

BIOLOGY and CULTURE **of Penaeus monodon**

**Brackishwater Aquaculture Information System
Aquaculture Department
Southeast Asian Fisheries Development Center
Tigbauan, Iloilo, Philippines**

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PENAEUS MONODON



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**BRACKISHWATER AQUACULTURE INFORMATION SYSTEM
AQUACULTURE DEPARTMENT
SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER**

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FOREWORD

The quest for information on the biology and culture of *Penaeus monodon* (giant tiger prawn or "sugpo") has been incessant since governments and industry have seen the importance of this species in generating foreign exchange.

To respond to this demand, the Brackishwater Aquaculture Information System (BRAIS), a project implemented by the SEAFDEC Aquaculture Department, has drawn from the expertise of its scientists to document the current state of aquaculture of *P. monodon* and to recommend future directions for research and courses of action for industry.

This publication is the second in the series of BRAIS State-of-the-Art Reviews. The funding support of the International Development Research Centre (IDRC) of Canada for this volume and all other activities and output of BRAIS is most gratefully acknowledged.

It is hoped that the information provided in this volume will benefit aquaculturists, policy makers, researchers, entrepreneurs, and the general public.

F.J. Lacanilao
Chief
SEAFDEC Aquaculture Department

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 of this book.

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INTRODUCTION

J. Honculada Primavera*

The giant tiger prawn *Penaeus monodon* is only one among approximately 100 species of penaeid prawns and shrimps commercially important in capture fisheries and/or aquaculture. Its large size, fast growth rate, high survival, resistance to handling and successful breeding in captivity make it the predominant culture species in the Indo-Pacific region.

In Asia, prawn culture had its beginnings with the harvest of prawns as by-products from brackishwater milkfish ponds. This traditional culture has since evolved to the present extensive, semi-intensive, and intensive culture systems with increasing stocking rates and the corresponding intensification of feeding and water management schemes.

Since its establishment in 1973, the SEAFDEC Aquaculture Department (AQD) has undertaken pioneering R & D work on prawn culture. Results of these experimental and pilot studies have been disseminated through various publications, training, and extension programs. At least half of the approximately 260 AQD papers published in scientific journals and edited proceedings as of mid-1988 are on prawns and shrimps. In 1984, the Department organized the First International Conference on the Culture of Penaeid Prawns/Shrimps which gathered around 300 of the world's leading scientists and prawn culturists.

It is within this historical perspective that AQD has prepared this state-of-the-art review of the biology and culture of *P. monodon*. Individual reviews on biology, maturation, larval rearing, grow-out, nutrition, and diseases have been authored by AQD researchers who are authorities in their respective fields. Each paper consolidates and synthesizes current information on the biology and culture of *P. monodon* generated both from within the Department and outside.

*Technical Lead Person

Chapter One

BIOLOGY AND ECOLOGY

Noel B. Solis*

For the culture of any species to evolve from tradition or art to science, basic information on the biology of the species is required.

This paper reviews current information on *Penaeus monodon* including taxonomy, morphology, distribution, and bionomics and life history. The last covers reproduction, development of embryo, larva up to adult, spawning, food and feeding, and physiology.

Problems that have cropped up with the intensification of prawn culture, e.g. discharge of pesticides from grow-out ponds, are highlighted. Other conflicts such as the conversion of mangroves and other estuaries, considered nursery grounds of various marine fauna including *P. monodon*, into fishponds; overexploitation of wild spawners with no stock assessment data; and indiscriminate throwing away of other prawn and finfish fry from wild collections in favor of *P. monodon* fry could adversely affect the ecology of mangroves and other marine ecosystems.

TAXONOMY

The genus *Penaeus* Fabricius (1798) was placed on the Official List of Generic Names in Zoology as Name No. 498 upon the discovery and description of *Penaeus monodon* by John Christ Fabricius in 1798 (Mohamed 1970). With the revision of the specific name *monodon* by Holthuis, the two species have become stabilized and the name *P. monodon* is generally accepted for the present species (Hall 1961, Mohamed 1970, Motoh 1981). No subspecies are currently recognized for this species and *P. monodon manillensis* (Villaluz and Arriola 1938) proved to be based on an abnormal specimen of *P. semisulcatus* (Mohamed 1970, Motoh 1981).

*Research Associate of SEAFDEC Aquaculture Department

Definition

The taxonomic definition of the giant tiger prawn is as follows:

Phylum Arthropoda

Class Crustacea

Subclass Malacostraca

Order Decapoda

Suborder Natantia

Infraorder Penaeidea

Superfamily Penaeoidea

Family Penaeidae Rafinesque, 1815

Genus *Penaeus* Fabricius, 1798

Subgenus *Penaeus*

Species *monodon*

Scientific name: *Penaeus (Penaeus) monodon* Fabricius, 1798.

It has four synonyms:

Penaeus carinatus Dana, 1852

P. caeruleus Stebbings, 1905

P. monodon var. *manillensis* Villaluz

and Arriola, 1938

P. bubulus Kubo, 1949

The FAO names are giant tiger prawn (English), crevette geante tigre (French), and camaron tigre gigante (Spanish).

The term shrimps and prawns are common English names used synonymously due to the absence of systematic basis to mark a distinction (Wickins 1976, Holthuis 1980). In an attempt to clarify the issue, Holthuis (1980) traced the origin of the names shrimps and prawns and its usage in various countries. In general, shrimps refer to the smaller animals and prawns to the larger ones, while according to Food and Agriculture Organization (FAO) Convention, shrimps refer to marine

penaeids while prawns refer to freshwater palaemonids. In the present view, the term prawn will be used following the accepted usage at SEAFDEC Aquaculture Department.

Considerable taxonomic works on the Penaeidae have been published throughout the world, many providing detailed information to interested workers. Motoh (1977) also compiled various common and vernacular names of commercially important penaeid prawns and shrimps.

For the identification of *P. monodon* postlarvae, Motoh and Buri (1981) published a key for penaeid postlarvae from Panay Island, Philippines; so did Prawirodihardjo et al (1975) in Indonesia, while Rao and Gopalakrishnan (1969) identified *P. monodon* and *P. indicus* juveniles in India.

MORPHOLOGY

The morphological features of *P. monodon* have been described in detail by workers from various countries, among whom are Bate 1888; Blanco and Arriola 1937; Villaluz and Arriola 1938; Kubo 1949; Holthuis 1949; Racek 1955, 1957, 1972; Hall 1956, 1961, 1962; Dall 1957; Cheung 1960; Racek and Yaldwin 1971; Motoh 1981; and Motoh and Buri 1984.

The following description includes important features sufficient for the identification of this species. The shell is smooth, polished, and glabrous. The rostrum extends beyond the tip of the antennular peduncle, is sigmoidal in shape, and possesses 6-8 dorsal and 2-4 ventral teeth, mostly 7 and 3, respectively. The carapace is carinated with the adrostral carina almost reaching the posterior margin of the carapace. The gastro-orbital carina occupies the posterior one-third to one-half distance between the post-orbital margin of the carapace and the hepatic spine. The hepatic carina is prominent and almost horizontal. The antennular flagellum is subequal to or slightly longer than the peduncle. Exopods are present on the first four pereopods but absent in the fifth. The abdomen is carinated dorsally from the anterior one-third of the fourth, to the posterior end of the sixth, somites. The telson has a median groove but without dorso-lateral spines. Figure 1 shows the various parts of *P. monodon* and the technical terms with taxonomic importance.

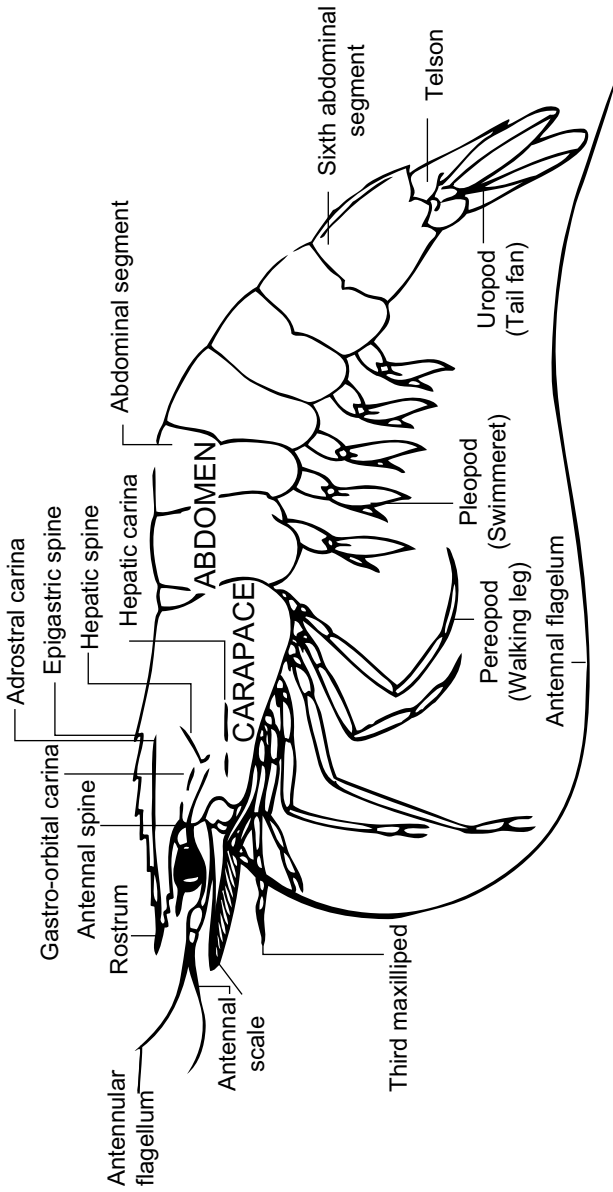


Fig. 1. Lateral view of *P. monodon* showing important parts (Motoh 1981)

A live giant tiger prawn has the following characteristic coloration: carapace and abdomen are transversely banded with red and white, the antennae are greyish brown, and the pereopods and pleopods are brown with crimson fringing setae. In shallow brackish waters or when cultured in ponds, the color changes to dark and, often, to blackish brown (Motoh 1981).

DISTRIBUTION

The giant tiger prawn is widely distributed throughout the greater part of the Indo-Pacific region, ranging northward to Japan and Taiwan, eastward to Tahiti, southward to Australia, and westward to Africa (Racek 1955; Holthuis and Rosa 1965; Motoh 1981, 1985).

In general, *P. monodon* is distributed from 30°E to 155°E in longitude and from 35°N to 35°S in latitude with the main fishing grounds located in tropical countries, particularly Indonesia, Malaysia, and the Philippines (Motoh 1985, Figure 2).

The fry, juvenile, and adolescent inhabit shore areas and mangrove estuaries, while most of the adults inhabit deeper waters down to 162 m (Motoh 1985). Distribution is sparse as evidenced by a few prawns collected at any one time.

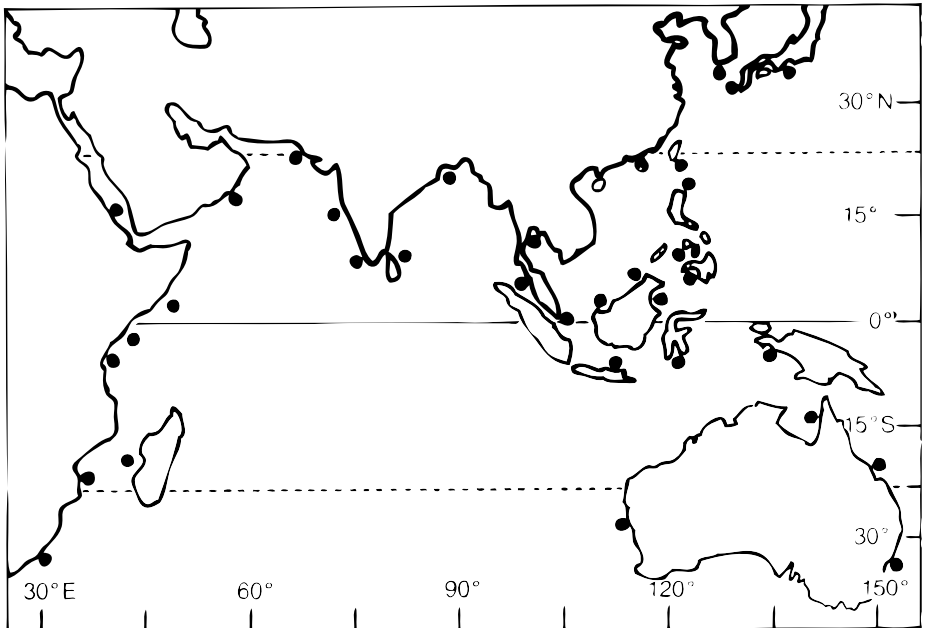


Fig. 2. Geographic distribution of *Penaeus monodon* (Motoh 1981)

BIONOMICS AND LIFE HISTORY

Reproduction

P. monodon is heterosexual. The female attains a relatively larger size than the male. The sexually mature prawn can be distinguished by the presence of the external genital organs: a joined petasma, a pair of appendix masculina on the exopods of the second pleopods, and a genital opening on the coxa of the fifth of pereopod for the male. In females, the thelycum is situated between the fourth and fifth pereopod with the genital opening on the coxa of the third pereopod.

The reproductive system of male and female *P. monodon* is shown in Figure 3. The following description is based on the studies of Motoh (1981, 1985).

Male genital organ. The internal reproductive organ of the male consists of paired testes, vasa deferentia, and terminal ampoules located in the cardiac region dorsal to the hepatopancreas. The testis is translucent and composed of six lobes, each connected in the inner margins leading to the vas deferens. The vas deferens consists of four portions, namely: the short narrow proximal vas deferens, a thickened larger median portion or the medial vas deferens, the relatively long narrow tube as the distal vas deferens, and the muscular portion referred to as terminal ampoule. The terminal ampoule contains the spermatophore and opens at the base of the coxopod of the fifth pereopods.

The spermatozoa of *P. monodon* are minute globular bodies composed of the head of about 3 microns in diameter and a short spike.

The petasma is a pair of endopods of the first pleopods formed by the interlocking hook-like structures. The appendix masculina is oval and is located on the endopod of the second pleopod.

Female genital organ. The internal reproductive organ of the female consists of paired ovaries and oviducts. The ovaries are bilaterally symmetrical, partly fused, and extend almost the entire length of the mature female. It is composed of the anterior lobe located close to the esophagus and the cardiac region of the stomach; the lateral lobes located dorsal to the

hepatopancreas; and the abdominal lobe which lies dorso-lateral to the intestine and ventro-lateral to the dorsal abdominal artery. The oviducts originate at the tips of the sixth lateral lobe and lead to the external genital opening at the coxopods of the third pair of pereopods.

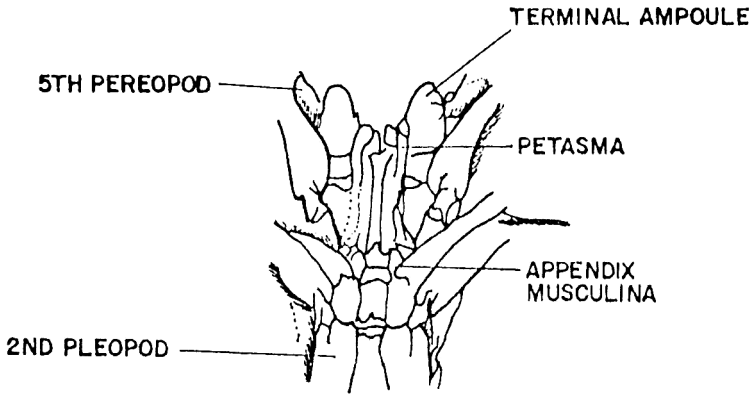
The thelycum, located between the fifth pair of pleopods, consists of an anterior and a pair of lateral plates. It receives the spermatophores during mating. In penaeids, the thelycum may be classified as closed or open type, and *P. monodon* belongs to the closed type.

Motoh (1981) compared the detailed internal reproductive organs of *P. monodon* with those of *P. setiferus* and *P. indicus*.

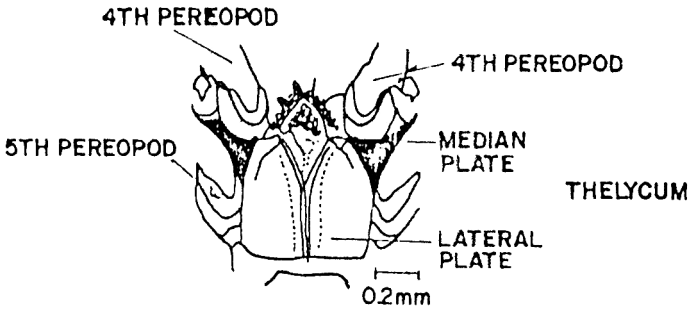
Sexual maturity. Motoh (1981) defined sexual maturity as the minimum size at which spermatozoa are found inside the terminal ampoule of the males and inside the thelycum in the females. The later indicates that copulation or the transfer of spermatophores from the male to the thelycum of the female has taken place. On this basis, Motoh (1981) reported that wild *P. monodon* males possess spermatozoa at 37 mm carapace length (CL) (about 35 g body weight or BW) and females at 47 mm CL (about 67.7 mm BW) although pond-reared prawns were mature only at 31 mm CL (about 20 g BW) and 39 mm CL (about 41.3 g BW), respectively. Primavera (1980) reported the presence of spermatozoa in both pond-reared and wild *P. monodon* males of 40 g body weight (38.5 mm CL), a minimum of 63 weight (about 46 mm CL) for wild females, and about 40 g body weight (41 mm CL) for pond-reared prawns.

From the viewpoint of reproduction, Primavera (1985) emphasized the importance of gonadal maturation and the presence of fully developed spermatozoa with tail or spike. Motoh (1981) reported that sperms without tail were observed in wild *P. monodon* males of smaller size or about 37 mm CL, while Primavera (unpubl.) recently made mention of 10-month old pond-reared *P. monodon* with immature (spikeless) sperm.

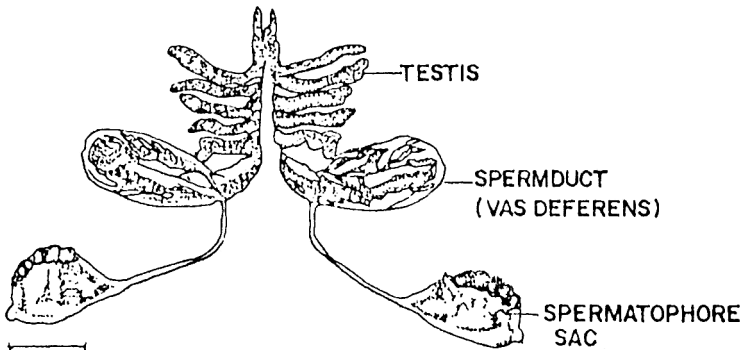
Ovarian maturation stages. The maturation of the ovary has been categorized into five stages, the classification of which is based on ovum size, gonad expansion, and coloration (Villaluz et al 1969, Primavera 1980, Motoh 1981, Tan-Fermin and Pudadera, in press). Figure 4 illustrates the stages of ovarian development in *P. monodon*.



