce this level of pigmentation, however, the feed would cost NT$270 (US$1 = NT$26) more per gram of prawn produced. Therefore, the commercial feed has no synthesized astaxanthin added to it at present.

The minimum exportable size is around 15 g. Successive harvesting is employed for size variation of the stock and market demand. A set net is used for partial harvesting or when harvesting for the live prawn market. The set net has the advantages of causing only minimal damage to the prawn and selecting large prawns. This net is employed only at night when *P. japonicus* is active and moving along the pond side. An electrical trawl is used during mid-crop harvest to catch all sizes of prawns or to force the prawns out of the sediment while the water temperature is very low and they are immobile in the sand.

For live transport to Japan, the harvested prawns are first acclimated to 10-12°C in tanks and then packed in styrofoam boxes containing pre-chilled sawdust. This entire procedure is performed inside a special room where the temperature is maintained at 10-20°C.

P. penicillatus

The merits of *P. penicillatus* as a culture species are many. For instance, this species can grow even at temperatures as low as 20°C. It has simple nutritional requirements and needs only a low level of protein in the feed. Spawning in captivity is easy and can be induced by eyestalk ablation. Also, an earthen pond bottom is adequate for growout (Liao and Chao 1983, 1987; Liao 1988a).

In Taiwan, *P. penicillatus* is cultured mainly on the southwest coast (Pingtung and Kaohsiung), west coast (Changhwa), and northeast coast (Ilan). Cultivated *P. penicillatus* production statistics are available beginning in 1986 (Table 1). *P. penicillatus* has become the second most important cultured prawn in Taiwan. It is generally monocultured and rotated with the *P. monodon* crop. It can be cultured in summer as well as in winter. There is a trend toward replacing *M. ensis* culture with *P. penicillatus* culture for the following reasons:

(1) *P. penicillatus* can be reared at a high density year-round;
(2) unit area production can be as high as 12 MT/ha;
(3) growth is faster than that of *M. ensis*; and
(4) survival rate is generally higher than that of *M. ensis*.

The culture facilities and management style for *P. penicillatus* are basically the same as those of *P. monodon*, which is, perhaps, one of the main reasons for the fast development of the industry. Aside from those mentioned above, some other merits make *P. penicillatus* ideal for culture (Liao 1988a). These are further elaborated with examples, and listed in Table 6.

P. penicillatus is eurythermal and can be cultured in Taiwan throughout the year. In southwest Taiwan, its growth in winter, when the water temperature may be as low as 15°C, is comparable to its growth in summer. Liao and Chao (1983) found that *P. penicillatus* may also grow at the low temperature of

Table 6. Five cases of *P. penicillatus* culture in Taiwan.

	Case				
	1[a]	2[a]	3[b]	4[c]	5[d]
Pond size (ha)	0.14	0.14	1.0-1.5	0.56	0.06
Stocking density (no./m^2)	171	286	48-52	124	20
Growing period	Oct-Mar	Jun-Oct	Jul-Sep	Apr-Jul	Aug-Nov
No. days	131	141	95	121	120
Survival (%)	64.6	44.3	75.7	90.0	80.5
Harvest size (g)	10.0	9.7	12.3	9.5	21.4
Production (kg/ha)	11,071	12,286	4,293	10,650	3,437
FCR	1.40	1.70	1.49	---	2.42
Temperature (°C)	---	23-20	22-33	28-31	25-32
Salintiy (ppt)	---	15-21	18-26	15-30	25-32

[a]Chen et al. 1988; [b]Chen and Liu 1989; [c]Liou 1987; [d]Liao and Chao 1987

20°C. Two continuous growout experiments (Cases 1 and 2 in Table 6) of the same duration were performed with *P. penicillatus* in Tungkang, Pingtung. The average harvest sizes were 10.0 and 9.7 g for the winter and summer crop, respectively. The feed conversion ratio for the winter crop, (1.40), was even better than that of the summer crop, (1.70). It was reported that when water temperature was higher than 30°C, the feeding rate of *P. penicillatus* increased, but growth slowed or even stopped. It is also suspected that slower growth reflects the lower water quality found during the summer.

It appeared that increasing stocking density from 120 to 280/m^2 had no significant effects on growth, but did influence survival. In cases 1, 2, and 4 (Table 6), the average harvest sizes were 10.0, 9.7, and 9.5 g, and survival rates were 64.6, 44.3, and 90.0% for stocking densities of 171, 286, and 124/m^2 respectively. Similar production volumes (11,071, 12,286, and 10,650 kg/ha in cases 1, 2, and 4, respectively) show that with this type of growout practice, the carrying capacity is 10-12 MT of prawn biomass/ha.

The increase in stocking density sacrifices survival rate, but not growth. It is feasible to use high stocking densities because the cost of *P. penicillatus* fry (NT$100 or US$2.85 per 1,000 PL8-12 in 1986) is about two third's that of *P. monodon* fry, and such intensive farming is common in Pingtung.

In the same growing season, but with a shorter growing period (95 days vs. 141 days), case 3 had a larger harvest size (12.3 g) than case 2 (9.7 g). Cases 4 and 5 had the same growing period, 120 days. It appeared that the much larger harvest size in case 5 (21.4 g) than in case 4 (9.5 g) was due to the much lower stocking density in case 5 (20 vs. 124/m^2). However, larger harvest sizes in cases 3 and 5 were attained at the expense of considerably lower production.

Large *P. penicillatus* can also be obtained in a polyculture system in which *P. penicillatus* stocking density is low. In a polyculture experiment (conducted in winter) on *P. penicillatus* and *P. monodon*, at a total stocking density of 15 pcs/m^2, 0.26 g *P. penicillatus* grew to 16.98 g in 120 days (Liao 1977). To obtain maximum profit, a choice between large harvest size and higher production will have to be evaluated at stocking.

Although *P. penicillatus* has mostly been monocultured in the past three years, it has been experimentally polycultured with *P. monodon* (Liao 1977). The experiment was conducted from November 1975 to March 1976. An equal number of *P. penicillatus* and *P. monodon* fry were stocked together, each at a density of 7.5 fry/m^2. After 120 days' rearing, the average sizes of *P. monodon* and *P. penicillatus* were 19.73 and 16.98 g, respectively. However, *P. penicillatus* grew faster than *P. monodon* during the cold season from December to February, when the average water temperature was about 22°C. This suggests that *P. penicillatus* culture is more favorable than *P. monodon* culture when water temperature is lower than 22°C.

The temperature range for growout in the aforementioned five cases was 22-33°C. Various conditions in these cases made it impossible to determine the optimal growout temperature range. When comparing two experiments having the same growing period, Liao and Chao (1987) indicated that warm water seemed to affect growth favorably. The experiment which took place in warmer months, from September to November, yielded a larger average size, 21.4 g (Liao and Chao 1987), than the experiment conducted in colder months (November to March), which yielded an average size of 17 g (Liao 1977). The temperature at which the energy expended would offset the increment in growth of *P. penicillatus* remains unknown. Optimal salinity range for growout is also unknown.

Juvenile *P. penicillatus* have a lower protein requirement than the other penaeids. After a 70-day feeding trial, no significant difference was observed in growth (from an initial weight of 0.38 g to a final weight of up to 5 g) among the prawns in the groups fed with 21.8% to 44.4% protein diets (Liao et al. 1987). When comparing the digestive enzyme activities of *P. monodon*, *P. penicillatus*, *M. ensis*, and *P. japonicus*, Chuang et al. (1985) found that *P. penicillatus* had the highest caseinolytic activity and a relatively high α-amylase activity, and suggested that this prawn would be able to efficiently utilize both protein and starch. This should translate into a lower protein cost in feed. Despite the indication of a low protein requirement and effective utilization of protein, *P. monodon* feed with 33-37% protein is commonly used in *P. penicillatus* growout, producing an FCR range of 1.40-2.42.

The average unit area production of *P. penicillatus* is comparable to or even better than that of *P. monodon* (Table 5). A high unit area production was attained in 1987, possibly because there were two crops that year. *P. penicillatus* is harvested by electrical trawl, set net, or by draining.

P. chinensis

Among the advantages of *P. chinensis* as a culture species are the following:

(1) it is relatively easy to propagate;
(2) it is a cold-tolerant species;
(3) it is a white prawn, which have a ready market in the U.S., Europe and Japan; and
(4) in Taiwan, it can be cultured in high salinity areas.

A growout experiment on *P. chinensis* was conducted at the Tainan Branch of TFRI, starting in early May, 1989 (Y.Y. Ting, pers. comm.). Artificially-propagated fry (PL16-22) weighing 0.008 g were stocked in six ponds. After 120 days of culture, the average sizes were 14.3, 11.7 and 9.4 g for stocking densities of 4, 15, and 20/m^2, respectively. Growth seemed to be inversely correlated with stocking density. The ranges of water temperature and salinity during this period were 22-34°C and 30-38 ppt. The average survival rates were approximately 55%. The salinity experiment showed that the use of brackish water resulted in higher survival but slightly slower growth. Growth apparently slowed when water temperature was over 33°C, but prawns still survived at a temperature as low as 3°C. The results suggested that *P. chinensis* could be feasibly cultured in Taiwan throughout the year. *P. chinensis* nutrition studies are underway.

Table 7. Wholesale price (Yen 1,000/kg) of various prawns in Tokyo on May 10, 1989.

	Origin					
	Indonesia	India	China	Hong Kong	Taiwan	Taiwan
	White (4 lb) headless frozen	White (2 kg) headless frozen	White (2 kg) headless frozen cultured	Kuruma (2 kg) headless frozen	Kuruma (2 kg) head on frozen	Kuruma head on live cultured
Size						
8/12	3,245	2,600	----	1,450	1,300	2,500-3,300
13/15	2,860	2,000	----	1,400	1,050	----
16/20	2,090	1,700	----	1,300	900	----
21/25	1,760	1,400	1,500	1,050	----	1,800-2,600
26/30	1,458	1,200	----	750	----	----
31/35	----	----	1,150	----	----	----
31/40	1,238	1,200	----	600	----	----
36/40	----	900	1,025	----	----	----
41/50	935	800	850	----	----	----
51/60	880	----	700	----	----	----
61/70	770	----		----	----	----
71/90	660	----		----	----	----

MARKET

P. penicillatus and *P. chinensis* are categorized as white shrimp. These are preferred by consumers because of their similarity in appearance to the Indian white prawn, *P. indicus*, and the banana prawn or Indonesian white prawn, *P. merguiensis*, which already have a ready market. Although they are all white shrimp (Indonesian white, Indian white, and China white), each of them commands a different price in Japan (Table 7). What price the "Taiwan white" would have among the white shrimp in Japan remains to be seen.

P. penicillatus has a promising domestic market in Taiwan. At a size as small as 5-10 g, it can pass for boiled sand shrimp or *M. ensis* in restaurants for a good price. This is likely to happen because *M. ensis* is quite difficult to culture. However, there are still disadvantages to marketing *P. penicillatus* in the restaurants. First, they do not easily survive out of the water (Table 1) and, therefore, are not suitable for selling in live form. Second, when they die, heavy pigmentation appears and the head is easily disconnected (Liao 1988b).

Since it is comparatively uniform in size (Liao 1988a), and has a smaller head-tail ratio than the other two prawns, *P. penicillatus* may be preferred headless and peeled. Although there are no data on the head-to-tail weight ratio of these three prawns, the ratio of carapace length to total length of the maximum sizes of these three prawns indicates that *P. penicillatus* has the smallest head-to-tail ratio (Table 2). *P. penicillatus*, on the average, had 39.64% [(28.66-17.30)/28.66] less head than *P. chinensis*.

The major market for *P. japonicus* is Japan. Its colorful appearance, delicious taste, and the possibility of being sold live help maintain its high price (US$25-60/kg, Table 8). Color is one of the major factors which determine the live *P. japonicus* price in the Japanese market. Less colorful than wild prawns, cultured *P. japonicus* sell at a lower price, with a difference of Yen 910-3,200 or US$7-26 (Table 8).

P. japonicus is hardy and can withstand handling. It is easily transported alive for a period of about 30 hours, packed with chilled sawdust in an insulated styrofoam box. The price for dead or frozen *P. japonicus* is much lower than that for both live *P. japonicus* and frozen white shrimp (Table 7). The survival rates during live shipping are an important factor in determining the auction price in the Tokyo market. The live *P. japonicus* market is limited, so the price is quite sensitive to the supply. *P. japonicus* is also attractive in the Italian market, since it is similar in appearance to *P. kerathurus*, an indigenous species in the Mediterranean Sea (New 1988). This species is also projected to soon become popular in other parts of the world.

Table 8. Tokyo market prices (Yen 1,000/kg, three month average) of three sizes of captured and cultivated *P. japonicus*, and the difference in their prices. The prawns were imported from Taiwan during January and March of 1989. (Data from Japan Aquaculture News).

Size (g)	Captured	Cultured	Difference
71-100	7.36	6.49	0.91
40-50	7.53	4.33	3.20
34-39	5.52	3.22	2.30

CONCLUSIONS

Although Taiwan reached the peak of success with *P. monodon* culture in 1987, there has been a need to diversify the choice of culture species (Liao and Chao 1987). The *P. monodon* production crash in 1988 merely accelerated the search for alternative species, and it must be stressed that this search was begun in Taiwan many years ago. The process has, in fact, already attained success with at least two species, *P. penicillatus* and *P. japonicus*. These were only under experimental culture a few years ago, but are now commercially cultured on a large scale. The Taiwan prawn culture industry realizes the value of species diversification. Aquaculture is likened to horticulture and agronomy, in which having a variety of crops benefits both the consumer and the producer. The consumer will have more products from which to choose. The producer will not be so dependent on one product, such that if problems specific to that product arise or if market situations change, he loses everything. Taiwan's experience has provided proof that there is vast room for alternatives, possibilities, and a promising future.

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THE CULTURE OF *PENAEUS CHINENSIS* AND *P. JAPONICUS* IN KOREA

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INTRODUCTION

Doosan Industrial Co., Ltd initiated commercial shrimp farming in Korea in 1967, and we are now operating five farms scattered throughout the west coast, and one farm on the southern coast of the Korean peninsula.

The company also operates hatcheries to supply juvenile shrimp to its growout ponds, and to sell to other local shrimp farms.

Tables 1 and 2 show all the shrimp farms and hatcheries affiliated with the Doosan Industrial Company. The sites were selected on the basis of environmental parameters, with special emphasis on sediment constituents for *P. japonicus*. Substrate type does not seem to be as important for *P. chinensis*. Each farm was divided into several ponds according to its sediment constituents. The ponds which have sandy bottoms are being utilized for *P. japonicus*, the others for *P. chinensis*.

We use the extensive culture method, since it remains profitable. We are, however, studying the feasibility of either semi-intensive or intensive systems. With over 20 years of experience, we are considering developing our own system. We have already developed our own shrimp feeds: for *P. chinensis* and for *P. japonicus*. Our plant manufactures the two kinds of feeds which are now partly commercialized in the local market. We are going to sell to the international market beginning next year.

Shrimp farming is conducted in Korea despite unfavorable environmental conditions, particularly with respect to seawater temperature. Korea is in the regime of temperate water, which means that we have extreme cold periods during the winter months, and a short season with warm seawater during the summer months. Fig. 1 shows the monthly seawater temperatures

Table 1. Shrimp farms affiliated with Doosan Industrial Co., Ltd.

Year of Establishment	Location	Area (ha)
1967	Ahnheung	47.80
1981-1982	Namhae	21.40
1982	Dangjin	15.15
1983	Ahnmyun (1)	22.63
1984	Ahnmyun (2)	130.00
1986	Wonbuck	168.00
Total	6	404.98

Table 2. Shrimp hatcheries affiliated with Doosan Industrial Co., Ltd.

Location	Size (m^3)	Production	Capacity (inds)
Ahnheung	2,140 (2,606 tons)	6×10^7	$9 \times 10^{7*}$
Wonbuck	600 (600 tons)	2.7×10^7	$2.7 \times 10^{7*}$
Ahnmyun (2)	1,000 (1,000 tons)	3×10^7	$3 \times 10^{7*}$
Total	3,740 (4,206 tons)	11.7×10^7	14.7×10^7

**P. chinensis*

averaged from 1977 to 1988 at one of our farms on the west coast.

It can be seen in Fig. 1 that the hatchery phase for *P. japonicus* lasts from March to April, at which time the seawater should be heated. Hatchery activities for *P. chinensis* are restricted to only one month in May. At that time we can procure enough adults to meet our own demands and also the demands of local farmers. We have only one growout cycle per year. Growout lasts five months, from May to October, for *P. japonicus* and

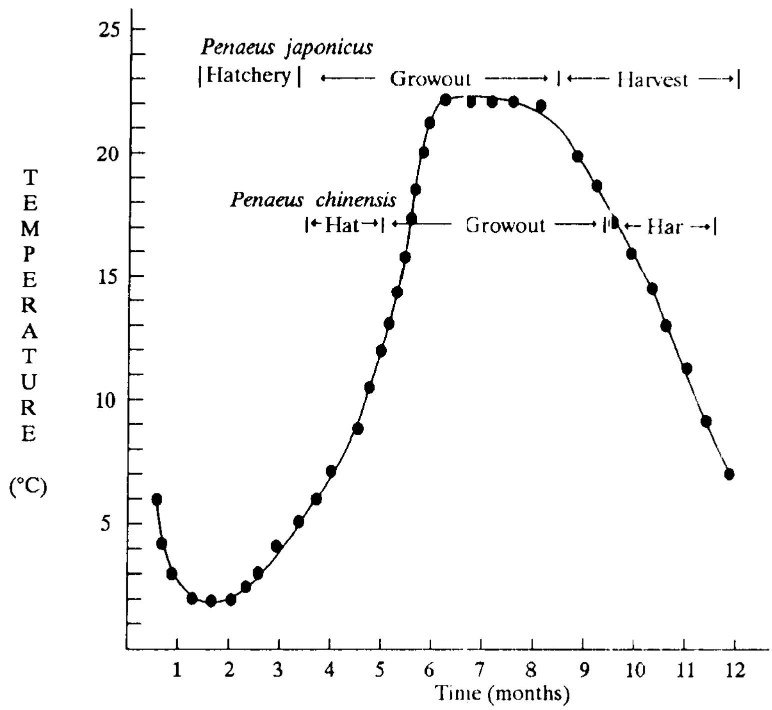

Fig. 1. Monthly seawater temperatures averaged from 1977 to 1988 at a coastal region of one of our farms on the west sea coast.

four months, from June to October, for *P. chinensis*. We regard this as a great disadvantage compared to farming in tropical countries.

P. japonicus harvest lasts for three months, from October to December, while harvest of *P. chinensis* lasts for two months, from October to November. Harvest time depends on the market demands and market prices, hence, the long harvesting period; it is not due to any technical difficulties of harvesting. *P. japonicus* are sold alive in either domestic markets or Japanese markets. *P. chinensis* are frozen immediately and sold mostly in domestic markets.

ENVIRONMENTAL PARAMETERS AND GROWTH RATES

We believe that the success of commercial shrimp farming depends on their location, environmental factors, nutrition and management.

Seawater Temperatures

Since we use an extensive culturing method, we cannot control water temperature, and are obliged to rely on natural variations of air and seawater temperatures. Our ponds are tidal lagoons and we exchange the water in the ponds with seawater during the tidal cycle. The area in which our major farms are located have one of the largest tidal amplitudes in the world; the largest tidal range is about 8 m. For this reason, we are sometimes unable to exchange the water in the ponds for long periods of time. During these times, the water temperatures in the ponds are subject to change according to the variation in air temperature. Because of the vastness of our major ponds, however, air temperature usually has little effect on pond water temperatures. This is why we use seawater temperatures rather than pond water temperatures in Figs. 1 and 2.

We understand that seawater temperature is a very important factor, particularly in commercial farms. However, as stated earlier, we cannot manipulate water temperature in our ponds because of their large size, therefore, we do not put much emphasis on water temperature. Our experience suggests, rather, that variations in annual production may be caused by other parameters, such as nutrition, inaccurate estimates of density in the ponds, effects of typhoons, etc.

Table 3 and Fig. 2 are comparisons of monthly growth rates for *P. chinensis* and *P. japonicus*. Twenty years of production records show annual fluctuations. The monthly weight of the two species described in this report are from pooled data. As can be

Table 3. Comparison of monthly growth rates of *P. chinensis* and *P. japonicus* (unit = g).

Month	*P. japonicus*	*P. chinensis*
Apr	0.02	---
May	0.5	0.01
Jun	2.0	1.5
Jul	7.0	7.0
Aug	12.0	12.0
Sep	17.0	19.0
Oct	20.0	25.0

seen in Fig. 2, the growth rate of *P. chinensis* is faster than that of *P. japonicus*. 0.01 g postlarvae which were released in the middle of May reached 25 g by the end of October, which is the preferred commercial size on the domestic market. The temperature in the ponds at the time of release was actually higher than the seawater temperatures. This is because we retain the pond water for a long time so that the rapidly increasing spring air temperatures can raise the pond temperature.

The growth rate of *P. chinensis* is much higher than the growth rate of *P. japonicus*, particularly from August to October. It is interesting to note that even though water temperatures decreased from September to October, *P. chinensis* maintained its growth, gaining 6 g during that period.

The weight of *P. japonicus* at the time of release was 0.01 g. This species usually reaches 20.0 g by the end of October, having a growth rate much lower than that of *P. chinensis*. However, this species is favored above *P. chinensis* because of its high market prices in our part of the world. The growth rates of *P. japonicus* correlated well with increases in water temperature, and growth is not expected after the end of October (when seawater temperatures drop below 18°C). It should be noted that the weights of *P. japonicus* increased very steadily, 5 g/month,

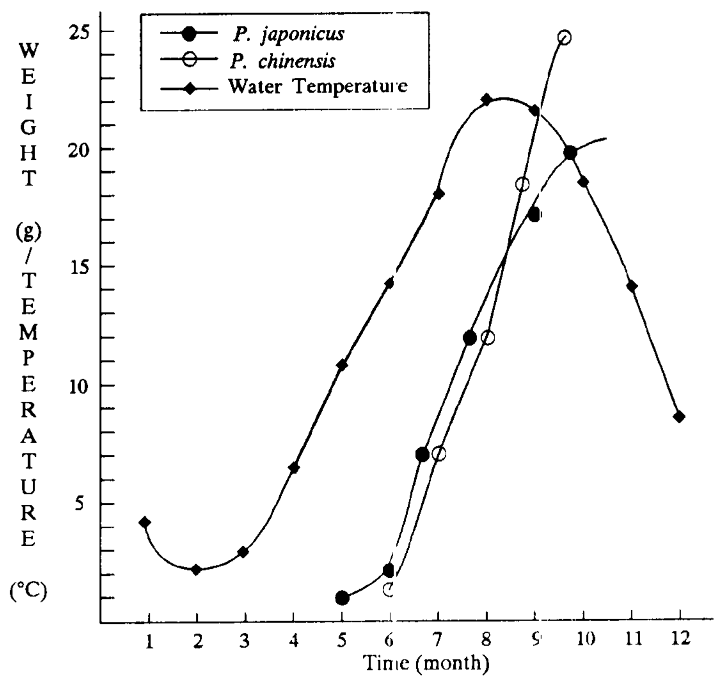

Fig. 2. Comparison of growth rates of *P. chinensis* and *P. japonicus*.

from June to September, while the growth rate of *P. chinensis* fluctuated; 5.5 g from June to July, 5 g from July to August, and 7 g from August to September.

P. chinensis has a very strong schooling behavior, and shrimp migrate throughout the pond day and night. *P. japonicus*, on the other hand, burrow into the sandy bottom during the day and are active only at night. Despite this, the active *P. chinensis* has a better growth rate than *P. japonicus*.

Dissolved Oxygen

We do not experience any serious deficiency in dissolved oxygen because we use an extensive system. However, we do operate paddle wheels and air injectors in each pond, particularly from night to early morning. Our survey results show that dissolved oxygen is supersaturated usually from 1400 to 0200 hrs., and gradually decreases from 0200 to 1000 hrs., showing less than 100% saturation. Supersaturation is caused by the photosynthetic activity of diatoms in the ponds.

Salinity

The salinity in our farms varies, but it may average anywhere between 26.0 and 31.0 ppt. We did, however, experience one period of extremely low salinity during the monsoon season when salinity was 20 ppt. However, production was not affected. Furthermore, several ponds in our farms have underground seepage which allows freshwater to flow into the ponds, but this has not caused any serious problems. These examples suggest that salinity may not be a critical environmental parameter, however, we do take extreme care to prevent the flow of agricultural waters into the ponds.

Hydrogen Ion Concentration

The hydrogen ion concentration (pH) depends on the amount of dissolved oxygen. With the increases in dissolved oxygen caused by active photosynthesis during the day, the hydrogen ion concentration increases to 8.6, but during the early morning, it decreases to 7.8. We still do not know the optimum hydrogen ion concentration which makes various enzymes active and results in better growth rates.

Nutrients

We never experience any lack of nutrients in our pond waters, but we have not checked for possible shortages of trace metals.

Competitors and Predators

One of our main problems is competitors such as gobid fishes, which enter and reproduce in the ponds. It is assumed that they consume a great deal of feed. There are many other fish which also enter the ponds as eggs, but their populations appear to be small. The main predator of shrimp in the ponds is the sea-gull, which is, unfortunately, a legally protected bird. We have used every possible method to scare them away, such as automatic cannons, but have not been successful.

Problem Areas

(1) Development of methods for overwintering gravid female shrimp in captivity for use as spawners

(2) Development of effective and economic cleaning techniques for pond bottoms

(3) Development of population density estimation techniques

(4) Identification of ecological characteristics of the shrimp such as schooling behavior and migration in the ponds

(5) Utilization of header group (we assume 8% in our farms)

(6) Identification of the most suitable hydrogen ion concentration in terms of physiological activity of the shrimp

(7) Protection from predatory birds

(8) Development of protective techniques for competitors (one of our scientific advisors is working on this and it appears that this problem will be solved)

(9) Development of effective and economic protective techniques for net fouling

(10) Studies on genetic engineering

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SHRIMP CULTURE INDUSTRY IN THE PEOPLE'S REPUBLIC OF CHINA

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INTRODUCTION

Marine shrimp resources abound in China. There are more than 100 species of common penaeid shrimp. Of these, over 40 are important commercial species (Liu 1955, 1959, Dong 1959, Liu and Zhong 1988, Sheng and Liu 1975). Abundant natural resources have provided shrimp stocks for aquaculture. However, it is very difficult to meet the increasing demand for shrimp if their culture depends only on natural resources, which are influenced by ambient environmental factors (i.e., weather, predators, food organisms, etc.). For example, historical statistics show that the output of the most important commercial shrimp, *Penaeus chinensis* (Osbeck) (or *P. orientalis* Kishinouye), in the Bohai Sea and the Yellow Sea has fluctuated dramatically.

The local landing quantity was 32,896 MT in 1980, but it sharply decreased to 7,374 MT in 1982. To reduce dependence on natural resources and to meet the increasing consumer demand, China's government has supported and encouraged the development of shrimp culture throughout the coastal provinces. Since 1978, the combination of finances, techniques, manpower and natural resources has helped China become one of the world's leaders in shrimp culture. The total output of cultured shrimp increased sharply from 260 MT in 1980 to 153,200 MT in 1987 (Table 1).

A REVIEW OF SHRIMP CULTURE IN CHINA

Although marine shrimp have been raised in China for at least 300 years, the

Table 1. The area and output of shrimp farming in the PRC.

Year	1980	1981	1982	1983	1984	1985	1986	1987
Area (10^3 ha)	9.34	13.7	16.5	19.5	33.4	59.6	85.1	131.3
Output (10^3 MT)	2.6	3.7	7.1	9.0	19.3	40.7	82.8	153.2
Unit output (MT/ha)	0.278	0.270	0.430	0.452	0.578	0.683	0.873	1.167

culturing technique was extensive and dependant upon natural seed, food organisms and tide force. The unit output was very low (<100 kg/ha).

In order to improve outputs, as early as the 1950's, the Chinese government encouraged and supported fisheries research and institutions of higher education to investigate the natural resources of shrimp and to study their ecology and taxonomy (Liu 1955, Dong 1959, Liu and Zhong 1988), hatchery techniques (Zhao 1965, Shandong Marine Fisheries Institute [SMFI] 1977, Yellow Sea Fisheries Research Institute [YSFRI] 1979), and culture methods (Qingdao Marine Fisheries Institute [QMFI] 1972, YSFRI 1979). The success of larval rearing techniques occurred in 1959, but the social chaos of the "Cultural Revolution" hampered the further development of fisheries sciences, as it did other natural sciences in China.

It was not until 1978, when the Chinese government began the practice of open policies, that the Bureau of Aquatic Products of the Ministry of Agriculture held a national meeting to confirm the fisheries policy of shrimp farming. Since then, the Chinese shrimp farming industry has entered a new age. Only 337 million hatchery-produced larvae were produced in 1980, but by 1987 the amount of postlarvae reached 72,443 million (Table 2), which not only meets the demand of shrimp farms, but can be used for stock enhancement as well.

PRODUCTION OF POSTLARVAE

Before 1978, there were no commercial shrimp hatchery facilities in mainland China. Shrimp production depended upon a supply of wild larvae. Because the supply was affected by unreliable environmental factors, the production of shrimp was unstable. With the successful postlarval rearing of the Chinese shrimp, the shrimp farming industry underwent a dramatic change.

Sources of Broodstock

There are three sources of broodstock defined by the reproductive characteristics of the shrimp and the location of shrimp hatcheries. The first type of broodstock is mature spawners which have reached their spawning fields. After being transported to hatcheries, the broodstock will be spawned within several days. This is the main source of broodstock in the northern part of China. The advantage of using this type of broodstock is that one does not incur the expense of overwintering shrimp in green-

Table 2. The production of postlarvae from 1980-1987.

Year	1980	1981	1982	1983	1984	1985	1986	1987
Total PL (x 10^6)	337	1,646	2,789	4,242	7,770	18,947	34,465	72,443
Total PL (10^3 per m^3)	5.8	26.5	37.1	52.5	79.0	138.0	155.7	208.1
Hatchery capacity (x 10^3 per m^3)	58	62	75	81	98	137	221	348

houses. However, supplies of mature spawners are subject to overfishing.

For this reason, a second source of broodstock is either adults which are on their overwintering migration line or cultured shrimp. For this second type of broodstock, healthy adult shrimp of both sexes are selected and kept in greenhouses until spring. Under artificially-controlled conditions, they are allowed to mature between February and April in Shandong and Liaoning provinces. In Zhejiang, Fujian, Guangdong, and Guangxi provinces, the natural water temperature is high enough to sustain overwintering broodstock. There, broodstock can be kept in outdoor ponds. This second type of broodstock is widely used, especially in the latter areas, because the cost is very low.

The third source of broodstock is shrimp which are caught during their reproductive migration. This type of broodstock is immature, so they must be conditioned for a period of time. Fortunately, *P. chinensis* is easier to mature than *P. monodon*, and eyestalk ablation is not needed to induce maturation.

Spawning

P. chinensis is a multispawner. Under artificial rearing conditions, a shrimp may spawn four or five and occasionally even seven times. One female shrimp 15 cm long is reported to have spawned more than 1.7 million eggs in seven spawns. The spawning interval is about 15 days; the shortest interval is five days, the longest 20 days.

Broodstock that are taken from natural spawning fields will enter the peak spawning period within two to five days. For technical reasons, not all female broodstock caught from natural spawning areas spawn in tanks. The percent of broodstock which are induced to spawn is about 30-50%, and mean fecundity is approximately 400,000-500,000 eggs. Spawning always takes place at night, so the broodstock are selected in the afternoon and then moved to the spawning tank.

Hatching

To obtain a higher hatching rate and healthy nauplii, it is very important to maintain optimum conditions. Water temperature has a significant influence on hatching.

Salinity is another important factor influencing hatching. Other factors, such as Hg, Cu, Zn and other heavy metals, insecticides, etc., greatly influence hatching, even though their concentration in seawater may be very low. For this reason, hatchery site selection is very important.