EXTERNAL GENITALIA OF MALE

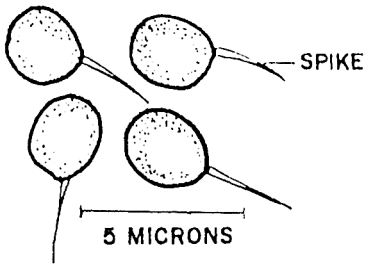
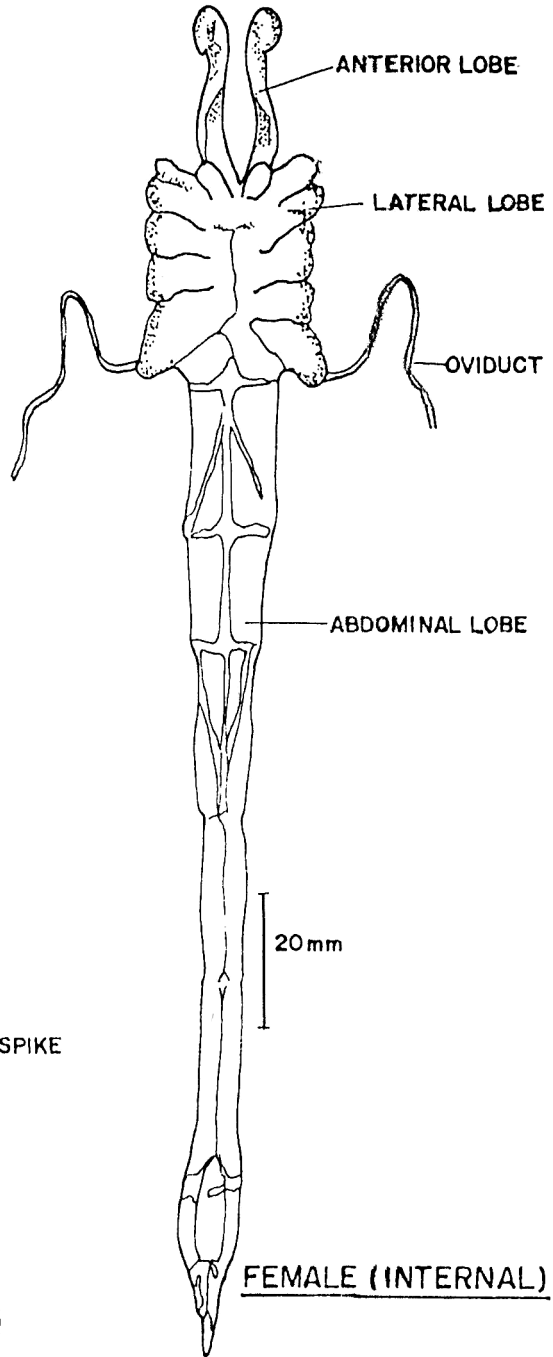


EXTERNAL GENITALIA OF FEMALE



MALE (INTERNAL)

Fig. 3. Reproductive system of *Penaeus monodon* (Motoh 1981)



MATURE SPERMATOZOA
(X 200 magnification)

FEMALE (INTERNAL)

Stage I and V (undeveloped and spent stages). Ovaries are thin, transparent, and not visible through the dorsal exoskeleton. Histological studies show that the ova averaging 36 microns are covered with a layer of follicle cells and the larger ones have nucleus and yolk granules (Motoh 1981). Tan-Fermin and Pudadera (in press) described Stage I as the perinuclear stage composed of perinuclear oocytes (46-72 microns) negatively stained with AB-PAS and Sudan Black. Oocytes bigger than 55 microns are enveloped by a single layer of follicle cells.

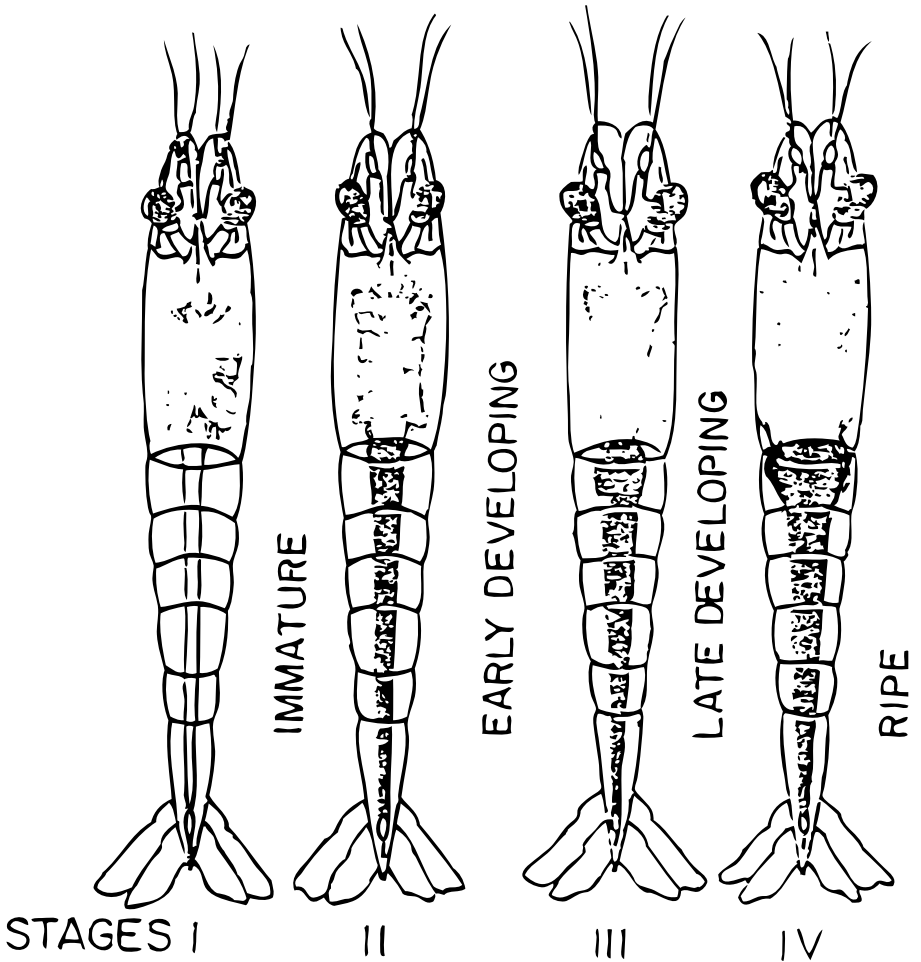


Fig. 4. External appearance of the ovaries of *Penaeus monodon* at different stages of maturity as seen through the dorsal exoskeleton (modified from Primavera 1983)

Similar features are observed in the spent stage which also contains some yolky oocytes, thicker follicle layer, or irregularly shaped perinucleolar oocytes (Tan-Fermin and Pudadera in press).

Stage II (developing stage). Referred to as early maturing stage, the ovaries are flaccid and white to olive green in color, and discernible as a linear band through the exoskeleton. The developing ova averaging 177 microns in diameter have yolk granules and cells believed to be nutritive bodies (Motoh 1981). The cells referred by Tan-Fermin and Pudadera (in press) as cytoplasmic inclusions are composed of small granules of glycoproteins, medium-sized globules of lipoglycoproteins, and few large lipid droplets.

Stage III (nearly ripe stage). Ovaries have glaucous color with the anterior portion thick and expanded. They are very visible through the exoskeleton, particularly at the first abdominal segment, when viewed against the light (Motoh 1981, Tan-Fermin and Pudadera, in press). The ova average 215 microns in diameter.

Stage IV (ripe stage). The ovary classified as ripe (mature) stage is diamond-shaped, expanding through the exoskeleton of the first abdominal segment. The isolated ovary appears dark olive green, filling up all the available space in the body cavity (Primavera 1980). Motoh (1981) reported the presence of a characteristic margin of peripheral rod-like bodies, the apexes of which radiate from the center of the egg. The ova average 235 microns in diameter. Tan-Fermin and Pudadera (in press) characterized this stage to consist mostly of yolky oocytes (288-408 microns) with additional rod-like bodies which contain acid and basic mucopolysaccharides but without lipids.

In some cases, ovaries are observed to be discontinuous, i.e., white in color in either the anterior or posterior portions with olive green color in the opposite ends. This condition is referred to as partially spent ovaries.

At present, these categories are used in the selection of wild spawners and prove to be generally effective. Prawns of Stage IV are used in hatchery operations. In the field, handling of the prawn for visual observation of the ovary color, size, and shape can not be avoided and can be stressful to the animal.

Fecundity. The number of eggs spawned varies according to the condition of the spawning female. Estimate of fecundity is mostly undertaken in the laboratory by counting the eggs from aerated spawning tanks.

For wild spawners of *P. monodon*, Motoh (1981) reported 248 000 to 811 000 eggs/spawn. Primavera (1985) mentioned that several researchers have observed lower fecundity. For captive and ablated females, fecundity ranges from 60 000 to 600 000 eggs/spawn because of small body size and uneven development of ovaries. Further detailed discussion on the subject is referred to Primavera (this volume).

In general, larger females produce more eggs than smaller females (Motoh 1981, Primavera 1985, Villegas et al 1986).

Morphological Development

Embryo. Eggs are spherical, yellowish green, and very minute, having a diameter ranging from 0.27 to 0.31 mm with an average of 0.29 mm. Eggs tend to sink slowly in still waters. Cleavage to 2-celled, 4-celled, morula, and embryonic nauplius stages occur approximately 0.5, 1, 1.8, and 11 hours, respectively, after spawning (Figure 5). The nauplius in each egg is observed to move intermittently before hatching (Villaluz et al 1969; Kunvankij 1976; Motoh 1979, 1981, 1985).

With significance in hatchery operations, Primavera and Posadas (1981) classified the eggs of *P. monodon* based on morphological criteria and hatching rates.

Larva. The larval stage consists of 6 nauplius, 3 protozoa, 3 mysis, and 3 or 4 megalopa substages, requiring about 1.5 days, 5 days, 4-5 days, and 6-15 days, respectively, for development (Villaluz et al 1969; Kunvankij 1976; Motoh 1979, 1981, 1985). Figure 6 illustrates the larval stages of *P. monodon*. Larvae exhibit planktonic behavior offshore with antennal propulsion for swimming in nauplius, antennal and thoracic propulsion in mysis, and abdominal propulsion in megalopa. While the nauplii utilize yolk granules within their body, feeding starts in protozoa and mysis (collectively called zoea) substages. The megalopa with the earlier juvenile stage (traditionally called postlarva or "fry" for commercial purpose) is transparent with, dark brown streak on the ventral side tip of

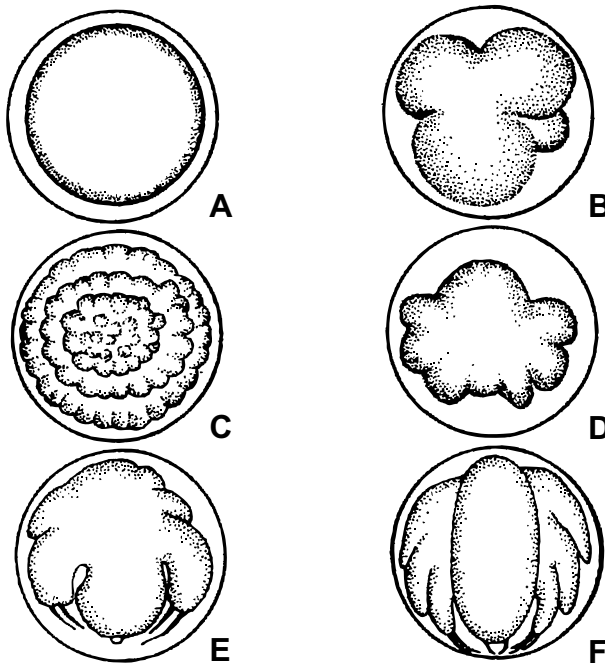
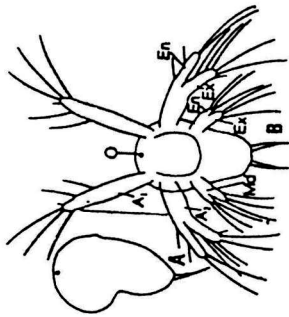


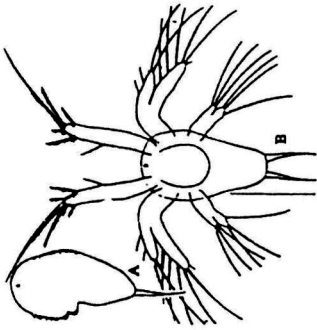
Fig. 5. Eggs of *P. monodon* at various embryonic developmental stages. (A) newly spawned eggs, (B) 4-cell stage (about one hour after spawning), (C) morula stage (about 1.8 hours after spawning), (D) early embryonic nauplius, (E) late embryonic nauplius, (F) embryonic nauplius about to hatch (Motoh 1981)

the antennular flagellum to the tip of the telson. Under laboratory conditions, postlarvae become benthic on the sixth day of the post-larval stage. In natural conditions, the megalopa enters the nursery ground. The carapace length of megalopa varies between 1.2 and 2.3 mm.

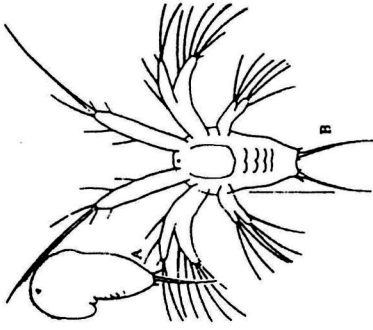
Juvenile. The earlier juvenile stage has transparent body with dark brown streak on the ventral side as in the megalopa. Motoh (1985) described the earlier juvenile stages as follows: (1) relatively shorter sixth abdominal segment compared to the carapace length, (2) greater body size, (3) complete rostral spine formula, (4) complete gill system, and (5) benthic behavior.



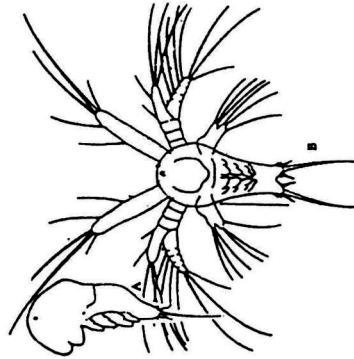
First nauplius, lateral (A) and ventral (B) views. A₁, first antenna; A₂, second antenna En, endopod; Ex, exopod; Md, mandible; O, ocellus.



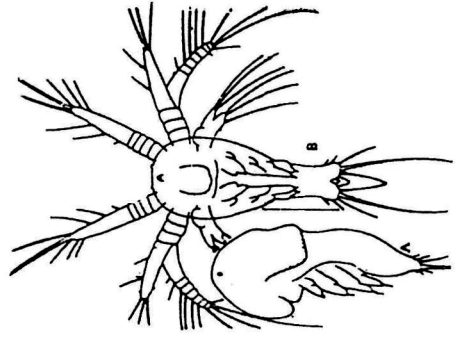
Second nauplius



Third nauplius



Fifth nauplius

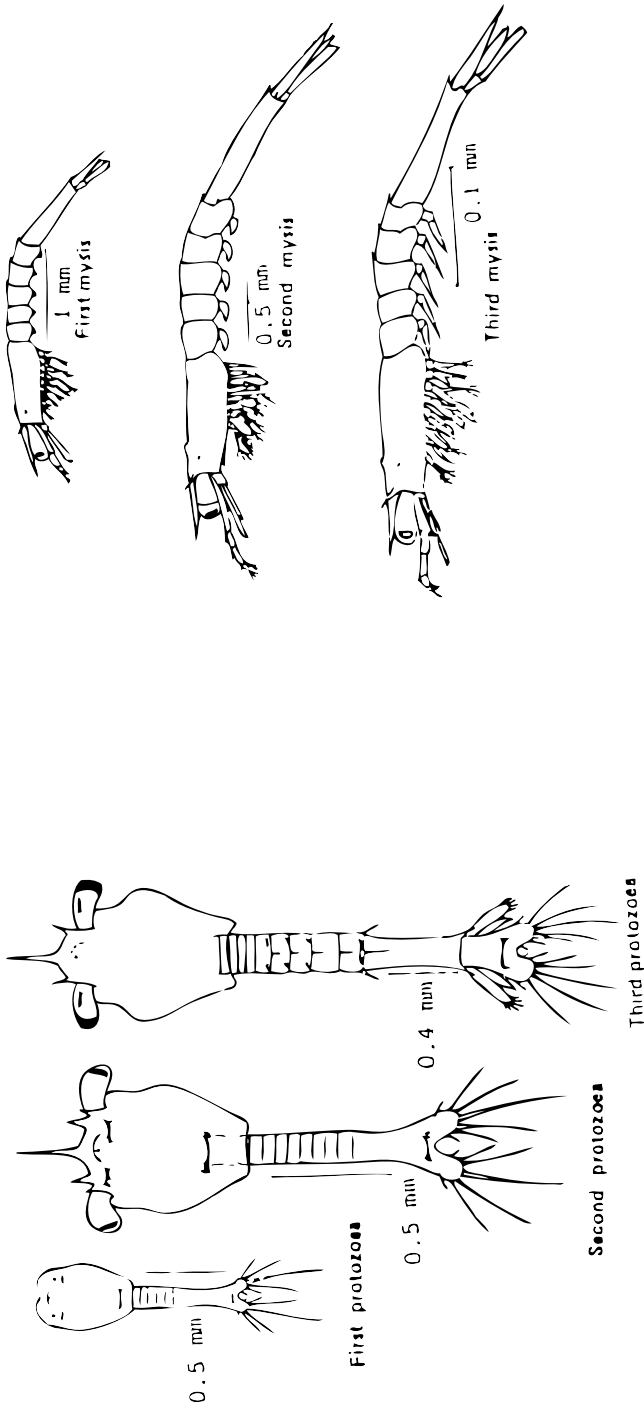


Sixth nauplius

(Scales represent 0.2 mm.)

Naupliar Substages

Fourth nauplius



Substages of Mysis

Protozoal Substages

Fig. 6. Larval stages of *P. monodon* (Motoh 1981, 1985)

In the later stage, the body becomes blackish in color and bulky, and the rostrum has 7 dorsal and 3 ventral spines. The juvenile crawls using the pereopods and swims using the pleopods as in adults. The carapace length varies from 2.2 to 11.0 mm.

Motoh (1981, 1985) and Motoh and Buri (1980, 1981) have described the early postmysis stages of the giant tiger prawn.

Adolescent. This stage resembles the adult prawn. Sexes are now distinct beginning at 11 mm CL. The minimum size of males possessing a jointed petasma is about 30 mm CL and the minimum size of females possessing adultlike thelycum is about 37 mm CL. The carapace length of the adolescent varies between 11 and 34 mm.

Subadult. This stage is the onset of sexual maturity. The male possesses spermatozoa in its terminal ampoules. The thelycum of the female now contains spermatozoa. At this stage (30 mm CL), females grow faster and migration from nursery to spawning grounds begins. In the course of migration, first copulation takes place between males and females having a minimum of 37 mm and 47 mm CL respectively.

Adult. This stage has appendages very similar to the subadult and is characterized by the completion of sexual maturity. It differs only with the subadult in size and habitat. Males possess spermatozoa, and females start to spawn offshore although a few spawn in shallow water. A second or more copulations may occur in majority of the species. Major habitat is the offshore area up to about 160 m depth.

The maximum total length recorded was 336 mm (Holthuis 1980), while a mature female of 307 mm from Madagascar was reported by Crosnier (1965) as cited by Mohamed (1970) and 330 mm total length by Racek (1972). In the Philippines, the largest male ever found was 71 mm CL while the female was 81 mm CL with 270 mm body length or 240 g weight (Motoh and Buri 1980). Carapace lengths of adults vary between 37 and 71 mm in males and 47 and 81 mm in females.

The life history phases of the giant tiger prawn are summarized in Table 1, and the diagram of the life history is shown in Figure 7.

Longevity

There is no reliable method developed to determine the age of an individual prawn. Villaluz et al (1969) believed that the life span of *P. monodon* is one to two years; Motoh (1981) estimated it to be about one and a half years for males and about two years for females. Mohamed (1970) cited Srivatsa (1953) who reported that the life span of prawns (including *P. monodon*) in the Gulf of Kutch is 12-14 months.

Spawning

Spawning is the release of eggs and spermatozoa by the female prawn into the water for fertilization. The spermatophore which contains the spermatozoa is deposited in the female thelycum during copulation long before spawning. Although there is no report on the actual process observed in the natural condition, the spawning behavior of *P. monodon* has been documented based on laboratory observations (Villaluz et al 1969, Aquacop 1977, Primavera 1980, Motoh 1981). Discussion on spawning behavior is described in detail by Primavera (this volume).

In the Philippines, Villaluz et al (1969) reported that no *P. monodon* spawners below 50 mm CL have been collected in the Panguil Bay area, and concluded that first spawning occurs at 56 mm CL. However, Motoh (1981) reported that spawning females ranged from 47 to 81 mm CL and came in four size groups, namely: 48-50; 60-62, 66, and 72 mm CL. This finding indicates that *P. monodon* spawns four times in its life span and probably has multiple spawnings in a single season (Primavera 1980). In Orissa, India, Rajyalakshmi et al (1985) reported gravid *P. monodon* with size range of 100-250 g (about 54-76 mm CL) off the Paradip Coast.

Specific location of spawning area depends greatly on secondary evidence like the presence of abundant spawners and larval forms. In the Philippines, *P. monodon* spawns in the sea close to the coast (Delmendo and Rabanal 1956) or in the mouth of the bays with water depth of about 20 m but mostly spawns in offshore water to about 70 m (Motoh 1981). Hall (1962) calculated a more specific spawning area of *P. indicus* with *P. monodon* at about 18-36 m deep. In the Paradip Coast, Orissa *P. monodon* spawns at 30-40 m

Table 1. Life history phases of the giant tiger prawn, *P. monodon* (Motoh 1981)

Phase	Begins at	Duration	Carapace length (mm)		Mode of Life	Habitat
			Male	Female		
Embryo	Fertilization	12 hours	0.29* ₁		Planktonic	Outer littoral area
Larvae	Hatching	20 days	0.5-2.2		Planktonic	Outer/inner littoral area
Juvenile	Completion of gill system	15 days	2.2-11.0		Benthic	Estuarine area
Adolescent	Stability of body proportion, development of outer genitalia	4 months	11-30* ₂ , 11-37* ₃		Benthic	Estuarine area
Subadult	Start of sexual maturity, first copulation	4 months	30-37* ₄ , 37-47* ₅		Benthic	Inner/outer littoral area
Adult	Completion of sexual maturity	10 months	37-71* ₆ , 47-81* ₆		Benthic	Outer littoral area

*₁ Egg diameter.*₂ Minimum size with jointed petasma.*₃ Minimum size with adult-like thelycum.*₄ Minimum size with spermatozoa in terminal ampoules.*₅ Minimum size with spermatozoa in thelycum.*₆ Maximum size ever found.

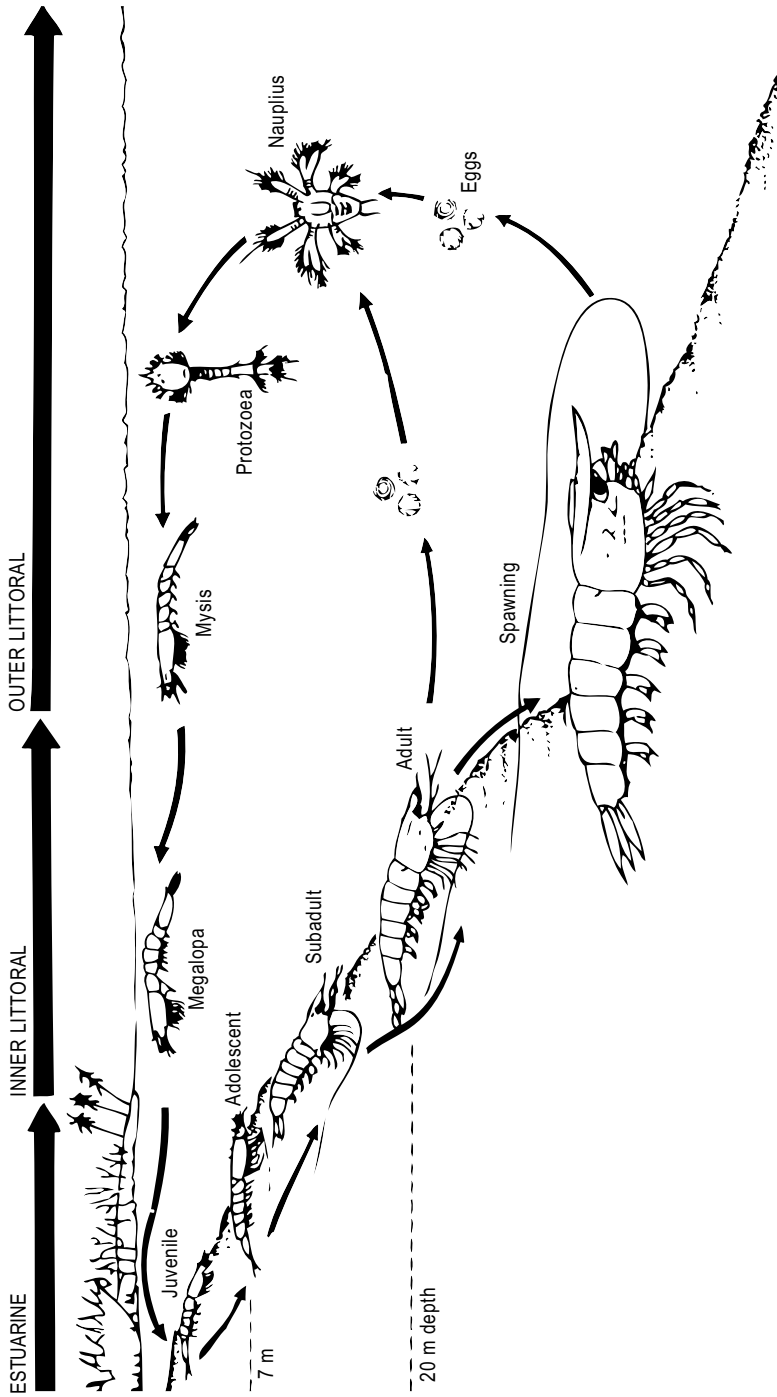


Fig. 7. Diagram of the life history of the giant tiger prawn, *P. monodon*. (Motoh 1981)

(Rajyalakshmi et al 1985), and in the coastal waters of Tungkang, Taiwan at 10-40 m (Su and Liao 1986).

In the Philippines, spawning of *P. monodon* is year-round but there seems to be two peak spawning seasons in a year: February-March or July and October-November although these vary from year to year (Motoh 1981). Hall (1962) reported February to April in Singapore; Rajyalakshmi et al (1985) in October through April corresponding to the post monsoon stability in the water movement and the increasing salinity in Orissa Coast, India; and Su and Liao (1986) from June to December in Taiwan.

Food and Feeding Habit

Hall (1962) generally considered penaeids to be omnivores with *P. monodon* in particular preferring crustaceans, vegetable matter, polychaetes, molluscs, fish, and insects. Thomas (1972) supported this finding and explained that mud and sand found in the gut were accidentally ingested. Villadolid and Villaluz (1951) reported that the fry stage of *sugpo* relishes plankton (*lablab*) food. Marte (1980) reported that *P. monodon* food also consisted of crustacea (small crabs and shrimps) and molluscs, making up 85% of ingested food. The remaining 15% consisted of fish, polychaetes, ophiuroids, debris, sand, and silt. This indicates that the giant tiger prawn is more of a predator of slow-moving benthic macroinvertebrates rather than a scavenger or detritus feeder. Kuttyama (1973) observed that debris composed of mud and organic matter constituted the main portion of the stomach content while crustaceans ranked next in quantity. Similar food items were also observed by Su and Liao (1986). All these findings suggest that *P. monodon* is more of a carnivore with preference for crustaceans particularly when in the natural environment, but it also feeds on other available organisms including algae.

P. monodon seems to have increased feeding activity during ebb tide (Marte 1980) and shows some food preferences during seasonal variations of food (Kuttyama 1973). This species feeds by seizing the food with its pinchers and pushing food to the mouth to nibble (Villadolid and Villaluz 1951). Undigested food is defecated four hours after ingestion (Marte 1980).

Physiology

Molting. Growth and the increase in size in crustacea are generally a function of the frequency of molting. Molting can occur anytime but more often at nighttime. Cited in the review by Wickins (1976), some conditions bring about a reduced increment during ecdysis so that the prawn may continue to molt but not grow.

During molting, the cuticle splits between the carapace and intercalary sclerite, paving the way for the cephalothorax and anterior appendage to withdraw, followed by the abdomen and posterior appendage emerging from the old shell with a forceful body flexure. The new cuticle takes about a few hours to harden in small prawns, to one or two days in larger animals (Villadolid and Villaluz 1951, Wickins 1976). Molting prawns characterized by soft shell are sensitive to stress and are good indicators of adverse environmental or nutritional conditions in the culture population (Wickins 1976).

Detailed reviews of the endocrine control of molting and reproduction in prawns were made by Adiyodi and Adiyodi (1970), Mantel and Farmer (1983), Adiyodi (1985), Kleinholz (1985), Skinner (1985), and Truchot (1983). Molting in crustaceans is believed to be controlled by two different hormones, namely: (1) molt-inhibiting hormone (MIH) secreted by the X-organ-sinus gland complex of the eyestalk (Kleinholz 1985, Skinner 1985). Molt-inhibiting hormone inhibits release of ecdysone by the molt gland. Closely associated with molting is reproductive maturation controlled by the gonad-inhibiting hormone (GIH) produced by the neurosecretory cells of the X-organ and transported to the sinus gland for storage and release. Induced gonadal maturation of penaeids through endocrine manipulation, such as eyestalk ablation, influences the molting cycle. Pudadera et al (1985) found marked changes in the internal structure of setae and cuticle throughout the molt cycle so that it is possible to properly time eyestalk ablation for induced ovarian maturation.

The physiological aspect of molting of *P. monodon* has received little attention. Although some works have been done on external factors, e.g., light, temperature, photoperiod, and salinity that may affect molting in penaeid prawns and shrimps (Bishop and Herrnkind 1976, Wickins 1976), no studies have been conducted on *P. monodon*. Meanwhile, Ferraris et al (1986)

reported a high degree of interaction between molting and salinity on osmotic and ionic regulation in *P. monodon*.

Osmoregulation. Crustaceans when subjected to change in water salinity have built-in mechanisms to adapt themselves to such change. It can be a mechanical response, such as burrowing, but the more efficient mechanisms are their physiological processes like osmoregulation by the organism. This process has been thoroughly reviewed by Mantel and Farmer (1983), Truchot (1983), Kleinholz (1985), and Skinner (1985). On the other hand, osmoregulation of *P. monodon* has been studied only by a few workers, e.g. Ferraris et al (1986) and Cheng and Liao (1986).

In the life history of *P. monodon*, spawning occurs in offshore waters where the larval stages are subsequently found. Post-larval, juvenile, and adolescent stages inhabit the nursery areas which are subjected to wide variations in salinity, temperature, and other environmental conditions. With proper acclimatization procedure, *P. monodon* postlarvae can also survive in fresh water (Pantastico and Oliveros 1980, Motoh 1981). The subadults and adults migrate to offshore areas where conditions are more or less stable. Behavior and survival are better understood, among others, in terms of the prawn's osmoregulation abilities. These physiological responses can be monitored by the changes in osmolality (or the number of particles such as ions, amino acids in solution) and the ion concentration of the blood (hemolymph) in relation to those of the medium (Ferraris et al 1986).

In the event when there is no osmotic gradient between the medium and the hemolymph, isosmotic point is attained. *P. monodon* in low salinity sea-water responds to osmotic gradient between the blood and external medium by gaining water, losing ions or both (hyperosmotic regulation) (Mantel and Farmer 1983). *P. monodon* juveniles are highly efficient regulators between 103 and 1480 mOsm/kg (30-50 ppt) and adults in over 444 mOsm/kg (about 15 ppt) (Cheng and Liao 1986). Isosmotic point for *P. monodon* juveniles of about 10 g is 730 mOsm/kg (Cheng and Liao 1986) or 676-720 mOsm/kg (26-28.5 ppt) (Ferraris et al 1986); for subadult (about 30 g weight or about 35 mm CL) 724-792 mOsm/kg (26-28.5 ppt) (Ferraris et al 1986); and for adults, 750 mOsm/kg (Cheng and Liao 1986). In general, *P. monodon* have isosmotic concentration at 20-30 ppt.

The isoionic points for *P. monodon* are 352 mEq/l for sodium and 320 mEq/l for potassium (Cheng and Liao 1986); with Ferraris et al (1986) finding chloride between 324 to 339 mM in 10 g prawns.

Relating these findings to the distribution of *P. monodon* in their natural habitat, Cheng and Liao (1986) attributed the abundant distribution of postlarvae to low salinity with due regard to other factors such as being genetically highly euryhaline species.

Identification of Postlarvae

Wild fry still support the seed requirements of the extensive culture operation. Inasmuch as there are many other *Penaeus* fry during collection, fry gatherers and users often mistakenly identify *P. monodon* fry with that of other penaeids. At present, scanty information has been found on the identification of *P. monodon* fry. Some published articles on the subject are those by Rao and Gopalakrishnan (1969) for the juveniles of prawns in India, Prawirodihardjo et al (1975) on fry of *Penaeus* in Indonesia and Motoh and Buri (1981) on fry along the shoreline of Panay Island in the Philippines.

Morphological characters and color (chromatophore or pigment patterns) are often used in the identification of penaeid postlarvae. The following morphological characters were used by Motoh and Buri (1981) to identify *Penaeus* postlarvae along the coast of Panay Island, Philippines: (1) shape of rostrum, (2) number of rostral spines, (3) relative length of the antennular flagellum, (4) presence of antennal spine, and (5) presence of spinules on the sixth abdominal segment (6th AS). Chromatophore patterns on the 6th AS, telson, and uropods were also utilized, especially with fresh materials.

Compared with larvae and postlarvae of known parentage and reared in the laboratory, Motoh and Buri (1981) distinctly separated the postlarvae of *P. monodon* from *P. semisulcatus*, whereas with the absence of distinct differences in morphological characters for species identification, *P. indicus* and *P. merguensis* were combined as a group, and *P. japonicus*, *P. latisulcatus*, and *P. longistylus* as another group.

P. monodon. The postlarvae of *P. monodon* are the largest among the species or groups. The body is slender and the modal CL is 2.6 mm. The rostrum is either straight or slightly bent upward at the tip, usually having five dorsal spines but devoid of ventral spines. The inner (lower) antennular flagellum is twice lower than the outer (upper) flagellum. The 6th AS does not have spinules (Motoh and Buri 1981).

Distinct with fresh postlarvae, chromatophores of dark brownish red extend from the tip of the inner antennular flagellum to the tip of the telson. When viewed microscopically, thirteen chromatophores align ventrally along the 6th AS or are densely distributed to form an almost continuous pattern (Prawirodihardjo et al 1975, Motoh and Buri 1981). The chromatophore on the antero-lateral margin of the 6th AS is absent.

P. semisulcatus. The postlarvae of this species are relatively small. The rostrum is usually bent upward and has six dorsal spines and one or no ventral spine. The inner antennular flagellum is about one and a half to two times longer than the other flagellum. The antennal spine is very small or absent (Motoh and Buri 1981).

Chromatophores are not so dense, numbering from six to twelve along the 6th AS. Only the base and the tip portions of the telson and uropods are pigmented (Prawirodihardjo et al 1975, Motoh and Buri 1981). One chromatophore is present at the antero-lateral margin of the 6th AS.

Motoh and Buri (1981) confirmed the similarities between the postlarvae of *P. monodon* and *P. semisulcatus* in the Philippines and that of the specimens from Indonesia.

P. merguiensis group. The postlarvae of this group, composed of *P. merguiensis* and *P. indicus* are the smallest among the other species or groups. The rostrum is long or one and one-half times larger than the CL. About two-thirds of the anterior portion of the rostrum is toothless both dorsally and ventrally, but the remaining portion has three to four dorsal teeth and none below. Antennal spine is absent.

In older postlarvae, the rostrum becomes more bent upward having six to seven dorsal and three to five ventral teeth. As in its adult form, the postlarvae are poorly pigmented,

hence, the species are referred to as white prawns. One prominent chromatophore at the antero-lateral margin of the 6th AS is present (Motoh and Buri 1981).

P. japonicus group. The postlarvae of this group represents *P. japonicus*, *P. latisulcatus*, and probably *P. longistylus*. The body is short and bulky. The rostrum is short and does not exceed the tip of the eye. There are five to seven dorsal but no ventral teeth. The inner flagellum is about one and one half longer than the length of the outer flagellum. The carapace has a modal length of 2.0 mm. These postlarvae are often mistaken as smaller post-larvae of *P. monodon* because they have similar longitudinal streaks of dark brown chromatophores. The chromatophores at the 6th AS are more than eight or sometimes countless and are usually absent at the antero-lateral margin (Motoh and Buri 1981).