Types of Hatcheries

In China, most hatcheries belong to the government. Almost all of them are capable of producing hundreds of millions of postlarvae for shrimp farmers. Recently, some private hatcheries, like backyard hatcheries in Thailand, have been founded in coastal provinces. Due to the lack of necessary knowledge and hatchery techniques, the private owners often invite technicians or experts from fisheries research institutions to be their technical consultants.

In both the northern and the southern parts of China, larger rearing tanks (10-50 m^3) and higher densities (100,000-200,000 larvae/m^3) are generally used. For climatic reasons, all hatchery facilities are indoors. The hatching season extends from April to early June in Liaoning, Shandong, and Jiangsu provinces. By contrast, in the Guangdong and Hainan provinces, most of the facilities are outdoors, and they have a longer hatching season (February to July). In the early part of the season, *P. chinensis* larvae are reared. In the later part of the season, *P. merguiensis* or *Metapenaeus ensis* larvae are cultured.

GROWOUT MANAGEMENT

Shrimp culture is generally categorized by three techniques: (1) extensive, (2) semi-intensive, and (3) intensive. Extensive farming is a traditional method. Ponds are generally 10-100 ha in size, although a few of them were hundreds of ha and resembled lakes with earthen dikes and clay bottoms. Water exchange depends on natural tidal fluctuation. The output of this method is very low, generally 200-300 kg/ha. Although intensive culture produces output as high as 7-10 MT/ha, the high cost of pumps, fuel, electricity, etc. has limited the use of this method. Consequently, most of the shrimp farms in China use semi-intensive methods. This system uses ponds with an area of moderate size: 2-10 ha in area, and 80-150 cm in depth. To improve water quality, water pumps are widely used to lift seawater during weak tidal periods. Air blowers and paddle wheels have been introduced only very recently.

Table 1 shows that the total annual output and the output per unit area are gradually increasing. China is generally believed to lead the world in total production of cultured shrimp, but the output per unit area is low when compared to the world shrimp farming standard. The reason for this is that the over-development of shrimp farms has brought about a series of problems:

(1) financial limitations force farmers to decrease the water depth and exchange rate;

(2) the shrimp farms are over-concentrated in some districts, (Shandong, Hebei, etc.) leading to problems obtaining sufficient inlet and outlet, and increasing the chance for epidemics; and

(3) there are no good formulated feeds.

However, these problems should be overcome in the near future.

Pond Preparation

The procedures used in pond preparation in mainland China are similar to those used in Taiwan. There are five steps: cleaning, plowing, sun drying, sterilizing and fertilizing. Some living food organisms, such as *Corophium* sp., *Uncoiola* sp., *Gammarus* sp., and polychaetes are introduced into the shrimp pond prior to stocking. One experiment illustrated that if 150-300 kg of *Corophium* sp. is introduced to a 1 ha pond, 75,000 larvae (PL 7-8) will grow to 8 cm in length without further addition of food. This successful method is being propagated in China.

Stocking

Stocking is a procedure in which postlarvae are moved from hatchery stations to growout ponds. Although the operation appears very simple, some issues must be emphasized. First, *P. chinensis* is a euryhaline species which can grow well at salinities ranging from 3-35 ppt, but sudden changes in salinity can cause high mortality. Experiments have shown that the difference in salinity should be no more than 10 ppt when postlarvae are transferred to a growout pond of lower salinity. If postlarvae are to be transferred to ponds with higher salinity, the difference in salinity should be 5 ppt or less. Another consideration is water temperature. If postlarvae are suddenly moved from 18 to 15°C seawater, they will be paralyzed. More dramatic change, from 18 to 10°C, will cause postlarval mortality.

Diet and Feeding

The cost of feed in shrimp production accounts for more than 50% of the total production cost. In order to decrease this cost, much effort has been put into the study of nutrition, feeding methods, processing methods, and the search for new sources of protein. Preliminary studies have illustrated that (1) the protein content of feed should be above 40%; (2) the necessary amino acids for growth and development of *P. chinensis* are tryptophan, histidine, methionine, threonine, isoleucine, phenylalanine, valine, arginine, leucine and lysine; (3) some polysaccharides, such as dextrin and the disaccharide sucrose can be used by *P. chinensis*; and (4) identified other elements necessary for the shrimp growth.

In the early years of shrimp farming, trash fish or cheap by-products (peanut and soybean cakes) were fed directly to shrimp. Formulated feeds are now widely used instead. The shrimp have a habit of gathering along the walls day and night, so their feed is distributed by hand along the pond banks or at some fixed places with concrete floors, four to six times a day.

HARVESTING AND PROCESSING

Harvesting

The harvesting season depends on growth, climate and marketing. In the northern part of China, as the water temperature declines to 10°C, the shrimp grow very slowly. Occasionally, cold currents will suddenly invade these areas in late fall. Water temperature may drop as low as 4°C, and mortality will occur. For this reason, the harvesting season in Liaoning province begins in late September. In Shandong province, it is in early October. There is more time available for growout in Guangdong and Hainan provinces. Harvesting there mainly depends upon the market.

Because *P. chinensis* do not burrow in the substrate, even during the daytime, draining is the typical harvesting method. Electric shockers are not used for harvesting shrimp in China. After harvesting, most shrimp are processed into "headless", "shell on and whole", and "head on" grades. In only a few farms near Hong Kong and Macao do they transport live shrimp to market.

SUMMARY AND FUTURE PROSPECTS

In the early 1980's, the Chinese shrimp industry began a new age when it began to rid itself of its dependence on wild seed. By 1987, the annual output reached 153,200 MT in mainland China. China has become the largest producer of cultured shrimp, and we expect that yields will improve in the near future.

In order to sustain long-term, stable development, the shrimp industry should focus its research efforts on the following:

(1) The genetics of shrimp. Once a wild animal or plant becomes a cultured organism, it is important to select for favorable traits. The shrimp that are cultured in growout ponds come from wild populations, and are thus adapted to the natural environment. An urgent task for the shrimp industry is to breed new varieties with the traits of faster growth, adaptation to artificial environmental conditions, and resistance to disease.

(2) The shrimp feed industry should focus on new protein sources. Although total aquatic products exceeded 10 million MT in 1988, the Chinese human population reached 1.1 billion on April 16, 1989. It is impossible to provide enough fish meal or trash fish to meet the demands for shrimp feed. We must exploit and utilize new resources. And finally,

(3) Studies of shrimp diseases should not be ignored. In the past two years, Taiwan's shrimp industry has encountered heavy losses due to disease.

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ON THE CULTURE OF *PENAEUS PENICILLATUS* AND *P. CHINENSIS* IN SOUTHERN CHINA

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INTRODUCTION

Many species of penaeid shrimp can be cultured in the southern provinces of China. Because of the subtropical climate in Southern China, shrimp may be grown larger than in Northern China. In Fujian, Guangdong and Guangxi, *Penaeus penicillatus* and *P. chinensis* are commonly cultured. A moderate amount of *P. merguiensis* is grown, but very little *P. monodon* and *P. japonicus* are cultured.

South China imports *P. chinensis* from North China to culture in spring. The local species, *P. penicillatus*, is cultured in summer, after *P. chinensis* is harvested. Thus the different species are grown in accordance with their different ecological and biological characteristics. Improved culture techniques and increased production capacity facilitated the initiation of 2-crop culture without any supplemental labor, facilities or construction. Consequently, we achieved a higher output per unit area and earned more profit.

In contrast to other penaeid species, female *P. penicillatus* are difficult to mature when maintained under the conditions of pond culture. If shrimp do mature, they are few in number and develop too late (after mid-June) to meet production requirements. To ease parent shrimp shortages and overfishing of wild *P. penicillatus* broodstock, we studied artificially controlled overwintering and ovarian maturation from 1984 to 1988. These studies and 2-crop culturing techniques are the subjects of this paper.

ARTIFICIALLY CONTROLLED OVERWINTERING AND OVARIAN MATURATION IN *P. PENICILLATUS*

Pond Management and Diet During Overwintering

P. penicillatus can be overwintered in indoor ponds and outdoor cement and mud ponds without any heating of the water. Prior to stocking in overwintering ponds, large healthy shrimp were selected and sterilized. The stocking density was 8-10 inds/m^2 at a female:male ratio of 3:1. The animals were fed fresh *Ostrea, Sinonvacula, Ruditapes* and

Table 1. Survival rate of overwintering broodstock (1987-1988).

Types of broodstock	Stocking date	Number (inds)	Date Individuals were checked	Number survived	Survival (%)
Overwintering	1/5/87	533	3/20	282	52.91
	1/16/88	2,263	4/12	1,627	71.89
Ablated	4/17/87	108	5/12	71	65.74
	4/12-26/88	1,627	4/29	1,366	83.96

trash fish. In the winter months, shrimp were fed 5-8% of their body weight (B.W.). This amount was gradually increased to 15-20% B.W. by spring. Feed supply was generally adjusted according to intake.

In the case of overwintering in concrete ponds, wastes on the bottom were siphoned daily, in the morning. Water was exchanged regularly at a third to a half pond volume. Pond water was 1.5 m deep. In mud ponds, water inlet and outlet depends on tidal fluctuations, the amount exchanged varying from a half during spring tides to a third during neap tide. Water temperature ranged from 11.0-16.6°C; salinity was approximately 26 ppt; and pH 8.0-8.2.

Survival Rate of Overwintering Broodstock

Of 533 shrimp stocked in concrete ponds on January 5, 1987, only 282 survived until March 20, a survival rate of 52.91%. From January 16 to January 25, 1988, 2,263 broodstock were purchased from a nearby market and stocked in mud ponds. Of these, 1,627 survived until April 12, a survival rate of 71.89% (see Table 1).

Duration of Ovarian Maturation in Overwintering Broodstock

Since *P. penicillatus* has a transparent shell, we could monitor ovarian development easily with the naked eye. Before unilateral eyestalk ablation, nearly all the overwintering broodstock were at stage I, with colorless and transparent gonads. It was very difficult to locate the ovaries, due to their small size at this stage. After ablation, the shrimp were intensively reared in concrete ponds without aeration. Ten days later, a few individuals matured quickly and produced eggs. In time, the number of spawners gradually increased, reaching a peak 15 to 17 days after ablation. We also observed that the maturation period could be shortened with slight aeration and heating.

Females matured and spawned repeatedly when under intensive culture. The interval for ovarian rematuration was four to seven days shorter than that of the first maturation. In 1987, the maturation rate of eyestalk-ablated shrimp overwintered in cement ponds was 59.15%; in 1988, the maturation rate of shrimp overwintered in mud ponds was 53.59%. The ablated female broodstock

Table 2. Maturity rate and survival of eyestalk-ablated broodstock (1987-1989).

Spawnings	Date	Individuals tested	Spawning individuals	Maturity (%)
1st	4/22-5/29/87	71	42	59.15
	4/26-5/12/88	1,336	716	53.59
2nd	5/17-6/2/87	71	12	16.9
	1988[1]	---	---	---
3rd	5/24-6/2/87	71	9	12.68
	1988	---	---	---
4th	5/28-6/2/87	71	3	4.22
	1988	---	---	----

[1]In 1988, only the first spawning percentage was recorded.

Table 3. Fecundities, fertilization and hatching rates of overwintering broodstock (1987).

Spawning	Fecundities (10,000/ind)			Fertilization) (%)	Hatching (%)		
	Max	Min	Mean		Max	Min	Mean
1st	16.22	4.71	10.21	81.00	98.00	-	56.20
2nd	8.01	0.94	4.47	16.70	88.30	-	12.50
3rd	16.99	1.55	9.72	0	0	0	0
4th	11.59	10.92	11.25	0	0	0	0

were capable of spawning up to four times (see Table 2).

Fecundities, fertilization and hatching rates of overwintering broodstock

The average body length (B.L.) of overwintering broodstock was 11.0-13.8 cm, and body weight was 18.0-40.4 g. Shrimp with mature ovaries were transferred to spawning tanks and usually laid their eggs that night or the next. Their fecundities, fertilization and hatching rates are shown in Table 3.

Table 3 shows that fertilization rate decreased from 81% in the first batch to zero in the third and fourth spawnings. Reasons for this decline in copulation include frequent ecdysis and death of males after overwintering, resulting in few mating opportunities despite an abundance of mature females. Table 4 presents a comparison between the initial spawning of overwintered and wild spawners.

With the exception of the higher fecundity of the larger wild *P. penicillatus*, data in Table 4 indicate that overwintered and wild broodstock differ very slightly. This experiment provides a scientific basis for the future overwintering of broodstock on a large scale.

Table 4. A comparison of overwintered and wild broodstock (1987).

	Overwintered	Wild
B.L (cm)	11.00-13.80	13.60-16.00
B.W. (gm)	18.00-40.40	35.00-49.70
Fecundities (10,000/ind)	10.21	12.00
Egg diameter (μm)	276.20	278.60
Diameter of fertilization membrane (μm)	290.60	296.60
Fertilization (%)	81.00	89.00
Hatching (%)	56.20	61.00
Larval survival (%)	19.20	19.50

ARTIFICIAL HATCHING OF *P. PENICILLATUS*

Spawning of Broodstock

In coastal regions of Fujian and Guangdong provinces, wild broodstock are used to produce the first batch of eggs the last three weeks in April. The peak of spawning is between mid-April and early June. Spawning usually occurs between 2200 and 0300 hrs. Most females produce 100,000-500,000 eggs, although some individuals may spawn as many as 1,000,000 eggs. After eyestalk ablation, pond-cultured overwintered shrimp can be induced to mature and spawn early. Each is capable of producing 50,000 to 200,000 eggs. After 4-7 days a female may spawn again, and continue to spawn (max. = 5 spawns/female) at 4-7 day intervals.

Hatching Method

In South China, most hatcheries are concrete ponds with roofs but no walls. The roof is commonly made of white plastic plates or other materials. There are a few indoor concrete hatcheries. The hatching ponds are usually rectangular with a volume of 10 to 100 metric tons (MT).

Mature shrimp are stocked in ponds of different volumes according to the stocking density used. After spawning, animals are removed and the eggs washed and transferred to another hatching pond. Alternatively, some eggs may not be washed but kept in the same pond after addition of water. At the Mysis I stage, a portion of the pond water is exchanged. Ponds are aerated throughout the hatching period.

Larval Rearing

Larval feeds

Metamorphosis is closely related to diet. The size, digestibility and concentration of feed are very important. Like other penaeid shrimp, *P. penicillatus* passes through six nauplius substages, three zoea substages and three mysis substages before becoming postlarvae. Nutrients must be given in accordance with the requirements of the different stages. Nauplii absorb nutrition from their own yolk. Zoea feed mainly on unicellular algae, as well as some rotifers (e.g. *Brachionus* sp.), and young molluscs. Beginning at the Zoea III stage, individuals are fed *Artemia* nauplii. Mysis feed on zooplankton, combined with unicellular algae, while postlarvae eat a mixture of *Artemia* nauplii and crushed shellfish meat.

The organisms currently used for larval foods include algae, *Nitzschia closterium, Phaeodactylum tricornutum, Chaetoceros* spp., *Platymonas* spp., *Dicrateria* spp., *Skeletonema costatum*; rotifers, *Brachionus* spp.; brine shrimp, *Artemia* sp.; and bivalves, mollusc larvae, etc.

Two methods are generally used in hatcheries for live food culture. One is to culture algae independently and then feed larvae the pure algae. The other is to add algae to larval-rearing ponds, which, through regular application of manure, reproduce rapidly and feed the larvae. The first method is often utilized for culturing live animal feed.

When quantities of live feeds are insufficient, soybean milk, egg yolk, marine yeast powder, and formulated diets are frequently used. However, it is commonly held that live feeds yield the best results. Because excess formulated diet can deteriorate the water quality, we divide the daily ration into six equal parts given every four hours.

Table 5 contains the results of our experiments in which *Platymonas* sp., *Phaeodactylum* sp. and *Chaetoceros* sp. were given alone or in combination as larval food for Zoea I to Mysis I.

Table 5. Survival rates of Zoea I to Mysis I given different feeds.

Feeds	Feed density (10,000/ml)	Survival (%)
Platymonas sp.	3-7	46
Phaeodactylum sp.	5-8	62
Chaetoceros sp.	10-15	65
Alga mixtures	5-10	70

We also attempted to rear the larvae on a mixture of animal and plant food organisms (see Table 6). Among the diatoms given, *Phaeodactylum tricornutum* and *Chaetoceros* sp. resulted in better survival than did *Platymonas* sp. The highest survival (97%) was achieved with the mixed feed (different unicellular algae and zooplankton from Mysis III to Postlarva I, Table 6).

Correlation between physical-chemical factors and larval development

SALINITY

P. penicillatus adults are capable of withstanding a wide range of salinities, but the early stages have a smaller range of salinity tolerance (Fig. 1).

At a salinity of 22 ppt, the hatching and survival rates of nauplii were approximately 70%, and 30% for zoeal and mysis stages (Fig. 1). This suggests that zoea and mysis have a lower tolerance for salinity variations. The optimum salinity during early development is 24-32 ppt. The zoea is the most sensitive to fluctuations in salinity (Table 7).

Table 7 indicates that Zoea I (Z1) do not molt at 17-20 ppt. As salinity increases, so do the molting and survival rates. Hence, the acceptable range of salinity for larval *P.*

Table 6. Survival rates of *P. penicillatus* larvae with mixed diets and animal food organisms.

Larval Stage	Feed ingredients (1,000/ml)		Survival (%)
Z3-M1	*Platymonas* sp.	20	85
	Phaeodactylum tricornutum	50	
	Chaetoceros spp.	80	
	Brachionus sp.	0.002	
	Artemia sp.	0.001	
M2-M3	*Platymonas* sp.	10	90
	Phaeodactylum tricornutum	30	
	Chaetoceros spp.	50	
	Brachionus sp.	0.001	
	Artemia sp.	0.002	
M3-P1	*Platymonas* sp.	10	97
	Phaeodactylum sp.	20	
	Chaetoceros spp.	30	
	Artemia sp.	0.003	

penicillatus is 22-34 ppt, and the optimum range is 24-32 ppt.

pH

Generally speaking, changes in pH are due to physical and chemical reactions and the activities of aquatic organisms. pH is often used as an indicator of water quality. Effects of pH variations on larval development are shown in Figure 2. The appropriate pH range for zoea and mysis is 7.6-8.8, the optimum, 8.14-8.70.

Table 7. Survival rates of zoea at different salinities.

Salinity (ppt)	No. of larvae Z1	Z2	Survival (%)
17	16	0	45
20	16	0	45
22	6	20	65
24	2	30	80
27	2	36	95

[NH_4-N] AND DISSOLVED OXYGEN (DO)

Decayed feed remnants, metabolic products of organisms, and excess manure contribute to the concentration of NH_4-N in hatchery ponds. In our experiment, when [NH_4-N] reached 4,000 mg-N/m^3, there was no obvious difference between the hatching rate of the experimental and control groups. When [NH_4-N] was 8,500 mg-N/m^3, hatching no longer occurred (Fig. 3).

Nauplii are also very sensitive to inorganic nitrogen. When [NH_4-N] reached 4,050 mg-N/m^3, 5% of the nauplii sank to the bottom. At 6,000 mg-N/m^3, larval abnormality occurred, and when the concentration was further elevated to 7,000 mg-N/m^3, the larvae failed to metamorphose and died.

In contrast with nauplii, zoea have a higher tolerance for inorganic nitrogen. Although the [NH_4-N] reached 9,000 mg-N/m^3, 12% of the larvae survived. However, 200

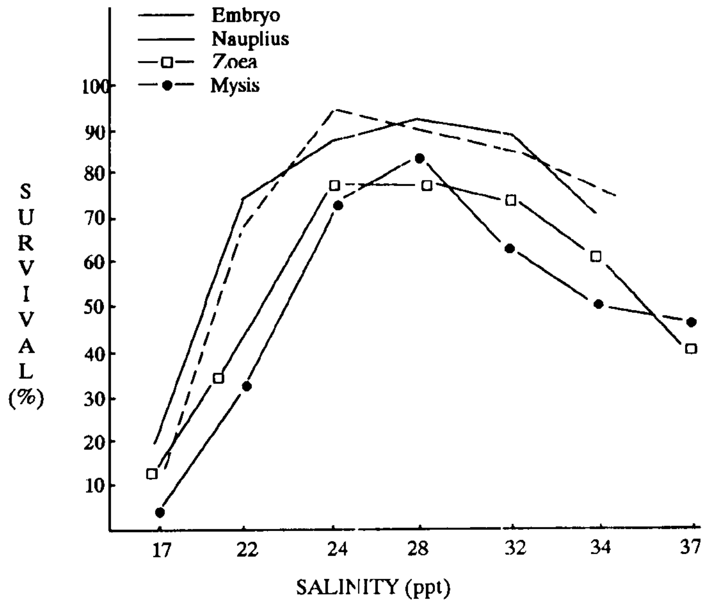

Fig. 1. Correlation between salinity and larval survival.

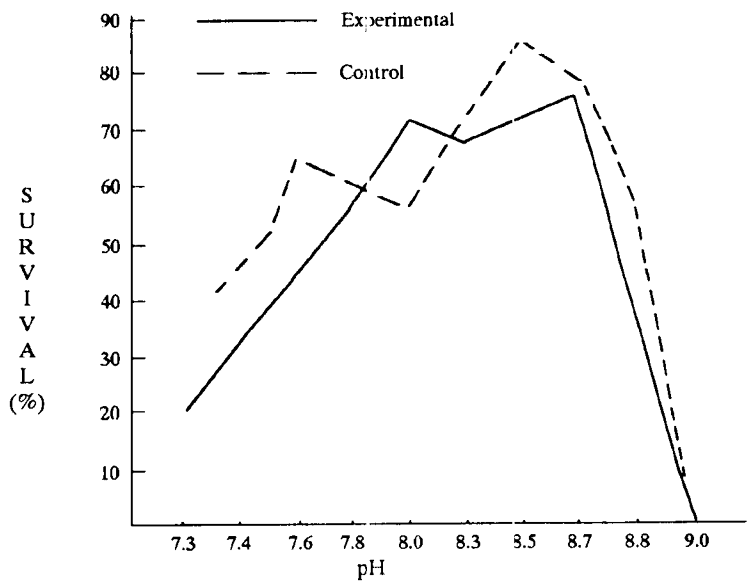

Fig. 2. Correlation between pH and larval survival.

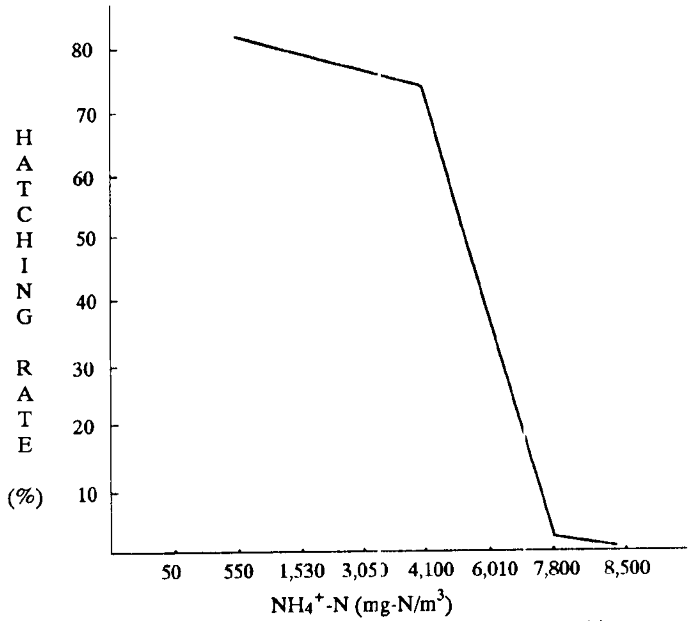

Figure 3. Correlation between inorganic nitrogen content and hatching.

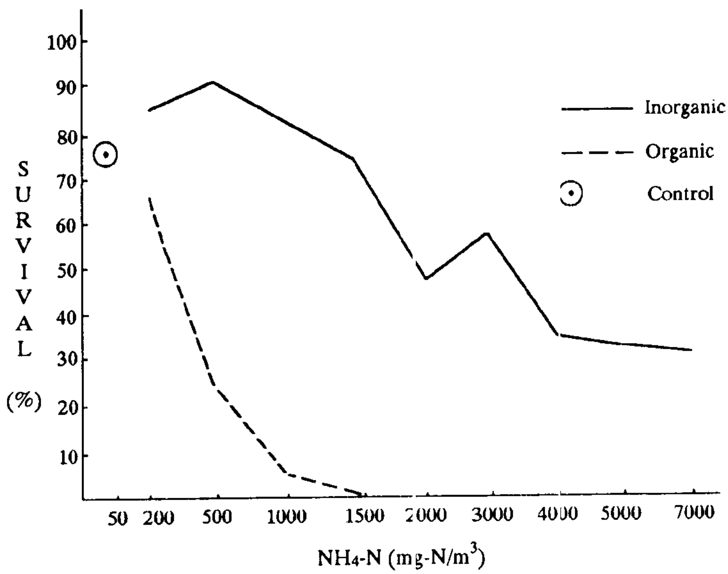

Fig. 4. Correlation between NH_4^+ content and larval survival

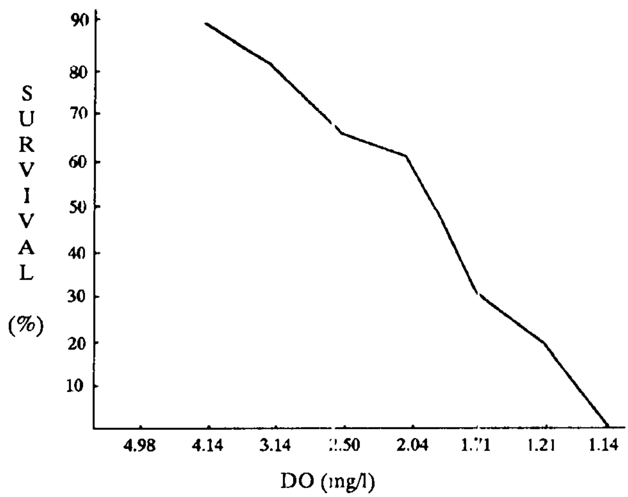

Fig. 5. Correlation between DO and survival of zoea.

mg-N/m^3 of organic nitrogen can have poisonous effects on zoea. When the organic nitrogen concentration was increased to 300 mg-N/m^3, many larvae died. Above 1500 mg-N/m^3, the larvae died without exception (Fig. 4). The result was the same for mysis larvae.

DO content has a direct effect on development and growth of *P. penicillatus* larvae (Fig. 5). As the larvae grow, oxygen intake gradually increases. Hence, aeration must be increased throughout the hatching and larval rearing period.

In Figure 5 we can see that when DO concentration was 4 mg/l, survival was high. When DO was 3 mg/l, there was some larval abnormality and a low survival rate. At 1 mg/l, all the larvae suffocated. For this reason, continuous aeration is usually maintained. If no heavy organic contaminants are present, DO content in pond water is generally within the range of larval adaptation.

Table 8 reviews the physical and chemical elements related to larval development and molting.

Table 8. The appropriate values of critical physiochemical factors related to larval development.

Factors	Range	Values
Temperature (°C)	Appropriate	19-32
	Optimum	24-28
Salinity (ppt)	Appropriate	22-34
	Optimum	24-32
pH	Appropriate	7.6-8.8
	Optimum	8.14-8.70
NH_4-N	Appropriate	<200
(mg-N/m^3)	Optimum	<1,500
DO (mg/l)	Appropriate	>4
	Optimum	---

TWO-CROP CULTURING

P. chinensis and *P. penicillatus* have become the most common species cultured in the coastal region of Southern China. Growout ponds range from 5 to 200 mu (15 mu = 1 hectare), but 10-30 mu ponds are most common. The depth of pond water ranges from 1-2 m; 1.5 m is common. In most areas, growout ponds are rectangular with mud and sand bottoms and independent water inlet and outlet. The daily exchange of water depends largely on tidal fluctuations. Water pumps and aerators are installed in every few ponds. In the middle and late stages of growout, one third to one half of the pond water is exchanged daily. The output per unit area is 90-250 kg/mu, the maximum 400 kg/mu. Diet consists of 80% formulated feeds and 20% small bivalves and trash fish.

Culturing Technique

In winter, after the shrimp have been harvested, the pond is prepared for the next year. After drainage, the bottom is plowed and cleaned with running water. If necessary, the pond bank and watergate are repaired. Several compounds, (e.g. CaO, 50-100 kg/mu; tea cake, 12-15 kg/mu; and $CaOCl_2$, 30 ppm), are used to sterilize the pond. The incurrent water is filtered through sieve cloth at the inlet gate, and depth is 30 to 50 cm.

Stocking

The quantity of shrimp stocked depends upon the depth of the pond and the water exchange rate and condition. For our experiment, a stocking density of 20,000-30,000 shrimp/mu was suitable.

Feeds

Diet should be in accordance with the requirements of the different stages. Fresh crushed mollusc meat is fed to the small shrimp (0.7-1.0 cm), which are transferred into growout ponds. Shrimp are fed three or four times a day. Small trash fish and formulated diet are fed when the shrimp reach a body length of 3 cm. After 6 cm, the formulated diet is the primary feed. Feeding times are reduced to three a day (in the early morning, late afternoon and at midnight) until harvest.

Water quality

The common method of regulating pond water quality is by the tide. After the shrimp are transferred into the growout ponds, water is added little by little. At an appropriate time (based on the pond condition), regular water exchange begins. When shrimp are about 7 cm, water is exchanged twice a day. During hot days (from mid-July to late August), pond water level should be kept high. In addition, to ensure adequate DO, water is exchanged primarily at night. Variation in the main water quality parameters is shown in Table 9.

Table 9. Range of variation in major water quality parameters during the experiment.

Range	Temperature (°C)	Specific gravity	Transparency	pH	DO (mg/l)
Max.	34.4	1.022	60	8.6	7.0
Min.	18.3	1.005	20	7.8	2.5
Mean	20-30	1.01-1.018	30-40	8.2-8.4	3.5

Growth of Shrimp in Two-Crop Culture

The development and activity of penaeid shrimp depend on water temperature. At favorable temperatures, the growth rate increases as water temperature increases. Experiments have shown that *P. penicillatus* reared in the southern part of Fujian have optimal growth in 21.2-29.0°C water. Above 32°C, growth slows and the shrimp are easily infected with disease. This apparently does not happen in *P. chinensis* (see Fig. 6).

In 1983 there was an insufficient supply of early crop shrimp, hence our stocking density was only 5,000 inds/mu (7.8/m^2). In all

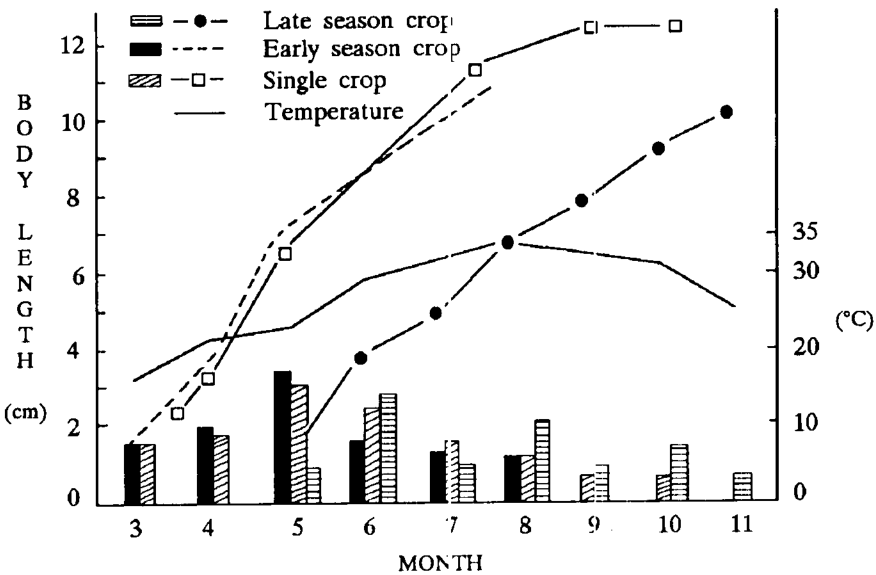

Fig. 6. Actual growth rates of 2-crop and 1-crop cultured penaeid shrimp.

other years we stocked 3,000-10,000 shrimp/mu (11.9-14.9 inds/m^2). The growth curve in Figure 6 shows that the early crop species, *P. chinensis*, was 1.5 cm long when released for growout. After 146 days, shrimp were 11 cm. The growth rate was relatively fast by April and May. In May, when the average water temperature was 23.2°C, length increased by 3.5 cm. The control group of *P. chinensis* and early-crop shrimp were transferred to growout ponds at the same time and grown for 190 days. The growth trends before August were similar. After August, the monthly growth rate declined gradually.