Chromatophore patterns of different *Penaeus* species shown in Figure 8 and the chromatophore patterns on the 6th AS, telson, and uropods shown in Figure 9 can aid in quick identification of each species or group.

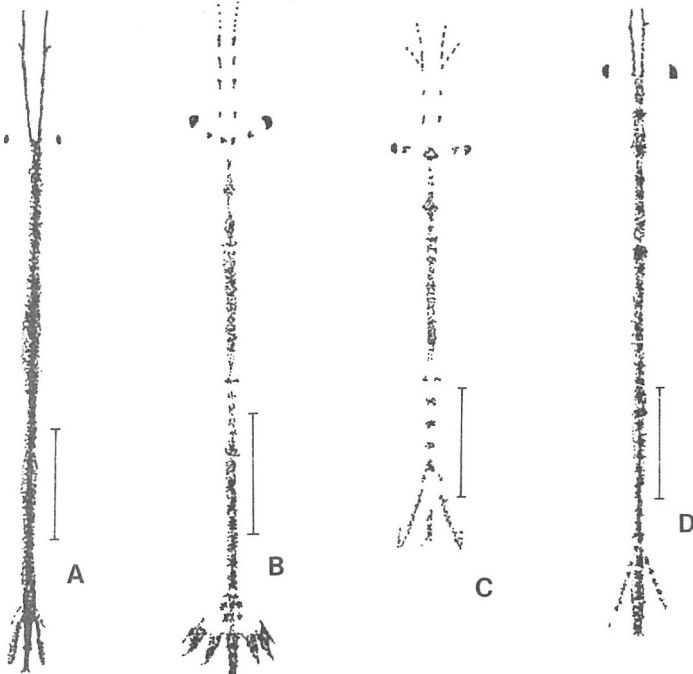


Fig. 8. Dorsal view of postlarval *Penaeus* showing chromatophore patterns for quick identification. (A) *P. monodon* (B) *P. semisulcatus* (C) *P. merguensis* group, (D) *P. japonicus* group. Scales represent 2.5 mm (Motoh 1981)

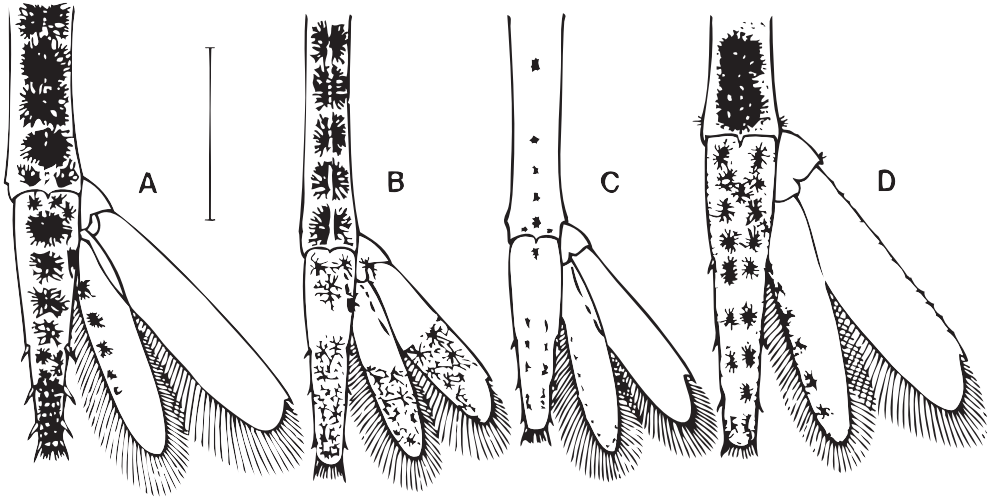


Fig. 9. Dorsal view of the sixth abdominal segment, telson, and uropods of postlarval *Penaeus* showing chromatophore patterns. (A) *P. monodon* (B) *P. semisulcatus* (C) *P. merguiensis* group, (D) *P. japonicus* group. Scale represents 1 mm (Motoh 1981)

The following is the key prepared by Motoh and Buri (1981) to identify post-larval *Penaeus* appearing at the shoreline of Panay Island, Philippines.

Key to postlarval *Penaeus* appearing at shore waters, based on morphological features

- 1) Rostrum stout and inferior to tip of eye, spinules on the sixth abdominal segment present*, antennal spine prominently present, carapace slightly longer than sixth abdominal segment*P. japonicus* group.
 Rostrum slender and exceeding tip of eye, spinules on the sixth abdominal segment absent, antennal spine absent or minute, carapace slightly or distinctly shorter than the abdominal segment.....2.
- 2) Inner (lower) antennular flagellum nearly 1.6 times the outer (upper), exceeding the latter by its distal one segment.....*P. merguiensis* group.
 Inner antennular flagellum 1.6 to 2.0 times the outer (upper) exceeding the latter by its distal two segments.....*P. semisulcatus*.
 Inner antennular flagellum more than 2.0 times the outer, exceeding the latter by its distal three segments.....*P. monodon*.

*When the number of rostral teeth is less than four, the spinules are sometimes poorly present or absent. In this case, other criteria are useful.

**Key to the postlarval *Penaeus* appearing at shore waters,
based on chromatophore patterns**

- 1) Number of chromatophores on the sixth abdominal segment less than seven. Antero-lateral chromatophore of the sixth abdominal segment present
P. merguensis group.
Number of chromatophores on the sixth abdominal segment more than seven. Antero-lateral chromatophore of the sixth abdominal segment present or absent.....2.
- 2) Number of chromatophores on the sixth abdominal segment less than 12. Antero-lateral chromatophore of the sixth abdominal segment present, chromatophores on the middle portion of telson and inner uropods absent
P. semisulcatus
Number of chromatophores on the sixth abdominal segment more than 12, antero-lateral chromatophore of the sixth abdominal segment absent.
Chromatophores on the middle portion of the telson and inner uropods present
3.
- 3) Chromatophores on the sixth abdominal segment dense and thickly continuous
P. monodon.
Chromatophores on the sixth abdominal segment discontinuous or confluent
P. japonicus.

Common to all workers is the use of morphological characters and color patterns for identification, with Motoh and Buri (1981) also using morphometric measurements in identifying *P. monodon* from *P. semisulcatus* and two other groups, *P. merguensis* and *P. japonicus*.

Motoh and Buri (1981) confirmed the similarities between the post-larvae of *P. monodon* and *P. semisulcatus* in the Philippines and Indonesia.

For detailed descriptions, Motoh and Buri (1981) provided a key with illustrations while Prawirodihardjo et al (1975) tabulated the differences between *P. monodon* and *P. semisulcatus*.

PROBLEMS AND PROSPECTS

Findings on biology and ecology of *P. monodon* have contributed significantly to its aquaculture. What was before an extrinsic species in the brackishwater pond culture of milkfish is now a cash crop of great demand in intensive monoculture. Fry collection from the wild has intensified to meet the demand for seeds usually for extensive culture while improvement in hatchery techniques has resulted in the proliferation of commercial hatcheries supplying the seeds for intensive culture. Despite these advances, a myriad of problems remain.

First, there is a conflict in the use and management of natural resources. The estuarine areas, rivers, and mangroves which are considered nursery grounds of wild *P. monodon*, are often identified for fishpond development or reclamation for social, commercial, or industrial purposes. This is a complex problem requiring concerted efforts of intergovernmental agencies to formulate and to religiously implement policies on the conservation of natural resources.

Second, there is no conservation effort during collection from the wild of *P. monodon* fry where finfish fry and larvae, other penaeid fry, and crustaceans of potentially high economic value are often discarded indiscriminately. Measures should be taken to return the live fry or larvae of other organisms to the shorewater. Policies on proper management and collection of wild fry should be adopted.

Third, overexploitation of wild stock, especially the spawners of *P. monodon*, is apparent. Stock assessment studies are thus necessary to pave the way for sea ranching open-water stocking in certain protected areas to replenish wild stocks.

For aquaculture scientists, the physiological aspects of the biology of *P. monodon* remain a major area for future research. More baseline information on molting is needed. The manipulation of hormonal and environmental conditions that control frequency and time of molting could improve growth and survival in culture, reproductive maturation for broodstock, and lastly, artificial fertilization techniques beneficial for genetic stock improvement and hybridization studies.

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Chapter Two

MATURATION, REPRODUCTION, AND BROODSTOCK TECHNOLOGY

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Maturation generally refers to physiological maturity or the development of the gonads or primary reproductive organs producing eggs and sperm capable of fertilization. However, maturation may also refer to functional maturity or the ability to mate with the completion of the secondary sexual organs. In penaeids, the secondary genitalia - thelycum and petasma - develop ahead of the ovaries and the testes.

This review describes first maturation in *Penaeus monodon*; endocrine, nutritional, and environmental methods of induced maturation; broodstock constitution; maintenance and other operations; and a comparison of maturation tanks, pens, and cages.

BROODSTOCK

Female Maturation

According to Motoh (1981), *P. monodon* females with CL above 47 mm have structurally complete thelyca, consistent with his observation that most wild females of this size were positive for spermatozoa. In ponds, however, minimum size of *P. monodon* with sperm was smaller at 39 mm CL.

Ovarian maturation stages of *P. monodon* have been classified using *in vivo* examination or histological criteria of size and kind of ova. Motoh (1981) described five categories for wild *P. monodon*--undeveloped (Category 1), developing (2), nearly ripe (3), ripe (4), and spent (5)--based mainly on progressively increasing mean ovum diameter (from 35 to 235 microns) and external ovarian appearance. Also using external examination and dissected specimens, Primavera (1982) came up with five similar groupings and gave the equivalent stages used

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in actual sampling of broodstock at SEAFDEC AQD (Stages 0, I, II, III, IV, and V). Based on histology, Tan-Fermin and Pudadera (in press) reduced the number of stages for wild *P. monodon* to only four: (1) previtellogenic stage - oogonia to oocytes in chromatin nucleolus and/or perinucleolus eosinophilic (equivalent to Stage 0); (2) vitellogenic stage - eosinophilic yolky oocytes (Stages I and II); (3) cortical rod stage - oocyte with peripheral rod-like bodies (Stages III and IV); and (4) spent stage - remaining oocytes with yolk and/or cortical rods, thicker follicle layer and few dark irregular perinucleolar oocytes (Stage V). Mean and maximum oocyte diameter were also significantly different among the four groups.

Male Maturation

Male *P. monodon* become capable of mating with the complete fusion of the petasma (by means of numerous hooks) at 34 mm CL (Motoh 1981). Physiological maturity with the presence of ripe sperm was noted at 31 and 37 mm CL for pond and wild males, respectively. However, Motoh (1981) observed that sperm in wild males below 37 mm CL showed only a body (without tail or spike). Primavera (1978) observed that both pond and wild males of at least 40 g body weight produced mature sperm while Ruangpanit et al (1985) noted immature males without sperm from both pond and wild *P. monodon* of unspecified size.

Rather than sacrifice the males in the process of checking under the microscope for spikes, hatchery workers use the more practical method of looking for enlargement and opaque whitening of the terminal ampoules that indicate spermatophores containing mature sperm.

Mating

P. monodon is a closed thelycum penaeid in which the prerequisite to mating or spermatophore transfer is the molting of the female.

Precopulatory behavior in *P. monodon* starts with the attraction of one to three hard-shelled males to a newly molted female which they follow as she makes brief upward movements (Primavera 1979). When one male positions itself directly below

the female, the pair engages in parallel swimming movements during which the male tries to align his ventral side to that of the female. If successful, the male quickly shifts from parallel position to perpendicular to the female. He curves his body in a U-shape around the female, flicking head and tail simultaneously, presumably inserting the spermatophores inside the thelycum at this time.

Mating requires a minimum water volume and depth; limited frequency and success have been experienced in small and shallow tanks (Primavera 1979, Poernomo and Hamami 1983). Complete darkness (Aquacop 1980) as well as bright floodlights (Primavera, unpubl.) can also hinder mating in *P. monodon*. Salinity may have no effect on mating because females caught from brackishwater estuaries and ponds possess sperm in their thelyca.

Fertilization of eggs from initial spawnings of captive broodstock is dependent on sperm from mating in the wild or pond environment. Failure of mating in captivity will ultimately lead to unhatched (unfertilized) eggs due to loss of spermatophores once the female molts. The decrease in hatch rates in *P. monodon* spawns, averaging 96% up to 10 days after ablation down to 0% afterwards (Muthu and Laxminarayana 1977), may be traced to non-mating of captive broodstock.

With unsuccessful mating of broodstock, artificial spermatophore transfer is being tested in *P. monodon* and other penaeids. Spermatophores are extracted either manually or electrically and inserted in the thelycum of a newly molted female. While Muthu and Laxminarayana (1984) obtained a low hatch rate of 2.4% from only one out of 10 attempted transfers, higher mean hatch rates of 71.87% and 82.35% were produced by insertion of one and two spermatophores, respectively, by Lin and Ting (1986), all on ablated *P. monodon* females. *In vitro* fertilization gave 49.4-63.1% hatching when the sperm homogenate was added right after spawning (Lin and Ting 1986).

Source of Broodstock

P. monodon broodstock may be obtained from the wild or from ponds. Wild broodstock are caught from coastal waters by tide-dependent stationary gear such as corrals, lift and lever

nets, and by trawlers and other fishing boats. It has been observed that wild broodstock (and wild spawners) from brackishwater areas give lower hatch rates compared to those from offshore waters (Posadas 1986).

In Aquacop (1983), the rearing of *P. monodon* broodstock involves a series of 3-stage pond transfers over 9-12 months during which density from 10-20/m² is gradually decreased to 1-2/m² with feeding of artificial and fresh feeds. Pond broodstock used at SEAFDEC AQD are grown under extensive conditions of low stocking density and natural food with or without supplementary feeding over 6 months in a single pond without transfer or with transfer to a second compartment. Age at ablation varies from 5 (Primavera 1978) to 15 months (Santiago 1977) from spawning. Satisfactory maturation, spawning, and metamorphosis of larvae to post-larvae have been obtained from females with a minimum age of 8 months (Millamena et al 1986; Primavera unpubl.). In the wild, *P. monodon* attains full maturity and spawning at 10 months (Motoh 1981).

Although pond-reared prawns have produced good quality larvae, the state-of-the-art is to use wild broodstock in places where *P. monodon* is indigenous and easily available. The first reason for this is the non-availability of pond broodstock because holding the prawns beyond the regular 3-4 month cropping period means a longer turnover period and economic loss to the farmer. Second, wild broodstock give a faster turnover and produce in 4-8 weeks the same number of larvae that pond broodstock can yield in 8-12 weeks. Lastly, pond stock require a maturation pellet often not commercially available in addition to natural food such as squid, mussel, and trash fish, whereas wild broodstock can be maintained on natural food alone.

Transport, Acclimation, and Prophylaxis

Ideally, the hatchery should be located close to wild and pond broodstock sources to minimize transport stress and costs. The prawns may be transported in sea water provided with aeration and ice, if necessary to lower temperature. A one-ton tank (canvas, fiberglass, etc.) can accommodate up to 400 prawns if travel time is one hour or less. With periods of 4-5 hours, not more than 200 prawns/ton should be stocked. Early morning or

late afternoon transport is recommended to avoid high midday temperatures; otherwise, ice can be added to the transport water.

Upon arrival, the prawns are disinfected in 25-50 ppm formalin and acclimated over a one-week period. Few or no additional deaths indicate that the animals have recovered and are ready for ablation.

Stocking

Stocking density of *P. monodon* in tanks is 2-7/m² depending on the water quality and exchange rate and prawn size such that biomass should not exceed 300-400 g/m² (Primavera 1985).

Sex ratios are generally maintained at 1 ♀: 1 ♂ to ensure mating success. Higher female ratios (1.5-3 ♀:1 ♂) are more economical because egg and larval production per tank are maximized (Pudadera et al 1980a).

INDUCED MATURATION

Male penaeids generally mature in captivity so that induced maturation mainly concerns females. Three basic approaches have been employed to induce ovarian maturation in penaeids--endocrine (ablation), nutritional, and environmental. So far, maturation in *P. monodon* has been induced only through eyestalk ablation although diet and environmental parameters may enhance reproductive performance.

Table 1 summarizes information on ablation, food, and environmental conditions for *P. monodon* maturation.

Eyestalk Ablation

In decapod crustaceans, ablation of the eyestalk destroys the X-organ and sinus gland that produces and stores, respectively, the gonad-inhibiting hormone (Adiyodi and Adiyodi 1970).

In *P. monodon*, the eyestalk can be ablated or destroyed by means of incision-pinching, cutting, or cautery with the eye

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Table 1. Physiochemical parameters, stocking, feeding and water management in maturation tanks for *Penaeus monodon* (after Primavera 1985)

References	Ablation	Brood-stock source	Age	Stocking density (no/m ²)	Sex ratio	Daily water exchange rate	Water management
Alikunhi et al 1975	+	pond			1:1		recirculating
Aquacop 1977a, b; 1979; 1980 1983	+	pond	9-12 mo	5	1:1	200-300%	flow-through
Santiago 1977	±	pond	15 mo	0.8	1:1		
Primavera 1978	+	pond	5 mo	4	1:1	30%/3 days	replacement
Primavera et al 1978	±	pond	1-2 yr	5-6	1-2:1	30%/3 days	replacement
Primavera et al 1979	+	pond		6	2:1	200-400%	flow-through
Pudadera et al 1980a	+	wild		4-5	2:1	200-400%	flow-through
Pudadera et al 1980b	+	wild		5	1-4:1	200-400%	flow-through
Pudadera and Primavera 1981	+	pond		6	1:1	200-400%	flow-through
Vicente et al 1979	+	wild & pond		7.5/ton	3.3:1		
Beard and Wickins 1980	+	captive		1.6	1:12	15%/wk	recirculating
Ruangpanit et al 1981	+	wild		13/ton	1:1		
Ruangpanit et al 1985	+	wild		4	1:1	100-200%	flow-through
Simon 1982	+	pond & wild	5-8 mo	7	1:1	100-250%	flow-through
Poernomo and Hamami 1983	+	pond		2.7	1:1	20-50%/2-3 days	replacement
Emmerson 1983	±	wild		2.2/ton	1:1	30%/2 days	replacement
Hillier 1984	+	wild		2.3	3:1		
Posadas 1986	+	wild		5-6.4	1:1	100%/2 wk	recirculating
Millamena et al 1986	+	pond	8 mo	4	1.3:1		flow-through

Temperature (°C)	Salinity	pH	Light intensity & quality	Photo-period hr light	Food
27.8-30.6	24-31				mysid, shrimp and artificial pellet
25.5-30	34	8.2	10%, 100 lux	natural	squid, mussel, troca and pellet
22.5-33.2	33±1.6		outdoor pens		
23.8-26.2	30-34	7.8-8.1		natural	salted mussel
				natural	salted mussel
24-34	27.6-30.2		60%	natural	pellet, mussel, squid
28.6-33.6		7.0-8.2	40-60%	natural	brown mussel and pellet
25-30.5	15.4-34.8	7.2-8.1	60%	natural	brown mussel and pellet
21.3-33.6	28-36	7.9-8.1	1,210-3,500 lux: blue, red natural	natural	
26-28.5	32.3-34.1			natural	mussel, pellet, and fish
28±2	30±2		40-70 lux	19 hr	mussel and shrimp
26-8	30-31	7.8-8.0		natural	squid, cockle and prepared feed
28-31				natural	green mussel and cow liver
26.5-30.5	28-32		fluorescent light	14 hr	squid and clams
26-28	25-30			natural	squid, cockle and prepared feed
27±2.2	30±3		70 uW (reduced)	cm ²	pellet, prawn
26-31			green	natural (12 hr)	
27.0-30.8	15, 25, 32	7.25-8.8	reduced	natural	pellet and mussel
26-31	30-32.5			natural	pellet, squid and annelids

removed totally or only partially retaining the outer corneal layer. The objective is to prevent the loss of body fluids and infection by the use of cautery or by retention of the corneal layer which eventually forms a scar (Primavera 1978).