P. penicillatus 0.9 cm long were reared in an intermediate nursery pond up to mid-August. They grew to 5.5 cm and were stocked into growout ponds after the *P. chinensis* were harvested (mid-August). They were grown for an additional 94 days. Growth was fastest in June, when the average water temperature was 29°C. In one month, body length increased by 2.9 cm. *P. penicillatus*, a local species, is more tolerant to high temperature. The histogram in Figure 6 shows that in August when the water temperature reached 34.4°C, the growth rate was higher than in July and September. This was because shrimp were transferred from the high density intermediate rearing pond to larger growout ponds. Length increased 1.4 cm in 11 days. When water temperature dropped to 22°C, the growth rate was lower. By then the shrimp had grown to market size and were harvested. Economic returns would have been low had they been reared longer.

The Intermediate Nursery Rearing of the Summer Batch of *P. penicillatus*.

The intermediate rearing and management of *P. penicillatus* are the two most important factors determining the success of this type of 2-crop culturing. If management during the intermediate rearing period is poor, shrimp will be unhealthy, growth will slow such that shrimp will be unable to grow to marketable size, and production levels for the second growout period will not be reached. The pond must be thoroughly cleaned, predators should be excluded, and feed should be adequate to prevent cannibalism.

As part of our routine feeding and management procedures, fresh, crushed mollusc meat is fed to 0.9 cm shrimp 4-6 times a day. Ponds are approximately 40 cm deep. Water is added as the shrimp grow. When the shrimp are 3 cm long, water exchange begins. At 4-5 cm, they are fed crushed bivalves (*Musculus senhousei* or *Laternula* sp.) three times a day. This continues for no more than 66 days. The average length after this period is 5.5-6.1 cm. By this time, the spring batch of *P. chinensis* will have reached marketable size and been harvested. Then *P. penicillatus* from the intermediate rearing ponds are transferred into spring growout ponds. In 78 to 126 days, the summer batch of *P. penicillatus* reaches a marketable size. By this time it is middle or late November, water temperature is 22°C, and growth has slowed. There is no advantage to growing the shrimp further.

Economic Gains of Two-crop Culturing

The southern part of China is more suitable for 2-3 crop culturing of shrimp because the climate allows for a longer growout period. There are more species of shrimp for culturing. We have chosen *P. chinensis* and *P. penicillatus* for 2-crop culturing, thus improving the culture technology. The criterion for the success of a technique is whether or not profit is increased.

Table 10 shows that 2-crop culturing in Fujian and Guangdong provinces is more profitable than 1-crop culturing. The popular opinion is that 2-crop culture of penaeid shrimp in Southern China is very feasible. The species used are appropriate because they can be reared in different seasons. Many farmers in Fujian, Guangdong and Guangxi are adopting this new technique and the economic gains are very good.

CONCLUSIONS

(1) When provided with a favorable environment, high quality diets, and effective management, female *P. penicillatus* can be induced to spawn early by means of unilateral eyestalk ablation. Without eyestalk ablation, only a few individuals mature, and by that time it is too late for practical production. The ablated spawners can remature and spawn repeatedly (up to four times). As the technique becomes more widespread, cultured broodstock may solve the problem of inadequate numbers of broodstock, reduce the cost of hatching, and prevent overfishing of the increasingly exhausted supply of wild spawners.

Egg diameter, fertilization and hatching rate, and larval survival of the first batch of eggs from overwintered broodstock are similar to those of wild broodstock. The only difference is that the average number of eggs is lower.

(2) Years of practice and large-scale application of the 2-crop culturing technique show that the selection of *P. chinensis* and *P. penicillatus* for culture in the spring and summer, respectively, is appropriate because they can be cultured with high yield in low or high salinities. The adoption of this technique in Fujian, Guangdong, and Guangxi is economically feasible.

(3) In Southern China, *P. chinensis* is cultured first because it has higher mortality, slower growth and is susceptible to disease at higher temperatures. The local species, *P. penicillatus*, is then reared in the same ponds after *P. chinensis* is harvested.

(4) 2-crop culturing increases production and income without additional rearing facilities, management personnel or basic investment.

(5) The intermediate culture pond, which should have its own drainage, can be located near the water inlet of the first-crop growout pond or located separately, depending on the size needed. Based on the usual stocking density, there should be one, 1 mu intermediate culturing pond for every 5-8 mu growout pond.

Table 10. Comparison of the economic feasibility of two-crop and one-crop culture of penaeid shrimp.

Site	Culture species	Culture period	Culture area (mu)	Rearing density (10^4/mu)	Size of fry (cm)	Production (kg) Total	Production (kg) Mean/mu	Amount of feed (kg)	Profit (RMB) per mu	Profit (RMB) Total
Fujian	Two-crop:									
	P. chinensis	Apr. 2-Aug. 7 (122 days)	3.09	0.5	1.5	155.6	50.4	15.6	214.0	
	P. penicillatus	Aug 10-Dec. 3 (126 days)	3.09	0.8	6.1	267.7	86.6	15.7	274.9	488.9
	P. chinensis	Mar 26-Aug. 17 (146 days)	3.40	1.0	1.5	368.7	108.5	20.7	452.5	
	P. penicillatus	Aug. 19-Nov. 20 (94 days)	4.40	0.9	5.5	261.0	60.3	34.5	197.6	650.1
	One-crop:									
	P. chinensis (Control)	Mar. 26-Oct. 6 (190 days)	32.80	0.8	1.0	314.0	78.5	44.8	284.1	284.1
Guangdong	Two-crop:									
	P. chinensis	Apr. 2-Jul. 15 (106 days)	32.80	0.8	1.0	1,656.2	53.0	21.0	111.0	
	P. penicillatus	Jul. 30-Oct.16 (78 days)	32.80	0.8	6.1	2,508.7	76.5	15.9	463.5	574.5
	One-crop:									
	P. chinensis (Control)	Apr. 2-Oct. 3 (185 days)	3.80	0.8	0.8		40.3	41.0	63.7	63.7

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EFFECTS OF SOME ENVIRONMENTAL FACTORS ON THE GROWTH OF THE CHINESE SHRIMP, *PENAEUS CHINENSIS*

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INTRODUCTION

Increasing the potential of shrimp culture depends on studying the ability of shrimp to adapt to environmental changes. Quality and quantity of diet, water temperature, salinity, pH and dissolved oxygen are obviously the major environmental factors influencing shrimp growth. This paper summarizes the results of studies on the effects of temperature, salinity, dissolved oxygen and total ammonium-N on the growth of *Penaeus chinensis*, the Chinese shrimp.

ENVIRONMENTAL FACTORS

Temperature

Penaeus chinensis can tolerate lower water temperatures than any other penaeid species. It is distributed mainly in the area of the Yellow Sea and the Bohai Sea along the coast of Shandong, Hebei and Liaoning provinces. *P. chinensis* is also found along the west coast of Korea, and to a lesser degree in the East China and South China Seas. A eurythermal species, *P. chinensis* grows well and is active at water temperatures ranging from 18 to 30°C, but cannot tolerate water temperatures above 39°C. At temperatures below 13°C, the shrimp becomes sluggish. When kept at 3 or 4°C, the shrimp will lie down on the bottom and slowly die.

Okamasao (1970) reported that the optimum water temperature for the growth of Chinese shrimp was 24 or 25°C. If the temperature exceeded 25°C, growth rate would decline sharply. Cultivating postlarvae (PL2-10) under different temperatures in the laboratory, Wang Kexing (1984) found that the higher the temperature within the range of 20 to 30°C, the higher the growth rate. Growth of postlarvae at 30°C was 11 times greater than that of postlarvae at 20.9°C. Growth rates at 30°C were also higher than those obtained at 25°C. The increase in growth rate did not cease until 33°C.

This experiment indicated that optimal water temperatures for the growth of *P. chinensis* are from 20 to 30°C. A similar result

Table 1. Growth increments (in mm) for juveniles (5 cm in length) cultivated in different water temperatures for 14 days.

Temperature (°C)	Growth Increment Mean	SD
10	0.9	0.05
15	3.7	0.07
20	5.7	0.06
25	8.6	0.06
30	9.3	0.07
35	7.8	0.05

was obtained from this author's experiments on the growth of juveniles (5 cm in body length) cultivated at different temperatures (Table 1, Fig. 1).

The ability of *P. chinensis* to adapt to higher temperatures undoubtedly reflects its tropical origins. Though mainly distributed in the Yellow Sea and the Bohai Sea, the shrimp still retain the biological feature of higher growth rate with higher temperature.

Salinity

Most species of the genus *Penaeus* are euryhaline, but Chinese shrimp can tolerate an even greater range of salinities than the other species. *P. chinensis* grows well in reserve ponds which are 4% salt and in very brackish water near 0.2%. If acclimated, it can grow in water with even lower salinities.

Yu and Zongyao (1985) reported the following for 0.7 cm long juveniles: slightly more than 24 hrs for adaptation to a sudden change in salinity; decreased growth rate at salinity 3.7%; the higher the salinity, the lower the growth rate; high growth rates at salinities ranging from 1.132% to 3.1%; and better

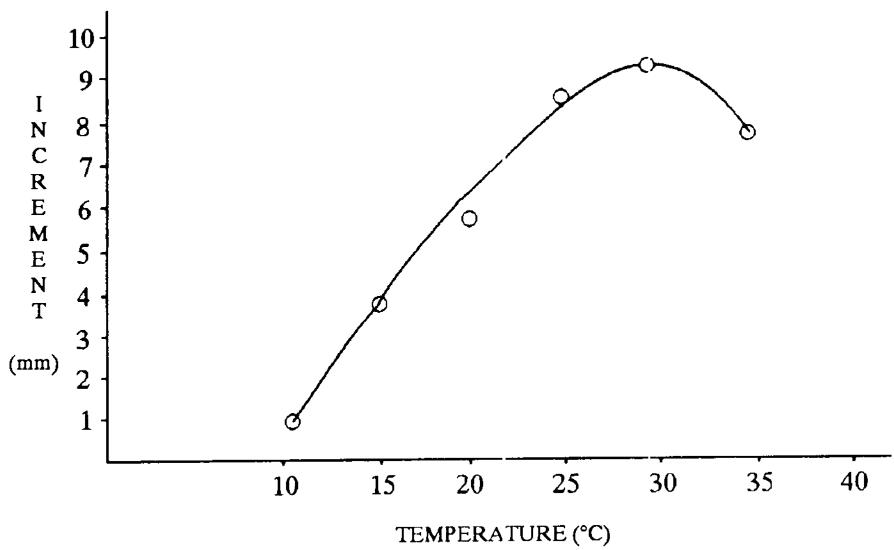

Fig. 1. The effect of different temperatures on the growth rate of *P. chinensis* cultivated for 14 days.

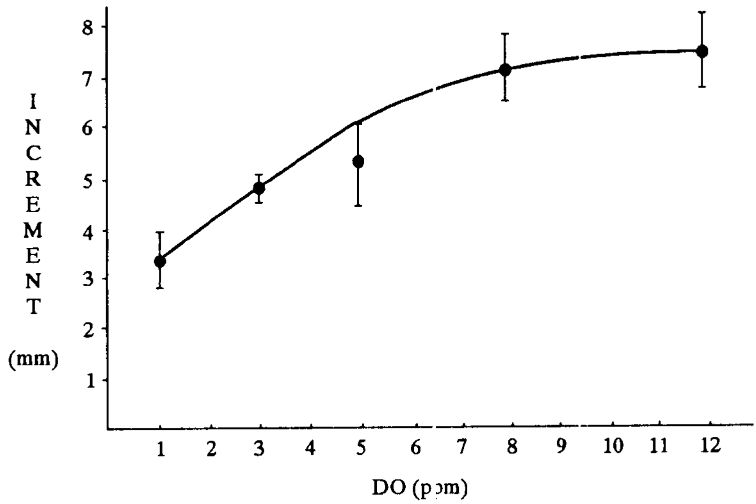

Figure 2. Variation in growth of 4 cm *P. chinensis* cultivated for 10 days in different concentrations of DO at 24-26°C.

adaptation to lower than higher salinities with sudden changes in salinity.

Dissolved Oxygen

Little research has been done on the effect of different concentrations of DO on the growth of Chinese shrimp. In one report, the oxygen consumption rate was determined by the DO concentration. The critical value of DO for shrimp varied with the size of the shrimp and water temperature; and there were differences between individual shrimp. Critical values of DO for an adult were 1.3 ppm at 15°C and 1.75 ppm at 20°C. After analyzing oxygen consumption rate and tolerance to low concentrations of oxygen, the researchers concluded that high concentrations of oxygen were suitable for the growth of shrimp. Hence, DO concentration in the culture environment should be at least half the saturated one. In water with a DO concentration of 1 to 1.4 ppm, a shrimp could survive but would not grow (Table 2, Fig. 2). This is the lower limit for shrimp survival. At DO <5 ppm, the growth was still limited, but

Table 2. The effect of different DO concentrations on the growth of *P. chinensis* (4 cm) cultivated at 24-26°C for 10 days.

DO		Growth increment	
Mean	SD	Mean	SD
1.05	0.5	0.35	0.07
3.00	0.5	0.50	0.06
5.00	0.5	0.53	0.09
8.00	1.0	0.72	0.07
≥12		0.73	0.07

increased when DO concentration increased from 1 to 5 ppm. When DO was greater than 6 ppm, shrimp growth was no longer limited.

The DO concentration in a great number of shrimp ponds is <5 ppm for at least half of every day and impedes growth. An experiment performed by this author showed that shrimp stopped feeding at DO concentrations <1 ppm. There was little decrease in feeding when DO decreased to 1.5 ppm; the difference was not significant compared with feedings in higher concentrations of DO. Thus, the diet coefficient of shrimp cultivated at low DO must be greater than that at higher concentrations (Table 3).

Total Ammonium-N

In studies of the toxicity of different forms of nitrogen and the effects of nitrogen-compound on the growth of 10 species of shrimp, including the Chinese shrimp, Wickins (1976) pointed out that only free NH_3-N had strong toxicity. The proportion of NH_3-N to total ammonium-N was determined by water temperature, pH and air pressure. The critical value of NH_3-N for the growth of shrimp was 0.1 ppm; growth was affected if the concentration of NH_3-N exceeded this threshold.

This conclusion was supported by results of our experiment in which a small amount of ammonia (even less than 3 ppm of ammonium-N) caused a sharp decline in the growth rate of shrimp. Although growth decreased steadily when the concentration of ammonium-N exceeded 5 ppm, the growth rate curve leveled off (Table 4, Fig. 3).

The research discussed above shows that water temperature, salinity, dissolved oxygen and ammonium-N are the major environmental factors influencing shrimp growth. Growth rate generally reflects the interaction of all environmental factors in the shrimp culture ponds. By adjusting these factors to optimum values, the ideal growth rate can be obtained.

Table 3. The effect of different concentrations of DO on the amount of food consumed by *P. chinensis* at 24-26°C.

DO (ppm) Mean	SD	Daily feeding (g/ind)
1.0	0.5	0.00
1.5	0.5	0.49
3.0	0.5	0.53
5.0	0.5	0.52
8.0	1.0	0.59
>12		0.53

Table 4. The increase in body length of 4 cm-long shrimp cultivated in different concentrations of total ammonium-N for 10 days (pH: 8.3-8.4, temp: 20 °C).

Total ammonium-N (ppm)	Growth increment Mean	SD
0.0	1.15	0.15
0.6	0.69	0.18
1.0	0.72	0.15
2.0	0.70	0.16
5.0	0.54	0.08
7.0	0.53	0.17
14.0	0.26	0.06

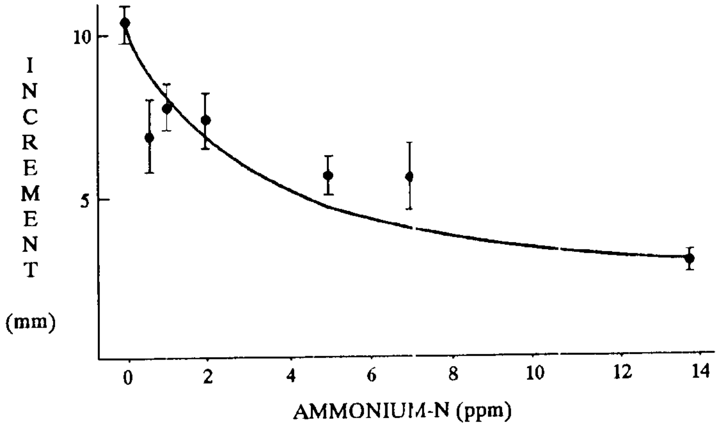

Figure 3. The effect of total ammonium-N on the growth of 4-cm long shrimp cultivated at 20°C and 8.3-8.4 pH for 10 days.

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ON THE GROWTH OF CULTURED *PENAEUS CHINENSIS* (OSBECK)[1]

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INTRODUCTION

China began studies on the rearing and culturing of *Penaeus chinensis* in the 1950's. Since 1952, the scientists of the Institute of Oceanology, Academia Sinica (IOAS) have conducted a series of studies on the biology, nutrition, and effect of disease (Liu 1955, Liu et al. 1959, Hao 1959, Wu et al. 1965) on *P. chinensis*. Cooperative efforts with the Yellow Sea Fisheries Institute, Ocean University of Qingdao, and the Shandong Mariculture Institute have been quite fruitful. Large-scale rearing and culturing techniques were developed in the early 1980's. Since then, shrimp culture has developed quickly in China.

This paper discusses the growth of cultured shrimp and briefly describes shrimp culture research conducted by IOAS.

PRODUCTION OF FRY

Scientists at IOAS have studied the breeding, spawning and larval development of shrimp under different conditions of water quality and food supply (Liu 1955, Liu et al. 1959, Wu 1965). In May, 1960, the first rearing of postlarval Chinese shrimp was accomplished. Information on the effects of temperature, salinity, dissolved oxygen, pH, NH_3-N and heavy metals on fertilization and larval development, and information on nutritional requirements, laid the foundation for subsequent large-scale production of postlarval shrimp (Wu et al. 1965).

In 1977, the report on improving the survival rate of shrimp larvae by using EDTA-Na was published. Since then, EDTA-Na has been widely used in hatcheries in China (Section of Shrimp Experimental Ecology (SSEE) of IOAS 1977).

The parameters of management techniques such as water treatment, aeration, food supply, water exchange, etc. were also established (W. Zhang et al. 1980, W. Zhang 1981, IOAS 1982). In 1981, 287 million postlarvae were produced in Ganyu county, Jiangsu province alone. This was the highest production of all the counties in China (postlarval production nationwide averaged 144,000/m^3 in 1980, and 262,000/m^3 in 1981).

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SHRIMP CULTURE

For both the intensive and extensive culturing of Chinese shrimp, a basic problem is the development of effective feed. Manifold formula dosages of shrimp feed have been developed on the basis of nutritional and physiological studies of shrimp. The formula feed of Huang Dao-III studied by IOAS has proven to be the best shrimp feed in Shandong province. This feed is mass produced in the factory and available inside or outside Shandong. Experimentation has established models of feeding for different sizes of shrimp (N. Zhang et al. 1983) and are used as standards of feeding in most shrimp farms (Shandong Marine Cultivation Institute 1983).

For effective utilization of breeding ponds we conducted an intensive culture experiment from June to October. The average yield was 1.98 kg/m^2 in 1987 (total 78.43 m^2) and 2.72 kg/m^2 in 1988 (total 227.7 m^2). The highest yield of shrimp was 2.80 kg/m^2 in 1987, and 2.93 kg/m^2 in 1988. The average body length and weight were 120.2 mm and 20 g.

MATING AND INDUCING MATURATION OF SHRIMP

Controlling the Mating of Shrimp

In 1977, we studied the relationship between Chinese shrimp mating and tide and found that the peak of mating is usually during the last ten days of October, when the mating rate is approximately 82.1%. The second peak is in early November and the rate is 17.9% (Gao 1980). Shrimp mating (the rate is 100%) in captivity has been established through controlling physical conditions of growout or breeding ponds.

Large-scale experiments on the overwintering of broodstock were performed from 1980 to 1983 (IOAS 1982, W. Zhang 1984) and relevant techniques established. In 1981, cultured broodstock overwintered in Ganyu County and 4,084,200 postlarvae were obtained. The average yield was 80,600/m^3 (IOAS 1982).

Unilateral eyestalk ablation was used to induce ovarian maturation. Survival rate of the treated shrimp was as high as 100% (Liang et al. 1983). A comparison of eyestalk ablation methods showed that the pinching-cautery method was the best; it is simple and easy to perform.

Shrimp Growth In Ponds

The Chinese shrimp is a large species. The body length of adult females ranges from 180 to 210 mm; males are approximately 150 mm. In recent years, the body length of cultured shrimp in China has usually ranged from 100 to 120 mm. Market price corresponds to the size of the shrimp (N. Zhang et al. 1985). Accordingly, the main objective in shrimp culture today is to increase shrimp size and thus get a higher price.

Chinese shrimp culture is typically semi-intensive using earthen ponds. Pond size ranges from <1 ha to 10-20 ha. The majority are 3-5 ha, and have a water depth of 1-1.5 m. Data from two ponds on a shrimp farm in

Table 1. The growth of the Chinese shrimp, *P. chinensis*, in Pond 5 of a shrimp farm in Haiyang County, Shandong province.

		May	June	July			Aug			Sept			Oct
		14	24	4	14	24	3	13	23	2	12	22	2
		(Stocking)											(Harvest)
Average body length (mm)		8	43.2	57.0	68.1	76.6	79.6	85.2	91.5	98.0	105.8	113.3	119.3
Average daily growth increment (mm)			0.9	1.38	1.11	0.85	0.77	0.42	0.63	0.63	0.80	0.80	0.53
Water	6:00			22.2	23.0	23.4	25.0	26.4	23.2	23.0	21.0	18.8	16.6
temperature	14:00			27.2	32.0	31.4	31.0	30.8	30.0	29.4	27.2	23.6	23.0
(°C)	mean			25.0	26.2	28.0	27.2	28.2	29.6	26.8	23.9	21.7	19.43

Haiyang County, Shandong illustrate typical shrimp growth rates on Chinese farms. Pond 5 is 4.66 ha in area, 1.2 m in depth, and daily water exchange is 8%. After harvest in October, average shrimp body length is 119.3 mm (Table 1), and the average yield is 1,125 kg/ha. Pond 9 is 2.46 ha in area, 1.2 m in depth, and daily water exchange is 15%. After harvest in October, average shrimp body length is 117.9 mm (Table 2), and average yield is 2,302 kg/ha. The growth rate in the two ponds is the same, and yield differs only moderately.

In the last few years, the conditions of a few growout ponds have improved, as can be seen in the following examples. The quality of shrimp has thus improved markedly; body length now reaches 140-150 mm.

Experiments performed in 1987 by IOAS in shrimp farms of the Shengli Oil Field

Table 2. The growth of *P. chinensis* in Pond 9 of a shrimp farm in Haiyang County, Shandong province.

		May	June	July			Aug			Sept			Oct
		14	24	4	14	24	3	13	23	2	12	22	2
		(Stocking)											(Harvest)
Average body length (mm)		8	43.5	57.6	68.6	76.3	81.9	87.3	97.3	100.1	107.4	114.0	117.9
Average daily growth increment (mm)			0.9	1.41	1.10	0.77	0.56	0.54	1.00	0.28	0.73	0.66	0.39
Water	6:00			22.2	23.4	23.4	25.0	26.8	23.1	23.0	21.0	19.5	16.5
temperature	14:00			27.2	32.0	31.4	31.2	31.0	29.5	29.8	27.3	23.8	22.5
(°C)	mean			25.0	26.2	28.0	27.7	28.3	26.8	27.0	23.9	21.4	19.3

Table 3. The growth of *P. chinensis* on the farm of Fengcheng, Gime County, Shandong province, 1982.

	May 19 (Stocking)	June 17	27	July 7	17	27	Aug 7	17	27	Sept 7	17	27 (Harvest)
Average body length (mm)	7	27	38	55	76	85	95	104	119.5	128.5	137.0	150.1
Average daily growth increment (mm)		0.7	1.10	1.70	2.10	0.90	1.00	0.90	1.55	0.90	0.85	1.31
Average water temperature per ten days (°C)			23.70	26.07	28.40	29.20	29.97	28.90	25.93	26.58	22.00	28.35

yielded the following results: In six, 5 ha ponds, postlarvae (7 mm long) were stocked May 25-27 and harvested from September 27 to October 1. The average body length and weight were 153.5 mm and 43.48 g, and yield was 1,275 kg/ha. On a shrimp farm in Qingdao, the average body length harvested from two ponds was 145 mm and 150 mm, and yield was 2,250 kg/ha in 1988.

In 1987 at Ma Shanzhai shrimp farm in Muping County, Shandong province (5 ponds totalling 37.97 ha, water depth 1.7 m, water exchange more than 40% daily), the average body length was 145 mm, average weight was 40.77 g, and total yield was 1,263 kg/ha. In 1982, at Fengcheng shrimp farm, in Gime County, Shandong province, the average body length of the harvested shrimp was 150.1 mm (Table 3).

These data indicate that growth from July 7-17 was close to that observed in shrimp in Haiyang County (Tables 1 and 2). From the last ten days of July to August, the average daily increase in body length was 1 mm. In the two ponds in Haiyang County it was 0.6 mm. The growth rate at both sites was similar during September and October.

DISCUSSION

Mathematical analysis of the growth of *P. chinensis* (N. Zhang 1985) indicates that shrimp in nature grow quickly from about July 10 through August. For example, the average body length of shrimp in Jiaozhou Bay was less than 100 mm on August 4, but 131 mm (females) and 122.3 mm (males) on August 27 (Table 4). The growth rate of fry released in mid-August was 10 mm every five days (Liu in press).

The data suggest that the lower growth rate of shrimp in ponds is caused by unfavorable conditions. Accordingly, improving the conditions of culture ponds from the last ten days of July to August is very important for increasing the growth rate of shrimp.

The water temperature in nature from the last ten days of July to August is approximately 25°C, which is favorable for shrimp growth. Shrimp do not grow well in ponds with water temperatures higher than 30°C. In August, if the water depth of a pond is 1.8 m, the water temperature at the bottom is 2°C lower than that at the surface. Consequently, increasing the water depth of culture

Table 4. The growth of *P. chinensis* in Jiaozhou Bay.

		Aug. 4	Aug. 27	Sept. 23	Oct. 21
Female	Body length (mm)	97.1	131.0	152.3	181.1
	Average daily growth increment (mm)	2.1	1.5	0.8	1.0
Male	Body length (mm)	95.7	122.3	141.3	149.4
	Average daily growth increment (mm)	2.1	1.2	0.7	0.3

ponds and increasing the rate of water exchange not only improves water quality, but also makes the water temperature close to that of natural sea water, which is favorable for shrimp growth.

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ORIGIN AND NURSERY OF CULTURED *PENAEUS CHINENSIS* FRY[1]

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INTRODUCTION

Shrimp culture in China has grown rapidly in the last decade. Although China's annual production of cultured shrimp is presently the largest in the world, problems remain with shrimp culture. The size, quality and supply of shrimp fry; water quality management; nutrition and feeds; and the control of diseases are particularly important factors. There are many problems associated with fry production. Since the quality of fry greatly influences the size and yield of harvested shrimp, it is economically very important.

Experiments were performed to:

(1) investigate the suitability of different types of fry,
(2) determine the best size of fry for use in the growout phases,
(3) determine whether a nursery phase is necessary, and
(4) decide upon the best nursery method and stocking density.

These experiments were conducted from 1986-1989 at the Academia Sinica Huangdao Mariculture Experimental Station at Qingdao and at a few other shrimp farms in China. This paper briefly summarizes some important findings of those studies.

[1]Contribution number 1762 of the Academia Sinica Institute of Oceanology

MATERIALS AND METHODS

Experiment 1

From 1986-1987 fry culture trials were conducted in seven ponds at the Huangdao Mariculture Experimental Station. Each pond had an earthen bottom and stone walls with two sluice gates on opposite sides, and was 2 m deep with a surface area of 666 m^2 (1 mu). Water depth was 1.5-1.8 m. Pond water could be exchanged through a sluice gate during the spring tide. A jet pump with a capacity of 270 m^3/h was installed in a pouring canal and could be operated concurrently with the gates, if necessary.

Experiment 2

Another experiment was conducted at a private shrimp farm in Jimo County, Qingdao in 1988. The total area of the farm was 134 ha. There were 21 ponds of different sizes, ranging from three to 10 ha. The embankments were all earthen, and each pond had sluice gates for intake and outlet of water. The seawater in the pond could be changed through the sluice gates during the spring tide. Each pond was equipped with a jet pump having a capacity of 400-500 m^3/h, which made it possible to change approximately 10% of the total volume of pond water every day.

The bottoms of most of these ponds had ringlike ditches, about 1.5 m in depth. The water depth was 0.8-1 m.

Experiment 3

In 1989, a third experiment was carried out at a large shrimp farm consisting of 31 shrimp ponds, 120 ha in total area. The ponds were earthen with two 1.3 m wide sluice gates. Water depth was 1.3-1.8 m, and 8-15% of the water could be changed daily by electric power.

The *P. chinensis* fry used in the experiments were all artificially bred from both wild and overwintered spawners. The overwintered spawners were primarily cultured shrimp which had been overwintered in an indoor tank. The wild spawners were captured in the Yellow Sea in the spring. The shrimp were fed mainly formulated feed, supplemented by small portions of fresh or live food, frozen trash fish and small shrimp. The feed was supplied 2-5 times daily at a day:night ratio of 4:6. The temperature, salinity, pH, and dissolved oxygen were recorded daily. Water color, transparency, illumination, NH_3-N, and N and P content were determined at irregular intervals. Body length and weight were measured every 5-10 days. Amounts of excess feed, and the presence of diseases, if any, were recorded so that we could adjust the amount of feed used.

RESULTS

Fry Cultured in Nursery Ponds

7 mm fry were stocked from breeding tanks to nursery ponds where they grew to 20 mm in length.

Table 1. Growth and survival of *P. chinensis* in the nursery phase at different stocking densities and initial body lengths (Experiment 1).

Pond No.	Pond area (m^2)	Density ($inds/m^2$)	Average body length (mm)							Survival (%)
			June 4	June 14	June 23	July 3	July 13	July 25	July 29	
A1	666	450	7.08	10.8	15.6	30.0	37.8	43.5	46.5	17.81
A2	666	300	7.08	12.1	17.4	31.1	38.6	46.0	46.8	85.85
A3	666	150	7.08	12.9	17.7	33.3	37.1	47.8	48.8	100.00
A4	666	150	6.08	12.4	18.6	35.7	42.0	49.6	52.3	69.26
A5	666	150	11.30	17.5	20.6	40.7	44.1	50.4	51.4	100.00
A7	666	15	11.30	22.8	27.8	39.3	49.1	55.3	58.2	

The fry transferred to ponds A1, A2, and A3 were all about 7.08 mm (Experiment 1; Table 1). The resulting survival rates were 17.81%, 85.85% and 100% for stocking densities of 450 ind/m^2, 300 ind/m^2 and 150 ind/m^2, respectively, when they were grown to 50 mm. The average body length was inversely related to stocking density. Ponds A3, A4, and A5 all had the same densities (150 ind/m^2) but were stocked with shrimp of different lengths. The survival rate in the two growout ponds stocked with 7.08 mm and 11.30 mm fry was 100%, while the pond stocked with 6.08 mm fry resulted in only 69.26% fry survival (Table 1).

From the results of the 1988 trial at the 134 ha shrimp farm with three nursery ponds (Experiment 2; Table 2) and that of the trial at a 120 ha shrimp farm in 1989 (Experiment 3; Table 3), the following conclusions can be drawn:

(1) 7-10 mm is a suitable size for fry when stocking into nursery ponds, whereas 6 mm is too small and will result in a low survival rate.

(2) Survival rate and body length will decrease as the stocking density increases. The appropriate choice of stocking density for fry to be grown from 7 to 50 mm is 150 ind/m^2. If one wishes to grow the same fry to only 20 or 30 mm, density can be increased to 300 ind/m^2. The survival rate of fry during mass production is generally only 40%.

(3) The high stocking density in the nursery ponds yields a lower growth rate than that of fry stocked directly into growout ponds. As evidenced in Table 1, fry stocked at 15 ind/m^2 may grow 6-10 mm longer than fry stocked at 150-300 ind/m^2, when grown to 50 mm.

(4) Besides water temperature, salinity, and pH, the main factor influencing the survival rate of fry in early growout is feed.

The Suitability of Different Types of Fry

In the northern part of China, most shrimp fry used in culture are hatched from:

(a) the eggs spawned by overwintered spawners from late April to early May;
(b) the first batch of fry propagated by wild spawners in mid May; or

Table 2. Culture conditions, water quality parameters, and production and survival for the 1988 nursery trials (Experiment 2).

Pond No.	14	15	16
Area (ha)	6.87	6.73	6.07
Average depth of pond (m)	1.2	1.1	1.1
Water depth (m)	0.8	0.7	0.7
Chemicals used to kill predators	calcium hypochlorite	calcium hypochlorite	calcium hypochlorite
Date of water intake	April 29	May 2	May 2
Fertilizer	urea and calcium superphosphate	urea and calcium superphosphate	urea and calcium superphosphate
Date of fry stocking	May 23	May 22	May 28
Number of fry stocked (x 10^3 ind)	6,610.0	13,570.0	9,023.7
Fry size (mm)	6-7	6	5
Amount of water changed per day	added water (2,000 m^3)	added water (approx. 2,000 m^3)	supplied the missing water (3-4 cm)
Range of water temperature	18.6-28.0°C	18.4-27.5°C	19.0-27.5°C
Range of salinity	32.7-38.6%	31.3-39.0%	35.4-38.0%
Range of pH	8.26-8.82	8.54-9.23	8.20-8.74
Date of harvest	June 13 to June 14	June 13 to June 23	June 17 to June 23
Number of juvenile shrimp harvested (ind)	3,702,752	3,556,214	1,141,121
Survival (%)	56.00	26.20	12.65

Table 3. Culture conditions, water quality parameters, and production and survival in 1989 nursery trials (Experiment 3).

Pond No.	4	12	18	25
Period of nursery culture	May 3-May 26	May 4-May 26	May 8-May 29	May 18-June 5
Range of temperature (°C)	13.0-26.5	13.0-26.5	13.0-25.5	15.5-25.5
Range of salinity (%)	28.5-31.8	28.5-31.8	28.5-33.4	31.8-33.4
Area (ha)	3.87	4.30	4.30	5.80
Number of fry stocked (x10^3)	8,068.6	5,834.0	9,953.0	8,433.0
Stocking density (ind/m^2)	209	135	234	146
Number of juvenile shrimp harvested (x10^3)	3,669.96	2,450.90	3,327.26	3,752.47
Size of fry (inds/kg)	9,000-9,800	8,000-8,400	4,660-15,540	9,920-14,170
Survival (%)	46.0	42.0	33.4	44.5
Feed cost /1,000 inds (Yuan)	2.000	2.304	2.164	0.884
Remarks	Cost of frozen small shrimp is 0.8 Yuan/kg			

(c) the second batch of fry propagated by wild spawners from late May to early June.

Table 4 shows the difference in growth rate between these three types of fry stocked at the same farm in 1988 (Experiment 2).

Table 4. Differences in growth between fry from overwintered and wild spawners with and without nursery culture.

Pond No.	11	21	20	6	7	14	15
Area (ha)	8.80	3.00	6.07	6.93	7.00	6.87	6.73
Type of pond	without nursery culture	"	"	"	"	with nursery culture	"
Stocking date	May 1	May 1	June 1	June 13	June 14	June 14	June 20
Origin of fry	From overwintered broodstock without nursery culture	"	Second batch of fry from wild broodstock without nursery culture	First batch of fry from wild broodstock after nursery culture	"	"	From overwintered broodstock after nursery culture
No. of fry stocked (x 10^3)	3,036	1,530	1,040 (200)[1]	420	422	520	440
Average body length on June 20 (mm)	45.8	47.7	23.3	28.6	31.4	31.4	45.2
Harvest date	Oct. 9	Sept. 28	Sept. 30	Oct. 7	Oct. 3	Sept. 26	Sept. 27
Yield (kg)	7,851.45	6,537.95	3,896.1	6,651.45	6,026.7	6,039.35	4,357.15
Average body length at harvest (mm)	117.7	117.1	120.9	122.0	126.0	124.1	121.9
Survival (%)	15.5	25.4	---	86.0	70.2	59.0	54.2
Food conversion ratio	5.13	3.41	5.04	2.87	3.23	3.36	4.87

[1]See text

(1) The fry hatched from overwintered spawners were stocked on May 1, 1988. They grew well in the early growout period and were 20 mm larger (on June 20) than fry propagated from the wild spawners. Their growth rate decreased later, however. At harvest, around October, all the shrimp were about the same size, regardless of whether they were grown at a higher stocking density without nursery culture (ponds 11 and 21), or at a lower stocking density with nursery culture (pond 15).

(2) The first batch of fry from wild spawners either remained in the original pond, 14, or were moved to pond 7. Their growth rates were rather high in both ponds. When harvested, the unit production and the size of shrimp were identical, and higher than those of fry hatched from overwintered spawners.

(3) In pond 20 the second batch of fry from wild spawners was stocked on June 1. High mortality resulted because the postlarval shrimp were weak. Only a few shrimp survived to mid-June, consequently 200,000 more individuals were subsequently re-stocked.

Stocking Density of Fry in Growout Ponds

The number of fry to be stocked per unit area may be calculated according to the following formula:

The number of fry to be stocked (number of fry per hectare) = [the expected yield per hectare (kg/ha) x *the expected shrimp size at harvest (number of shrimp per* kg)] / *the estimated survival rate.*

Our experimental results, coupled with information from semi-intensive production facilities in China, suggest the expected yield per ha is 1,500-2,250 kg. If the expected yield of shrimp is 40-50 individuals per kg, the estimated survival rate of fry after the nursery culture should be 60-70%.

According to this calculation, the number of fry to be stocked will be 100,000-150,000 per ha. If 7 mm fry are used for growout stocking without a nursery period, the amount should be divided by 40% of the survival rate of the fry stocked in nursery ponds.

DISCUSSION

The Necessity of a Nursery Phase

In most Chinese shrimp farms, we stock 7 mm fry directly into growout ponds, but some farms prefer to stock the larger fry produced in nurseries. Most farms do not maintain nurseries because:

(1) production cost will rise due to the construction of special nursery ponds,
(2) the growth rate of shrimp fry will decline during the nursery phase with its high stocking density, and
(3) extra labor and time are needed to transfer the shrimp fry to the growout ponds.

We know that the period immediately after stocking is critical to the fry survival rate. In most culture areas in China, the weather is dry in spring, and the salinity and pH often exceed the range of optimal conditions for fry. We must keep in mind that the number of fry is the basis for calculations of the quantity of feed needed. It is of vital importance to estimate the exact number of fry to be stocked into the growout pond in order to minimize the amount of feed used. This is, however, difficult to achieve without nursery culture. Furthermore, with the adoption of a nursery phase, there will be more time to propagate natural food organisms and kill predators in the growout pond. For these reasons, we recommend using an intermediate nursery phase.

The Results of Nursery Culture Experiments

The nursery phase is greatly affected by the stocking density, water quality and feed quality. The fry stocked in the nursery ponds should be 7 mm, and should be transferred to the growout ponds when 20 mm. According to our results, there is no need to stock at 30-40 mm as some shrimp farms do. Growing fry to the larger size reduces growth, and increases the difficulty of transport to the growout ponds.

In most areas in Northern China, the first batch of fry raised from wild spawners are stocked into growout ponds in mid-May. The fry raised from overwintered spawners are stocked in growout ponds from late April to early May. They usually have low growth and survival rates due to low water temperature and cold currents. According to our experiments in the past two years, the growth rate of fry raised from overwintered spawners is definitely lower than that of the fry hatched from wild spawners. Stocking after the end of May will cut the culture period short and affect the yield and size of shrimp. Such fry are not advisable for use in shrimp culture.

Fry Stocking Density in Growout Ponds

Because the conditions in the growout ponds differ greatly, the stocking density used is variable. The stocking density depends greatly on the environment of the growout pond, water, feed types, expected size of shrimp, and expected unit production.

SECTION II

Discussion Group Summaries

DISCUSSION GROUP A - Design of Growout Systems

INTRODUCTION

The topics for Discussion Group A included the physical characteristics of growout ponds, water system design, and growout pond preparation. Comparative data are presented in Tables 1-3 and discussed below.

PHYSICAL CHARACTERISTICS OF GROWOUT PONDS

In Korea, China, and Japan, shrimp ponds are much larger than those in Taiwan or the U.S. In China, rectangular shaped ponds vary from 1-10 ha (most are 3-5 ha) in size (also see Liu Chapter 2, and Hu Chapter 9). In Japan, rectangular ponds are usually 3 ha. In Korea, square ponds are constructed in enclosed bays and vary from 6-20 ha. However, in Taiwan, rectangular ponds vary from .1 to 1.5 ha. The same pond design is used for *P. chinensis*, *P. penicillatus*, and *P. japonicus;* however, a mud/clay or mud/sand substrate is used for *P. chinensis* and *P. penicillatus* and a sand substrate is used for *P. japonicus* (Table 1).

WATER SYSTEM DESIGN

The water system design for growout ponds makes use of the natural tidal flow in Korea where the majority of ponds are in enclosed bays. In China, some ponds use natural tidal flow, but the majority pump their seawater from coastal waters. In Taiwan, water is pumped from coastal areas. The water exchange rates are 10-30% daily for all three species, but tend to occur as high exchange over a short time interval, especially when relying on tidal exchange. In Korea, water exchange is the primary management

Table 1. Physical characteristics of growout ponds.

	Shape	Area (ha)	Depth (m)	Substrate
P. chinensis				
N. China[1]	Rectangular	2-10	1-2	Dirt
Korea	Square	6-20 or 30	1.5	Dirt (clay)
P. japonicus				
Korea	Square	6-20 or 30	1.5	Sand
Taiwan	Rectangular	.1-1.5	0.8-1.5	Dirt or sand
Japan	Rectangular	3	1.8-2.2	Sand
P. penicillatus				
Taiwan	Rectangular	.1-1.5	0.8-1.5	Mud, clay
S. China[2]	Rectangular	1-10	1-1.5	Mud, clay

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

Table 2. Growout pond water systems.

	Water source	Flow rate (% per day)	Filtration system	Waste water	Aerators
P. chinensis					
N. China[1]	Tides or pumps	10-20	Some farms have settling ponds	Discharge to ocean. No treatment	Most do not; a few have them for emergencies.
Korea	Tides (majority) or pumps (in upland areas)	30	Screen	same	Yes, 1 per 1.2 ha (3 hp; 24 h/day)
P. japonicus					
Korea	Tides (majority) or pumps (in upland areas)	30	Screen	same	Yes, 1 per 1.2 ha (3 hp; 24 h/day)
Taiwan	Pumps	10-30	Sand/screen	same	Yes, 4-8/ha
Japan	Tides, pumps	10-30	Screen	same	Yes
P. penicillatus					
Taiwan	Pumps	10-30	Sand/screen	same	Yes, 4-8/ha
S. China[2]	Tides or pumps	30	Screen	same	Most do not; a few have them for emergencies.

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

tool for maintaining water quality. 30% of the water is exchanged daily through tidal sluice gates and occasionally the level of the pond is lowered by 90% and refilled when water quality is poor. In Northern China, 10-20% of the water is exchanged in *P. chinensis* ponds, and in Southern China 30% is exchanged in *P. penicillatus* ponds. In Taiwan and Japan, the amount of water exchange varies from 10-30% per day in both *P. penicillatus* and *P. japonicus* ponds (Table 2).

The only type of filtration systems employed for growout ponds are sand or screen filters placed where the water enters the pond. The purpose of the filter is to screen out predators only. In some areas of China (e.g., Hebei province) farmers think settling ponds improve water quality. Aerators are rarely used in China, but are common in Korea, Taiwan and Japan (Table 2).

PREPARATION OF GROWOUT PONDS

The treatment of ponds varies from country to country. In China, ponds are rarely limed or fertilized between production cycles. Ponds are dry throughout the winter, then they are tilled, and the organic layer is removed prior to stocking (also see Chen Chapter 8). In Korea and Japan, ponds are never limed or fertilized; they are dry throughout the winter, and tilled prior to stocking. In Taiwan, ponds are limed, tilled,

Table 3. Treatment of ponds prior to filling.

	Lime	Fertilizer	Other
P. chinensis			
N. China[1]	No	Some-1 month before stocking (add Urea or Phosphate)	Till and remove dark layer
Korea	No	No	Zeolite in pond when polluted. Till pond 2-3 times in spring prior to stocking
P. japonicus			
Korea	No	No	Zeolite in pond when polluted. Till pond 2-3 times in spring prior to stocking
Taiwan	Yes	Tea Seed Cake Phosphate at first, then none	Disking, pave with fresh sand
Japan	No	No	Drain, dry, plow, perhaps wash or replace sand, examine screen on fence apple calcium hypochlorite to kill predatory fish
P. penicillatus			
Taiwan	Yes	Tea Seed Cake Phosphate at first, then none	Disking, pave with fresh sand or desk pebble
S. China[2]	No	No	Till and remove dark layer

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

a fresh layer of sand or desk pebble is spread on the bottom, and phosphate is added prior to stocking. In Japan and Taiwan, *P. japonicus* ponds are dried, tilled, and a fresh layer of sand is added prior to stocking. Tea Seed Cake (10-13% saponin) in Taiwan and Korea, and calcium hypochlorite in Japan, is added to kill predatory fish prior to stocking (Table 3).

DISCUSSION GROUP B - Growout Management Practices: Growout Production Statistics and Nursery Systems

INTRODUCTION

This group reviewed growout management practices and production statistics for *P. chinensis*, *P. penicillatus*, and *P. japonicus* in China, Korea, Taiwan and Japan. In addition, the physical characteristics of nursery systems and nursery management practices were reviewed. Comparative data are presented in Tables 1-5 and discussed below.

GROWOUT SEASON AND POND MANAGEMENT

The growout period for *P. chinensis* and *P. japonicus* is five months in Northern China, Korea, Japan, and Taiwan. *P. japonicus* is cultured during the winter in Taiwan and Southwestern Japan, and in the summer and fall in Korea and mainland Japan. *P. chinensis* is cultured from March through August in Southern China and is followed by a second crop of *P. penicillatus* or *P. monodon* (also see Hu Chapter 9). *P. chinensis* is cultured from May to October in Northern China and Korea. In Taiwan, *P. penicillatus* is cultured for 3.5-4.5 months, from the summer through early fall (Table 1).

The environmental parameters monitored vary by country. In Northern China, a few farms monitor temperature, pH, DO, NH_4, and transparency. In Korea and Japan, water quality is closely monitored by observing the phytoplankton bloom. In addition, Korean farms monitor substrate quality and take daily temperature measurements. In Japan and Taiwan, farms monitor temperature, salinity, pH, DO, and transparency (Table 1).

During this session, there was a discussion about the most important variables involved in good pond management. Both Chinese and Korean participants agreed that business management was the most important variable, followed by water quality. The primary management tool for water quality is water exchange. Other important variables to control are quality and quantity of feed and stress from rapid environmental changes. The participants from Taiwan felt that feeding strategies were the most important variable in good pond management, followed by water quality. Water quality was the most important variable in Japan, followed by quality of feed and avoidance of overcrowding.

GROWOUT DENSITY, GROWTH RATE AND HARVEST SIZE

Stocking densities varied from 10-30 PLs per m^2 for *P. chinensis* in Northern China (see Hu Chapter 9 for densities used in S. China). In Korea, *P. chinensis* PLs were stocked at higher densities than *P. japonicus* (25-40 vs. 15-25/m^2, Table 2). Both Chinese and Korean producers believe that *P. chinensis* can be intensively cultured if water quality can be maintained. All participants agreed that high densities lead to increased susceptibility to disease.

Intensive culture experiments in which *P. chinensis* were grown at densities as high as 200 per m^2 have been conducted in both Korea and China (see Chen Chapter 8). Under experimental conditions, Korean scientists found that 100 per m^2 is the optimal density. However, under commercial production conditions, lower densities (30 per m^2) are optimal due to the limited number of warm days (20-25°C) in Korea. Semi-intensive culture of *P. japonicus* in Korea, Taiwan, and Japan included densities ranging from 15-60 per m^2 (Table 2).

In Taiwan, both *P. japonicus* and *P. penicillatus* are initially stocked at high densities. Subsequently, a mid-crop harvest is used to lower densities to 1/3-1/2 of the original stocking density. Taiwan reported that the optimal density for *P. japonicus* is 20-40/m^2, resulting in survival rates of 50-60%. Densities greater than 60/m^2 always resulted in lower survival rates (30-40%). *P. penicillatus* exhibited faster growth rates at densities of 20-50/m^2 than at densities greater than 100/m^2 (Table 2, also see Liao and Chien Chapter 6).

Growth rates at different temperatures and for different periods were discussed throughout the workshop. *P. chinensis* and *P. japonicus* were cultured under nearly identical conditions in Korea, and exhibited similar growth rates. Data from China and Korea revealed that *P. chinensis* show similar growth rates in both locations (also see

Table 1. Growout duration, dates and environmental parameters.

	Length of growout (months)	Growout dates	Environmental parameters monitored
P. chinensis			
N. China[1]	4-5	May to Oct 15	Temp., pH, O_2, NH_4, transparency
S. China[2]		Mar to Aug	Data not available
Korea	5	May 15-30 to Oct 30	Water quality, substrate quality
P. japonicus			
Korea	5	Apr 15-30 to Oct 1-Dec 15	Water quality, substrate quality
Taiwan	4.5-6	Oct to Apr	Salinity, pH, DO, transparency
Mainland Japan	5	Apr or May to Dec	Plankton, temp., salinity, DO, pH, transparency
SW Japan		July or Aug to May	Data not available
P. penicillatus			
Taiwan	3.5-4.5	June-Aug to Sept-Oct	Salinity, pH, DO, transparency
S. China[2]	4-8	Apr to Nov	Data not available

[1]Chiefly Liaoning, Hebei and Shandong provinces
[2]Fujian and Guangdong provinces

Zhang Chapter 11, Hu Chapter 9, and Kim Chapter 7). Korea reported a mean growth rate of 1.5 g per week and a maximum growth rate of 3 g per week for both species (Table 2).

Taiwan reported slightly lower growth rates for *P. penicillatus* and *P. japonicus*. For *P. penicillatus* the growth rates reported at the workshop ranged from 0.83-0.85 g/wk. The experimental growth rates reported in Liao and Chien (Chapter 6) were 1.25 g/wk (also see Hu Chapter 9). Japan reported growth rates of 1-1.25 g/wk for *P. japonicus*.

Northern China and Korea reported a maximum harvest size of 25 g after five months for *P. chinensis* and *P. japonicus* (Table 2; also see Liu Chapter 2). Harvest date was primarily determined by weather and growth rates (but see Kim Chapter 7). In Taiwan, the maximum harvest size for *P. penicillatus* was 15 g after 4.5 months. For *P. japonicus*, harvest size varied from 15-20 g after 4.5-6 months (Table 2). In Taiwan, harvest date depends on growth rate, survival, and market price. In Japan, *P. japonicus* are mainly harvested at 18-45 g, but there is usually a mid-crop harvest at 12-15 g (Table 2). Harvest date is determined by density and occurs when overcrowding is imminent.

GROWOUT YIELDS AND SURVIVAL RATES

P. chinensis yields varied between 1,000-1,500 kg/ha/crop in Northern China (also see

Table 2. Density, growth rate, and harvest size in growout systems.

	Stocking density (individuals/m^2)	Growth rate	Size at harvest (g)
P. chinensis			
N. China[1]	15-30 (PL5-7)	1-2 cm/10 days	15-25 (11-13 cm)
	9-12 (PL25)		
Korea	30 (PL20)	2-3 g/5 days	25
	25-40 (range)		
P. japonicus			
Korea	15 (PL30)	2-3 g/5 days	For international market, >17
	15-25 (range)		For domestic market, 5-15
Taiwan	Semi-intensive: 30-50	15-20 g/4.5-6 mo	20
	Intensive: 120-200		
	Mid-crop harvest		
Japan	Usually 25-30 juveniles (0.1-1.0 g)	20-25g/5 mo	18-45, but thinning harvest at 12-15
P. penicillatus			
Taiwan	If desired harvest size is 5-12g:	Domestic, 5-15	
	100-200, 12-15 g/3.5-4.5 mo		
	12-18g: 20-40		
S. China[2]	20-40 (PL7-10)	2-3.5 cm/mo	20

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

Liu Chapter 2). Korea reported much greater *P. chinensis* yields (4,000 kg/ha/crop) and indicated this was the minimum production level necessary to make a profit. *P. japonicus* yields of 1,500-4,000 kg/ha/crop were reported by both Taiwan and Korea. Japan reported the highest yields for *P. japonicus* (5,000-7,000 kg/ha/crop). Both Taiwan and China reported extremely high yields for *P. penicillatus* (Table 3). Survival rates varied from 30-70% for *P. chinensis*, from 30-85% for *P. japonicus*, and from 50-60% for *P. penicillatus* (Table 3). The low survival rate quoted for *P. chinensis* was for PL5-7 and the higher survival rate was for PL25.

PHYSICAL CHARACTERISTICS OF NURSERY PONDS

In China, Korea, Taiwan and Japan, nursery ponds are unheated, simple systems. They are rectangular and about the same depth as growout ponds. In China, shrimp are nursed in a corner, separated from the rest of the pond by a net. When the shrimp get larger (0.5-1.5 g or 2-3 cm), the net is removed and the shrimp have access to the entire pond. There is a controversy in China over the usefulness of nursery ponds, and most farm operators think they are not necessary (see Cao and Jiang Chapter 12). Nursery ponds are used for about 10% of the growout ponds in China (Table 4). In Taiwan and Japan, it is agreed that nursery ponds are necessary, and they are used by most shrimp producers.

In Korea, a five-stage nursery system is used. PLs are initially confined to a corner of the pond. Pond size is controlled with nets and the area is enlarged every 10-20 days before the shrimp are released into the main growout pond (Figure 1). Growth rates vary from 0.1-0.5 g per week (Table 5). Nursery ponds are believed to be an effective method of controlling predation when the shrimp are small, hence they are used by most farm operators. Nursery ponds are eventually converted into growout ponds in China and

Table 3. Survival rates and yields in growout systems.

	Survival (percent)	Yield (kg/ha/crop)
P. chinensis		
N. China[1]	30 (PL5-7) 60-70 (PL25)	1,000-1,500
Korea	50	4,000
P. japonicus		
Korea	50	1,500
Taiwan	40-60	1,500-4,000
Japan	30-85	5,000-7,000
P. penicillatus		
Taiwan	Oct-Apr. 50-60	6,000-12,000
S. China[2]	50-60	1,500-6,000

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

Table 4. Nursery pond design.

	Shape	Area (ha)	Depth (m)	Substrate
P. chinensis				
N. China[1]	Corner net in growout pond	.01-0.1	1-2	Dirt, mud or sand
Korea	Five stage nursery system; using nets in rectangular growout pond	0.1	1.5	Clay, sand mud
P. japonicus				
Korea	Five stage nursery system; using nets in rectangular growout pond	0.1	1.5	Sand
Taiwan	Most are rectangular	0.05-0.2	0.8-1.0	Sand
Japan	Same as growout pond	3	1.8-2.2	Sand
P. penicillatus				
Taiwan	Most are rectangular	0.05-0.2	0.8-1.0	Sand
S. China[2]	Most are rectangular	0.1-1.0	1-1.5	Dirt

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

Korea. Thus, the pond depth and substrate are the same as in growout ponds (Table 4).

Nursery ponds are much smaller than growout ponds in China and Korea. In China, nursery ponds are 0.01-0.1 ha and growout ponds are 1-10 ha. In Korea, nursery ponds are 0.1 ha and growout ponds are 6-20 ha. In Taiwan, nursery ponds are only slightly smaller than growout ponds (0.05-0.2 vs. 0.1-1.5 ha). In Japan, growout and nursery ponds are the same size (3 ha, Table 4).

NURSERY MANAGEMENT PRACTICES

In China, *P. chinensis* are nursed for 10-20 days (also see Cao and Jiang Chapter 12). In Korea, *P. chinensis* are nursed for 10-20 days in each of the increasingly larger netted sections of the growout pond (nursery period = 40-60 days). Stocking densities vary from 150-300/m^2 in China to 1,000/m^2 in Korea. In China, survival rates are estimated at 50-80%

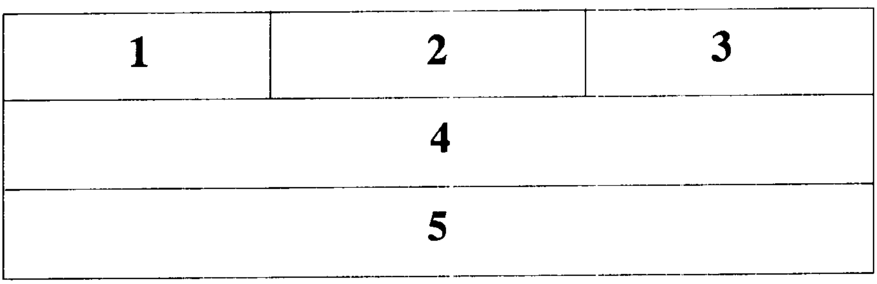

Fig. 1. Nursery pond design in Korea. Shrimp are initially stocked in area #1, which is separated from the rest of the pond by a net.

Table 5. Nursery management practices.

	Length of nursery (days)	Stocking density (individuals/m^2)	Growth rate	Survival (%)
P. chinensis				
N. China[1]	10-20	150-300	1.0 cm/10 days	50-80
Korea	40-60/stage	1,000	0.1-0.5g/wk	60-70
P. japonicus				
Korea	40-60/stage	1,000	0.1-0.5g/wk	60-70
Taiwan	15-30	600-1,000	Data not available	10-20
Japan	40-50	100-150 PL20	0.1-0.15g/wk	70
P. penicillatus				
Taiwan	15-30	600-1,000	Data not available	10-20
S. China[2]	12-20	1,000	Data not available	30-40

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

during the nursery phase and in Korea, 60-70% (Table 5).

P. japonicus are nursed for varying lengths of time, ranging from 15-30 days in Taiwan to 40-60 days in Korea. *P. japonicus* are nursed for 40-50 days in Japan or until they are 0.5-1.5 g. In Korea, nauplii were stocked at densities of 1,000/m^2. In Taiwan, PLs of an unknown size were stocked at 600-1,000/m^2. In Japan, PL20s were stocked at 100-150/m^2. Survival in nursery ponds ranged from 60-70% in Korea and Japan. In Taiwan, survival was as low as 10-20% (Table 5). In Taiwan, shrimp are fed both fresh and manufactured feed, and in Japan, they are only given formulated feed.

P. penicillatus are stocked in nursery ponds at 600-1,000/m^2 for 15-30 days in Taiwan. In Southern China, they are stocked at 1,000/m^2 for 12-20 days. Survival rates range from 10-20% in Taiwan and 30-40% in China (Table 5).

DISCUSSION GROUP C - Nutrition and Feed Types in Growout and Nursery

INTRODUCTION

The following topics were reviewed for both growout and nursery systems: types of feed and feeding rates, protein requirements, conversion ratios, and feed costs. These topics were reviewed for both growout and nursery systems. Comparative data are presented in Tables 1-5 and discussed below.

GROWOUT FEEDS

In China and Korea, *P. chinensis* are most commonly fed formulated feed. However, in China the type of food used ranges from 100% formulated to 100% fresh, depending on availability and price. Availability of formulated or fresh feed is affected by season and geographic location of the farm. Table 1 contains data on the number of shrimp feed mills in China and their capacities. In China, about 70% of the feed is formulated (Table 2; also see Hu Chapter 9, Liu Chapter 2, and Chen Chapter 8). In Korea, about 80% of the feed is formulated. The remainder is made up of trash fish, krill, and shellfish. When temperatures are high, during the summer months, fresh food is rarely used. When temperatures are low, before harvest, shrimp are fed more fresh food.

P. japonicus is primarily fed a formulated diet in Korea and Taiwan (Table 2, also see Liao and Chien Chapter 6). In Korea, they use fresh food before harvest to improve color (colorful shrimp are preferred by the Japanese market). In Taiwan, farmers use Monodon feed (diet developed specifically

Table 1. Capacities of shrimp feed mills in China (1986)[1].

Provinces	Production capacity (kg)	Numbers of mills with capacity >3,000 mt/y
Tianjin	10,000	2
Hebei	28,000	5
Liaoning	46,900	8
Shanghai	8,000	2
Jiangsu	30,000	3
Zhejiang	10,000	2
Fujian	40,000	2
Shandong	40,000	6
Guangdong	40,000	4
Total	310,500	37

[1]Source: State Aquaculture Division, March, 2, 1989. There are no statistics for years prior to 1986

Table 2. Growout feed types and feedings rates.

	Feed types	Feeding rates	#times/day	Time of day
P.chinensis				
S. China[1]	70% formulated (range from 100% fresh to 100% formulated)	Depends on type of culture	4-6	4x: 8 am, 2, 4, 8 pm 6x: 6, 10, 2, 6, 10, 2 2x: 6-7 am and 6 pm
Korea	80% formulated 20% trash fish, krill, shellfish	Intensively to satiation	4-6	Same as China but add more feed at night
P.japonicus				
Korea	80% formulated fresh feed (small fish molluscs, krill)	Twice a day	2	Sunset and midnight, never during the day
Taiwan	Monodon feed supplemented w/trash fish	In early stages, fed 15% body weight per day, gradually reduced to 3%	2-3 (at night)	5 pm, 10 pm, 2-4 am
Japan	1. Formulated 2. Mixed feeding of formulated feed and frozen trash fish and crustacean.	If using only formulated feed, 15% of body weight, gradually reduced to 1%	1	After sunset
P.penicillatus				
Taiwan	Monodon feed supplemented w/ trash fish	In early stages, fed 15% body weight per day, gradually reduced to 3%	4-6, mostly 4	6 am, 10 am, 4 pm, 10 pm

[1]Fujian and Guangdong provinces

for *P. monodon*) for *P. japonicus*. The feed is supplemented with trash fish. During the winter, fish oil and vitamin C are added. In Japan, two different feeding strategies are used for *P. japonicus*. Some farms only use a formulated diet, while others use a combination of formulated feed and frozen trash fish and crustaceans. *P. penicillatus* diets include Monodon feed and trash fish (Table 2, but also see Hu Chapter 9).

In China, feeding rates vary according to the culture technique used (Table 1). No feed is used on extensive farms. On semi-intensive and intensive farms, the feeding rate depends on the quality of feed; shrimp are usually fed 2-6 times per day (Table 2).

P. chinensis cultured in Korea are fed to satiation (Table 2). Shrimp are fed 4-6 times per day, but more feed is distributed at night. *P. japonicus* in Korea are only fed twice, at sunset and midnight, never during the day.

Both Taiwan and Japan feed *P. japonicus* about 15% of their body weight during the early life stages (Table 2). As the shrimp grow, the feeding level is reduced to 3% body weight in Taiwan and 1% body weight in Japan. In Taiwan, *P. japonicus* is fed 2-3 times

Table 3. Growout protein levels, feed conversion ratios and costs.

	Protein	FCR	Feed cost
P. chinensis			
S. China[1]	40-45%	2.5-4:1	$0.81-1.10/kg
Korea	45-48%	2-2.5:1	$2.00/kg
P. japonicus			
Korea	55-58%	2.5 1	$3.85/kg
Taiwan	50% (50-60% protein necessary)	1.4-2:1	$1.60-1.80/kg
Japan	58-62%	2:1 until December 2.6 1 after	$5.00/kg
P. penicillatus			
Taiwan	Requirement probably<30%	1.4-1.7:1	$1.10-1.30/kg

[1]Fujian and Guangdong provinces

per night (see Table 2 for times), and in Japan, once per night just after sunset.