The incision-pinching method commonly used for *P. monodon* and other penaeids has been described in detail by Primavera (1978). Females selected for ablation should be of a minimum size (80-90 g) or age (8-10 months for pond stock), healthy, and hard-shelled. The thelycum must be uninfected and appear slightly bulging or convex with whitish vertical streaks indicating the presence of spermatophores (Primavera 1983). Ablation is performed on either eye but an already diseased or damaged eye should be ablated to leave one healthy (unablated) eye. Santiago (1977) observed that ablation of a single eyestalk was sufficient to induce maturation in *P. monodon*.

Survival rates of 0%, 38% and 49% for bilaterally ablated, unilaterally ablated, and unablated *P. monodon*, respectively, were obtained after 196 days (Santiago 1977). Ablation-related mortality in *P. monodon* was observed by Primavera et al (1978) but not in Aquacop (1977a) or by Vicente et al (1979).

With reference to the molt cycle, ablation during the postmolt leads to mortality because of added stress on the female and excessive loss of hemolymph (Aquacop 1977a). Ideally, ablation should be undertaken during the intermolt for maturation to follow. Ablation during the premolt leads to molting with a subsequently longer latency period of 2-4 weeks before maturation in *P. monodon* (Aquacop 1979, Primavera et al 1979).

The latency period represents the interval between ablation and maturation/spawning and is affected by molt cycle stage, age, and source of broodstock and other factors at the time of ablation. Wild subadult *P. monodon* caught in mangroves took 40 days to mature and 69 days to spawn after ablation (Hillier 1984) compared to a minimum of only 3 days for wild adults from offshore (Primavera and Borlongan 1978, Simon 1982). Similarly, wild *P. monodon* from offshore Indian Ocean took only 4-5 days to spawn after ablation in contrast with 20-30 days for females from brackishwater Songkhla Lake

(Ruangpanit et al 1985). Salinity may therefore affect the latency period.

The great majority of captive maturation in *P. monodon* has been from ablated females. Very few workers have reported maturation in unablated females (Santiago 1977, Primavera et al 1978, Aquacop 1980, and Emmerson 1983) with successful spawns (16.7 to 82.0% hatch rate) only from Emmerson (1983).

The maximum number of spawns/molt cycle is greater from ablated (6) compared to unablated (3) *P. monodon* (Beard and Wickins 1980, Hillier 1984, and Emmerson 1983). Similarly, the proportion of first spawns in the molt cycle is higher for unablated (67%) compared to ablated (36%) *P. monodon*, meaning the latter have spawns mostly from rematurations (Emmerson 1983). Therefore, ablated females will tend to show a decline in fecundity, hatch rates, and egg viability given the greater number of spawns in a molt cycle. Nevertheless, many commercial hatcheries prefer to do eyestalk ablation because the resulting predictability in spawns and nauplii supply compensates for the decreased spawn sizes and spawn quality (Primavera 1985). Also, *P. monodon* broodstock are replaced 6-8 weeks after ablation (Simon 1982, Primavera 1983) so that only the first, or at most, second spawns in a molt cycle are harvested thereby eliminating the less viable later spawns.

Nutrition

Food sources. Molluscs including squid and mussel (Primavera et al 1979), cockle and clams are commonly fed to *P. monodon* broodstock either alone or in combination with pellets. Aquacop (1979) obtained best results using a squid-containing pellet with 60% protein.

In the wild, 85% of ingested food of adult *P. monodon* consisted of small crabs and shrimps and molluscs (Marte 1980). The more frequent occurrence of molluscs and other non-crustaceans during months when *P. monodon* showed a higher feeding index may reflect changes in dietary requirements related to gonad development during the spawning season (Marte 1982).

Feeding of broodstock is at a daily rate of 3.5% for dry feed and 10-30% for wet feeds (Primavera 1983) or *ad libitum*

once to three times a day. Marte (1980) observed that feeding activity of female *P. monodon* was significantly higher than that of males.

Lipid requirement. Wild immature *P. monodon* females showed an increase in ovarian lipid levels upon reaching full maturity from 5.8 to 17.0% and from 7.5 to 21.9% in unablated and ablated females, respectively (Millamena et al 1985). The fatty acid profile showed 12.14-24.87% and 11.81-21.50% total fatty acids in unablated and ablated females, respectively, consisting of 20:4w6, 20:5w3, and 22:6w3 fatty acids. Similar proportions of the same polyunsaturated fatty acids (PUFA) were found in the spawned eggs, indicating their importance in the reproductive process.

Another experiment assessed the effect of different lipid sources on maturation and spawning of ablated pond-reared *P. monodon* (Millamena et al 1986). Reproductive performance in terms of number of spawns and production of eggs and nauplii was superior in females given pellets with cod liver oil (longer chain C₂₀ and C₂₂ PUFA and lower w3:w6 ratio).

In Aquacop (1979), *P. monodon* matured on pellets alone spawned unfertilized eggs and therefore early maturing females were fed fresh troca univalves to improve egg viability. Conversely, an all-natural food diet (squid and marine worms) gave the lowest spawning and hatching rates from ablated *P. monodon* (Primavera et al 1979). In contrast, wild *P. monodon* broodstock gave satisfactory results with only natural food in the absence of pellets.

Feeding rhythm. Wild adult *P. monodon* were given two feed types (squid and pellet) at three daily feeding frequencies over a one-week period to determine feeding rhythm (Primavera et al 1987). The prawns consumed significantly greater amounts of squid per feeding as frequency decreased (3.2 g every 3 h, 6.7 g every 6 h, and 10.2 g twice daily). There was no significant difference in amount of feed consumed at one feeding time for either feed type at any feeding frequency. Nevertheless, there was a general trend for greater amounts of squid consumed in the afternoon and evening hours compared to morning - the 3-h feeding frequency showed a major peak at 1800 h (dusk) and a minor peak at 1200 h (noon).

Environment

Even under ideal conditions, eyestalk ablation causes some degree of stress to the female prawn. It should therefore be considered a stop-gap measure until less stressful methods, along environmental and dietary manipulation, are developed. Among various environmental parameters, the control of light appears to be the most promising.

Light. Maturation tanks may depend on natural light under a roofed structure or an artificial light inside a completely enclosed building with walls and ceiling.

Light intensity. Reduced light levels down to 70 uW cm^{-2} led to faster maturation and spawning in unablated and ablated *P. monodon* (Emmerson 1983, Hillier 1984). Dark covers may also reduce intensities in maturation tanks (Primavera 1983) to around 200 lux or less. Wurts and Stickney (1984) recommend that light intensities for captive maturation should simulate levels in the natural spawning grounds of the species based on observations that light intensities used for *P. setiferus* have reached up to 4000 times those in the natural spawning grounds.

Light quality. Unablated *P. monodon* attained only partial maturation under blue and natural light but not under red light (Pudadera and Primavera 1981). More recently, Primavera (unpubl.) obtained maturation in unablated *P. monodon* subjected to different wavelengths in tanks. Green light gave best results (2.7×10^6 nauplii, 63.1% hatch rate) followed by natural light (0.78×10^6 nauplii, 86.7% HR) with poor results under cool white light and blacklight blue light. In a follow-up study using only green light, ablated females produced 8.25×10^6 nauplii with 61.8% HR compared to 0.54×10^6 nauplii and 68.4% HR from unablated females (Primavera, unpubl.). Green light at reduced intensities combined with unilateral ablation induced maturation in wild immature *P. monodon* (Hillier 1984).

Photoperiod. Increased photoperiod of 19 h failed to induce maturation in unablated *P. monodon* (Beard and Wickins 1980). *P. monodon* broodstock are maintained either under a natural photoperiod (Aquacop 1977b, Primavera 1983) or a 14 h photoperiod (Simon 1982).

Salinity. Ruangpanit et al (1985) observed a higher maturation rate and proportion of spawns with fertile eggs after

ablation in *P. monodon* females collected from the Indian Ocean compared to those from Songkhla Lake. A spawning ground, the Indian Ocean has 33 ppt salinity compared to 22-28 ppt in Songkhla Lake. However, the differences in other environmental factors make this observation inconclusive.

Posadas (1986) showed that ablated *P. monodon* can mature and spawn at 15, 25, and 32 ppt but require full seawater salinity for incubation and hatching of eggs. Moreover, females could not tolerate a net shift of 17 ppt from maturation salinity of 15 ppt to spawning salinity of 32 ppt and therefore eggs did not hatch.

Substrate and tank color. A comparison of black and white sand substrates showed significantly greater nauplii production and hatch rates from ablated *P. monodon* in tanks with white sand (Pudadera et al 1980a). Other workers (Simon 1982; Millamena, pers. comm.) have obtained maturation and spawning in ablated *P. monodon* in tanks with bare substrates.

Another recent study (Primavera et al, in prep.) determined the effect of tank color and female (eyestalk and/or carapace) tags on reproductive performance and survival of ablated *P. monodon*.

OTHER ASPECTS OF BROODSTOCK AND MATURATION

Spawner Monitoring and Retrieval

Monitoring ovarian maturation in dark-shelled species such as *P. monodon* requires a light source. This can be done by scooping out females and holding against the light or, with less stress, by flashing a beam from an underwater light against the female (Primavera 1983).

End-products of maturation may be retrieved as gravid females, eggs, or nauplii (Primavera 1985). Spawner retrieval is more manageable in 10-20 m³ tanks than in tanks larger than 20 m³, and more efficient with frequent monitoring of broodstock. Nightly checking of a 12 m³ tank yielded 48 spawners producing 6.8×10^6 nauplii compared to only 3.0×10^6 from 29 spawners with thrice weekly monitoring (Pudadera et al 1980a). Although egg collectors (Simon 1982) and nauplii collectors have

been tried for *P. monodon*, retrieval of spawners gives the advantages of individual records of female measurements, fecundity and hatch rates, and easier processing of eggs.

Spawning Behavior

Spawning in *P. monodon* generally occurs between 2200 and 0200 h and the following description is based on reports by Villaluz et al (1969), Motoh (1981), and Primavera (1983).

A ready-to-spawn female becomes restless and actively swims upwards in circles with the last three pairs of pereopods held tightly together in flapping movement. Eggs are released through the gonopores (simultaneous with sperm release from the thelycum) over a period of 2-7 min. Movements of the pleopods keep the female actively swimming and also disperse the eggs and nonmotile sperm. The pink-orange scum associated with spawning is not so abundant in tanks provided with gentle aeration (Primavera 1985).

Gravid *P. monodon* that do not spawn for 2-3 successive nights but retain the ovarian outline may have the "milky ovary" disease caused by a microsporidian.

Fertilization, Incubation, and Hatching

The events following spawning are described for *Sicyonia engentis* which is closely related to penaeids. These include sperm binding, acrosomal reaction, ovum jelly extrusion, fertilization or sperm-egg fusion and hatching membrane formation (Clark et al 1984). Ovum jelly extrusion or the cortical reaction involves the extrusion of cortical rods to form a corona or jelly layer as observed for *P. monodon* by Primavera and Posadas (1981). Abnormal spawns for *P. monodon* eggs laid in masses remain unfertilized and unhatched (Villaluz et al 1969) perhaps due to a failure of the cortical reaction (Aquacop 1977a).

Development of *P. monodon* eggs has been described by Motoh (1981); time of hatching is 12-15 h after spawning. To estimate the number of nauplii that will hatch out, the proportion of good eggs from a random sample is determined following the morphological classification of Primavera and

Posadas (1981). Hatch rate is correlated with egg quality and its determination gives hatchery personnel enough lead time to prepare the required larval rearing tanks.

Salinity in spawning tanks has ranged from 28 to 35 ppt for *P. monodon* (Villaluz et al 1969, Primavera and Borlongan 1978, Simon 1982, Hillier 1984). Among various temperature-salinity combinations, Reyes (1981) obtained highest mean hatch rate in *P. monodon* eggs incubated at 33 ppt at temperatures of 23°C and 33°C whereas 23 ppt and 28 ppt at any given temperature level produced weak larvae.

A temperature range of 26-29°C has been recorded for incubation of *P. monodon* eggs (Villaluz et al 1969, Primavera and Borlongan 1978, Hillier 1984). Increasing temperature levels of 23, 28, and 33°C had no effect on hatch rate of *P. monodon* eggs but significantly decreased incubation period (Reyes 1981).

Aside from the required temperature and salinity, spawning tank water should be chlorinated to remove all microorganisms. The chelating agent EDTA (ethylenedinitrotetraacetic acid) may also be added (Simon 1982, Hillier 1984). Gentle aeration must be maintained at a low rate of 4 bubbles/s (Emmerson 1980).

Maximum egg density should be 3 000/l or 600 000 eggs for a spawning tank with 200 l of water. Wild spawners of 150-200 g body weight producing more than a million eggs should have at least 400 l of spawning water.

After a spawning, the eggs are cleaned by removing any scum and passing the eggs through a series of meshes to remove both coarse and fine dirt particles (Primavera 1983).

Spawn Size (Fecundity) and Spawn Quality (Hatch Rate)

Several researchers have reported a wide range of 57 650 to 550 300 eggs per spawn from wild ablated *P. monodon* (Emmerson 1983, Hillier 1984) and 60 000 to 747 500 from pond ablated females (Alikunhi et al 1975, Muthu and Laxminarayana 1977, Primavera 1978, Aquacop 1980). The wide range of egg numbers could be due to varying female sizes (50 to 200 g) and inclusion of egg counts from both partial and complete spawns. Similarly, hatch rates range from 0 to over 90% depending on

nutrition, sex ratio, water depth, and other physiological factors that may affect egg quality and/or mating efficiency.

Primavera (1982) reported higher mean fecundity and hatch rate of 270 000 eggs and 36%, respectively, from wild ablated *P. monodon* (n=213) compared to only 204 400 eggs and 20% hatch rate from ablated pond stock females (n=111). For wild, unablated spawners, Motoh (1981) reported greater egg numbers of 248 000 to 811 000 eggs per complete spawning. The smaller spawn sizes from ablated females may be due to the inadequacy of present maturation systems in providing the full nutritional and environmental requirements for captive maturation of *P. monodon*. It could also be due to the GIH secreted by the neurosecretory cells of the remaining unablated eyestalk in unilaterally ablated females.

Both greater egg numbers and (perceived) higher hatch rates explain the preference of many Philippine *P. monodon* hatchery operators for wild spawners over ablated broodstock.

MATURATION TANKS, PENS, AND CAGES

By far the most popular and convenient means of holding captive *P. monodon* broodstock is the land-based broodstock or maturation tank. Marine offshore pens are site-specific (requiring a protected cove or bay), offer less security against poachers, are inconvenient for broodstock maintenance and monitoring, and have not progressed beyond the experimental stage (Primavera and Gabasa 1981).

Maturation tanks are usually incorporated within the hatchery complex due to the continuous sea-water supply requirement for the tanks and the convenience in immediate transfer of ripe females or newly hatched larvae to larval rearing tanks (Primavera 1983).

Tanks may be made of cement, ferrocement, fiberglass, and plastic or canvas-lined aluminum or wooden tanks. Tank size is based as much on the biological requirements of the broodstock as on the convenience of the hatchery personnel, hence the popularity of a 10-12 m³ circular tank with 0.8 to 1.0 m water depth (Primavera 1983, 1985). Large tanks yield better maturation and mating performance based on past trials comparing 40-1 aquaria, 1-m³, 4-m³, 50-m³, and 200-m³ tank by

Primavera (1979) and other workers (Vicente et al 1979, Poernomo and Hamami 1983, Hillier 1984).

Ideally, maturation tanks should have a flow-through water system with 100-400% daily exchange rate to achieve excellent results. However, when flow-through is not feasible as when sea water is polluted, turbid (during typhoons), or heated (when water temperature is low), sea water may be recirculated through filters.

Filters may be biological and/or mechanical and installed externally or inside the tanks as in a sand-gravel substrate with the aid of air-water-lifts. Aside from flow-through and recirculating water, simple aeration together with regular replacement of water may be used in maturation tanks. The disadvantage with aeration, however, is that the tank is prone to fouling. Ablated *P. monodon* achieved maturation and spawning only after air stones were replaced with a subgravel filter and air-lift recirculation inside plastic lined pools (Muthu and Laxminarayana 1977).

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Chapter Three

HATCHERY OPERATIONS AND MANAGEMENT

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Considerable advancement has been made in the field of larval rearing of penaeids since the pioneering work of Hudinaga (1942). Hatchery technology has improved from laboratory scale experiments to industry level practice in a span of two decades for the West (Cook and Murphy 1966, Mock et al 1980), and in over just a decade in Taiwan (Liao 1985, 1986, Chiang and Liao 1985), as well as in the Philippines (Villaluz et al 1969, Parado-Estepa and Primavera 1988). Despite the commercial success of hatcheries for *Penaeus monodon* in Taiwan and in the Philippines, the tremendous variability in larval survival makes hatchery production unpredictable.

The following state-of-the-art for hatchery technology describes the results of basic researches as well as major industry practices relating to the following areas: site selection, hatchery design, larval rearing techniques particularly in the development of live and artificial feed, water management, and nursery practices for postlarvae. Several problems are given attention and recommendation are provided where there are solutions to the constraints presented.

SITE SELECTION

There are two important factors which determine the success of a prawn hatchery: (1) proper site selection and (2) proper technical management. In many cases, hatcheries are sited or constructed with inadequate planning and survey, either to minimize expenditure or to hasten construction. With proper site selection, prawn hatcheries have greater chances of commercial success. The criteria that follow are useful considerations before putting up a prawn hatchery.

Ecological suitability covers an assessment of water quality with reference to temperature, salinity, pH, dissolved oxygen content, organic and sediment load, nutrients, biological

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populations present, and fluctuations of the foregoing parameters.

Sufficient information defining desirable water quality parameters is available (Wickins 1976, 1986; Catedral et al 1977a, b; SCSP 1982; SEAFDEC Working Committee 1984; Murai 1985; Reyes 1985; Seidman and Lawrence 1985; Liao and Murai 1986; Kungvankij et al 1986a, b). Water quality parameters and their optimal ranges for hatchery and nursery rearing are shown in Tables 1 and 2, respectively. There are more parameters to be rigidly considered in larval rearing compared to post-larval or nursery rearing of prawn.

Climate in the area is another consideration as it affects water quality, most important factors of which are temperature and salinity (Reyes 1985; SEAFDEC Working Committee 1984; Kungvankij et al 1986a, c).

The site must be far from congested areas and possible sources of pollution like industrial discharges and ricefield effluents. Several studies have shown the correlation of hatchery survival rates with levels of heavy metals, chemicals, and other industrial pollutants in coastal waters (Cook and Murphy 1966; Cook 1969; Mock and Neal 1974; Beard and Wickins 1980; Sommani 1980; Chen 1981, 1985; Chen et al 1985; Chou et al 1985).

Fresh water and its source are also important factors in prawn hatchery operations. The most common source of fresh water is surface water which is easily contaminated. An alternative source is well water but which may also contain high mineral contents such as iron and manganese which are not suitable for prawn hatchery (Chen et al 1985, Kungvankij et al 1986c).

The hatchery must be near the source of spawners. When spawners come from broodstock sources, it is advisable that hatcheries be located near grow-out ponds or fishing grounds which may supply broodstock material in quantity. Posadas (1986) observed that eggs spawned from offshore wild spawners have higher hatching rates compared to those coming from brackishwater sources. There are no studies, however, comparing the relative performance of ablated and wild or unablated spawners with regard to spawning, quality of eggs, nauplii, and general larval performance in *P. monodon*.

Table 1. Water quality parameter ranges suitable for shrimp/prawn hatchery (SCSP 1982)

Parameter	Range	
	Freshwater	Seawater
Temperature	28° - 31°C	24° - 31°C
pH	7 - 8.5	7.5 - 8.5
D.O.	> 5 mg/L	> 5 mg/L
Salinity		28 - 33 ppt
Hardness	> 20 mg/L as CaCO ₃	
Turbidity	< 50 FTU	< 50 FTU
Fe	< 1.0 mg/L	
Mn	< 0.2 mg/L	
Hg	< 0.001 ppb	< 0.01 ppb
Heavy metals		< 0.01 ppm
Pesticides	undetectable by GLC 0.001 ppb	undetectable by GLC
B.O.D.	< 1.0 mg/L (5 days)	< 1.0 mg/L (5 days)
Unionized NH ₃	< 0.1 mg/L	< 0.1 mg/L
NO ₂ - N	< 0.02 mg/L	< 0.02 mg/L

Table 2. Water quality parameter ranges suitable for farming *Penaeus monodon* in Taiwan (Chen 1985)

Parameter	Range
Temperature	28 - 33°C
pH	8.0 - 8.5
D.O. (critical)	3.7 ppm
Salinity	15 - 25 ppt
Heavy metals	
HG	0.0025 ppm
Cu	0.1 ppm
Cd	0.15 ppm
Zn	0.25 ppm
H ₂ S	0.033 ppm
NH ₃	0.1 ppm

The economic success of hatcheries depends on its access to roads, markets, electricity, farm grower's supplies, and research centers for technical assistance. Proximity to market minimizes handling stress and expenditure in transport of fry to grow-out areas (Klemetson and Rogers 1983, Israel et al 1986, Griffin et al 1984).

HATCHERY DESIGN, EQUIPMENT, AND FACILITIES

Procurement of hatchery equipment and construction of facilities depend a lot on design which determines production target and size of rearing facility. Hatchery design, in turn, is influenced by level of financial inputs, scale of operation, technical expertise, and level of management efficiency that will run the operation (Reyes and Torres 1985).

Prawn hatchery designs evolved out of two larval rearing systems, the Japanese and the Galveston types, otherwise referred to as community (big tank) and separate (small tank) tank culture methods, respectively. The differences between these lie in the type of species which can be favorably cultured, size of rearing facilities, use of direct or indirect (separate algal tank) fertilization, stocking densities, and production costs (Liao 1984). Liao (1984) believes that the separate tank method is best for *P. monodon* larval operations.

Size of the hatchery must be based on its functional requirements and economic efficiency (Kungvankij et al 1986c). A small-scale project is defined based on capital investment, operational area, production level, and ownership (SCSP 1982). Kungvankij et al (1986c) expanded the description to include medium-scale and large-scale hatcheries. According to production methods, Taiwan has the S, M, R types (Chiang and Liao 1985) based largely on stocking densities applied and level of sophistication of rearing procedure.

Several designs or prototypes of prawn hatcheries have come about, from the most simple (Platon 1978, SCSP 1982, SEAFDEC Working Committee 1984) to the most sophisticated set-ups of Mock and Neal 1974, Mock et al (1977), Simon (1981), Treece (1985), Chwang et al (1986), Kungvankij et al (1986a, c), and Liao (1986). On the whole, hatchery design and size are decided on these considerations: facility and efficiency of

management and the innovative skills of the technician and/or hatchery operator.

Tank System

Holding and rearing tanks. The size and number of rearing tanks can be estimated (Reyes and Torres 1985, Kunvankij et al 1986c).

Typical sizes of tanks for different purposes are (in metric tons):

Nursery tanks	- 5-40 mt
Larval rearing tanks	- 1-10 mt
Spawning tanks	- 0.25-1.0 mt
Algal tanks	- 1-5 mt
<i>Artemia</i> tanks	- 0.25-0.5 mt
Maturation tanks	- 15-30 mt with or without bottom substrates
Sea-water reservoir	- Capacity should be 30-50% of maximum total water consumption per day.

Tank shapes differ widely. These may be circular, rectangular or square with conical or sloping bottom toward the drain pipe. Sharp corners should be avoided, to do away with dead spots and to clean the tank effectively. Tank height should be capable of holding at least 1 m depth of water for the rearing tanks and about 0.5-0.6 m for the algal tanks.

The reservoir should be elevated so that water supply distribution would require less energy input. Algal tanks should be placed higher than the larval/nursery tanks so that transfer of natural food could be done by gravity.

Tank materials. Several materials have been tested and can be considered in constructing tanks--reinforced concrete, ferrocement, concrete hollow blocks, fiberglass, canvas with marine plywood support, or laminated plastic sheets with bamboo reinforcement (SCSP 1982, SEAFDEC Working

Committee 1984, Reyes and Torres 1985, Kungvankij et al 1986c).

Air, Seawater and Freshwater Supply, and Distribution Systems

Air, seawater, and freshwater supply, and distribution systems comprise the life support system of a hatchery. For the seawater intake system, Simon (1981), SEAFDEC (Working Committee 1984), and Kungvankij et al (1986c) have outlined several methods. Pumping may be direct or from a sump pit, inshore well or from seabed, using perforated PVC pipes. Inshore wells are very popular in Taiwan as studies show that water taken with subsand prefiltration has less chemical and heavy metal pollutants compared to waters taken from coastal areas (Chen et al 1985).

Air for the hatchery can be provided by aerators, blowers, or compressors. For medium- to large-scale hatcheries, a blower is preferred to compressors because it is safer, easy to use, and provides oil-free air (Kungvankij et al 1986a,c). For tanks with less than 2.0 m water depth, a high volume, low pressure air is sufficient to provide enough water movement and dissolved oxygen needed by the larvae to survive. For backyard to small-scale hatcheries, portable aerators are used because of the following advantages: (a) tanks can be aerated separately thereby reducing energy consumption when hatchery is not operating at full capacity, and (b) there are no aeration distribution lines to be put up, cleaned, and disinfected regularly (SEAFDEC Working Committee 1984).

Centrifugal pumps are used for seawater intake due to its higher total head capacity (Kungvankij et al 1986a). Marine pumps and submersible pumps are also necessary for water transfer from sedimentation chambers to holding areas or in distributing algae to larval/nursery tanks. Pump size and capacity vary widely depending on use and efficiency (SCSP 1982, McVey and Fox 1983, Reyes and Torres 1985, Kungvankij et al 1986c). Distribution lines are usually of PVC material due to the corrosive nature of the environment.

A filtration chamber (sand and gravel, either gravity or reverse type) may be built in conjunction with the storage tank or reservoir (Reyes and Torres 1985, Kungvankij et al 1986c).

Building and other Facilities

Provision for roofing of the laboratory area, blowers, pumps, generators, and larval tanks is advisable. Roofing of larval area or building an indoor hatchery also permits easier control of temperature and salinity, and prevents contamination, thereby ensuring higher survival of larvae. Roofing materials range from translucent, transparent plastic, to materials creating a darkroom effect such as those used in Taiwan (Liao 1986).

Practical procedures in estimation of hatchery facilities, including tank sizes, blower and pump capacities are outlined in Reyes and Torres (1985) and in Kungvankij et al (1986c).

LARVAL REARING

Penaeid larval rearing techniques were developed primarily using the community culture method practiced by Hudinaga and Kittaka (1966). Consequently, methods and procedures tended to be more specialized needing more control of culture conditions, thus requiring smaller tank systems, separate algal production tanks, and more intensified stocking and monitoring procedures. Thus, the Galveston method (Cook 1969, Mock and Murphy 1970, Mock et al 1980) was developed. Most hatcheries today are gradations in development between the two methods.

In the Philippines, rearing techniques were greatly influenced by the community culture method (Villaluz et al 1969, Villaluz et al 1977). However, the development of barangay or backyard type of hatchery in 1977 (Platon 1978, 1979) showed more influence of the Galveston type of culture. The present trend in the industry is the development of small-to medium-scale, compact, and modular hatcheries for easier management and more technical control.

In Taiwan, development trends favor large tanks, increased stocking densities, popular use of formulated larval diets, and a horizontal subdivision of operations and labor among hatcheries (Chiang and Liao 1985, Liao 1986).

The Indonesian hatcheries, practice either the community culture or the separate tank culture method (Tiensongrusmee 1980, Nurdjana et al 1985). However, with the advent of

technical expertise and funding from the West and the use of formulated diets, the trend of development is toward construction of smaller tanks and intensified stocking densities (Tiro, Jr., pers. comm.).

The method developed in Tahiti is a modification of the Galveston method with the rearing parameters under strict control and independent of environmental factors (Aquacop 1983). With *P. monodon*, stocking densities are inferior to other penaeid species cultured due to its characteristic fragility during the larval stages and its susceptibility to pathological problems (Aquacop 1986).

Larval Stages

Familiarity with the different larval stages is a basic requirement in hatchery operations. This is particularly important in determining the right kind of feed to give (either natural or formulated) and in carrying out other hatchery procedures. The egg and larval developmental stages are well described by Motoh (1979, 1981). There are three larval stages, namely: (1) nauplius, (2) protozoa, and (3) mysis. The whole larval period lasts from 9 to 10 days at warm temperatures (28-32°C) and from 10 to 12 days during the rainy, cold months (25-29°C).

Tank Preparation

Maintenance of sanitation and good water quality are the two most important tasks in the hatchery. For hatcheries located in good sites with biologically clean water, tanks are simply cleaned with detergent solution and chlorox, or sprayed with hot water and diluted chlorox applied to sides (McVey and Fox 1983), then dried for at least a day before stocking. After each run, tanks as well as the pipelines and materials used in the hatchery are disinfected with 12% Na hypochlorite at 200 ppm for 24 hours (Kungvankij et al 1986a,c).

With disease-causing organisms already inherent in the surrounding waters, disinfection rates remain at 200 ppm with Na hypochlorite for the sand filters, reservoirs, rearing tanks as well as for the drainers, filters, etc. Sometimes, muriatic acid is used to bleach white tank sides and bottom.

Stocking of Nauplii

Spawners may be placed directly in larval rearing tanks or in separate spawning tanks. Use of separate spawning tanks is presently the preferred practice to allow spawner and/or egg treatment in a separate culture milieu. Another advantage is that the larval tanks can be stocked with a predetermined number of nauplii per liter (Parado-Esteva and Primavera 1988).

Stocking densities for nauplii (N_{III}N_{IV}) being practiced are 50-100 ind/liter (SCSP 1982, SEAFDEC Working Committee 1984) or 100-150 ind/liter (Aquacop 1983, Kungvankij et al 1986a). For large tanks, Simon (1981) reported a range of 20-40 nauplii/liter.

Spawners may be disinfected with formalin (50 ppm) and Furanace (3 ppm) (Platon 1978) or with Treflan (0.5-1.0 ppm), KMnO₄ (3 ppm), and formalin (25 ppm for 10-15 min) (Kungvankij et al 1986c).

Eggs may or may not be treated. Preventive treatment consists of dipping eggs in 1.0 ppm methylene blue or 0.5 ppm malachite green for 10 min, or 3.0 ppm KMnO₄ for 30 min (Kungvankij et al 1986c). Mock (1982) reported egg treatment with malachite green (0.06 ppm) as sufficient. Earlier reports (Platon 1979) gave a dose of 5.0 ppm for malachite green for egg treatment. Lio-Po et al (1978) reported the toxicity of malachite green on the larvae of *P. monodon* in direct proportion to the dose and length of exposure time, although no adverse effects were noted on development and molting.

When spawners or eggs receive no treatment, nauplii may be given a prophylactic dose of 0.1 ppm Treflan R (Lio-Po and Sanvictores 1986) or 5.0 ppm given to egg and nauplii (Aquacop 1983).

Liao (1977, 1984, 1986; Liao and Chao 1983) did not report any disinfection or prophylactic and/or a curative treatment given to penaeid larvae.

Feeds and Feeding

Several larval rearing schemes are being practiced in different hatcheries. Basically, the difference lies in variations

of feeding and management schemes which are influenced by site, season (Hudinaga and Kittaka 1975), sizes of tanks used, and the innovative skills or experience of the technicians (Liao 1986, Kungvankij et al 1986c).

Most hatcheries, regardless of size, require the culture of at least two, sometimes four types of living food organisms--unicellular algae or yeasts for protozoa stages, rotifers for transitional period from protozoa to mysis, and *Artemia* for mysis to post-larval stages (Wickins 1986).

Proper identification or selection of the most adequate live food organism propelled the development of hatcheries into successful industry practice. Phytoplankton species which are popularly cultured and used as feed include *Chaetoceros* sp., *Tetraselmis* sp., and *Skeletonema* sp. (Kungvankij 1972, 1976; Simon 1978; Quintio and Villegas 1982; Aujero et al 1983; Liao et al 1983; McVey and Fox 1983; Liao 1984, 1986; Wilkenfeld et al 1984; Kungvankij et al 1986a, c).

Simplification of algal production techniques led to studies using frozen algae (Mock and Murphy 1970, Aujero and Millamena 1981). Combinations of algal feeding with prepared diets such as egg yolk (Gabasa 1982, Quintio and Reyes 1983, Quintio et al 1983, SEAFDEC Working Committee 1984), soybean curd or meal (Liao 1986, Kungvankij 1986c), and baker's yeast (Villegas et al 1980) were tried. Feeding with marine yeast was reported by Aujero et al (1985) and Kungvankij et al (1986c).

Protein sources, alternative to the costly *Artemia* nauplii, were also developed using processed/minced fish tissue (Khannapa et al 1980, Kungvankij et al 1986b). In an effort to make *Artemia* a complete food for penaeid larvae, enrichment techniques with essential amino acids have been developed (Leger et al 1986, Kontara 1986).

The development of artificial larval diets may be the greatest improvement yet in larval rearing schemes with regard to simplification of feeding regimes. Three main types of artificial larval feed are: (1) freeze-dried or processed natural products (e.g., BP, AS, *Spirulina*), (2) microparticulate diets, and (3) microencapsulated diets. The last type is gaining popularity in hatchery use because of the ease in preparation and the wide range of dietary ingredients already incorporated

in the diet (Jones 1985, Scura et al 1985, Jones et al 1987). However, all these prepared and formulated diets still cannot altogether replace the use of live natural feed in hatcheries, although recent research findings indicate that carrageenan-bound diets may support larval development and could be used as a total algal replacement diet (Yashiro et al 1985; Jones et al 1987; Bautista and Millamena, unpubl.).

With phytoplankton as main feed during the larval stages, adequate timing and proper programming are necessary to meet day-to-day food requirements. One has to take precaution in cases when algae fail to bloom or collapse during the culture period.

Water Management

One of the major factors contributing to inconsistent post-larval production is water quality. Most prawn hatcheries have not operated successfully due to poor management of water quality (Chen HC et al 1984, Chen JC et al 1984). Maintenance of water quality cannot be overemphasized as it directly relates to survival. The most important water parameters to be monitored during the larval stages are temperature ($30 \pm 2^\circ\text{C}$), salinity ($32 \pm 2\text{‰}$), and pH (7.8-8.3) (Liao 1986, Body and Liao 1987). Ammonia levels should not exceed 1.5 ppm for NH_4 and 0.1 ppm for NH_3 (Kungvankij et al 1986c).

Water, before coming into the hatchery, usually passes through subsand or mechanical filters, and then disinfection follows using either or most of these methods: chlorination (10-200 ppm), surface active chemicals, oxidizing agents, heat, and ultraviolet radiation (Treece 1985, Wickins 1986). Sometimes, addition of the disodium salt of EDTA (ethylene diamine tetraacetic acid) is practiced to chelate heavy metals as well as enhance hatching rates of eggs and naupliar metamorphosis (Simon 1978, 1981; Mock 1982; McVey and Fox 1983; Sunaryanto 1986; Licop 1988).

Water treatment prior to stocking may consist of NaEDTA, anti-fungal, and anti-bacterial prophylactic doses. Treflan (at 0.1 to 0.2 ppm) is sufficient to deter fungal infection but does not affect egg and nauplius development and survival (Lio-Po and Sanvictores 1986). Bacterial treatments consist of application of chloramphenicol (2-6 ppm preventively and 2-10

ppm curatively) (Aquacop 1983) and antibiotics such as Maracyn I, Maracyn II, and Terramycin (McVey and Fox 1983). Simon (1981) reported that Furanace, tetracycline, and/or Erythromycin are routinely used at 0.5-1.0 ppm every two days during the post-larval stages or as required during the earlier stages.

Lagenidium is reportedly controlled by malachite green (0.01 mg/l). Chloramphenicol (1.0 ppm) and Oxytetracycline (3.00 ppm) are given for bacterial infection and 10% formalin (5.0 ppm) for *Zoothamnium* infestation (SCSP 1982). For the recent hatchery problem caused by luminous bacteria, Sunaryanto and Mariam (1986) reported prophylactic treatment using Chloramphenicol, Furazolidone, and Prefuran. Treatment dosages range from ≥ 1.0 ppm for Prefuran, ≥ 20 ppm for Chloramphenicol, and ≥ 10.0 ppm for Furazolidone.