In Taiwan, *P. penicillatus* are fed to satiation, 4-6 times per day. Feeding times are given in Table 2.

PROTEIN LEVELS AND FEED CONVERSION RATIOS IN GROWOUT

Formulated feed for *P. chinensis* contains 40-45% and 45-48% protein in Southern China and Korea, respectively (Table 3). Feed conversion ratios (FCR) are 2.5-4:1 in China, and 2-2.5:1 (for formulated diets) in Korea. Feed prices are quoted in Table 3 (also see Liao and Chien Chapter 6).

P. japonicus have a higher protein requirement. In Korea, *P. japonicus* farmers use a 55-58% protein diet (Table 3). In Taiwan, they mainly use a 50% protein diet, although experts there reported that 50-60% was required (also see Liao and Chien Chapter 6). In Japan, they use a 58-62% protein diet (Table 3).

P. penicillatus has the lowest protein requirements. Taiwanese scientists said the protein requirement is probably <30%, and the FCR ranges from 1.4-1.7:1 (Table 3, also see Liao and Chien Chapter 6).

NURSERY FEEDS

In China, *P. chinensis* is held in the nursery from PL5-25 and given formulated feed, fresh crushed molluscs, small shrimp, and fish (Table 4). Some organic fertilizer is occasionally used in ponds. In Korea, PL20's are nursed until they reach 1 g (about 45 days) and given high quality formulated feed. Sometimes fresh feed is used in Korea.

P. japonicus is given a formulated diet in Japan and held in nursery ponds from PL20 to 1 g (about 45 days, Table 4). In Korea, the nursery phase also lasts about 45 days (PL25 to 1 g) for *P. japonicus*. The nursed shrimp are fed a higher quality feed than is used in

Table 4. Nursery feed types and feeding rates.

	Duration of nursery phase	Feed types	Feeding rates	#times/day	Time of day
P.chinensis					
N.China[1]	PL 5-7 to 25	Formulated, fresh crushed molluscs, also small shrimp and fish	To satiation	Mostly 4, up to 6	Mostly during daylight
Korea	PL 20 to 1g	Mostly formulated, some fresh, sometimes tanks fertilized	To satiation	Every 4 hours, more at night	Every 4 hours
P.japonicus					
Korea	From PL 25 to 1g, (about 45 days)	Mostly formulated, some fresh, sometimes tanks fertilized	To satiation	4	8, 2, 8, 12
Taiwan	PL-15 or 25, PL-25 or 35	PL 10-35: *Artemia* ground shrimp and fish, steamed egg (supplemented with fish meal and vitamins) artificial feed crumb	Green water method, less artificial feed	Mostly 3	8 am, 5 pm, 10 pm
Japan	PL 20 to 0.5-1.0g (40-50 days)	Formulated feed	15-30% of body weight or as much as will consume	2	Morning and evening
P.penicillatus					
Taiwan	PL5-15 or 25, PL5-25 or 35	PL 10-35: *Artemia* ground shrimp and fish, steamed egg (supplemented with fish meal and vitamins) artifical feed crumb.	Green water method, less artificial feed	Mostly 3	8 am, 5 pm, 10 pm

[1]Chiefly Liaoning, Hebei and Shandong provinces

growout. In Taiwan, *P. japonicus* and *P. penicillatus* are held in the nursery from PL10-35 and fed *Artemia*, ground shrimp and fish, steamed egg, fish meal and vitamins and some artificial feed crumb. See Hu (Chapter 9) for details on *P. penicillatus* nursery feed in Southern China.

P. chinensis in China and Korea, and *P. japonicus* in Korea are fed to satiation, four times a day during the nursery phase (Table 4). In Taiwan, they feed the nursery ponds three times per day and use the green water method for *P. japonicus* and *P. penicillatus*. As a result, less artificial feed is used during the nursery phase. In Japan, they use a formulated diet for *P. japonicus* and feed 15-30% body weight twice each day.

Table 5. Nursery protein levels and feed conversion ratios.

	Protein requirement	FCR
P.chinensis		
N.China[1]	40-45%	2.5-4:1
Korea	Ca. 50%	1.3-1.5:1
P.japonicus		
Korea	55-58%	1.5:1
Taiwan	50-60%	2.0-3.0:1
Japan	58-62%	1.0:1
P.penicillatus		
Taiwan	43% and upwards	2.0-3.0:1

[1]Chiefly Liaoning, Hebei and Shandong provinces

PROTEIN LEVELS AND FEED CONVERSION RATIOS IN NURSERY

P. chinensis are fed the same protein ration diet for nursery and growout in China (Table 5). The FCR varies from 2.5-4:1. In Korea, they use a 50% protein feed for *P. chinensis* and the conversion ratios range from 1.3-1.5:1.

P. japonicus nursery feed is 50-62% protein (Table 5). In Japan, they achieve a 1:1 FCR using a 58-62% protein feed. The Korean experts quoted an FCR of 1.5:1, while Taiwan stated that the FCR ranges from 2-3:1.

The protein ration for *P. penicillatus* in Taiwan is 43% or greater (Table 5). This results in an FCR of 2-3:1. Both *P. penicillatus* and *P. japonicus* exhibit greater survival than *P. monodon* during the nursery phase.

DISCUSSION GROUP D - Environmental Influences On Growth

INTRODUCTION

The topics for Discussion Group D included levels of temperature, salinity, pH, dissolved oxygen, transparency, H_2S, NH_3, and COD (chemical oxygen demand) in growout ponds. Optimal levels and ranges are given for many of these variables. The data are presented in Tables 1-5 and discussed below.

TEMPERATURE

Temperature tolerance and growth at different temperatures are critical parameters to consider when planning to culture shrimp in a particular location. The effect of temperature on growth was considered in detail during this discussion group.

Growth occurs in *P. chinensis* at temperatures as low as 14 and as high as 30°C. In China, 20-30°C is considered to be the optimal temperature range for *P. chinensis* (also see Zhang Chapter 11). In Korea, the optimal range is said to be between 20 and 25°C. Mortality of *P. chinensis* occurs at 4 and 38°C. Chinese scientists said that growth decreases at 14-18°C (Table 1, also see Liao and Chien Chapter 6, Hu Chapter 9 and Yang Chapter 10).

Participants from Taiwan, Korea and Japan disagreed about which temperature values resulted in optimal growth, and about the upper and lower temperature limits for growth of *P. japonicus*. Taiwan said that

Table 1. Relationship between temperature and growth.

	Temperature (°C)				
	Growth range	Best growth	Slow growth	Upper limit (lethal)	Lower limit (lethal)
P.chinensis					
N. China[1]	14-30	20-30	14-18	38	4
Korea	15-30	20-25	<15	-	5-6
P.japonicus					
Korea	10-30	22-27	<15	-	5-6
Taiwan	12-33	20-28	28-33	-	4
Japan	12-35	25-28	15-25	-	5-6
P.penicillatus					
Taiwan	12-33	20-28	28-33	-	-
S. China[2]	-	23-30	<20	-	-

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

growth occurs at temperatures as low as 15 and as high as 30°C. In Korea, growth was said to occur between 10 and 30°C, and in Japan, growth takes place between 15 and 35°C. The optimal temperature for *P. japonicus* is between 20 and 28°C, according to Taiwanese scientists. Korean and Japanese scientists said that 22-28°C is the optimal temperature for growth, and the lower lethal temperature is 5-6°C. Both Japanese and Taiwanese participants said that there is no growth <12°C and that shrimp stop feeding at 10°C. In Taiwan, the upper limit for growth is 33°C; growth slows between 28 and 33°C (Table 1).

Taiwanese participants said that the temperature tolerance, and the relationship between growth and temperature are the same for both *P. penicillatus* and *P. japonicus*. However, the paper submitted by participants from Taiwan states that the optimal temperature for *P. penicillatus* is 25-30°C, and the minimum spawning temperature is 23°C (see Chapter 6). In Southern China, they have found that optimal growth occurs between 23 and 30°C, and the lower limit for growth is 20°C (Table 1; also see Hu Chapter 9)

SALINITY

The optimal salinity range for *P. chinensis* during growout is 20-40 ppt, according to the Chinese discussion group participants (also see Yang Chapter 10). In Korea, they have found that optimal salinities vary between 25 and 30 ppt (Table 2, also see Kim Chapter 7). None of the participants were aware of any attempts to control salinity, since natural seawater is used in shrimp ponds. In China, *P. chinensis* has been found in river mouths and estuaries at salinities of 2 ppt.

The range of salinities for *P. japonicus* is 20-28 ppt according to scientists from Taiwan. However, salinities as low as 15 and as high as 38 ppt occur in shrimp ponds. Salinities range between 15 and 25 ppt in *P. penicillatus* ponds in Taiwan. In Southern China, salinities range from 12-29 ppt (Table 2, also see Liao and Chien Chapter 6 and Kim Chapter 7).

pH AND DISSOLVED OXYGEN

In China, the optimal pH for *P. chinensis* is 8-9 and the lower and upper limits are 6 and 9, respectively (also see Yang Chapter 10). In Korea, the pH in *P. japonicus* and *P. chinensis* growout ponds is 8-8.9 but 8.4-8.6 is optimal (also see Kim Chapter 7). The pH range for *P. japonicus* is 7.8-8.8 in Taiwan, and 8-8.6 in Japan. The broadest pH range is found in *P. penicillatus* culture in Taiwan (7.6-9, Table 3).

The optimal dissolved oxygen (DO) level for *P. chinensis* is 4-6 ppm in both Korea and Northern China. The range of DO levels found in *P. chinensis* ponds in Korea is 3-7 ppm. In China, 1 ppm is thought to be lethal for *P. chinensis* (Table 4).

Korean experts also said that *P. japonicus* DO tolerances range from 3-7 ppm, but the optimal level is 4-6 ppm. In Japan, DO is 3-8 ppm (Table 4).

In Taiwan, *P. penicillatus* is thought to be more sensitive to low DO levels than *P.*

Table 2 Relationship between salinity and growth.

	Salinity (ppt) Growth range	Best growth	Lower limit (lethal)
P.chinensis			
N. China[1]	-	20-40	2
Korea	15-33	25-30	-
P.japonicus			
Korea	15-33	25-30	-
Taiwan	20-28	-	-
Japan	32-38	-	-
P.penicillatus			
Taiwan	15-25	-	-
S. China[2]	12-29	-	-

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

japonicus. The lower DO limit for *P. penicillatus* is 4 ppm (Table 4).

H_2S, NH_3, COD AND TRANSPARENCY

H_2S has not been a problem in *P. chinensis* and *P. japonicus* ponds in Korea because the ponds are only used once a year for shrimp culture. Ponds are dry during the winter and tilled before filling in the spring. In China, H_2S levels are usually less than 0.1 ppm in *P. chinensis* ponds. In Taiwan, H_2S levels in the sediment are very low in *P. japonicus* ponds as a result of the burrowing behavior of the shrimp. In Japan, they find 4-8 ppm H_2S in the water immediately above

Table 3. Relationship between pH and growth.

	pH Growth range	Best growth	Upper limit (lethal)	Lower limit (lethal)
P.chinensis				
N. China[1]	-	8-9	9	6
Korea	8.0-8.9	8.4-8.6	-	-
P.japonicus				
Korea	8.0-8.9	8.4-8.6	-	-
Taiwan	7.8-8.8	-	-	-
Japan	8.0-8.6	-	-	-
P.penicillatus				
Taiwan	7.6-9.0	-	-	-

[1]Chiefly Liaoning, Hebei and Shandong provinces

Table 4. Relationship between dissolved oxygen and growth.

	Dissolved oxygen (ppm)		
	Growth range	Best growth	Lower limit (lethal)
P.chinensis			
N. China[1]	-	>4	<1
Korea	3-7	4-6	-
P.japonicus			
Korea	3-7	4-6	-
Taiwan	>4	-	-
Japan	3-8	-	-
P.penicillatus			
Taiwan	>4	-	-

[1]Cheifly Liaoning, Hebei and Shandong provinces

the sediment, and no H_2S in the water column (Table 5).

The NH_3 levels in *P. chinensis* and *P. japonicus* ponds in Korea do not exceed 5 ppm. In China, NH_3 has not exceeded 0.2 ppm, and in Japan, they measure NH_3 at 0-1 ppm. In Taiwan, the NH_3 levels are just now being investigated (Table 5).

Chemical oxygen demand (COD) has been measured in China, Korea and Japan. The COD levels are 5 mg/l in *P. chinensis* and *P. japonicus* ponds (Table 5).

Transparency is frequently measured in shrimp ponds. In China investigators said that when the water is too transparent (>50 cm), shrimp do not grow. If transparency is less than 30 cm, they exchange the water to increase transparency. Taiwanese participants said that they also maintain transparency between 30-50 cm in *P. penicil-*

Table 5. H_2S, NH_3, COD and transparency levels in shrimp ponds.

	H_2S	NH_3	COD	Transparency (Secchi disk)
P.chinensis				
N. China[1]	<0.1 ppm	<0.2 ppm	5mg/l	30-50 cm
Korea	-	<5 ppm	5mg/l	30 cm
P.japonicus				
Korea	-	<5 ppm	5mg/l	30 cm
Taiwan	None in water, H_2S in sediment is low	Ongoing research	-	-
Japan	None in water, 4-8 ppm in water of bottom soil.	0-1 ppm	5mg/l	30-200 cm
P.penicillatus				
Taiwan	-	Ongoing research	-	30-50 cm

[1]Chiefly Liaoning, Hebei and Shandong provinces

latus ponds (Table 5). In Japan, transparency varies between 30 and 200 cm in *P. japonicus* ponds. In Korea, transparency is maintained at 30 cm (Table 5).

DISCUSSION GROUP E - Effects of Disease and Predation on Growout

INTRODUCTION

Disease and predation can seriously impact production of penaeid shrimp. Taiwan has probably suffered the greatest losses from disease, consequently, their researchers have done a great deal of disease-related research. Four types of pathogens cause disease in cultured shrimp: (1) viruses (eg. MBV), (2) bacteria (both internal and epicommensal), (3) fungi, and (4) protozoa (mostly epicommensal ciliates). The major predators in growout ponds are fish and birds.

DISEASES

Incidence

Thirty-four shrimp diseases have been identified by researchers at the Shandong University of Oceanography in Northern China. There are two serious diseases, one caused by a gram negative *Vibrio* (a bacteria), the other by an epicommensal bacteria (also see Liu Chapter 2). The *Vibrio* infections are more serious, and losses may range from 10-30%. Epicommensal fouling by ciliates reduces growth, but can be eliminated when the shrimp molt. Korean shrimp producers do not have much disease-related mortality in their stocks, though *Vibrio* infections do occur in both *P. chinensis* and *P. japonicus* in Korea. The epicommensal bacteria *Leucothrix* is a common gill parasite, and disease-causing ciliates have also been found in growout ponds. *Vibrio* and ciliates infect *P. japonicus* cultured in Japan, while the fungus *Fusarium* is rare. Both *P. japonicus* and *P. penicillatus* grown in Taiwan have been diagnosed with bacterial infections of the hepatopancreas, epicommensal ciliates, external bacterial infections, and black spot disease (etiology unknown). Furthermore, *P. penicillatus* in Taiwan have MBV (Table 1). No cases of runting or deformities as a result of disease were reported during the discussion.

Causes

Scientists in Northern China attribute the incidence of disease to poor water quality which may result from overcrowding and/or overfeeding. In Korea, water and sediment quality (H_2S fouling at pH = 7.2-7.5) are thought to be the cause of disease. Infections are more common in *P. chinensis* in hot weather, and the burrowing *P. japonicus* is more susceptible to disease than *P. chinensis*. Japan cites overcrowding and "carelessness about nutrition" as causes of disease. Finally, the Taiwanese experts listed the following disease-related factors: (1) deterioration of sediment and water quality, (2) overcrowd-

Table 1. Diseases and treatments.

	Types of disease	Treatments
P. chinensis		
N. China[1]	*Vibrio*, ectoparasites, few viral and fungal	Antibiotics added to feed for bacterial diseases.
Korea	*Vibrio*, *Leucothrix*, fungus, ciliates	Antibiotics added to feed for bacteria, 30 ppm formalin for fungus and protozoa, best treatment is to exchange 90% water.
P. japonicus		
Korea	*Vibrio*, *Leucothrix*, fungus, ciliates	Antibiotics added to feed for bacteria, 30 ppm formalin for fungus and protozoa, best treatment is to exchange 90% water.
Taiwan	Bacterial infections of hepatopancreas, epicommensal ciliates and bacteria, black spot disease	For protozoa: formalin, saponin, methylene blue (see text).
Japan	Mostly *Vibrio, Fusarium* rare, ciliates observed	Antibiotics for bacterial diseases.
P. penicillatus		
Taiwan	Bacterial infections of hepatopancreas, epicommensal ciliates and bacteria, black spot disease, and MBV	For protozoa: formalin, saponin, methylene blue (see text), For MBV: furazolidone, neomycin, streptomycin, oxytetracycline, chloramphenicol, tetracycline, nitrofurazone.

[1]Chiefly Liaoning, Shandong and Hebei provinces

ing, (3) poor nutrition, (4) excess or unnecessary medication, and (5) pollution.

Treatments

Workers in Northern China, Korea and Japan add antibiotics to the feed if shrimp are diagnosed with bacterial diseases. Korean farms will sometimes add 30 ppm of formalin to treat fungus and protozoa, but experts believe that the best treatment for disease is lowering the pond water to 10% of its original volume and then refilling with tidal flow. For the treatment of protozoan infections, the Taiwanese add the following chemicals and flush: (1) up to 25 ppm formalin, (2) 5 ppm of a 10% solution of saponin, and (3) 8 ppm methylene blue. Furthermore, MBV infections in *P. penicillatus* may be treated with any of the following: (1) furazolidone, (2) streptomycin, (3) oxytetracycline, (4) chloramphenicol, (5) tetracycline, and (6) nitrofurazone. There is no treatment for bacterial diseases (Table 1).

Table 2. Types of predators/competitors and treatments.

	Predators/competitors	Treatments
P. chinensis		
N. China[1]	Gobi, perch, birds, rats, crabs, humans	Screen at inlet, 15-20 ppm saponin, (prior to stocking) rotenone, many other chemicals, lime
Korea	Sea gulls, other birds, gobi, crayfish	Screen at inlet
P. japonicus		
Korea	Sea gulls, other birds, gobi, crayfish	Screen at inlet
Taiwan	Birds, fishes	For fishes: 1) filter water through sand, screen at inlet, 2) dry and clean pond bottom prior to stocking (treat with lime, saponin, etc.). For birds: steepen bank slope, put string along pond bank
Japan	Mainly fish	Screen at inlet, dry pond prior to culture, apply calcium hypochlorite
P. penicillatus		
Taiwan	Birds, fishes	For fishes: 1) filter water through sand, screen at inlet, 2) dry and clean pond bottom prior to stocking (treat with lime saponin, etc). For birds: steepen bank slope, put string along pond bank
S. China[2]	Sea snakes (*Eleutheronema tetradactylum*), birds, rats, crabs, humans	Data not available

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guandong provinces

PREDATION

Gobi and perch are the most serious predators of cultured shrimp in China. The sea snake, *Eleutheronema tetradactylum*, is a problem in Southern China, while all culture areas in China also suffer losses due to birds, rats, crabs, and human poaching. In Korea, sea gulls and gobi feed on cultured shrimp (also see Kim Chapter 7). Large gobi eat freshly-molted individuals, while the smaller fish compete with the shrimp for food and oxygen. Crayfish may also inhabit sandy bottoms and eat shrimp feed. Fish are the main predators in Japan, while Taiwan cited problems with both fish and birds (Table 2). Korea, Northern China and Japan all reported that losses due to predation may be severe. There are several ways to counter the negative effects of predators and competitors in growout ponds. These include the use of screens and chemicals (saponin, calcium hypochlorite, etc.; see Table 2).

DISCUSSION GROUP F - Design and Management Practices in Hatchery Systems

INTRODUCTION

The topics for Discussion Group F included the physical design, water system, feeds, and management practices for *P. chinensis, P. japonicus* and *P. penicillatus* hatcheries. Hatcheries usually rear shrimp from eggs to PL5-PL30. In some cases, the resulting postlarvae are stocked into nursery ponds, or they may be transferred directly to growout ponds. Hatchery-raised fry are the sole source of postlarvae for growout operations in Northern and Southern China, Taiwan, Korea and Japan.

In addition to maintaining high water quality, a major concern of hatcheries is the production of live food (including both algae and live animal feed) in sufficient quantities. Although the first larval stage of shrimp, the nauplius, does not require food, the subsequent zoeal stage feeds on algae, mysis eat both algae and zooplankton, and the postlarval stages are usually given zooplankton and/or artificial feeds (see Liao and Chien Chapter 6, Table 3 for comparative hatchery data for all three species).

PHYSICAL DESIGN

In Northern China, Korea, Taiwan, and Japan, hatchery tanks are either round or rectangular and constructed of either concrete or fiberglass-reinforced plastic (FRP, Table 1). Hu (Chapter 9) indicates that in Southern China, shrimp larvae are reared in covered, concrete ponds, most of which are rectangular. Tanks vary greatly in size. For example, Korean hatchery tanks range from 2-150 m^3 for *P. chinensis*, while those for *P. japonicus* can be larger than 200 m^3 (also see Rho, Chapter 3-4). In Southern China, hatching ponds may be 10-100 m^3 in size (Hu, Chapter 9). Tank depth ranges from 1-2 m for the three species (Table 1).

WATER SYSTEM

Larval rearing requires a source of clear, clean seawater. All countries use some method for purifying the pumped seawater. In Northern China, both settling tanks and bolting silk are used (see Wang and Ma, Chapter 5 for a complete description of water supply systems in *P. chinensis* hatcheries in Northern China). Korea follows sand filtration with settling and then cartridge (5-10 μm) filtration. Both Japan and Taiwan utilize sand filtration only (Table 2).

As for water sterilization, it is rare or absent in Taiwanese and Japanese hatcheries. Korean hatcheries treat their water with UV light prior to hatching and Northern China sterilizes the water chemically (Table 2). Liu (1983) reported that 2-10 ppm of Na-EDTA is added to the water to

Table 1. Physical characteristics of hatcheries.

	Shape	Construction materials	Volume (m^3)	Depth (m)
P. chinensis				
N. China[1]	Rectangular	Concrete; fiberglass rare	20-100	1.5-1.8
Korea	Round	Cement and FRP	2-150	1-1.5
P. japonicus				
Korea	Round	Cement and FRP	50-200	1-1.8
Taiwan	Round or rectangular	FRP or cement	100-200	1.5-2
Japan	Rectangular	Concrete	60-200 or larger	2
P. penicillatus				
Taiwan	Round or rectangular	FRP or cement	50-100	1.5-2

[1]Chiefly Liaoning, Hebei and Shandong provinces. In most cases data were not available for the southern provinces.

chelate zinc, copper and other heavy metal pollutants.

Heating the larval-rearing water is unnecessary in Korea and some parts of Southern China. Various methods are used in the locales where heating is required. In Northern China, coal boilers are common, though electric infra-red radiating plates placed above tanks may also be used. (See Wang and Ma, Chapter 5 for more information on heating systems used in Northern China.) Taiwanese hatcheries may have one of three heating devices: an electric boiler, heating wires applied to the tank bottoms, or

Table 2. Hatchery water systems.

	Water source	Filtration	Sterilization	Exchange rate
P. chinensis				
N. China[1]	Pumped to settling tank	1. Sand 2. Bolting silk (120-150 mesh)	Chemical	After 3-4 days, 10-100 %/day
Korea	Pumped	1. Sand 2. Settled 3. Cartridge-filtered	UV	50-60 %/day
P. japonicus				
Korea	Pumped	1. Sand 2. Settled 3. Cartridge-filtered	UV	50-60 %/day
Taiwan	Pumped	Sand	Most have none	Every 2-3 days, 10-100 %
Japan	Sand-filtered seawater	Sand	None	20-40%
P. penicillatus				
Taiwan	Pumped	Sand	Most have none	Every 2-3 days, 10-100 %

[1]Chiefly Liaoning, Hebei and Shandong province

glass immersion-style heating sticks. Either a stainless steel coil on the bottom of a tank or a titanium coil on the sidewall of a tank may be used to provide heat in Japanese hatcheries.

Water exchange rates vary among locations. Korean hatcheries exchange 50-60% of the tank water per day (also see Rho, Chapter 3-4). In Northern China there is no water exchange for the first 3-4 days, then the daily exchange rate may be 10-100%, with the lower rates characterizing earlier stages (also see Wang and Ma, Chapter 5). This is similar to practices in Southern China (Hu, Chapter 9). Taiwanese hatcheries exchange water every 2-3 days, at which time the daily rate may be anywhere from 10-100%. Finally, in addition to a daily water exchange rate of 20-40%, Japanese hatcheries add 15 cm of water daily, beginning at the mysis stage and continuing until the larvae reach 22 cm (Table 2).

LARVAL FEEDS

Propagating algae may be accomplished by inoculating the larval tanks with cultured diatoms and then allowing them to reproduce naturally. This algal culture technique has been termed the "Japanese" method. Diatom growth is further encouraged in Japanese hatcheries by the addition of fertilizer (specifically, SH medium) to the culture water. In Korea, if algal growth in the tanks is too slow, diatoms are grown separately and fed to the shrimp (see Rho Chapter 3-4 for complete descriptions of diatom cultivation for *P. japonicus* and *P. chinensis*). Northern China hatcheries culture approximately 30% of their algae in separate tanks. (Also see Wang and Ma, Chapter 5; and see Hu, Chapter 9 for a description of algal culture for shrimp larvae in Southern China.) The algal feeding density varies from 100,000 to 500,000 cells/ml among countries (Table 3).

A number of different species of diatoms are used to feed shrimp larvae. The most common genera include *Chaetoceros, Phaeodactylum, Nitzschia, Skeletonema, Isochrysis*, and *Navicula* (Table 3; Wang and Ma, Chapter 5; also see Hu, Chapter 9 for a list of algal species cultured in Southern China and survival rates of *P. penicillatus* larvae given different feeds).

For mysis and postlarvae, live animal feeds are usually cultured separately and then added to the larval-rearing tanks. Without exception, *Artemia* are used as a food source, but rotifers and even shrimp mysis may be used for food as well (see Table 3; Wang and Ma, Chapter 5; Hu, Chapter 9). The cost and quality of *Artemia*, a major food source for larvae, are important issues. In Northern China, *Artemia* cost 4,000-5,000 RMB per metric ton (.49-.61 $US/pound). Japanese and Taiwanese hatcheries pay much more, 30-35 $US per pound, while in Korea the going rate is 60-90 $US per pound. In Japan and Taiwan, *Artemia* cysts are acceptable if they have a hatching rate of >80%. Anything over 70% is acceptable in Korea.

The use of artificial feed for mysis and postlarvae is uncommon in Northern China (but see Wang and Ma, Chapter 5). In Korea, however, 50-700 μm formulated feed (the particle size depends on the larval stage being fed) is used (see Rho, Chapter 3-4 for details

Table 3. Larval feed.

	Types of algae	Algal feeding density (cells/ml)	Types of live animal feeds
P. chinensis			
N. China[1]	*Chaetoceros, Isochrysis, Phaeodactylum, Platymonas, Nitzschia*	100,000	*Artemia*, some rotifers
Korea	*Skeletonema, Chaetoceras, Navicula, Nitzschia*	300,000-500,000	*Artemia*, shrimp mysis, rotifers
P. japonicus			
Korea	*Skeletonema, Chaetoceros, Navicula, Nitzschia*	300,000-500,000	*Artemia*, shrimp mysis, rotifers
Taiwan	Mostly *Skeletonema* and *Chaetoceros*	160,000-200,000	*Artemia*; Rotifer use uncommon
Japan	*Chaetoceros, Nitzschia, Skeletonema, Thalassiosira*	100,000-300,000	*Artemia* (from mysis through PL4)
P. penicillatus			
Taiwan	*Skeletonema, Isochrysis, Chaetoceros, Tetraselmis*	10,000-200,000	*Artemia*, Rotifer use uncommon

[1]Chiefly Liaoning, Hebei and Shandong provinces

about feed types, concentrations, and feeding frequency). Formulated feed is also used extensively in Japanese hatcheries. Taiwanese hatcheries commonly supply "brine shrimp flake" and BP and AP (artificial plankton) to both zoea and mysis. Additional food types for PL5 and subsequent postlarval stages in Taiwan include steamed eggs, ground fish, and shrimp. In Southern China (Hu, Chapter 9), soybean milk, egg yolk, marine yeast powder and formulated diets are used when sufficient quantities of live feed are not available.

HATCHERY MANAGEMENT

Management practices vary according to species and geographic location. In Northern China, larvae are kept in the hatchery to the PL7 stage, usually 20 days. In Taiwan, both *P. japonicus* and *P. penicillatus* larvae are transported from the hatchery as PL5's, that is, after 15.5 days for *P. japonicus* and after 13.5 days for *P. penicillatus*. *P. chinensis* in Korea are grown to PL20-25 (40 days), whereas *P. japonicus* are reared longer, to PL 30 (32-40 days, see Table 4).

The initial density of larvae may be anywhere from 3,000-200,000 nauplii per m^3 (Table 4; also see Wang and Ma, Chapter 5; and Rho, Chapter 3-4). Survival rates from egg through the end of the hatchery phase range from a low of 6.2% for *P. chinensis* in Korea to the more commonly reported 30% for *P. chinensis* in Northern China and *P. penicillatus* in Taiwan (Table 4; also see Rho,Chapter 3-4; and Liao and Chien, Chapter 6). Reported yields are as low as 3,000-10,000 per m^3 (for *P. japonicus* in Japan), and as high as 150,000-200,000 per m^3 (for *P. chinensis* in Northern China, Table 4).

The price of postlarvae varies markedly. Northern and Southern China reported the same price for both *P. chinensis* and *P. penicillatus*: $7-12 per 10,000 PL5-7 and $20-50 per 10,000 PL25. Doosan Industrial Co. in Korea produces *P. japonicus* and *P. chinensis* PL20-25 for $5 per 1,000 and sells them for $8 per 1,000. The going rate in Taiwan for *P. penicillatus*, PL20-25, is $5.1-6.4 per 1,000 and $7.6-9.0 per 1,000 for PL30-35. Finally, in Japan the cost of *P. japonicus*, PL20, is $3.5 per 1,000.

Table 5 contains production statistics for shrimp hatcheries in China from 1980-1987.

REFERENCES

Liu, R. 1983. Shrimp mariculture studies in China. *In*: Proc. 1st Int. Conf. Warm Water Aquacul.-Crustacea, pp. 82-90.

Table 4. Hatchery management practices.

	Length of hatchery	Nauplii density (per m^3)	Survival (%)	Yield (per m^3)
P. chinensis				
N. China[1]	To PL7 (20 days)	200,000-500,000	30	150,000-200,000
Korea	To PL20-25 (40 days)	50,000-70,000	6.2	8,000-10,000
P. japonicus				
Korea	To PL30 (32-40 days)	50,000-60,000	11	10,000
Taiwan	To PL5 (15.5 days)	100,000-150,000	25	60,000
Japan	To PL20-30 (30-40 days)	30,000-70,000	10-30	3,000-10,000
P. penicillatus				
Taiwan	To PL5 (13.5 days)	200,000-500,000	30	70,000

[1]Chiefly Liaoning, Hebei and Shandong provinces

Table 5. Production and capacity of Chinese hatcheries (1980-1987).