Current research trends intend to do away with all variables (e.g., algal quality, *Artemia*, water quality) by more controlled culture techniques and the optimization of the larval rearing system. This is the reason for the intensification of research on the development of a recirculated water system through biological filtration (Wickins 1983, Aquacop 1986). Typical water management schemes for close mariculture systems in which water is recirculated, may consist of a number or all of the following: sediment settling, mechanical filtration, biological filtration, physical absorption, and disinfection (Treece 1985).

During the culture period, accumulation of fecal matter and the decomposition of excess food (whether live or artificial) cause the deterioration of the water quality of the culture medium. Kungvankij et al (1986c) described water exchange as (a) batch (or static exchange), (b) semi-batch, (c) flow-through, (d) recirculating, or (e) a combination of methods. Water change may start on the fourth day after stocking (at Protozoa II) or when any of the parameters present a problem for larval survival. Batch water exchange may range from 30-50% and may be done every other day or daily starting mysis stage. Semi-batch and flow-through methods are usually implemented as treatment protocols in cases of disease attacks and fluctuations in water quality parameters. However, one must be aware not to apply water change when most of the population are undergoing molting especially during late mysis and post-larval stages (Parado-Estepa and Primavera 1988).

Siphoning of excess food and wastes at the tank bottom is also done during mysis and post-larval stages when bottom sedimentation becomes highly apparent (Kungvankij et al 1986c).

Monitoring

While hatchery techniques still aim to achieve higher and predictable survival rates, hatchery performance still relies on the experience and skill of hatchery operators/technicians. Regular monitoring of water quality parameters, feed densities, larval development, and presence/absence of disease in culture tanks comprise the day-to-day chores in the hatchery.

Liao (1986) attributed the success of Taiwan hatcheries to the diligence of operators/technicians who monitor feed quantity and larval quality at least six times a day, from morning to midnight.

A daily record of physico-chemical parameters, feeding, and larval observation is helpful towards understanding the results of the rearing activity (SEAFDEC Working Committee 1984).

Harvesting

Harvesting may be done during $M_{11}M_{111}$ or PL_4PL_5 stage which could be nursed in outdoor bigger tanks, or finally at PL_{20} to PL_{25} for grow-out.

Harvesting procedures are outlined for small tanks by the SEAFDEC Working Committee (1984) and for small- to medium-size tanks by SCSP (1982) and Kungvankij et al (1986a,c). Water in the tank is reduced to one-fourth capacity and the larvae are collected through the drain/harvesting pipe into a harvesting box or *hapa* net. These are scooped and placed in 20-l basins for population estimate.

NURSING OF POSTLARVAE

Larval rearing may terminate at the $M_{II}M_{III}$ or the PL_4PL_5 stage, when fry are harvested and are further reared in nursery systems for two to four weeks before final stocking in

grow-out ponds. Nursery systems supply the transition areas where young postlarvae are acclimated to environmental conditions similar to grow-out ponds (Parado-Estepa and Primavera 1988).

Nursery systems may consist of concrete tanks (Mock and Neal 1974, Mock et al 1977, Kneale et al 1982) with or without recirculating water systems, earthen ponds (Apud et al 1983), and net cages located in bays, lagoons, or fishponds (De la Pena et al 1985).

Tank Nursery

The materials most commonly used are fiberglass, concrete, marine plywood, or bamboo. Substrates are installed in the tank in straight or zigzag fashion. Substrate materials are usually of nylon or polypropylene netting or locally made bamboo slats.

Stocking densities may range from 5 000-10 000/ton. A variety of feeds are introduced to the 5-day old postlarvae to wean them from phytoplankton and *Artemia* diet (Djunaidah and Saleh 1986). Either mussel meat, trash fish, and *Acetes* are given, after being blended to the desired size and consistency. Feeding is at 2 g/ton or 10% of the total biomass. Formulated diets are fast becoming popular in post-larval rearing (Manik et al 1980).

Water management consists of 50% water change and/or flow-through to encourage good growth and better survival rates (Kungvankij et al 1986c). Excess food should be siphoned out regularly.

Salinity may be lowered by 2-5 ppt per day until the salinity of the grow-out pond is approximated.

Pond Nursery

Usually a pond nursery is utilized to grow PL₁₀ to PL₁₅ fry to juvenile sizes of 1-2 g. An area of 500-2000 m² with water depth at 40-70 cm is used. Stocking density is from 100 to 150 ind/m². The most important aspects of pond preparation to be done before stocking are the elimination of pests and

predators (by application of rotenone) and fertilization to encourage benthic algae to bloom. Sometimes active feeding is administered. Water change may be tidal. The culture period may last from 35-60 days (Baliao, pers. comm.) with recovery rate from 65-95% (Baliao, unpubl.).

Cage Nursery

This system is site specific to cover bays and lagoons, although it could also be applied in conjunction with grow-out ponds. De la Pena et al (1985) described the system as follows: The cage is made of nylon netting supported by bamboo or stainless steel and buoys or floats. Stocking densities may range from 5 000-10 000 PL/m³. Feeds given are trash fish and/or mussel meat, blended or ground and spread on a feeding net which is positioned vertically inside the net cage. Management consists of daily checks of net damage and the physico-chemical parameters of the bay water. Larval quality is also monitored daily.

ECONOMICS OF HATCHERY PRODUCTION SYSTEM

Israel et al (1986) have two important conclusions in their comparative report on the different scales of *P. monodon* hatchery production systems. Prawn hatcheries whether small-, medium-, or large-scale are all highly profitable business operations, as shown by the the very high levels of computed undiscounted and discounted profitability indicators before and after sensitivity analyses. Of the three systems, however, the smaller hatcheries showed a better profitability performance.

Platon (1978) and the SEAFDEC Working Committee (1984) showed the benefit-cost analyses for backyard to small-scale hatcheries. Kunvankij et al (1986c) showed the economics of a medium-scale hatchery. Agbayani (1985) reported the production economics of an integrated prawn hatchery-floating cage nursery project of the SEAFDEC Batan Station. All these studies showed the high profitability of *P. monodon* hatchery operations.

Several models for budget analyses of penaeid shrimp hatchery facilities have been published based on the Texas A&M hatchery facilities (Johns et al 1981, Griffin et al 1985) where

the relationships between the engineering design of facilities, the environmental and managerial factors affecting shrimp growth and survival, as well as the factors affecting production costs and profit, were presented.

PROBLEMS AND RECOMMENDATIONS

As mentioned earlier, a disturbing fact surfaces side by side with the commercial success of prawn hatcheries. This is the unreliability or unpredictability of post-larval survival. Lawrence and Huner (1987) recognized several variables affecting a successful hatchery operation: (a) nauplii quality, (b) algal quality and quantity, (c) *Artemia*, and (d) water quality. These variables determine the problems of the prawn hatchery.

Spawner Supply and Selection

The problem of obtaining a consistently good quality batch of nauplii necessarily relates to quality of spawners that are received by the hatchery. Lawrence and Huner (1987) reported that the difference in quality of larvae batches may be due to the following: (a) spawning females (i.e., between wild and matured in captivity), (b) period of time the female has been kept in "production" mode, (c) the diets fed to maturation stock, and (d) the physical and hormonal manipulations performed on broodstock animals to encourage them to be productive.

Liao (1984, 1986) recognized this problem and suggested that researches should center on nutritional requirements, reproductive physiology, and process of cultivation to facilitate maturation without resorting to artificial means (i.e., ablation). One of the culture methods recommended is sea ranching.

Adaptations to Site Conditions and Site Selection

As discussed earlier, with stringent criteria defining a suitable site, most hatchery entrepreneurs decide on constructing a hatchery with little or no site selection process at all, to cut down pre-investment costs. Usually, hatcheries are situated along the same coastline, within sight of each other, on the

assumption that if one hatchery produces postlarvae successfully, the site must be suitable. Most often, in cases such as this, the site may not be the source of hatchery problems but the waste mismanagement of one hatchery which could have repercussions on all hatcheries located in the area.

Availability and Quality of Live and Formulated Food

Mass culture of algae causes problems, sometimes when one least expects it. Algal collapses as well as quality of cells vary within the culture period and cause mortalities or weakening of larvae when fed. Hatchability of *Artemia* cysts also depends on quality of batches produced. A need to optimize feeding regimes of live food is a must, to predict survival rates in hatcheries. Corollary to this, a complete formulated larval diet which is economical and can replace live feeds (or at least dependency on live feeds) must be developed.

Disease

With intensification of stocking densities, it is inevitable that an environment inimical to the larvae develops and opens weakened larvae to attacks by disease-causing organisms. Disease also is inevitable in an area where waste water from hatcheries is indiscriminately put back into the coastal water without treatment. Many new disease-causing organisms have developed and have been observed because of the indiscriminate use of antibiotics as prophylactic agents in hatcheries. Most hatcheries also do not observe proper sanitation in their surroundings as well as in their tanks. There is a need for strict observance of sanitary rules and prophylactic measures in hatcheries.

Water Quality

There are seasonal changes in water quality of coastal waters (Chen et al 1985, Chen 1985). Industrial pollution contributes to the deterioration of water supply sources for hatcheries. More controlled culture techniques should be practiced to optimize the larval rearing system being used. This could be enhanced by development of a recirculating system through biological filtration, automation of different hatchery

procedures, and constant monitoring of incoming water as well as coastal water for signs of pollution.

Reliable Technicians

The boom in hatchery business created the need for trained technicians who are reliably schooled in basic theories related to larval rearing and who can be depended upon to make the right decisions most of the time. The technicians must be diligent and should consider hatchery work a twenty-four-hour job.

Many technicians working in hatcheries today are neither trained nor have they undergone sufficient training. It is suggested that these technicians should undertake thorough training to understand the basics of larval rearing technology, and should establish constant contact with training institutions or with fellow technicians to gain insights into new management techniques in the prawn hatchery industry.

Information Flow

In the Philippines, the archipelagic nature of the country deters a smooth communication flow between: (1) hatchery operator and another hatchery operator, (2) research institution and hatchery operator/technician, and (3) hatchery operator and pond grower.

A feedback mechanism between the research institution and the hatchery operator is necessary. Also, hatchery operators should develop open communication lines among themselves to prevent excessive competition and subsequent collapse of postlarvae price. It is also important that a network of information be developed between hatcheries and pond grow-out to properly time hatchery harvests with pond stocking periods.

Formation of cooperatives is recommended, and government should take the initiative to form a communication or information network among these prawn industry components to facilitate growth and development of a successful hatchery industry, following the Taiwanese model.

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Chapter Four

PRAWN GROW-OUT PRACTICES IN THE PHILIPPINES

Florentino D. Apud*

Prawn farming in the Philippines is generally classified into three: extensive, semi-intensive, and intensive (Apud et al 1983, Apud 1985). While intensive farming is gaining rapid development in marginal and elevated areas along the shoreline, extensive and semi-intensive farming is done mainly in former milkfish culture areas.

Regardless of the type of farming being practiced, most farmers are usually confronted with the problem of standardizing their operation. Production can vary from one crop to another or from one pond to another and even from one individual, site, and/or facility to another. In effect, there is a need to standardize prawn farming practices for consistent reference. Presently, prawn farming is viewed more as an art rather than as exact science.

This paper deals mainly with the state of the art of prawn pond culture, specifically with pond management practices, including site suitability, engineering design, and harvest and post-harvest handling. For added insight, problems and prospects in the industry are briefly discussed with some recommendations.

SITE SUITABILITY

The major environmental factors generally observed to have great influence on prawn production are climatic conditions and water and soil quality. Better production is observed in areas having short and not so pronounced dry season with moderate rainfall distributed almost throughout the year. A pronounced long dry season can affect production because of increasing temperature and salinity. High temperature (31-33°C) and high salinity (28-33 ppt) promote excessive growth of benthic algae in nutrient-rich water. Overgrowth of benthic algae disturbs the ecological pond

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condition by having extreme fluctuations in dissolved oxygen (Subosa, pers. comm.). In daytime, dissolved oxygen is usually high due to rapid photosynthetic activity while from midnight to early morning, oxygen is depleted due to respiration of all plants and animals including plankton (Apud et al 1983).

To remedy the situation, some farmers particularly those engaged in intensive farming select areas with adequate source of good seawater and freshwater quality that can be manipulated to maintain desirable levels of temperature and salinity. Fish farmers are also concerned with water pH. At a reading below 6.5, the condition tends to become acidic; hence, production is poor. At pH 9.0 and above, ammonia in water becomes toxic to animals (Norfolk et al 1981). The water pH is usually influenced by soil pH; hence, knowledgeable fishpond operators avoid areas with potential high acidity.

The bottom elevation easily reached by ordinary high tides is preferred for extensive culture ponds in order to enhance water management by gravity flow. Higher elevation is chosen for intensive and semi-intensive ponds to easily achieve complete draining and better exposure of pond bottom during drying period.

Accessibility of the project to land transport is also preferred by prospective operators to facilitate supervision and transport of input materials and products. Availability of cheap power source and ice is also beneficial to the operation, especially for the intensive culture system.

ENGINEERING DESIGN

Prawn farmers in extensive and semi-intensive culture systems usually utilize ponds originally designed for milkfish culture. Minimal improvements are introduced depending on the existing conditions of milkfish ponds for extensive system, while more improvements are made for semi-intensive culture in terms of depth, and gate and canal system. In contrast, the intensive culture ponds are so designed following the standard requirements in terms of pond elevation, size of compartments, gates and canal system, access road, and provisions for pumps, electrical, and aeration system. A typical design of intensive and semi-intensive culture ponds is shown in Figure 1.

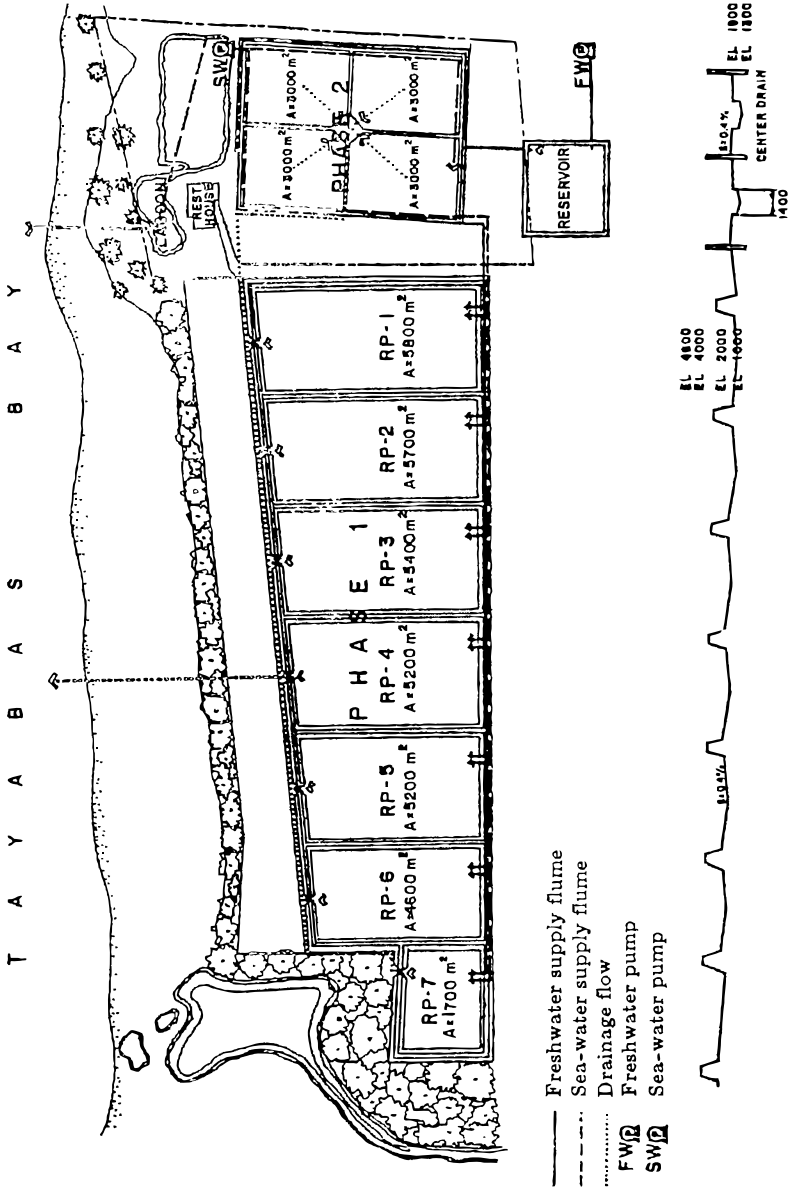


Fig. 1. A typical design of semi-intensive (Phase 1) and intensive (Phase 2) culture ponds (Inland Resources Development Corporation 1988)

The improvements in pond engineering design have contributed a lot to the success of the prawn grow-out operation. An improved design can effectively provide the best environmental conditions for prawns in terms of good water quality through efficient pumps, supply canal, drain canal, water gates, and filtration system at lesser efforts. The design using ferrocement gates (Figure 2) and dikes developed at SEAFDEC Aquaculture Department has reduced cost, minimized routine maintenance work, and provided safety to the stock. Standard shape for intensive ponds is either circular, octagonal, rectangular, or square with a manageable size of no more than 0.7 ha per pond. The pond bottom has a slope of 0.4-0.5 percent from the side towards the center. The circular movement of

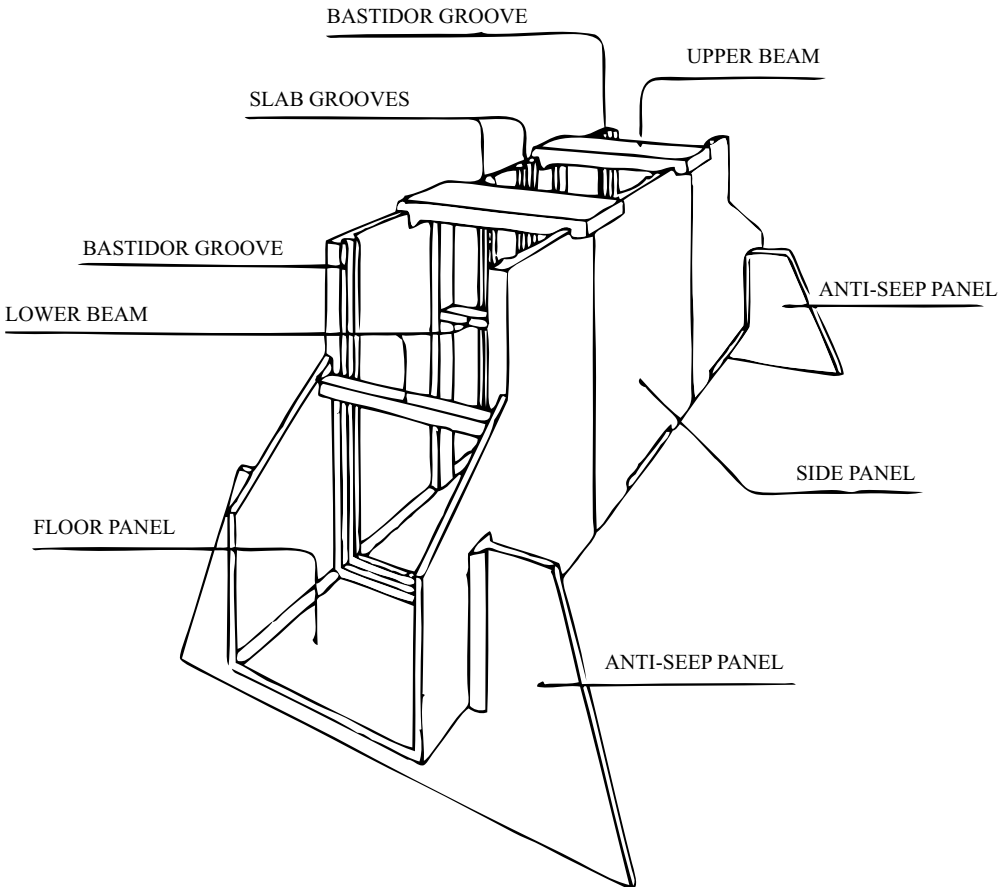


Fig. 2. Ferrocement sluice gate at LRS SEAFDEC AQD (Torres 1983)

water created by paddlewheels concentrates wastes products toward the center drain. These wastes are in turn flushed out daily or every other day as the need arises.