	1980		1981		1982		1983	
Province	PL's produced (10^3 inds)	Hatchery capacity (m^3)	PL's produced (10^3 inds)	Hatchery capacity (m^3)	PL's produced (10^3 inds)	Hatchery capacity (m^3)	PL's produced (10^3 inds)	Hatchery capacity (m^3)
Liaoning	4,118.7		42,600	7,050	179,540	7,050	772,400	9,269
Hebei	180.0		2,540	1,470	13,670	1,500	94,080	1,896
Tianjin	15,580.0	388	9,470	388	24,280	500	53,180	833
Shandong	197,866.0	29,000	971,950	23,620	1,383,720	28,000	1,411,090	33,261
Jiangsu	55,122.0	23,360	432,960	15,249	842,360	21,000	1,304,210	16,056
Shanghai	7,000.0	400	3,800	400	1,500	400	3,850	400
Zhejiang	12,838.5	1,376	24,140	670	111,720	2,600	223,850	2,882
Fujian	37,070.7	3,696	70,100	8,216	165,910	8,216	281,520	9,497
Guangdong	4,740.0		80,010	3,800	44,650	4,000	56,770	5,100
Guangxi	2,860.0		8,680	1,310	22,160	2,000	41,760	1,588
Total	337,375.9	58,220	1,646,250	62,173	2,789,510	75,266	4,242,710	80,782

Table 5. Continued

Province	1984		1985		1986		1987	
	PL's produced (10^3 inds)	Hatchery capacity (m^3)	PL's produced (10^3 inds)	Hatchery capacity (m^3)	PL's produced (10^3 inds)	Hatchery capacity (m^3)	PL's produced (10^3 inds)	Hatchery capacity (m^3)
Liaoning	2,551,270	22,692	6,740,070	36,432	11,146,530	50,610	21,082,110	72,023
Hebei	298,480	2,756	1,868,700	12,540	4,230,760	21,111	8,378,910	33,689
Tianjin	179,870	833	443,780	5,205	602,870	7,581	1,897,640	10,732
Shandong	2,439,440	34,712	5,319,090	42,250	8,248,070	56,056	17,346,910	85,207
Jiangsu	1,532,220	19,563	3,015,850	18,424	4,070,450	25,917	7,845,740	29,189
Shanghai		400		400				
Zhejiang	385,740	2,780	850,960	5,750	2,842,290	15,050	4,812,310	19,428
Fujian	63,550	5,666	351,033	6,488	2,140,170	29,100	4,572,970	54,129
Guangdong	127,040	5,843	325,795	9,230	1,093,680	13,392	6,347,980	38,214
Guangxi	192,880	3,176	31,796	600	90,770	2,575	158,670	5,520
Total	7,770,490	98,421	18,947,074	137,319	34,465,590	221,392	72,443,240	348,131

DISCUSSION GROUP G - Environmental Influences on Growth Rates

INTRODUCTION

Discussion during this session focused on environmental factors which may influence growth rates in the hatchery. "Environmental factors" is here broadly defined to include environmental variables such as temperature and salinity as well as disease and other stresses.

ENVIRONMENTAL VARIABLES

Acceptable temperature ranges reported for embryo-PL7 are in Table 1. Furthermore, 80-95% of *P. chinensis* eggs will hatch at 18-25°C. Seventy-five percent hatching will also occur at 11-12.5°C, but will take more than twice as long.

The coolest overall temperature ranges were reported for *P. chinensis* in Northern China, 18-26°C, whereas the warmest temperatures were for *P. penicillatus* in Southern China, 23-32°C. Temperature data for all other species and locations fell within the range of 22-30°C (Table 2; but see Rho Chapters 3-4; also see Liao and Chien Chapter 6, Table 4, for a comparison of optimal parameters for all three species; and Wang and Ma Chapter 5).

Researchers were also asked about the lowest temperature at which larvae could be maintained. For *P. chinensis* that value was reported as 15°C in Northern China and Korea. Southern China and Taiwan reported 18.5 and 20°C as the lower limits for *P. penicillatus*, while Korea gave 15°C for *P. japonicus*. Finally, Japan indicated that larval growth in

Table 1. Suitable temperature ranges for larval stages.

	Temperature (°C)				
	Embryo	Nauplius	Zoea	Mysis	PL1-7
P. chinensis					
N. China[1] Korea	18-24	20-22	22-24	23-24	25-26
P. japonicus					
Korea Taiwan Japan	27-30	27-30	27-30	27-30	25-28
P. penicillatus					
Taiwan	23-29	26-32	26-29	26-29	25-30
S. China[2]	23-29	26-32	26-29	26-29	

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

Table 2. Ranges of environmental variables.

	Temperature (°C)	Salinity (ppt)	pH	DO
P. chinensis				
N. China[1]	18-26	16-37	7.8-8.6	5 mg/l
Korea	22-24	23-32	8.0-8.2	Constant aeration
P. japonicus				
Korea	27-28	30-33	8.5	Constant aeration
Taiwan	25-30	20-47	8.0-8.3	Constant aeration
Japan	25-28	32-34	8.1-8.6	Constant aeration
P. penicillatus				
Taiwan	23-30	18-31	8.0-8.3	Constant aeration
S. China[2]	23-32	25-32	No data available	No data available

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Fujian and Guangdong provinces

P. japonicus was dramatically reduced below 25°C.

Acceptable salinities for *P. chinensis* were 16-37 ppt in Northern China (however, only PL1-7 were able to tolerate salinities as low as 16-23 ppt) and 23-32 ppt in Korea. Taiwan reported the highest salinities; 20-47 ppt was the range given for *P. japonicus*. *P. japonicus* is cultured at 30-33 and 32-34 ppt, in Korea and Japan, respectively. The reported salinity range for *P. penicillatus* was 25-32 ppt in Southern China (also see Hu Chapter 9, Fig. 1) and 18-31 ppt in Taiwan (Table 2; also see Liao and Chien, Chapter 6, Table 4, for optimal salinity ranges). Additional data on salinity ranges at various larval stages were compiled during the background literature review and are presented in Table 3.

The acceptable pH range for larval *P. chinensis* culture in Northern China was given as 7.8-8.6; all other values reported during the discussion group fell within this range (Table 2; but see Rho Chapter 3; also

Table 3. Salinity and pH value ranges at various stages.

		Embryo	Nauplius	Zoea	Mysis	Postlarvae
Salinity (ppt)	Lower limit	20.35	20.41	21.58	20.25	9.37
	Upper limit	39.13	45.77	42.23	47.00	46.55
	Suitable	23.82	23.82	25.23	23.00	11.08
		36.97	41.53	37.79	44.20	43.48
	Optimal	24.54	27.23	27.23	25.30	16.60
		35.08	38.00	35.28	39.80	39.38
pH	Suitable	7.50	7.45	7.45	7.25	7.25
		8.78	9.00	9.05	9.30	9.30
	Optimal	7.84	7.75	7.80	7.60	7.60
		8.60	8.60	8.60	9.00	9.00

see Hu, Chapter 9, Fig. 2). Table 3 lists additional pH ranges at various larval stages. Finally, dissolved oxygen (DO) levels are 5 mg/l in Northern China, whereas Korea, Taiwan, and Japan all report constant aeration of hatchery tanks. Hu (Chapter 9, Fig. 5) presents the relationship between zoea survival and DO.

DISEASE

Due to their lack of serious disease problems in cultured larvae, Korea and Japan have not conducted much scientific investigation into the types, causes, and treatments of disease. Meanwhile, Northern China reports the incidence of *Vibrio*, fungal, and ciliate diseases in *P. chinensis* hatcheries (also see Wang and Ma, Chapter 5 for a more thorough discussion of the types, causes, and treatments of disease in larval *P. chinensis* grown in Northern China). In Taiwan, *Vibrio*, black gill disease, protozoan diseases (especially the ciliates *Epistylis* and *Zoothamnium*) and white turbid diseases affect *P. japonicus*. All of the aforementioned have also been found in *P. penicillatus* in Taiwan, in addition to midgut gland disease. Furthermore, *P. penicillatus* in Taiwan carry MBV (Table 4).

Where they have been investigated, diseases are generally thought to be caused by poor water quality. In addition, *P. chinensis* larvae in Northern China may be susceptible to disease because of poor quality feed. In Taiwan, protozoa are suspected to come from *Artemia*, while MBV in *P. penicillatus* is transmitted from broodstock (60% of spawners there carry MBV though they appear healthy). The impact of diseases on hatcheries appears to be negligible in Korea and Japan, however, greater losses have occurred in Northern China and Taiwan. In Northern

Table 4. Serious larval diseases and their treatment.

	Types of disease	Treatments
P. chinensis		
N. China[1]	*Vibrio*, fungus, protozoa (ciliates)	Malachite green for fungus, chloramphenicol and oxytetracycline for *Vibrio*
Korea	Not studied	None
P. japonicus		
Korea	Not studied	None
Taiwan	*Vibrio*, black gill disease, protozoa (esp. the ciliates *Epistylis* and *Zoothamnium*), white turbid disease	No data available
Japan	No major problem now	None
P. penicillatus		
Taiwan	*Vibrio*, black gill disease, protozoa (esp. the ciliates *Epistylis* and *Zoothamnium*). Larvae may harbor MBV. Midgut gland disease present but severity unknown.	No data available

[1]Chiefly Liaoning, Hebei and Shandong provinces

China, damages range from minor to 100% loss of crop.

Information on treating diseases in hatcheries is available only for *P. chinensis* in Northern China. Malachite green is used to treat fungus, while chloramphenicol and oxytetracycline have been effective against *Vibrio*. A satisfactory treatment for protozoa has not been found (Table 4). The absence of disease in Japan and Korea may be a result of drying the larval tanks completely before use. In Korea, both larval tanks and growout ponds are dry for long periods during the year. In Northern China, both broodstock and tanks are sterilized at the start of the hatchery process. Finally, for both *P. japonicus* and *P. penicillatus* hatcheries in Taiwan, tanks are sterilized with BKC and also coated with a substance that provides a poor surface for bacterial growth.

STRESS

There is general agreement among scientists in the northern provinces of China that there are three causes of stress in hatcheries: water which is too warm, high organic content (chemical oxygen demand [COD] exceeding 5 mg/l) and the presence of heavy metals in the water. In Korea, fluctuations in salinity and water temperature are sources of stress. Pond bottom deterioration has a negative impact on *P. japonicus* in Taiwan, whereas *P. penicillatus* larvae may be weakened by the use of high temperatures (to speed growth) and certain chemicals (to "hike up survival") during the hatchery phase.

DISCUSSION GROUP H - Maturation Systems

INTRODUCTION

Discussion during this session was generally limited to topics concerning the maturation (in nature and in captivity) of *P. chinensis* in Northern China (but see Hu, Chapter 9 for details on the overwintering, maturation and spawning of *P. penicillatus* in Southern China, and Rho, Chapter 3 and 4 for information concerning the spawning of *P. chinensis* and *P. japonicus*, respectively, in Korea). Northern and Southern China, Taiwan, Japan, and Korea depend primarily upon wild broodstock which they capture in the spring (see Chen, Chapter 8 for descriptions and merits of the three types of broodstock used in Northern China). Since they have abundant supplies of wild spawners, scientists are just beginning to study the optimal overwintering parameters, diseases and other stresses which might affect captive broodstock. It is generally believed that wild broodstock are more fecund than the smaller, weaker, overwintered spawners.

Captive and wild stocks of *P. chinensis* are very easy to mature, when compared to other commercially important penaeid species. Although most of the maturation information came from the scientists in Northern China, much of what was reported concerning the reproductive behavior of *P. chinensis* was confirmed by the Korean experts.

NATURAL REPRODUCTIVE CYCLE OF *P. CHINENSIS*

P. chinensis is a closed-thelycum species which mates in the fall (approximately mid-October) after a molt. Males are capable of multiple matings, and typically do not survive long after mating is complete. Individuals mature at the age of six months (when they are approximately 12-13 cm long). The spermatophore remains implanted in females through the winter, until spawning occurs in March or April. This is possible because ecdysis does not normally occur (at least in mated females) from October-April. Nearly 100% of the females collected in late October in deep sections of the Bohai Bay had whitish spermatophores visible within their tightly sealed thelycum.

Ovarian development is correlated with rising temperatures (>15°C) and the increased availability of food in March or April. Over a period of four weeks, females typically spawn several times (up to seven, see Wang and Ma, Chapter 5) at 3-20 day intervals. Fertilization rates are high for eggs from early spawns (up to 99%) and low for eggs generated later (perhaps <10%, also see Wang and Ma, Chapter 5).

OBSERVATIONS OF MATURATION IN CAPTIVE *P. CHINENSIS*

Scientists from Northern China reported that many pond-raised *P. chinensis* which attain a size of 12-13 cm or more reach maturity, even at the relatively high stocking densities typical of growout ponds. Mating does occur, and a "significant" proportion of the mature females are found to bear spermatophores. This occurs in the absence of eyestalk ablation, photoperiod control, or special diets.

Spermatophore-bearing females are moved to hatcheries or other enclosures in which they are overwintered at temperatures no lower than 8-10°C. In the spring, water temperatures are raised to 15°C and the shrimp are given a diet of fresh, crushed bivalves, locally-collected nereid polychaetes, and squid, etc. In this manner the females are induced to spawn.

The following information concerning broodstock production and maintenance was compiled during the background literature review. In 1979, the Yellow Sea Fishery Research Institute (YSFRI) put forth the following guidelines for holding spawners: 1) Suitable overwintering temperatures are 8-20°C. Optimal temperatures are 13-18°C. Mortality will occur at <5°C and >39°C. Sudden changes in temperature will cause mortality. 2) Maturation tanks should be 6-14 m^2 in area and 0.6-0.8 m in depth. The stocking density is 10 per m^2. 3) Spawners are fed 6-8% of their body weight per day when held at 18-19°C. Furthermore, Zhang (1984) proposed the following: 1) Broodstock should be overwintered at 7-11°C. Sudden changes and extreme temperatures should be avoided. The lower threshold is approximately 5°C, while temperatures >14°C will cause molting and subsequent loss of spermatophores. 2) The stocking density should be 8-10 individuals per m^3 and the female:male ratio should be 3:1. 3) Water quality parameters: illumination <100 lux, pH 8 ± 0.2, salinity 30-34 ppt, DO >6 ppm, and NH_4-N <0.1 ppm. The low illumination is to prevent excess algal growth, which can retard molting. (Tsumura [1986] reported that high concentrations of algae interfere with the transmission of spermatophores during copulation.) And 4) avoid disturbances such as striking sounds, strong light on the water surface, and the presence of large moving objects in the water (Notes from the Published Literature on *Penaeus chinensis*, 1989).

RECOMMENDATIONS

Beginning in the spring of 1991, it will be illegal to capture gravid *P. chinensis* in the People's Republic of China during their spring spawning migration. For this reason, Chinese scientists are presently investigating techniques for overwintering broodstock, and also for increasing the low mating rate which is characteristic of captive spawners (Wang and Ma, Chapter 5). At this time, researchers could only give recommendations as to appropriate stocking methods. They suggested maintaining broodstock in separate ponds (apart from growout shrimp) at approximately 5 per m^2. A male:female ratio of 1:2 was recommended for holding broodstock for short periods, as is required to support one annual growing season in temperate areas. For maintaining broodstock year-round, as would be the case for operations in tropical and sub-tropical areas, a male:female ratio of 1:1 was proposed.

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DISCUSSION GROUP I - Harvesting and Processing Technologies

INTRODUCTION

Participants in this session were asked to describe the methods and equipment used for harvesting and processing *P. chinensis*, *P. japonicus*, and *P. penicillatus*.

An ideal harvesting technique would be one that allowed for the rapid, economical, and efficient removal of shrimp from growout ponds. Additionally, the shrimp should be in good condition, uninjured, and possess hard shells. In some cases, it is necessary to select only large individuals, in others it is important to harvest all of the shrimp from a pond. The timing of harvest will likely depend upon the condition of the shrimp (including size, health, and time since last molt); the market; weather conditions (especially temperature); and the processing schedule (see Chen, Chapter 8 for a discussion of the timing of harvest in Northern China).

Due to their behavior, some species may require special techniques. *P. japonicus*, for example, exhibit a burrowing behavior, hence they often require harvesting methods different from those used for *P. chinensis* and *P. penicillatus*. Also, it is especially important that *P. japonicus* not be injured during harvesting since most are to be sold live. In some cases, night harvesting is preferred.

HARVESTING

Manual harvest with nets is standard for *P. chinensis* in Northern China and Korea. Because of their burrowing behavior, *P. japonicus* are harvested with electric trawls in Korea, Japan, and Taiwan. Japan also utilizes pound nets and baited traps, while the Taiwanese supplement the use of electric nets with baskets and lift cranes (also see Liao and Chien, Chapter 6). *P. penicillatus* may be harvested manually, via nets, as is the case in Southern China, or with electric trawls, baskets, and lift cranes as in Taiwan (Table 1; also see Liao and Chien, Chapter 6).

P. penicillatus ponds are harvested once, at the end of the growing season, in Southern China. Successive harvesting is used for *P. japonicus* in Taiwan. This may be a response to market conditions for that species (see Discussion Group J). Korean experts indicated that the duration of harvest for a 5-10 ha *P. chinensis* pond was 3-5 days.

The researchers from Northern China noted that it was sometimes difficult to coordinate harvesting with processing. Korean scientists, on the other hand, were principally concerned with the fact that slow harvests can induce *P. chinensis* to molt, resulting in undesirable "soft shrimp." For *P. japonicus* in Korea, harvesting must be scheduled to avoid the high mortality which often accompanies harvest during cold weather.

Table 1. Harvesting and processing techniques.

	Harvesting method	Duration of harvest	Processing
P. chinensis			
N. China[1]	Drain harvest with nets	3-5 days (5-10 ha pond)	Hand
Korea	Drain harvest with nets	No data available	Hand
P. japonicus			
Korea	Electric net (at night)	No data available	Most sold live
Taiwan	Electric net, basket, lift crane	Successive	Most sold live
Japan	Pound net, electric shocker trawl baited trap	No data available	Most sold live
P. penicillatus			
Taiwan	Electric net, basket, lift crane	One-time	Hand
S. China[2]	Drain harvest	No data available	Hand

[1]Chiefly Liaoning, Hebei and Shandong provinces

[2]Guangdong and Fujian provinces

PROCESSING

P. japonicus, most of which are sold live, are ordinarily chilled and placed in crates with chilled, moist sawdust (also see Liao and Chien, Chapter 6). They survive transport well when carefully packaged in this manner. *P. penicillatus* is grown largely for local consumption in Southern China where it is sold head-on, fresh. Further processing, e.g. deheading, grading, etc., is usually done by hand. Northern China uses the following grades: "headless," "shell on and whole," and "head on" (Chen Chapter 8). See Table 2 for information about China's shrimp storage facilities.

Table 2. Cold storage facilities for cultured shrimp in China[1].

Provinces	Number of plants	Amount frozen (MT/day)	Storage capacity (MT)
Liaoning	24	360.0	7200
Shandong	17	589.5	19359
Hebei	4	50.0	800
Jiangsu	21	257.0	9970
Zhejiang	8	465.0	14200
Fujian	5	43.4	1800
Guangxi	2	32.0	280
Total	81	1796.9	53609

[1]Source: State Processing Division. March 2, 1989.

DISCUSSION GROUP J - Shrimp Marketing and Economics

INTRODUCTION

The purpose of Discussion Group J was to gather information about the market conditions and production economics associated with *P. chinensis*, *P. japonicus* and *P. penicillatus* culture. Although economic parameters are often subject to rapid change, some (e.g. production costs and farm prices) may be expected to change more quickly than others (e.g. the product form and farming system used). Nevertheless, we decided that a compilation of current marketing and economic parameters for cold-tolerant species would be useful.

Monetary values are reported in $US. The conversion rates at the time of the workshop were: 1 $US = 3.7 Yuan, 25.5 NT, and 670 Won. Unless otherwise noted, the experts indicated there were three marketing channels through which cultured shrimp are funneled: (1) Producer to Processor, (2) Processor to Packager, and (3) Packager to Exporter.

MARKET CONDITIONS

Northern China exports 95% of its cultured *P. chinensis*, primarily to the U.S. and Japan, with some exported to Europe. The remaining 5% of production (lower quality product) is consumed domestically. The shrimp are frozen and shipped in 2 kg (4.41 lb) packages. Most shrimp sold in this manner have a heads-on weight of 15-25 g, although the Chinese experts noted that 20-25 g is optimal (Table 1). Tail yields of *P. chinensis* are 56-58%.

The scientists from Northern China reported the following problems: (1) the U.S. market is accustomed to 5 lb boxes, (2) feed costs are very high, and (3) energy (electricity) shortages.

Table 1. Market conditons.

	Target market	Product forms	Product size (heads-on, g)
P. chinensis			
N. China[1]	U.S. and Japan	frozen	15-25 (20-25 optimal)
Korea	Korea	frozen	25
P. japonicus			
Korea	Japan and Korea	live	15-20 (some 25)
Taiwan	Japan	live	>17
Japan	Japan	live	10-50
P. penicillatus			
Taiwan	Japan and U.S. (potential)	Unknown	5-15

[1]Chiefly Liaoning, Shandong and Hebei provinces

P. chinensis in Korea is consumed domestically. It is harvested at a heads-on weight of 25 g and sold frozen (Table 1). The main concern of the Korean experts was the high cost of production. Seventy percent of the *P. japonicus* cultured in Korea is exported to Japan; the remainder is consumed domestically. This species is primarily sold live, at 15-25 g (most are 15-20 g, Table 1). One difficulty exporters face is a demanding Japanese market. Buyers prefer shrimp which are so lively that they "jump."

The market for *P. japonicus* cultured in Japan is domestic. Live shrimp (10-50 g) are sold from producers to receiving agents and then to "middlemen" before finally reaching the consumer (Table 1). In Japan, it is difficult to obtain large tracts of land for aquaculture, which would reduce the cost of production.

As with the other countries that produce *P. japonicus*, Taiwan exports its product live to Japan. Most individuals are >17 g (Table 1). Due to its limited size, the market in Japan is easily saturated, hence prices may fluctuate widely according to supply.

There is no international market as yet for the *P. penicillatus* cultured in Taiwan. Experts have indicated that the U.S. and Japan are both potential markets for this white shrimp which is reported to have tail yields reaching 70%. It is presently consumed domestically at 5-15 g (Table 1).

PRODUCTION ECONOMICS

Farming System

Most of the penaeids cultured in China, Korea and Japan are grown under semi-intensive culture. Densities range from 10-60 per m^2. Intensive culture in Northern China is only experimental at present. In Taiwan, however, both *P. japonicus* and *P. penicillatus* are grown intensively as well as semi-intensively. The densities used for intensive culture range from 90-200 per m^2 for *P. japonicus* and from 120-200 per m^2 for *P. penicillatus*.

Data on farm sizes were not available for all countries. Farms in Northern China vary in size, but most are within the 40-80 ha range. In Japan, 150 *P. japonicus* farms comprise the 600 ha which are currently under cultivation.

Northern China, Korea, and Japan produce only one crop of penaeids per year. In a few places in Southern China, two crops are produced; one crop of *P. chinensis* is followed by *P. penicillatus* (also see Hu, Chapter 9). One crop of *P. japonicus* follows *P. monodon* culture in Taiwan. Alternatively, farmers may produce 1-2 crops of *P. penicillatus* after the *P. monodon* season.

Investment Costs

The cost of constructing ponds and purchasing equipment varied a great deal among the countries included in this discussion. China reported the cheapest construction

Table 2. Investment costs.

	Pond construction and equipment (per ha)	Land (per ha)
P. chinensis		
N. China[1]	$12,162	Owned by government
Korea	$16,032	$445,000/10 ha minimum
P. japonicus		
Korea	$30,000	$445,000/10 ha minimum
Taiwan	$19,600/yr (to rent)	$157,000-$314,000
Japan	$166,000	Coastal tidal zone owned by govermnemt
P. penicillatus		
Taiwan	$19,600/yr (to rent)	$157,000-$314,000

[1]Chiefly Liaoning, Shandong and Hebei provinces

and equipment costs, ($12,162 per ha), and Japan the most expensive ($166,000 per ha, Table 2).

In China, all land is owned by the government. Since many shrimp farms are on land with no agricultural value, they incur no land costs. Joint ventures in that country must contribute cash to compensate for land costs, but there is no standard price assigned to the land. Land is expensive in Korea. Ten hectares (at the minimum purchase price of $445,000, minimum interest rate, 16%) is the smallest amount of land one may buy in Korea. The cost may be higher by as much as $90,000 per ha. The coastal tidal zone in Japan is owned by the government. In Taiwan the cost of land ranges from $157,000-$314,000 per ha (Table 2).

Annual Operating Costs

Korea and Japan reported their postlarval costs in $/crop/ha, China and Taiwan in $/1,000. In Korea, *P. chinensis* postlarvae are $1,333/crop/ha, and *P. japonicus* $2,580/crop/ha. Japanese producers pay $830/crop/ha for their *P. japonicus* postlarvae. The price of postlarval *P. chinensis* is $0.81 per 1,000 in China. *P. japonicus* and *P. penicillatus* postlarvae are $3.9 per 1,000 in Taiwan (Table 3).

The cost of feed makes up a large percentage of the operating costs of shrimp farms. Quality of feed and the feed conversion ratio (FCR) help determine the feed costs for a particular operation. For example, the scientists from Northern China reported different feed costs for farm-made and commercial shrimp feed (Table 3). In China, there is a trade-off associated with using imported feed. It is much more expensive than local feed, but it has a better FCR.

Total feed costs ($/crop/ha) were available only for *P. chinensis* and *P. japonicus* farms in Korea and Japan (Table 3). Annual feed costs ranged from $8,422/crop/ha for *P. chinensis* in Korea, to $70,040/crop/ha for *P. japonicus* in Taiwan (Table 3).

Table 3. Cost of postlarve and feed.

	Postlarvae	Feed cost (per kg)	FCR	Total feed cost (/crop/ha)
P. chinensis				
N. China[1]	$0.81/1,000	Farm made: $.27 Commercial: $.81-$1.1	Farm made: 3-4:1 Commercial: 2.5-3:1	
Korea	$1,333/crop/ha	$2.00		$8,422
P. japonicus				
Korea	$2,580/crop/ha	$3.85		$8,538
Taiwan	$3.90- $9.80/1,000	$1.60-$1.80	1.7-2:1	
Japan	$830/crop/ha	$5.00		$70,040
P. penicillatus				
Taiwan	$3.90- $9.80/1,000	$1.10-$1.30	1.4-2:1	

[1]Cheifly Liaoning, Shandong and Hebei provinces

Labor costs are given in Table 4. In China there is no set wage rate. Minimum wage is about $81 per month and farm managers make between $320 and $400 per month. Usually workers share in the profits and losses. Experts reported that shrimp farms generally employ one person per 2-3 ha. In Korea, labor is a bit more expensive for *P. chinensis* farms than for *P. japonicus* operations ($5,824 vs. $5,200/crop/ha). Furthermore, Korean farms employ 1-2 people per ha. Japan has the highest labor costs; $29,839/crop/ha (Table 4).

Energy expenses make up 15-20% of the annual operating cost of *P. japonicus* and *P. penicillatus* farms in Taiwan. In Northern China, energy, especially diesel fuel for generators and pumps, costs about $81 per month. Japan reported that producers must pay $11,189/crop/ha for energy (Table 4). Finally, another annual expense for some operations is the price of chemicals. Scientists in Northern China indicated that farms

Table 4. Annual cost of labor, energy and chemicals.

	Labor (/crop/ha)	Energy (/crop/ha)	Chemicals (/crop/ha)
P. chinensis			
N. China[1]	$181/mo	$81/mo	$0
Korea	$5,824	$1,035	$254
P. japonicus			
Korea	$5,200	$448	$254
Taiwan	$706-$1,726/mo	15-20% operating cost	Data not available
Japan	$29,839	$11,189	$500
P. penicillatus			
Taiwan	$706-$1,726/mo	15-20% operating cost	Data not available

[1]Chiefly Liaoning, Shandong and Hebei provinces

Table 5. Yield, cost of production and farm price.

	Yield (kg/ha)	Production cost (per kg)	Farm price (per kg)
P. chinensis			
N. China[1]	high: 1,500-3,000 low: 150-300	$5.4-$8.1	$5.4-$8.1
Korea	4,000	$6.5	$8
P. japonicus			
Korea	1,500	$18	$25
Taiwan	2,000-4,000 crop	$9.8-14.1	$7.8-11.3
Japan	5,000-7,000	$37	$69
P. penicillatus			
Taiwan	6,000-12,000/crop	$5.9-7.8	$4.7-$6.2

[1]Chiefly Liaoning, Shandong and Hebei provinces

do not buy chemicals. Korean *P. chinensis* and *P. japonicus* farms typically pay $254/crop/ha for chemicals, Japan $500/crop/ha (see Table 4).

Yield, Cost of Production and Farm Prices

Yields are presented in Table 5. The highest yield per ha was reported from Japan: 5,000-7,000 kg. Taiwan reported the following per crop yields: 2,000-4,000 kg for *P. japonicus* and 6,000-12,000 kg for *P. penicillatus*. The range of yields for *P. chinensis* in China is 150-3,000 kg/ha, whereas Korean *P. chinensis* farms obtain yields of 4,000 kg/ha (Table 5).

Farm prices will often vary with the availability of wild shrimp. In Northern China, the cost of production and the farm price for *P. chinensis* are equal: $5.4-$8.1 per kg. Thirty to fifty percent of the *P. chinensis* operations are profitable. Korea has a large wild shrimp catch, hence the domestic market cannot absorb too many cultured shrimp. Korean farms make a profit of $1.50 and $7.00 per kg for *P. chinensis* and *P. japonicus*, respectively. It costs Taiwanese farms $5.9-7.8 to grow one kg of *P. japonicus* which they can sell for $9.8-14.1. The production cost of *P. penicillatus* in Taiwan is $5.9-7.8 per kg, the farm price $4.7-6.2 per kg (Table 5).

Data on shrimp production in the coastal provinces of China are presented in Tables 6 and 7. Tables 8 and 9 contain prices for the different sizes and shrimp products exported from China.

Table 6. Area and production of shrimp farming in China, 1980-1987 (national statistics).

	1980		1981		1982		1983	
Province	Pond area (10^3 ha)	Production (10^3 MT)	Pond area (10^3 ha)	Production (10^3 MT)	Pond area (10^3 ha)	Production (10^3 MT)	Pond area (10^3 ha)	Production (10^3 MT)
Liaoning	0.45	0.10	1.30	0.20	1.9	0.70	3.6	1.8
Hebei	0.06	0.04	0.10	0.04	1.0	0.04	1.8	0.2
Tianjin	0.57	0.04	0.20	0.08	0.1	0.09	0.5	0.2
Shandong	5.32	1.20	7.90	1.60	8.3	2.10	7.8	3.2
Jiangsu	1.79	0.70	2.50	1.20	2.9	2.10	3.7	2.3
Shanghai	0.06	0.01	0.02	0.03	0.1	0.05	0.2	0.2
Zhejiang	0.16	0.04	0.20	0.04	0.3	0.20	0.9	0.5
Fujian	0.48	0.10	0.70	0.10	0.9	0.20	0.7	0.3
Guangdong	0.09	0.20	0.40	0.30	0.7	1.50	0.2	0.2
Guangxi	0.35	0.04	0.40	0.03	0.3	0.05	0.4	0.5
Total	9.33	2.47	13.72	3.62	16.5	7.03	19.8	9.4

Table 6. Continued.

Province	1984		1985		1986		1987	
	Pond area (10^3 ha)	Production (10^3 MT)	Pond area (10^3 ha)	Production (10^3 MT)	Pond area (10^3 ha)	Production (10^3 MT)	Pond area (10^3 ha)	Production (10^3 MT)
Liaoning	8.5	6.00	17.1	11.90	21.3	24.70	27.7	43.5
Hebei	3.1	1.00	5.9	5.20	9.7	12.00	14.0	24.9
Tianjin	0.3	0.50	2.2	1.10	2.8	2.40	3.5	4.4
Shandong	11.2	5.30	17.2	9.10	23.4	17.40	35.0	33.9
Jiangsu	4.9	3.50	8.4	5.90	8.7	8.40	10.9	11.8
Shanghai	0.4	0.50	2.7	2.10	0.9	5.80	1.3	2.0
Zhejiang	1.2	1.20	0.7	0.75	5.4	1.40	7.1	7.2
Fujian	1.2	0.40	2.9	1.70	7.0	6.20	14.2	13.3
Guangdong	2.2	0.90	2.0	2.80	5.1	4.40	16.1	11.6
Guangxi	0.4	0.03	0.4	0.06	0.7	0.08	1.2	0.3
Total	33.4	19.33	59.5	40.61	85.0	82.78	131.0	152.9

Table 7. Shrimp production in China (1980-1987)[1].

Province	1980 P. *chinensis* (MT)	1980 Others (MT)	1981 P. *chinensis* (MT)	1981 Others (MT)	1982 P. *chinensis* (MT)	1982 Others (MT)	1983 P. *chinensis* (MT)	1983 Others (MT)
Tianjin	2,128		781		398		1,046	
Hebei	2,261		868		341		1,088	
Liaoning	9,064		5,103		2,421		4,771	
Jiangsu	1,346		696		424		321	
Zhejiang		204		116		14		76
Fujian		619		418		648		1,032
Shandong	18,097		14,047		3,790		8,213	
Guangdong		1,808		2,672		714		2,703
Guangxi		814		802		864		794
Shanghai		11						
Total	32,896	3,456	21,495	4,008	7,374	2,240	15,439	4,605

[1]This table based is on the PRC Annual Aquatic Reports

Table 7. Continued.

Province	1984 *P. chinensis* (MT)	1984 Others (MT)	1985 *P. chinensis* (MT)	1985 Others (MT)	1986 *P. chinensis* (MT)	1986 Others (MT)	1987 *P. chinensis* (MT)	1987 Others (MT)
Tianjin	460		1,054		534		276	
Hebei	811		2,029		2,117		1,566	
Liaoning	1,982		5,873		5,550		3,625	
Jiangsu	561		252	409	156	632	683	
Zhejiang		52		64		180		77
Fujian		1,944		2,750		1,401		11,621
Shandong	4,196		11,475		8,281		3,782	
Guangdong		3,680		6,030		7,915		8,710
Guangxi		1,849		2,588		2,639		3,445
Shanghai								
Total	8,010	7,525	20,683	11,841	16,638	12,767	9,932	23,853

Table 8. Shrimp export statistics for China, 1980-1986[1].

Product		1980	1981	1982	1983	1984	1985	1986	Total
Frozen, small	Quantity (kg)	19,519,071	16,449,360	8,969,180	7,436,652	11,631,829	12,325,903	23,504,588	99,836,583
	Price ($US)	170,262,349	147,170,027	94,168,439	71,099,631	90,835,327	83,778,506	185,262,216	842,576,495
Frozen, large	Quantity (kg)		880,057	737,462	402,173	451,364	1,085,769	2,606,745	6,163,570
	Price ($US)		3,064,632	2,511,614	995,427	1,062,951	2,029,450	9,363,662	19,027,736
Fresh, deshelled	Quantity (kg)		4,687,742	3,483,857	2,095,456	3,758,413	3,260,852	11,388,910	28,675,230
	Price ($US)		27,702,893	20,447,710	13,481,956	17,672,759	14,942,636	54,289,117	148,537,071
Dried, deshelled	Quantity (kg)	432,422	112,702	218,199	103,916	90,264	265,575	1,424,642	2,647,720
	Price ($US)	942,388	661,966	137,822	292,365	474,633	666,890	3,582,596	6,758,660
Other	Quantity (kg)	2,663,106	1,373,493	1,434,515	835,637	1,129,039	2,478,631	2,060,320	11,974,741
	Price ($US)	7,737,962	5,011,638	5,162,971	3,088,389	3,317,533	9,275,247	5,932,809	39,526,549
Subtotal	Quantity (kg)	22,614,599	23,503,354	14,843,213	10,873,834	17,060,909	19,416,730	40,985,205	149,297,844

[1]Source: State Customs Office, Feb. 25, 1989

Table 9. Export prices of cultured and captured shrimp in China, 1986-1988[1].

Count	1986		1987	1988	
	Spring ($US)	Fall ($US)	Spring ($US)	Spring ($US)	Fall ($US)
8-12	17,650	15,850	17,450		26,000
13-15	16,150	14,950	16,450	19,000	24,000
16-20	13,250	13,850	14,150	16,800	18,200
21-25	11,800	12,500	12,150	13,500	15,000
26-30	10,350	11,350	10,450	10,500	11,000
31-40	8,850	9,150	7,800	7,400	8,100
41-50	7,550	8,150	7,250	5,500	6,100
51-60	6,250	6,650	6,750	4,700	5,000
61-70	4,750	5,150	5,950	4,400	4,400
71-90	4,250	4,050	4,450	4,200	4,200
91-110	3,850	3,650	3,950	3,900	3,900

[1]Source: State Processing Division, March 2, 1989.

DISCUSSION GROUP K - Issues and Outstanding Questions Regarding the Culture of Cold-Tolerant Shrimp in the U.S.

INTRODUCTION

Discussion during this final session was mainly about the questions and doubts the participants had about raising cold-tolerant species in the U.S. The questions/issues fell into four categories: (1) disease, (2) marketing and economics, (3) hatchery, and (4) the necessity of importing new shrimp species. Many participants cited the need for further studies before investing too heavily in these exotic species, but some expressed the opinion that production trials should be started.

DISEASE

Disease was a major concern of the workshop participants. Specifically, both U.S. and Asian experts raised doubts about the availability of specific pathogen free (SPF) shrimp for importation. Dr. Burzell noted that two attempts to import SPF *P. chinensis* to Hawaii have been unsuccessful. There are regulatory problems associated with importing exotic species and concern that diseases of imports will infect shrimp currently under production.

MARKETING AND ECONOMICS

Questions were also raised about the potential market for *P. penicillatus* and/or *P. chinensis*. The profitability of growing one or two crops of these species compared to growing *P. vannamei* (also an exotic species and the predominant species cultured in the U.S.) was discussed. Participants questioned the best market for *P. chinensis* (some indicated that it would be the "large fresh shrimp market"). The issue of consumer acceptance of a new species was also raised. Feed costs, nutritional requirements and yields were a concern, as well as the fact that the tail percentage of *P. chinensis* is lower than that for *P. vannamei*.

Some of the Asian participants questioned the likelihood of making a profit culturing shrimp in an industrialized nation like the U.S. They cited high land and labor costs as obstacles. Professor Yang even suggested that it would be better for potential U.S. shrimp producers to establish joint ventures in China, where land and labor are cheap, than to import *P. chinensis*.

DOUBLE-CROPPING AND HATCHERY CONSIDERATIONS

The possibility of double-cropping was raised during this session. Two double-crop scenarios were suggested: *P. chinensis* followed by *P. chinensis*, and *P. chinensis* followed by *P. penicillatus*. One concern was the possibility that in the U.S., it would be too warm in mid-summer to produce postlarvae for the second crop. While optimistic about culturing both *P. chinensis* and *P. japonicus* in the U.S., Mr. Kim was skeptical about the practicality of double-cropping with shrimp.

THE NECESSITY OF IMPORTING A NEW SPECIES

Echoing the concerns already raised about disease and problems associated with removing *P. chinensis* from its native environment, several of the participants recommended caution. Professors Chen and Liu expressed the opinion that the U.S. should fully explore the potential of its local shrimp species before importing exotic animals, which may prove to be no better. Furthermore, Professor Liu noted that while *P. chinensis* breed as far north as the Bohai Bay, they must migrate southward in the winter to escape cold temperatures. He also expressed doubts about its adaptability to year-round warm temperatures like those in Hawaii, and cited the need for more research.

SECTION III

Economic Analysis

The Culture of Cold-Tolerant Shrimp: Proceedings of an Asian-U.S. Workshop on Shrimp Culture, Honolulu, HI, 1990

A FINANCIAL ANALYSIS OF *PENAEUS CHINENSIS* CULTURE IN THE UNITED STATES

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INTRODUCTION

This paper presents a comparative financial analysis of four different *P. chinensis* production scenarios. The AIP workshop found that *P. chinensis* grows faster and at lower temperatures than *P. vannamei*. *P. chinensis* grows at temperatures as low as 14 and as high as 30°C (Sect. II, Disc. Group D). Growth at these low temperatures may add two to three months to the effective growing season for shrimp in certain areas of the United States where shrimp are now cultured. In addition, *P. chinensis* is a closed thelycum species, which allows for synchronized spawning. Thus, large tank culture is possible in the hatchery and farmers are able to simultaneously stock nursery ponds with large numbers of postlarvae.

Sites in South Carolina (SC) and Texas (TX) were selected for analysis because shrimp are produced on the coasts of both states, and these locales are appropriate for future farming efforts with *P. chinensis*. Cost data for *P. vannamei* production were collected for both sites in cooperation with producers, researchers, and economists. Production parameters for the cold-tolerant species were selected from the data presented at the AIP workshop, papers presented by workshop participants and the published literature. The analysis includes regional production costs adapted to cold-tolerant species.

P. penicillatus and *P. japonicus* were not examined in this financial analysis. Data presented at the AIP workshop revealed that *P. penicillatus* has a limited tolerance to low temperatures. Liao and Chien (Sect. I, Chapter 6) state that the optimal temperature range for *P. penicillatus* is 25-30°C, and data from Southern China (Sect. II, Disc. Group D) indicate that growth stops at 20°C. *P. japonicus* was excluded because of the extremely high production costs associated with it and its limited market (Sect. II, Disc. Group J). *P. japonicus* is primarily marketed live in Japan.

Production Scenarios

Four scenarios involving *P. chinensis* were analyzed. They represent a range of possible operations, but determination of the

[1]Applied Analysis Inc. is an aquaculture consulting firm based in Honolulu, Hawaii. Participants in this study include Lawrence Rowland, Ping-Sun Leung, Yung C. Shang, Kulavit Wanitprapha and Stewart Anderson.

most profitable operation will require more extensive study. The four scenarios are summarized in Table 1 and described below.

Scenario 1 is the production of one crop of *P. chinensis* for the entire growing season. A larger animal (33 g) is produced by taking advantage of early stocking and late harvesting.

Scenario 2 is also the production of one crop of *P. chinensis*, but only to 25 g harvest weight. China and Korea report harvesting at 25 g or less (Sect. II, Disc. Group B). Also, U.S. production practices are established for animals of 25 g or less. Thus, this situation provides a more conservative alternative to a single crop of *P. chinensis* cultured for the entire growing season.

In Scenario 3, two crops of *P. chinensis* are produced in one growing season. This takes advantage of the early stocking and late harvesting potential for *P. chinensis*. Nursery ponds are used to enhance management and overlap production between the two crops.

Scenario 4 is the production of one crop of *P. chinensis* followed by one crop of *P. vannamei*. This takes advantage of the early stocking capability of *P. chinensis*, which is followed by stocking a second crop of *P. vannamei*. Again, nursery ponds are used to enhance management and overlap production between the two crops.

Financial Analysis of Shrimp Farming in the United States

The economic analysis of shrimp farming is better understood by clarifying the different approaches available. Financial analysis traditionally takes the viewpoint of the individual participants, the farmer, private sector firms, or public corporations. It is based upon budget projections of estimated revenues and costs which are used to derive the profitability of a proposed project. Economic analysis, by contrast, takes the viewpoint of society as a whole and is often labeled a socio-economic analysis. Economic analysis uses the same discounted cash-flow measures as financial analysis, but requires a different treatment of taxes, subsidies, prices, and interest to estimate returns to society (Gittinger 1982).

The extension of these approaches for evaluating living production systems has

Table 1. Production scenarios and harvest size.

Scenario#	Species (1st Crop/2nd Crop)
1	*P. chinensis* to 33 g
2	*P. chinensis* to 25 g
3	*P. chinensis* to 23.5g / *P. chinensis* to 25g
4	*P.chinensis* to 16g / *P.vannamei* to 15.2g SC
	P.vannamei to 18.5g TX

given rise to bioeconomics. Bioeconomics is a term employed by Allen et al. (1984), whereby, "Mathematical analogs, or models, are used to express the relationships between biological and physical elements of production systems and, in combination with analytical techniques, are the tools of economic assessment." Bioeconomics represents the "means of relating the biological performance of a production system to its economic and technical constraints."

The Gulf Coast Research Laboratory Consortium uses the process of economic evaluation to promote the development of the U.S. shrimp industry. The Consortium, sponsored by the U.S.D.A., has asked researchers and economists in South Carolina, Texas, and Hawaii to define a common economic context, and use it to evaluate the economic consequences of both existing and proposed shrimp culture practices. Consortium members from the Waddell Mariculture Center in South Carolina and Texas A & M University contributed data for this analysis.

Texas has been active in the economic evaluation of shrimp farming for many years. Adams et al. (1980) and Griffin et al. (1981) explored different aspects of bioeconomic modeling for shrimp culture. Johns et al. (1981a, 1981b) developed budget analyses of the maturation and hatchery components of shrimp aquaculture. Griffin et al. (1984) and Huang et al. (1984) extended their analyses to regional and proposed commercial operations. Recent economic focus (Sturmer 1987, Juan et al. 1988) has been on intensive raceway nursery systems. The trend in Texas literature suggests that most current work is dedicated to finding solutions to the low profitability which plagues U.S. shrimp farming.

ASSUMPTIONS AND PARAMETERS

Farm Size

The South Carolina and Texas farm systems are hypothetical operations that were created by local producers, researchers, and economists to evaluate the feasibility of *P. vannamei* farming in their respective areas. These farm systems are chosen for analysis because they represent the existing situation, not because they are the most profitable.

The South Carolina farm has six 2-ha growout ponds, 1.07 m deep. The farm also includes five 0.1-ha nursery ponds, 1 m deep. The Texas farm has twenty 2.02-ha growout ponds, 1.22 m deep. The farm also includes sixteen, 0.1 ha nursery ponds, 1 m deep (see Table 2).

The size and number of growout ponds are based on those found on existing farms in South Carolina and Texas (Griffin et al. 1989, R. Rhodes, pers. comm. 1989). The growout pond sizes are smaller than the 5-10 ha ponds used in the PRC and the 6-20 ha ponds used in Korea (Sect. I, Zhang Chapter 11; Sect. II, Disc. Group A). The depths are within the 1-1.5 m depths found in the PRC and Korea. The size and number of ponds are not necessarily the most effective for capital and operations in South Carolina and Texas.

There were no nursery ponds included in the Griffin et al. (1989) and Rhodes (pers.

Table 2. Farm size.

Location	Ponds (#)		Area (ha)	Depth (m)
South Carolina	5	Nursery	0.10[a]	1.00[a]
	6	Growout[b]	2.00[b]	1.07[b]
Texas	16	Nursery	0.10[a]	1.00[a]
	20	Growout[b]	2.02[b]	1.22[b]

[a]Disc. Group B, [b]Table 11.

comm.) data sets for Texas and South Carolina, respectively. Nursery pond size was based on data presented by Korean participants (Sect. II, Disc. Group B). The number of ponds needed to produce the required number of shrimp was calculated with the model.

Stocking and Harvesting Strategies

Stocking and harvesting strategies were based on the temperature ranges suitable for culturing *P. chinensis* and *P. vannamei*. Table 3 summarizes the temperature ranges found in both South Carolina and Texas. From March through November, temperatures are within the suitable range for *P. chinensis* culture (Sect. I, Liu Chapter 3, Wang and Ma Chapter 6, Liao and Chien Chapter 7, Kim Chapter 8, Chen Chapter 9, Hu Chapter 10, Yang Chapter 11; Sect. II, Disc. Group D).

All production scenarios for *P. chinensis* assumed stocking the first crop in nursery ponds on March 1. Nursery ponds were used in all cases to provide more manageability,

Table 3. Regional temperatures (°C).

	Texas[a]			South Carolina[b]		
Month	Min.	Max.	Avg.	Min.	Max.	Avg.
January	5.0	17.0	11.0	7.2	14.2	9.6
February	6.0	19.0	12.5	10.0	16.8	12.5
March	10.0	22.0	16.0	14.0	22.0	17.1
April	15.0	26.0	20.5	16.2	24.2	21.2
May	18.0	29.0	23.5	19.8	27.0	24.5
June	21.0	33.0	27.0	22.8	31.2	27.7
July	22.0	34.0	28.0	25.8	30.0	28.8
August	22.0	34.0	28.0	26.2	29.0	28.8
September	20.0	32.0	27.0	23.2	27.0	25.9
October	14.0	28.0	21.0	17.0	26.8	22.1
November	9.0	22.0	15.5	14.8	20.0	18.5
December	6.0	18.0	12.0	9.8	15.5	12.4

[a]Texas temperatures were taken at Houston. NOAA, Climatography of US, #81, Sept. 1982.

[b]South Carolina temperatures were taken at Waddell Mariculture Center. Minimum and maximum temperatures are from 1988. The average is the overall average for 1985 and 1988.

Table 4. Stocking and harvesting dates.

Scenario#	1st Crop/ 2nd Crop (species)	Nursery Stock	Growout Stock	Growout Harvest
1	*P.chinensis* (33g)	Mar 1	Mar 31	Nov 16
2	*P.chinensis* (25g)	Mar 1	Mar 31	Jul 20
3	*P.chinensis*	Mar 1	Mar 31	Jul 13
	P.chinensis	Jun 28	Jul 28	Nov 16
4	*P.chinensis*	Mar 1	Mar 31	Jun 8
	P.vannamei	May 12	Jun 23	Oct 19

better survival, and the ability to overlap production for a second crop. Although nursery ponds are occasionally covered in Hebei Province (Sect. II, Disc. Group B), pond coverings or greenhouses were not included as part of the nursery in either South Carolina or Texas. Griffin et al. (1989) suggest that at growth rates above 1.3 grams per week in growout, greenhouses become economically feasible in Texas, based on a study by Juan et al. (1988). The average growth rate for *P. chinensis*, 1.5 g per week (Sect. I, Kim Chapter 7), may justify greenhouses in the Texas setting. The nursery pond designs in the PRC and Korea are described in Sect. II, Disc. Group B.

Stocking strategies assume a very small window for stocking due to the ability to synchronize spawning and the use of the "large tank" hatchery culture system. One-to-two months are added to the traditional U.S. growing season associated with *P. vannamei* using such stocking strategies.

Due to the broader temperature tolerance of *P. chinensis*, harvesting is scheduled for mid-November in Scenario 1 and in the second Scenario 3 crop. Harvesting at this time adds approximately one additional month to the U.S. growing season for *P. vannamei.*

Table 4 and the Gantt charts (Figs. 1-4) show the timing of activities for a typical year of operation for the four different scenarios.

Hatchery, Nursery, and Growout Production

Hatchery production is based on farm size and stocking densities. Table 5 shows the postlarval production required per cycle for *P. chinensis* and *P. vannamei* in South Carolina and Texas. *P. chinensis* maturation and hatchery assumptions are based on the information presented in the AIP discussion groups and the papers presented during the workshop (Tables 6 and 7).

Table 8 summarizes growout production. *P. chinensis* growout and nursery production assumptions are listed in Tables 9 and 10. They include a 30-day nursery, a growout stocking density of 30 per m^2, and an average growth rate of 1.5 g per week. The *P. vannamei* growout assumptions for South Carolina and Texas are given in Table 11.

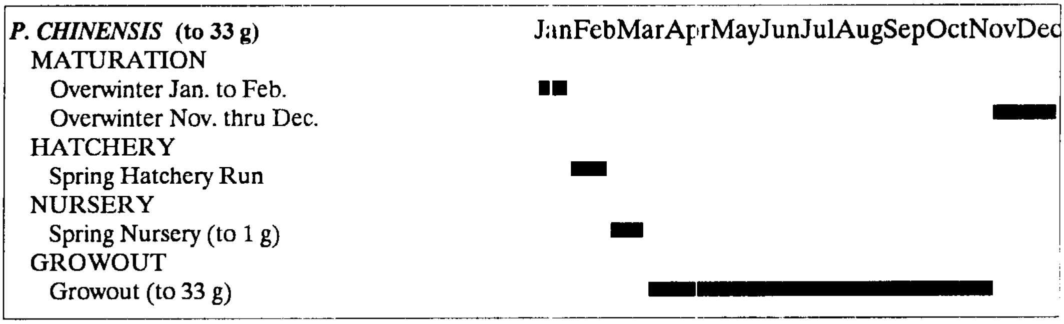

Fig. 1. Scenario 1: *P. chinensis* to 33 g.

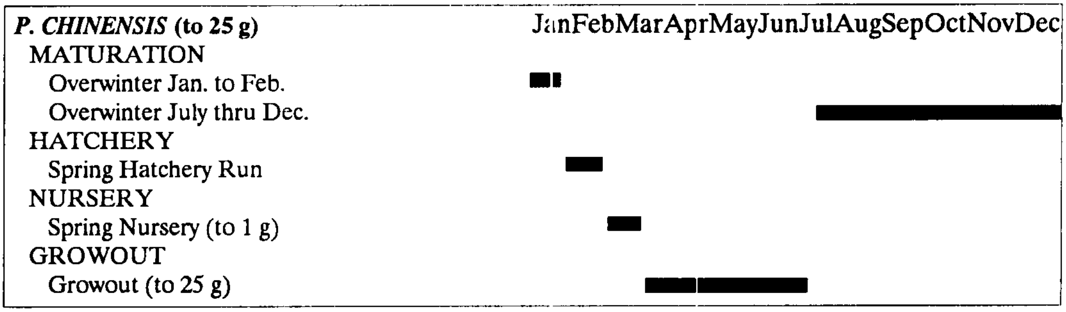

Fig. 2. Scenario 2: *P. chinensis* to 25 g.

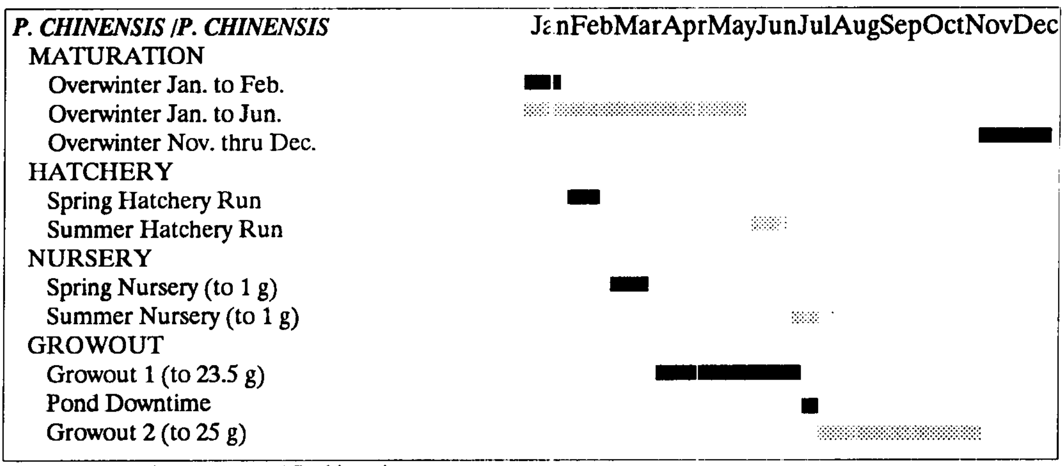

Fig. 3. Scenario 3: two crops of *P. chinensis*.

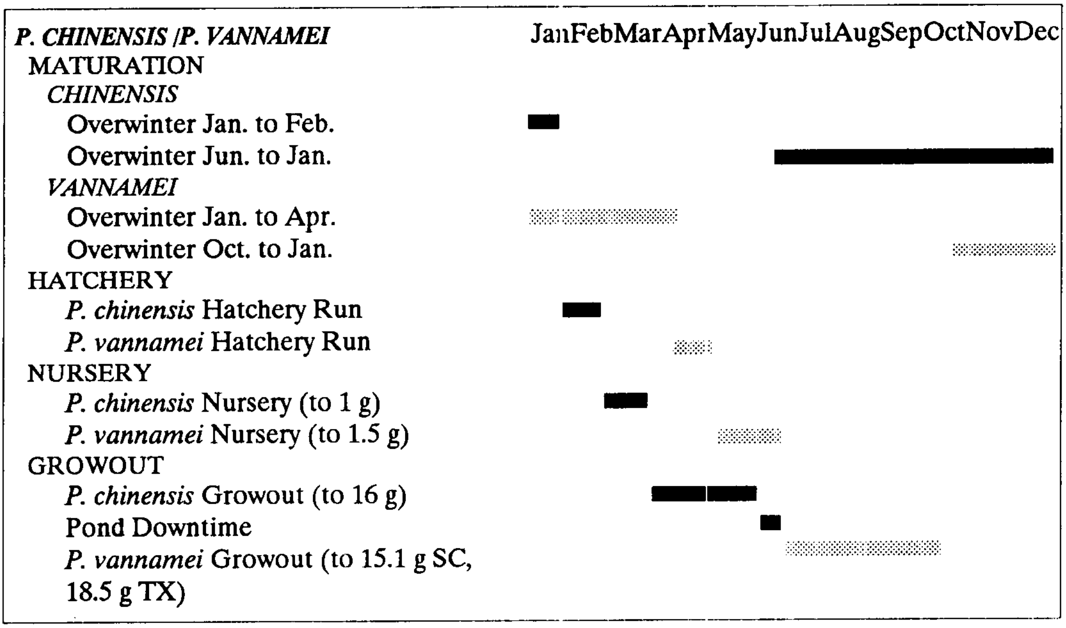

Fig. 4. Scenario 4: *P. chinensis* followed by *P. vannamei*.

Table 5. Hatchery production (PL's per cycle).

Species	South Carolina PL's/cycle	Texas PL's/cycle
P.chinensis	3,600,000	12,120,000
P.vannamei	2,400,000	9,465,720

Table 6. *P.chinensis* maturation assumptions

Maturation production	*P.chinensis*
Animal density (animals/m^2)	4[a]
Sex ratio per tank (M:F)	1:2[a]
Broodstock spawning (%)	90[b]
Spawner weight (g)	50[b]
Eggs per spawn	165,000[b]
Hatching success (%)	90[b]
Nauplii per spawn	148,500[b]
Broodstock residence time (mo)	4-8
Broodstock overwinter survival (%)	60,36@8mo
Tank bottom area (m^2)	14[c]
Tank depth (m)	0.75[c]
Exchange rate (%/day)	200

[a]Disc. Group H, [b]Rho, Chapter 3, [c]Asian Interchange Program, 1989a.

Table 7. *P. chinensis* hatchery assumptions.

Hatchery production	*P.chinensis*
Length of hatchery period (mo)	1.3[a]
Nauplii stocking density (animal/liter)	125[b]
Survival (%)	55[c]
Tank size (liter)	100,000[a]
Tank water volume at stocking (liter)	50,000
Exchange rate (%)	40[d]

[a]Disc. Group F, [b]Chen, Chapter 8, [c]Asian Interchange Program, 1989a, [d]Rho, Chapter 3.

Table 8. Growout production.

Scenario#	1st Crop/2nd Crop (species)	South Carolina (kg/cycle)	Texas (kg/cycle)	South Carolina (kg/ha)	Texas (kg/ha)
1	*P.chinensis* (33g)	42,768	143,985	3,564	3,564
2	*P.chinensis* (25g)	54,000	181,800	4,500	4,500
3	*P.chinensis*	50,760	170,892	4,230	4,230
	P.chinensis	54,000	181,800	4,500	4,500
4	*P.chinensis*	34,560	116,352	2,880	2,880
	P.vannamei	30,804	122,581	2,567	3,034

Capital Costs

Both farms were capitalized typical to their regions of the United States (Griffin et al. 1989, Rhodes pers. comm.). Capital costs were divided into three categories: development costs, fixed capital, and equipment. Development costs cover initial feasibility studies, if any. Fixed capital costs cover the following types of items: buildings, laboratories, pond construction, plumbing, electrical hardware, etc. Equipment costs include: office equipment, laboratory equipment, trucks, feeding equipment, harvesting equipment and other general farm equipment. All four production scenarios in South Carolina and Texas operate on the capital cost breakdown listed in Table 12.

Table 9. *P.chinensis* nursery assumptions.

Nursery operation	*P.chinensis*
Length of nursery (days)	30
Stocking density (animals/m^2)	1,000[a]
Harvesting weight (g/animal)	1[b]
Average survival (%)	80
Pond area (ha)	0.1
Average pond depth (m)	1[a]
Pond water exchange rate (%/day)	50
Feed conversion ratio	1.4:1[b]

[a]Disc. Group B, [b]Disc. Group C.

Operating Costs

Operating costs, excluding feed costs, were based upon costs derived from *P. vannamei* farms in South Carolina and Texas. In all cases, over 50% of total operating costs were accounted for by only two factors, feed and stocking costs. These two factors are explained in detail and followed by tables showing relationships of all cost categories.

Feed Costs

Feed costs were calculated for each scenario based upon production parameters and protein requirements for the species involved. According to Chinese and Korean scientists, the protein requirement for *P. chinensis* is 45% (Sect. II, Disc. Group C). In Korea, Doosan Industrial Co. has developed their own feed, which is 45% protein (Sect. I, Kim Chapter 7; Sect. II, Disc. Group C). An American-made feed of 45% protein, delivered to the farm, costs $0.99/kilogram (Rangen, Inc., pers. comm.; see Table 13).

Table 10. *P.chinensis* growout assumptions.

Growout production	*P.chinensis*
Length of growout season (mo)	Depends on scenario
Length of one growout period (mo)	Depends on scenario
Downtime per pond per cycle(mo)	0.5
Stocking density (animal/m²)	30[a]
Stocking weight (g/animal)	1[b]
Harvesting weight (g/animal)	Minimum 15
Average growth rate (g/wk)	1.5[c]
Average survival (%)	60[a]
Pond area (ha)	2-SC, 2.02-TX
Average pond depth (m)	1.07-SC, 1.22-TX
Pond water exchange rate (%/day)	10-SC, 20-TX
Feed conversion ratio	2.1:1[b]

[a]Disc. Group B, [b]Disc. Group C, [c]Kim, Chapter 7.

Table 11. *P.vannamei* growout assumptions.

Growout production	*P.vannamei* S.Carolina Semi-intensive[a]	*P.vannamei* Texas intensive[b]
Length of growout season (mo)	5.33	5.83
Length of one growout period (mo)	5.33	5.83
Stocking density (animal/m²)	20	23.43
Stocking weight (g/animal)	0.001	0.01
Stocking cost ($/1000PL)	10	8.2
Harvesting weight (g/animal)	20	23.26
Average growth rate (g/wk)	0.8	1
Average survival(%)	85	70
Number of ponds	6	20
Pond area (ha)	2	2.02
Average pond depth (m)	1.07	1.22
Pond water exchange rate (%/day)	10	20
Feed cost ($/kg)	0.66	0.77
Feed conversion ratio	2.5	2.2
Market price ($/kg)	5.4	7.74

[a]Rhodes, pers. com., 1989, [b]Griffin et al., 1989.

P. vannamei has a lower protein requirement than *P. chinensis*, and most American producers use a feed that has 30-35% protein ration. The feed costs reported for *P. vannamei* are $0.66 in South Carolina (Rhodes pers. comm.) and $0.77 in Texas (Griffin et al. 1989, see Table 13). According to Rangen Inc. representatives (pers. comm.), this price is most likely associated with a 35% protein shrimp feed produced by their company.

Table 12. Capital costs.

	South Carolina[a]	Texas[b]
Development cost	$5,000	$0
Fixed capital	$131,960	$596,000
Equipment	$81,350	$353,612
Total	$218,310	$949,612

[a]Rhodes, pers. com., 1989, [b]Griffin et al., 1989.

Table 13. Feed costs $/kg.

Species	South Carolina	Texas
P. chinensis[a]	$.99/kg	$.99/kg
P. vannamei[b]	$.66/kg	$.77/kg

[a]Rangen Inc. pers. comm., [b]Table 11.

Feed costs for the scenarios were based on the price of feed, quarterly feed rates, and quarterly survival. In most cases, quarterly feed rates were not available. Thus, declining feed rates were substituted for quarterly rates to yield the appropriate feed conversion ratios (Table 14). Similarly, mortality was assumed to occur in absolute increments to a final survival figure.

Feed costs per crop include feed costs for both nursery and growout. Nurseries used the same feed costs as growout. The feed conversion ratio was 1.4:1, and the overall survival rate was 80% (Sect. II, Disc. Groups B and C). The feed costs for each of the four production situations in South Carolina and Texas are listed in Table 15.

Postlarvae Cost

Postlarvae costs for *P. chinensis* (Table 16) were derived from hypothetical facilities and operating procedures for overwintering, maturing, and larval rearing of the species. The hatchery methods used in China and Korea, and stocking requirements of the production scenarios were combined to design and scale appropriate hatcheries and maturation facilities. Costs of constructing, equipping, and maintaining the facilities were extrapolated from the prototype maturation/hatchery facility at The Oceanic Institute.

A breakeven price was calculated for postlarvae produced in stand-alone South Carolina and Texas maturation/hatchery systems having both one and two hatchery runs per season. The break-even prices were used as the postlarvae or stocking cost in each production situation. The large tank (100 MT) style hatcheries were scaled to accommodate the demand for each scenario. It was assumed that no outside sales would help support the hatchery. The *P. chinensis* postlarvae (PL) costs ranged from $15-30 per 1,000 PLs for one hatchery run per season to $10-20 per 1,000 PLs for two hatchery runs (Table 16).

Table 14. Feed conversion ratio and overall survival.

Species	Feed conversion ratio	Overall survival (%)
P. chinensis	2.1[a]	60-16 wks, 36-33 wks
P. vannamei[b]	2.2 TX	70 TX
P. vannamei[b]	2.5 SC	85 SC

[a]Disc. Group C, [b]Table 11

Table 15. Feed costs ($/crop).

Scenario #	1st Crop/2nd crop (species)	South Carolina	Texas
1	*P.chinensis* (33g)	$93,798	$316,954
2	*P.chinensis* (25g)	$79,811	$311,837
3	*P.chinensis*	$110,421	$372,918
	P.chinensis	$117,213	$395,784
	Total	$227,634	$768,702
4	*P.chinensis*	$76,905	$260,083
	P.vannamei	$53,044	$218,001
	Total	$129,949	$478,084

Overwintering maturation costs were included in the postlarvae breakeven prices. No information is available on overwintering *P. chinensis* for a second hatchery run in summer. The development of a hypothetical system for such an operation is beyond the scope of this analysis. To account for these costs, overwintering costs for the spring batch of spawners were simply projected into summer.

Total Costs

Total annual operating costs for all scenarios in South Carolina and Texas are presented in Table 17. The highest operating costs were for two-crops of *P. chinensis* in one season. Operating costs, as percentages of total cost, are presented in Tables 18 and 19. Operating costs per kg of shrimp harvested are given in Tables 20 and 21.

Table 16. Postlarvae costs in $/1000.

Species	SC	TX
P. vannamei [a]	$10.00[a]	$8.20[b]
P. chinensis (1 hatchery run/ year)	$30.00	$15.00
P. chinensis (2 hatchery runs/year)	$20.00	$10.00

[a]See Table 11, [b]See Table 11

Shrimp Market Prices

Prices for the different species and sizes of shrimp were averaged from National Marine Fisheries Service (NMFS) New York Green Sheet prices for frozen Ecuador White shrimp for the period August 31 through December 15, 1989 (Table 22). The Ecuador White shrimp price was chosen as a baseline because it is a high quality cultured shrimp. A single species price was chosen to eliminate variations in prices across species resulting from marketing techniques and market preferences. It was assumed that no species is preferred over another in this analysis.

Each size and species of shrimp harvested was assigned a standardized price,

Table 17. Total annual operating costs.

Scenario #	1 *P.chinensis* (33g)	2 *P.chinensis* (25g)	3 *P.chinensis* *P.chinensis*	4 *P.chinensis* *P.vannamei*
South Carolina	$338,000	$307,000	$525,000	$401,000
Texas	$938,000	$866,000	$1,484,000	$1,170,000

Table 18. South Carolina scenarios: operating costs as percentages of total cost.

Scenario #	1 *P.chinensis* (33g)	2 *P.chinensis* (25g)	3 *P.chinensis* *P.chinensis*	4 *P.chinensis* *P.vannamei*
Feed	28	26	43	32
Stocking	32	35	27	33
Energy	10	6	7	8
Salaries	13	14	8	11
Labor	4	2	3	3
Chemicals	1	1	0	0
Lease rent	1	1	1	1
Other	3	3	2	2
Contingency	4	5	5	4
Depreciation	5	7	4	5
Total	100	100	100	100

Table 19. Texas scenarios: operating costs as percentages of total cost.

Scenario #	1 *P.chinensis* (33g)	2 *P.chinensis* (25g)	3 *P.chinensis* *P.chinensis*	4 *P.chinensis* *P.vannamei*
Feed	34	36	52	41
Stocking	19	21	16	22
Energy	10	6	6	7
Salaries	9	10	6	7
Labor	5	3	3	4
Other	6	6	4	4
Contingency	4	4	4	4
Depreciation	13	14	8	11
Total	100	100	100	100

Table 20. South Carolina scenarios-operating cost ($) per kg harvested.

Scenario #	1 *P. chinensis* (33g)	2 *P. chinensis* (25g)	3 *P. chinensis* *P. chinensis*	4 *P. chinensis* *P. vannamei*
Feed	2.20	1.48	2.18	1.99
Stocking	2.53	2.00	1.37	2.02
Salaries	1.01	0.80	0.41	0.66
Energy	0.79	0.35	0.34	0.47
Labor	0.30	0.13	0.13	0.18
Chemicals	0.05	0.04	0.02	0.03
Lease rent	0.09	0.07	0.04	0.06
Other	0.21	0.17	0.09	0.14
Contingency	0.35	0.26	0.23	0.26
Depreciation	0.37	0.39	0.20	0.32
Total	7.90	5.69	5.01	6.13

Table 21. Texas scenarios-operating cost ($) per kg harvested.

Scenario #	1 *P. chinensis* (33g)	2 *P. chinensis* (25g)	3 *P. chinensis* *P. chinensis*	4 *P. chinensis* *P. vannamei*
Feed	2.20	1.72	2.18	2.00
Stocking	1.26	1.00	0.69	1.08
Energy	0.63	0.27	0.27	0.34
Salaries	0.60	0.47	0.24	0.36
Labor	0.33	0.14	0.14	0.18
Other	0.36	0.29	0.15	0.22
Contingency	0.27	0.19	0.18	0.20
Depreciation	0.86	0.68	0.35	0.52
Total	6.51	4.76	4.21	4.90

based on the shrimp size and the head-to-tail ratio (Table 23). These are the calculations:

tail weight = harvest weight x *tail percentage*

Tail weight determines the count, which then determines the tails price (Table 24).

whole shrimp price = tail price x *tail percentage*

Financial Assumptions

Financial assumptions are consistent for each production situation, and are based on the guidelines proposed by the Gulf Coast Research Laboratory Consortium for financial feasibility analyses of U.S. marine shrimp farming techniques.

The calculation of the net present value (NPV) and internal rate of return (IRR) was projected on an after-tax cash flow. A dis-

Table 22. NMFS, frozen prices, August-December, 1989. New York Green sheet, Ecuador White.

Size count	Price ($/lb.)	Tail weight (g)	Price ($/kg)
15	8.79	30.3	19.34
16 - 20	6.68	22.7 - 28.4	14.70
21 - 25	5.27	18.2 - 21.6	11.59
26 - 30	4.81	15.1 - 17.5	10.58
31 - 35	4.55	13.0 - 14.6	10.01
36 - 40	3.88	11.4 - 12.6	8.54
41 - 50	3.70	9.1 - 11.1	8.14
51 - 60	3.27	7.6 - 8.9	7.19
61 - 70	2.92	6.5 - 7.4	6.42
71 - 90	2.55	5.0 - 6.4	5.61

count rate of 15% was used. This discount rate includes the after-tax cost of capital and a premium for risk. Income tax was calculated at 30% on taxable income. A zero inflation rate was applied to costs.

Prices are based on heads-on (whole) shrimp for projecting gross revenue. This assumption simplifies production cost comparisons by de-emphasizing possible marketing cost considerations. This does not imply that whole shrimp is the optimal market product form for any given location.

The analyses assume one year of start-up and construction activities and 10 years of production. The cash-flow analysis is over the entire 11 years.

Zero debt capital was used in the financial analysis. This simplifies the analysis relative to the return on equity and reflects the low debt ratio generally held by U.S. shrimp farms.

Table 23. Head-to-tail comparison of shrimp species.

	P.chinensis[a]	*P.vannamei*[b]
Head	43.00%	37.50%
Tail	57.00%	62.50%

[a]Disc. Group J, [b]J. Wyban, pers. comm.

FINANCIAL ANALYSIS

Two models were used in this analysis. The generalized shrimp model (a Lotus 1-2-3™ template), developed by Leung and Rowland (1989), was used for collecting production parameters, cost data, and production values. Yields and necessary feed requirements, water, energy, and labor use, capital and equipment requirements, and other specific operational parameters were calculated based on farm and facility design, and management and feeding strategies. This model was used by the representatives from South Carolina and Texas to characterize their respective operations.

The generalized data for each production scenario were projected and analyzed over 10 years using a second model. This model was necessary to integrate the timing and cost involved in stocking two crops per year over several years.

Table 24. Whole shrimp prices.

Species	Harvest weight (g)	Tail (g)	NY price[a] ($/kg)	Adj. price whole shrimp ($/kg)
P.chinensis	33	18.81	11.59	6.61
	25	14.25	10.01	5.71
	23.5	13.40	10.01	5.71
	16	9.12	8.14	4.64
P.vannamei	15.1	9.44	8.14	5.09
	18.5	11.56	8.54	5.34

[a]Table 22

A spreadsheet component of the second model translated the monthly and yearly production and cost data into profit and loss and cash-flow statements for financial analysis. Sensitivity of profitability to price was tested for each scenario as part of the financial analysis. Figure 5 provides an overview of the model structure.

The production situations were evaluated and compared using two discounted measures of profitability, net present value (NPV) and internal rate of return (IRR). The net present value is the present worth of the net cash flow generated over the life of the project. Net present value was calculated as follows:

$$NPV = \sum_{i=1}^{n} \frac{A_i}{(1 + r)^i}$$

where

NPV = net present value
A = net cash-flow in year i, and
r = discount rate

These are the criteria for net present value measurement:

NPV > 0, scenario would be profitable,
NPV < 0, scenario would not be profitable,
NPV = 0, scenario would be a break-even situation.

For mutually exclusive projects, such as regional scenarios, the NPV is a fair means of ranking project worth.

The IRR on an investment is the discount rate that makes the present value of the net cash flow equal to zero. It represents the average earning power of money used over the life of the project.

$$IRR = k$$

where

$$\sum_{i=1}^{n} \frac{A_i}{(1 + k)^i} = 0$$

If the IRR is greater than the appropriate opportunity cost of capital (15% in this case), the investment is feasible (Shang, 1981). As with NPV, mutually exclusive projects such

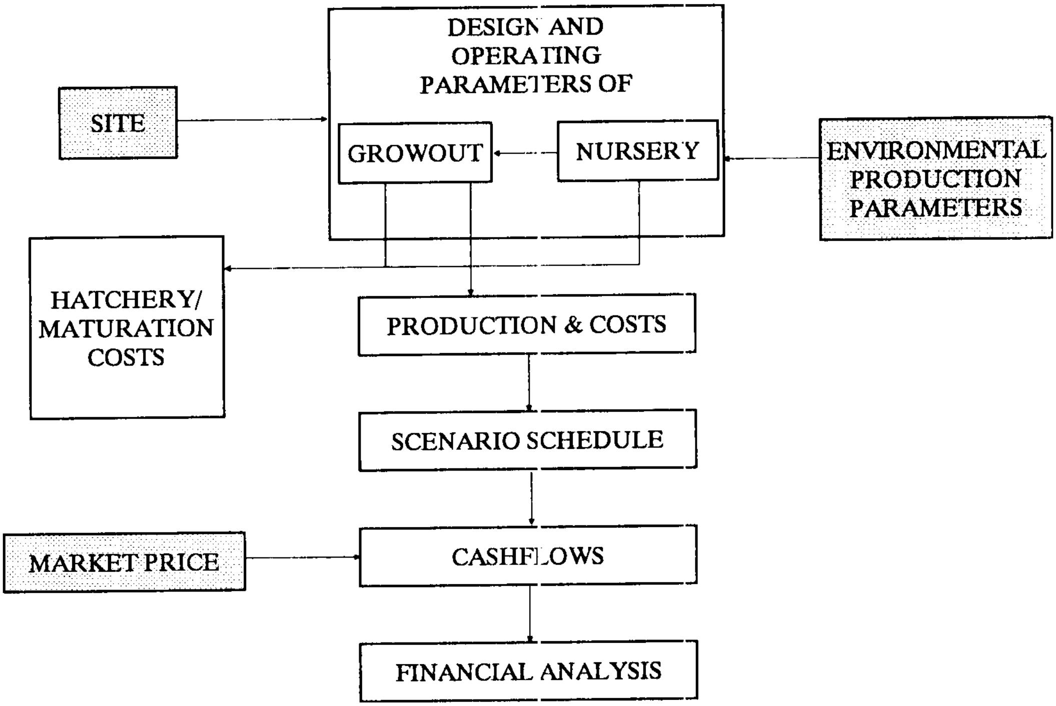

Fig. 5. The structure of the financial analysis model.

as the regional scenarios, each being of equal capital investment, can be ranked according to profitability with IRR. Ranking of independent projects across regions with different capital investments by IRR is not advisable without a confirming NPV figure.

RESULTS AND DISCUSSION

Profitability

NPV and IRR figures are presented in Table 25. If the NPV or IRR values are less than zero, they are not quantified and are listed as less than zero.

The South Carolina and Texas scenarios are listed in descending order of profitability, using NPV and IRR.

(1) Scenario 3 (2 crops of *P. chinensis*)
(2) Scenario 2 (1 crop of *P. chinensis* to 25 g)
(3) Scenario 4 (2 crops: *P. chinensis/P. vannamei*) and Scenario 1 (1 crop of *P. chinensis* to 33 g)

Table 25 shows the relative ranking of the scenarios for each region. When NPV and IRR are both considered, only Scenario 3 in South Carolina and Texas, is profitable. In both locations, the second ranking scenario is scenario 2. This result shows the profitability of raising one crop of *P. chinensis* to 25 g (Scenario 2) is not much different than one crop of *P. vannamei* in South Carolina. In Texas, the IRR for Scenario 2 is 12%, over double the *P. vannamei* crop, 5%, but both have negative NPV's. Scenarios 1 and 4 share the third rank in South Carolina with negative NPV's and IRR's. Scenarios 1 and 4 in Texas differ by one IRR percentage point, which is not significant.

Sensitivity Analyses

The sensitivity analyses show the changes in IRR for each scenario as the average base prices for the harvested shrimp decrease and increase by 10% and 20%. The prices for each species or size of shrimp are changed by the same percentage in each case.

Table 25. Internal rate of return and net present value for Texas and South Carolina.

Scenario #	1st Crop/ 2nd crop (species)	South Carolina NPV ($)	South Carolina IRR (%)	Texas NPV ($)	Texas IRR (%)
1	*P.chinensis* (33g)	<0	<0	<0	1
2	*P.chinensis* (25g)	<0	1	<0	12
3	*P.chinensis* *P.chinensis*	125,000	31	963,000	34
4	*P.chinensis* *P. vannamei*	<0	<0	<0	2
-	*P.vannamei*[a]	<0	1	<0	5

[a] Rhodes, pers. comm., 1989, Griffin et al., 1989.

The slopes of the lines plotted in Figures 6 and 7 represent the sensitivity of IRR to the change in price. The South Carolina scenarios are more sensitive to price changes than the Texas scenarios. This may represent the additional risk or additional efficiency associated with the South Carolina type of operation. Although the Texas operation is capitalized at about 4.3 times that of South Carolina, gross production is only about 3.4 times that of South Carolina. South Carolina's operating costs per kg of production are about 20% greater than Texas'. These differences may be explained, in part, by the inclusion of land as a capital cost in Texas and as an operations cost (lease) in South Carolina.

CONCLUSIONS

The results of this study are derived from a financial model simulation. The assumptions are based on cold-tolerant shrimp operations in PRC, Korea, and Taiwan and U.S. tropical shrimp operations in South Carolina and Texas. The assumptions are applied to a hypothetical shrimp operation in South Carolina and Texas. The results of this study are not as realistic as results derived from pilot or experimental operations. However, this study does provide a financial evaluation of cold-tolerant shrimp production in the United States based on research and commercial production results from the PRC, Korea and Taiwan.

Increasing production can be accomplished by various means. Here we examine species selection as a means of enhancing production. Financial analysis of species selection is relatively straight-forward for engineering and management issues where costs are readily available. Financial analysis of the biological and environmental issues surrounding species selection is less straightforward. Evaluation of the commercial potential for *P. chinensis* in North America is complicated by the cultural and economic practices of its native habitat. In this analysis the biological and environmental aspects of *P. chinensis* are superimposed upon the environmental and physical aspects of U.S. shrimp culture.

The major factors affecting overall profit are production level, major cost items, and market price. Production level is reflected in production parameters such as stocking density, survival, growth rate, and length of growing season. The long growing season that is possible with *P. chinensis* yields two crops of about 20 gram shrimp when the species is double-cropped.

Feed and stocking costs are the major costs in this analysis. Combined, they account for between 50% and 70% of operating costs. Stocking costs for the closed thelycum species approached levels comparable to *P. vannamei*. Although the economies of large tank hatchery systems were not fully explored in this study, the results suggest that larger hatcheries could produce seed at costs less than $10 per 1,000.

Market price affects profit level in varying degrees for different operations. The size and capitalization structure of the two operations in these analyses accounted for the differences in sensitivity to price changes.

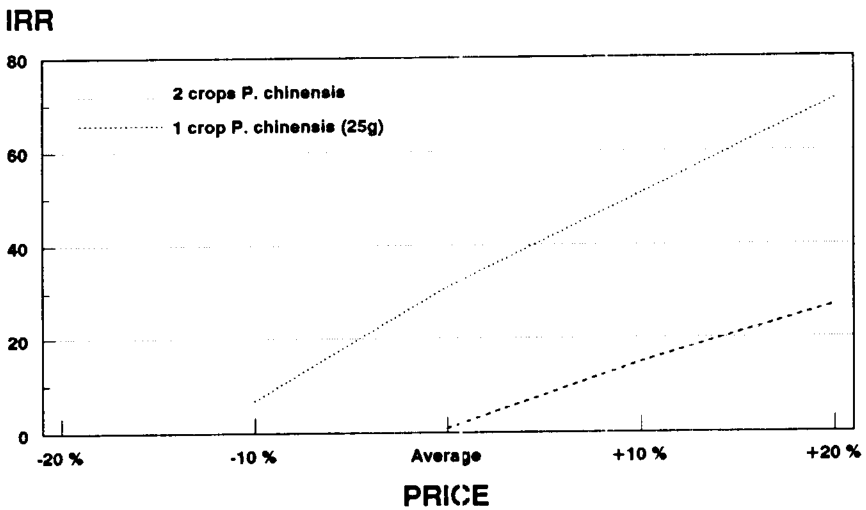

Fig. 6. IRR sensitivity to price for South Carolina scenarios. Scenarios 1 and 4 were not quantifiable, average price based on data from Aug. - Dec. 1989.

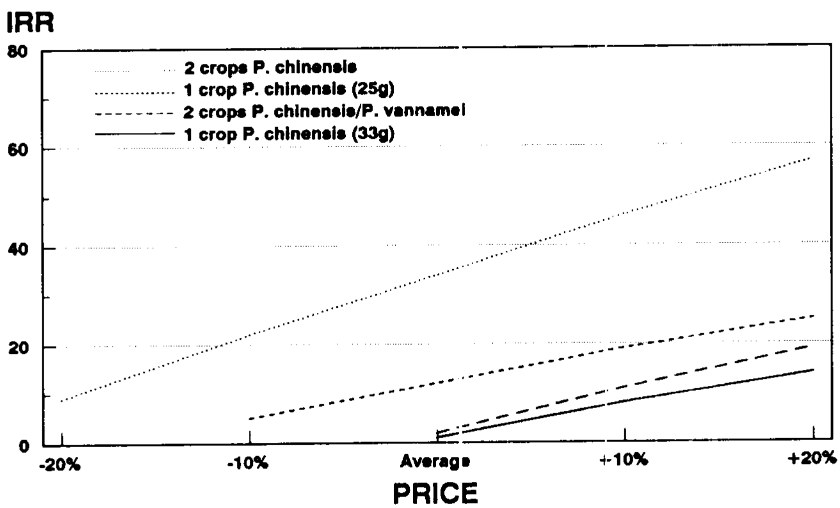

Fig. 7. IRR sensitivity to price for Texas scenarios. Average price based on data from Aug. - Dec. 1989.

Three factors contribute to the comparative profitability of double-cropping with *P. chinensis* over single or double-cropping with *P. vannamei*:

(1) temperature tolerance
(2) growth rate
(3) synchronized spawning

Tolerance of *P. chinensis* to cooler water temperatures adds 2-3 months to the effective growing season for shrimp in South Carolina and Texas. A combination of a higher growth rate than *P. vannamei* and the extended growing season resulted in a dramatic increase in production. Finally, synchronized spawning allows the use of large tank culture techniques in the hatchery. Large tank culture affords more efficient use of labor and other available resources.

Data presented at the AIP workshop and this analysis suggest that double-cropping *P. chinensis* in the U.S. may be profitable. The IRR for this scenario is 34 in Texas and 31 in South Carolina. These values are significantly greater than the IRR's in all other scenarios analyzed in this study. They are also significantly greater than the IRR for *P. vannamei* in Texas (IRR=5, Griffin et al. 1989) and in South Carolina (IRR=1, Rhodes pers. comm.).

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SECTION IV

Discussion

DISCUSSION

The purpose of the AIP program was to review the biological characteristics and production parameters for three cold-tolerant shrimp species (*Penaeus chinensis, P. penicillatus,* and *P. japonicus*). This discussion includes a summary of the advantages and disadvantages associated with culturing *P. chinensis, P. japonicus* and *P. penicillatus*, the pros and cons associated with introduction and culture of *P. chinensis* in the U.S., and a review of areas needing experimental verification and research prior to producing *P. chinensis* in the U.S.

Species-Specific Advantages and Disadvantages

The advantages and disadvantages associated with *P. chinensis, P. japonicus* and *P. penicillatus* are listed in Table 1. Both *P. chinensis* and *P. penicillatus* are easy to culture and can be grown on an earthen pond substrate. The techniques associated with *P. japonicus* culture are specific to that species and a sand substrate is required for pond culture. *P. japonicus* techniques are well documented in the literature and it has been cultured in many different countries. Limited information was available on the culture techniques for *P. penicillatus* and *P. chinensis* prior to the publication of this volume. Of the three species examined, *P. chinensis* appears to be most tolerant to low temperatures. Liao and Chien (Chapter 6) indicate that the geographical distribution of *P. chinensis* in nature and the minimum temperature for spawning make it the most cold-tolerant of the penaeids. Also, this species is cultured at higher latitudes and is naturally distributed in deeper waters than either *P. japonicus* or *P. penicillatus*. The relationship between temperature and growth is discussed throughout the Proceedings and there is some variance in the findings presented from different locations. However, two temperature relationships are worth reviewing. Growth stops in *P. penicillatus* at 20°C, in *P. japonicus* at 15°C and in *P. chinensis* at 14-15°C (Liao and Chien Chapter 6; Sect. II, Disc Group D). The minimum spawning temperature is 13°C for *P. chinensis*, 20°C for *P. japonicus*, and 23°C for *P. penicillatus* (Liao and Chien Chapter 6).

Table 1. Advantages and disadvantages associated with the culture of three penaeid shrimp species.

	P. chinensis	*P. japonicus*	*P. penicillatus*
Advantages	Easy to grow	Culture techniques well defined	Easy to grow
	Most cold tolerant	Cold-tolerant	Low protein required
	Ready market in U.S., Europe, Japan	High priced market	Large tail
	Broad salinity tolerance	Easily reproduced	Tolerates high densities
		Wild broodstock are readily available	
		Can be transported and sold live	
Disadvantages	High protein required	High protein required	Least cold-tolerant
	Difficult to obtain stocks	Requires sand substrate	Small size in culture
	Cannot be sold live	Market primarily limited to Japan	Cannot be sold live
		High culture cost	Develops heavy pigmentation and head is easily disconnected following death
		Sensitive to stress in culture	

P. penicillatus has the lowest protein requirement (%) of the three species examined. *P. chinensis*' protein requirement falls between those of *P. penicillatus* and *P. japonicus*, approximately 45%. *P. japonicus* has the highest protein requirement, 50-60%.

P. chinensis is a white shrimp primarily marketed frozen in the U.S. and Japan. The export market for *P. penicillatus* is unknown and it is currently sold locally in Taiwan and Southern China. Experts indicate that the market is probably similar to that for *P. chinensis*, since both are white shrimp. One of the key advantages of growing *P. penicillatus* is its small head-to-tail ratio. *P. penicillatus* is reported to have tail yields reaching 70%, whereas *P. chinensis* tail yields range from 56-58% (Sect. II, Disc. Group J). *P. japonicus* is primarily marketed live in Japan, where it is preferred for its colorful appearance.

Because it can survive shipping, this shrimp is sold live in restaurants and markets.

The availability of specific pathogen free (SPF) stocks of *P. chinensis* and *P. penicillatus* is unknown. Information presented by workshop participants revealed that disease has not been a significant problem for either species. However, participants from China and Korea stated that this was only because low densities are used in growout. Disease screening is rarely done in either China or Korea. Taiwanese participants noted that *P. japonicus* is resistant to Monodon baculovirus (MBV).

Pros and Cons for *Penaeus chinensis* Culture in the U.S.

The original impetus for this program was the commercial aquaculture community's interest in identifying a shrimp that could be cultured in the U.S. during periods when *P. vannamei* growth is temperature limited. Workshop results revealed that *P. chinensis* was the best candidate because of its good growth at low temperatures, ease of culture, and low culture costs. A financial analysis was done for *P. chinensis* culture in two locations on the U.S. mainland where shrimp are currently cultured (Sect. III).

That analysis suggests that double-cropping with *P. chinensis* is possible in both locations, and that it may be profitable. The three main factors that contribute to the comparative profitability of double cropping *P. chinensis* in the U.S. are: tolerance of low temperatures, good growth rates at low temperatures, and synchronized spawning. The latter allows for use of large tank culture techniques, which provides greater efficiency in the hatchery and simultaneous stocking of nursery ponds.

P. chinensis is currently only cultured in Korea and China. Several factors need to be evaluated, and experiments should be conducted prior to initiating *P. chinensis* culture in the U.S. Table 2 lists some of the pros and cons involved in the start up of *P. chinensis* culture in the U.S.

Table 2. Pros and cons associated with *P. chinensis* culture in the U.S.

Pros	Cons
Promising financial analysis results	Stocks have been difficult to obtain from China
Can be doubled-cropped in many U.S. locations	Availability of SPF stocks is unknown
Increases number of U.S. locations where shrimp can be cultured	Import permit process for exotic species is complicated in most states
Good growth at low temperatures	Experimental verification of production, growth rate and feed requirements is needed
Synchronized spawning	Maturation and overwintering techniques need to be developed
Market acceptance as a white shrimp	Captive broodstock required
Easily cultured, simple seed production	Optimum production technology undefined
	No U.S. expertise or experience

On the positive side, the financial analysis results indicate that *P. chinensis* culture in the U.S. may be profitable in either South Carolina or Texas, particularly when two crops are grown in one season. The high internal rates of return and net present values indicate that if the densities, growth rates and food conversion ratios reported from Korea can be achieved in South Carolina and Texas, this species may be extremely profitable. Comparison of the growth data at different temperatures with the temperature ranges in South Carolina and Texas reveals that this species can be double-cropped to a large size in U.S. locations where shrimp are now cultured, as well as at higher latitudes. Finally, the synchronized spawning behavior allows for immediate stocking of large numbers of ponds when water temperatures are acceptable.

Results of the first year's activities suggest that two areas need further work: (1) identification of a disease-free source of *P. chinensis* for U.S. shrimp producers, and (2) experimental verification of production costs associated with maturation and overwintering, and confirmation of temperature-specific growth rates and feed conversion ratios in the U.S.

Several attempts have been made to obtain *P. chinensis* stocks from Asia and as far as we know the few successfully imported stocks have been diagnosed with pathogens and subsequently destroyed. Two shipments of *P. chinensis* were imported to Hawaii in the late 1980's. One shipment of broodstock was imported from Hong Kong, and a second shipment of postlarvae was imported from Korea. The stocks were screened for pathogens by the State Veterinarian. Both stocks were diagnosed with low levels of Hepatopancreatic parvo-like virus (HPV). The broodstock were also positive for microsporidians and IHHN virus, and the postlarvae were also positive for Reo-like virus (REO). The availability of SPF stocks is unknown and disease screening has only rarely been done in Asia. However, workshop participants indicated that disease was not a problem in *P. chinensis* culture, even at densities as high as 30 per m^2 (Sect. II, Disc. Group E). However, average hatchery survival rates of 5-10% suggest there may be unidentified disease problems. Most participants felt that healthy wild and cultured stocks were available in China and Korea. The difficulties involved in obtaining healthy (SPF) brood or seedstock need to be examined.

In addition to disease screening, an aquaculturist must obtain permits to import a new animal species. In many states this is a long, involved process. In Hawaii, proposals for introduction of new species are reviewed by government agencies and the Department of Agriculture Importation Committee. Those who have been successful in obtaining permits estimate that the amount of time necessary to obtain a new species permit ranges from 6-12 months. Permits to import *P. chinensis* into Hawaii were issued as early as 1972, however, stocks were not imported until the late 1980's (Hawaii State Dept. of Agriculture, pers. comm.).

Experimental Verification of Production Costs

Many of the input values for the financial analysis now need to be verified experimentally in the U.S. The maturation costs used in the analysis were extremely conservative, since only a limited amount of work has been done in this area. Furthermore, overwintering costs had to be estimated, due to the limited data available in this area. Both maturation and overwintering methods need to be examined experimentally to more accurately reflect the costs involved in this area. Experiments with *P. chinensis* are needed to examine both temperature-specific growth rates and feed conversion ratios. With additional data, a more accurate analysis of the profitability of producing this species in the U.S. can be done.

SECTION V

Appendices

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APPENDIX II: WORKSHOP SCHEDULE

Monday, October 2, 1989

Speaker	Topic	Time
Dr. James Wyban	Intensive Culture of *P. vannamei* in Round Ponds	9:00 - 9:30
Mr. Jack Whetstone	An Overview of Extensive Penaeid Shrimp Farming in North America	9:30 - 10:00
Dr. George Chamberlain	Hatchery Systems in the United States	10:15 - 10:45
Dr. Byung-Ha Park	Status of Shrimp Culture in Korea	10:45 - 11:15
Professor Ruiyu Liu	The Present Status and Prospects of Shrimp Culture in China	11:15 - 11:45
Discussion Group Sessions		

Tuesday, October 3, 1989

Speaker	Topic	Time
Dr. Craig Browdy	Intensive Growout Systems in the Mainland United States	8:30 - 9:00
Mr. Young Gil Rho	Present Status of Seedling Production of *P. chinensis* and *P. japonicus* in Korea	9:00 - 9:30
Professor Kexing Wang	Progress of Fry Rearing Technique of *Penaeus chinensis* in China	9:45 - 10:15
Professor Yew-Hu Chien	Evaluation and Comparison of the Culture Practices for *P. japonicus, P. penicillatus* and *P. chinensis*	10:15 - 10:45
Dr. Yung C. Shang	A Review of the World Shrimp Market	10:45 - 11:15
Mr. Larry Rowland	Economic Model Explanation and Uses	11:15 - 12:00
Discussion Group Sessions		

Wednesday, October 4, 1989

Speaker	Topic	Time
Mr. Jin Ho Kim	Comparative Growth Rates of *P. chinensis* and *P. japonicus* Under Different Environmental Conditions	9:00 - 9:30
Professor Jiaxin Chen	Shrimp Culture in the People's Republic of China	9:30 - 10:00
Professor Cong-Hai Yang	Influence of Certain Environmental Factors on the Growth of *Penaeus chinensis*	10:30 - 11:00
Professor Naiyu Zhang	Growth of Cultured Chinese Shrimp, *Penaeus orientalis*	11:00 - 11:30
Discussion Group Sessions		

APPENDIX III: *PENAEUS CHINENSIS* BIBLIOGRAPHY

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APPENDIX V: *PENAEUS JAPONICUS* BIBLIOGRAPHY

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