POND MANAGEMENT PRACTICES

Pond management practices among prawn farmers vary according to culture system and style. Some farmers prefer to stock their fry directly in grow-out ponds while others choose to stock them first in a nursery pond, *hapa* nets, or net enclosure. The management practices considered seriously by prawn farmers regardless of the culture system being used are the following: adequate pond preparation, appropriate size of stock and stocking procedure, feed and feeding management, water management, control of pests and predators, harvest and post-harvest procedures, and marketing strategies.

Pond Preparation

Just like in agriculture, farms are adequately and properly prepared prior to planting. Success in rice production, for example, depends on how adequate the paddies are tilled and cleaned. In prawn farms, progressive farmers are very particular with drying of the pond bed. This practice eliminates pests and predators, releases toxic gases, disinfects harmful wastes, and mineralizes part of the organic matter making nutrients available (Apud et al 1983).

Pond conditioning. Most farmers engaged in intensive culture till the pond bed for better sunlight penetration and to loosen the soil. Treatment of lime is also done to sterilize the soil and control diseases and also to neutralize acidic conditions. According to Subosa (1986), lime stimulates the growth of nitrogen-fixing bacteria and other heterotrophic soil organisms, and therefore promotes bacterial breakdown of waste materials including green manure, waste food, and organic fertilizers. It also decreases the concentration of hydrogen ions and solubility of iron, aluminum, and manganese while increasing the availability of phosphates, molybdates, and exchangeable calcium and magnesium. Further, lime generally improves water quality.

Lime requirement is usually based on the pH of the soil. Experience in SEAFDEC AQD's Leganes Research Station and from the industry shows that a newly developed pond with pH of 4-5 may require a sizeable amount of lime to raise its pH to the desirable level of at least 7. For conditioning or prophylactic purposes, a rate of 1-2 tons hydrated lime per ha is applied. Ammonium sulphate (21-0-0) can be added to lime at a ratio of 1:5 in the watered portion of the ponds to eradicate remaining pests and predators during pond preparation (Norfolk et al 1981).

For convenience, some fishpond operators engaged in extensive and semi-intensive culture use certain chemicals to eradicate pests and predators. According to Villaluz et al (1969), this practice should not only be discouraged but totally eliminated in prawn farms to avoid residual effects. The use of organic pesticides such as derris root, teaseed cake, and tobacco dust has been encouraged by SEAFDEC AQD (Apud et al 1983).

Pond fertilization. Fertilization is another standard practice in pond preparation particularly for extensive and semi-intensive culture systems. Prawn farmers normally apply organic manure at 1-2 tons per ha. Usually inorganic fertilizers such as ammonium phosphate (16-20-0) and urea (46-0-0) at 75-150 and 25-50 kg per ha are added to enhance the growth of natural food.

This application is not needed for intensive culture except when there is very poor growth of plankton during initial cropping. Subosa (1986) has demonstrated the feasibility of producing prawn stocked at 7500 per ha reaching marketable size in 120 days through fertilization of organic manure and inorganic fertilizers at 1 ton chicken manure and 15 kg N + 30 kg P, respectively, per ha. The above amount was divided into eight equal parts and applied at two-week intervals starting two weeks before stocking until two weeks before harvest.

Gate screen or filter system. Proper screening or water filtration is one pond management practice that has been improved recently. Traditionally, the gate screen as utilized in milkfish ponds is made of bamboo slats with wooden frames. This allows a lot of unwanted species to enter the pond at egg or larval stages which in due time compete with cultured species. A modification was made earlier by placing a finer nylon screen over the bamboo slats. Although this was helpful,

the flow of water was very much interrupted. To improve the situation, the use of circular screening or "bulon" and bag net or "lumpot" was developed at SEAFDEC AQD (Primavera and Apud 1977). Eventually the use has spread among prawn farmers particularly those who are engaged in extensive and semi-intensive culture.

The filtration system for intensive culture is more effective and varies from one farm to another. The common practice is to use a fine bag net at the discharge or a series of screens at the concrete supply canal. Screening materials vary from the locally made to the expensive imported ones. These are usually made of strong materials with varying mesh sizes. A number of intensive farms in Negros are using imported perforated stainless sheets in the supply canal. This is quite expensive but durable and effective in preventing entrance of unwanted species.

Fry Stages at Stocking, Stocking Density, and Stocking Procedures

With the proliferation of hatcheries all over the country, a grow-out pond operator can avail of good quality fry throughout most of the year. Stages of fry usually produced in the hatchery range from PL₄ to PL₂₅. Fry gathered from the wild may range from PL₁₅ to PL₃₀. Regardless of source, prawn operators prefer older stages of fry for stocking in grow-out ponds. Ideally PL₃₀ to PL₃₅ give good results. The demand for older stages of fry has paved the way for a series of studies on the development of the nursery system (Apud and Sheik 1978, Cholik 1978, Apud 1979, Fernandez 1979, and Gabasa 1982).

Development of nursery system. Work on nursery systems was mainly concentrated on earthen nursery ponds except that of Gabasa (1982) who developed the tank system attached to the hatchery tank system. In 1983, the floating cage nursery system (Figure 3) was developed at SEAFDEC AQD Batan Station (De la Pena and Prospero 1984). The common objective of most studies on the nursery system is to be able to produce juvenile stages (PL₃₀ to PL₃₅) suitable for stocking in grow-out ponds from the earlier stages of PL₄ to PL₁₀. In due time, nursery techniques spread to the private sector. A number of investors in Roxas City put up nurseries to accommodate earlier stages of

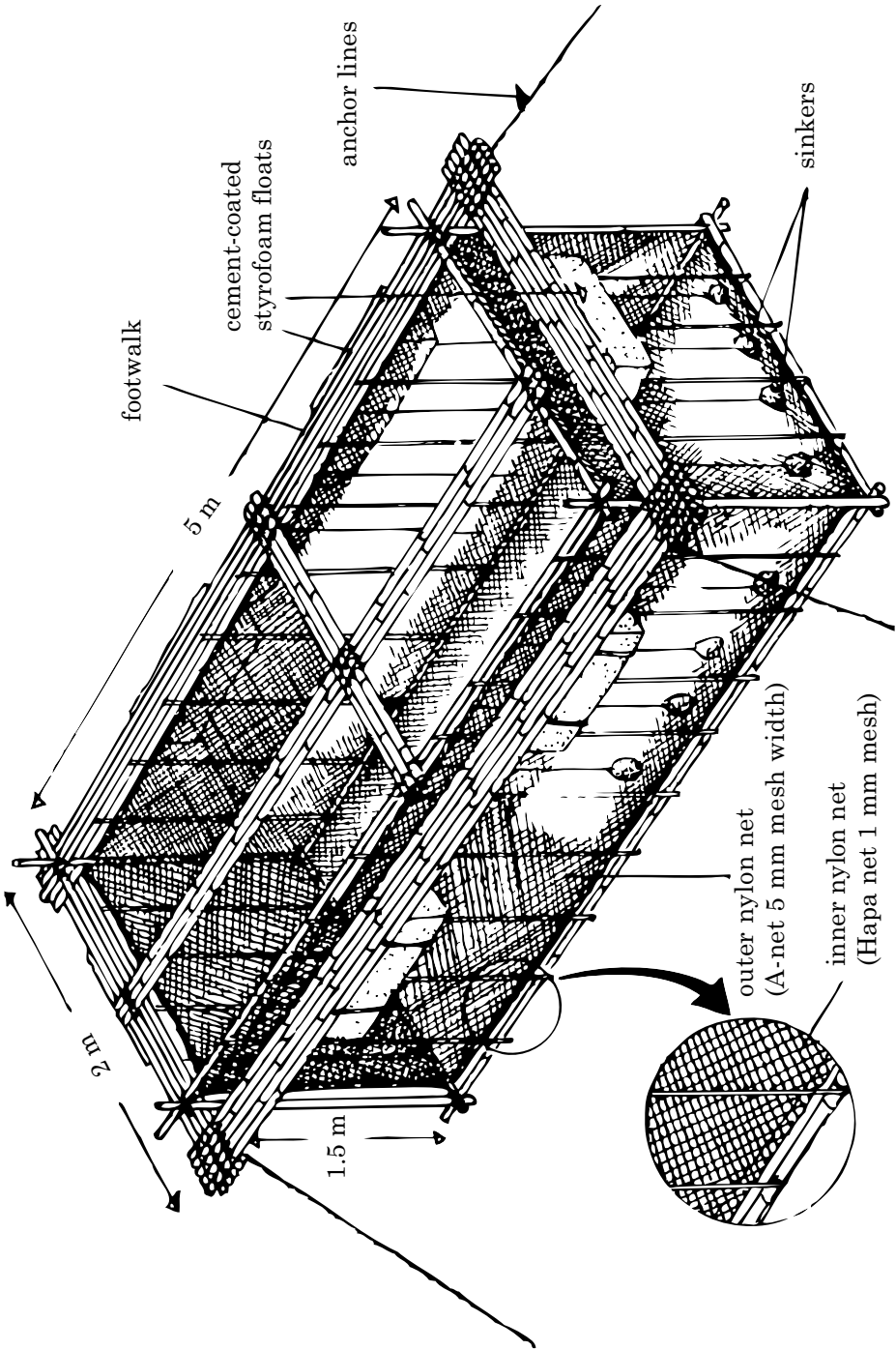


Fig. 3. Full view of a floating nursery cage with bamboo cage frame, floats, netting materials (de la Pena et al 1985)

fry they bought from hatchery operators which they later sold at juvenile stage to grow-out pond operators. Some hatcheries provide their own nursery system.

To reduce costs, some grow-out operators develop their own nursery or provide a net enclosure right in the grow-out pond where the fry are intended to be stocked.

Juveniles reared in a nursery pond or in a net enclosure adjacent to or within the grow-out pond area are merely transferred or released without acclimation. Tank-reared juveniles or fry from the wild may require acclimation to pond conditions. Failure to gradually adjust salinity and temperature of transport water to that of the pond water during stocking can result in high mortality. Some traditional farmers do not even care to know the salinity and temperature of transport and pond water. At present, prawn farmers are very particular with the salinity level of the fry source. If it differs from their pond salinity, they request the hatchery or nursery source to adjust the salinity of the transport water to that of their pond.

Stocking density. Stocking density is dependent on the culture system including food availability, water depth, and efficiency in water management. Fish farmers engaged in extensive operations stock 2 000-10 000 *P. monodon* per ha. When natural food is abundant, about 500-2 000 milkfish fingerlings per ha are added. Combining prawn with milkfish is favorable to both species. Results obtained from various studies on the polyculture of milkfish and prawn (Pudadera 1980, Eldani and Primavera 1981, Apud et al 1983) confirmed some beneficial effects. Eldani and Primavera (1981) specifically pointed out that one of the important benefits of prawn in polyculture with milkfish is the control of the population of chironomid larvae. These can occur at very high density (40 000-50 000 per sq m) during certain periods and compete with favored stock for food, oxygen and space. Gundermann and Popper (1977) reported the disappearance of *Chironomus* larvae in Fiji ponds several weeks after stocking with *P. merguensis* and *P. indicus*.

Stocking densities in semi-intensive operations vary from 20 000 to 80 000 per ha. These density levels are based on industry experience and the results of various studies on prawn grow-out conducted at SEAFDEC AQD Leganes Research Station (Mochizuki 1979, Apud et al 1981, Norfolk et al 1981,

Pascual, pers. comm., Corre, pers. comm.). At these density levels and industry experience, a survival rate of 60-80% and average body weight of 33-43 g are normally achieved in 120-135 days. Growth is highly dependent on water management and depth as well as on quality of supplementary feed or formulated diet. Stocking densities for intensive systems range from 100 000 to 400 000 per ha with the optimum of 150 000-250 000 per ha as practiced by most intensive growers. Survivals vary from 60 to 80% and average size from 28 to 38 g at a culture period of 120-135 days. Table 1 shows the different density levels and expected ranges in yield per ha per crop.

Table 1. Different density levels for *P. monodon* and expected yield per hectare per crop

Density levels (pcs/ha)	Yield/ha/crop (kg)
2 000 - 7 500	50 - 200
10 000 - 15 000	250 - 350
20 000 - 30 000	400 - 700
40 000 - 50 000	750 - 1 200
60 000 - 80 000	1 300 - 2 500
100 000 - 120 000	2 500 - 3 500
150 000 - 250 000	4 000 - 7 000
300 000 - 400 000	7 500 - 12 000

Fry transport and stocking. The proper time for transport and stocking is also keenly observed by grow-out pond operators. To ensure best results, harvest and transport of fry are done at the earliest possible time so that these should reach the pond before sunrise. Stocking including acclimation should be finished not later than 0900 h. Transport of fry is conveniently done with the use of oxygenated plastic bags. The bags are placed inside styrofoam boxes or "pandan" bags. Older or bigger fry are transported in aerated tanks. In both cases ice is used to reduce and maintain temperature at water at 20-22°C during transport period.

In order not to delay stocking, counting of fry is done at the source. This will also eliminate stress at the pond site where facilities are not as good as in hatcheries. Acclimation can be done by first allowing the oxygenated bags to float in the pond. When temperature of transport and pond water equilibrates, the bags are opened one by one and pond water is added gradually to adjust salinity. When fry are observed to start moving, the mouth of the bag is dipped and the fry are allowed to swim against the water. The adjustment of salinity by about 2 ppt per hour is advisable. For best results, fry are distributed throughout the area when released into the pond.

Feed and Feeding

Extensive farming of prawn relies heavily on natural food grown in the pond. Supplementary feeds are provided only occasionally when natural food production is low and stocking density is higher than 7 500 *P. monodon* per ha. In contrast, densities ranging from 20 000-80 000 per ha in semi-intensive culture require regular supplementary feeding in addition to natural food, while formulated diet is regularly provided 3-6 times per day in intensive farming.

Natural food and supplementary feed. The natural food growing in the pond varies according to pond condition and location. Extensive culture as practiced in Northern Panay, parts of Bataan, Bulacan, Pangasinan, Samar, Leyte, and some areas in Mindanao depends to a great extent on aquatic plants. The two most important species are *Najas graminea* and *Ruppia maritima*. Both plants normally occur in lower-salinity (10-20 ppt) areas. *R. maritima* has a crude protein content of 15% (Apud et al 1983). Both grow well in water 50-100 cm deep. Prawns graze on the soft parts of the plants associated with small animals and particularly on the decaying remains of the plants in the pond bottom (Primavera and Gacutan 1985). The plants likewise provide shelter or substrate and improve water quality as silt and other particles are deposited on their leaves and stems.

Filamentous green algae such as *Chaetomorpha* constitute another food item grown by some farmers in low-salinity areas. They also provide a refuge for small animals eaten by prawns, however, excessive growth can be harmful by entangling the fry.

Some farmers remedy the situation by stocking milkfish or applying inorganic fertilizers on the algal mats to soften the plants through plasmolysis.

Plankton, the microscopic plants and animals suspended in water, form the base of the food chain. Deep ponds of low to medium salinity (10-25 ppt) are conducive to plankton growth. Plankton bloom is detrimental as it can deplete oxygen early in the morning through respiration. On the other hand, moderate growth, particularly of zooplankton, can be beneficial as these are grazers of phytoplankton.

A microbenthic complex consisting of blue-green algae, diatoms, and other microscopic plants and animals known as *lablab* is a nutritious food for milkfish and young prawns. The environmental conditions under which it grows best (shallow water, 20-25 cm depth, and higher salinity of 28 ppt and above) are not suitable for prawn. Its excessive growth also depletes oxygen and deteriorates the pond bottom by producing ammonia and hydrogen sulfides during the decomposition process.

Although the "stock" in extensive culture depend heavily on natural food, some farmers provide various kinds of supplementary feed, such as trash fish, mussel meat, toads, chicken entrails, cattle hide, snails, etc. In semi-intensive culture, processed feeds (formulated diet) and/or trash fish are stored to provide adequate and ready supply of feeds.

Formulated diet. Formulated diets in pelleted form are mainly utilized in intensive and semi-intensive culture systems. The daily recommended rates which decrease with time are 12-13% of estimated total biomass of prawns. The daily ration is initially given twice a day, 40% in the morning and 60% in the afternoon during the first month. In the second month, feed is given three to four times a day; third and fourth months, five times a day. The earliest time the technicians start feeding is 0600 h and the latest is 0100 h. The percentage or amount given per feeding time depends upon the physico-chemical condition of the water and the response of the prawn to the feed at certain periods. Close monitoring of feed consumption, prawn population, molting, health condition, and average body weight including the physico-chemical parameters is beneficial for good feeding management. A typical example of determining the daily feed ration (DFR), total feed requirement (TFR), and projected feed conversion (PFC) is shown in Table 2.

A standard feeding time, feeding frequency, feed distribution and recommended feeding rates (FR) are shown in Table 3.

Table 2. A typical example of determining daily feed ration (DFR), total feed requirement (TFR), and projected feed conversion ratio (FCR)

Elapsed time (days)	Ave. body wt (g)	Estimated survival (%)	Feeding rates (% biomass)	Daily feed ration, (kg/day)	Feed required every 15 days (kg)
0	0.006	100	10.0	0.036	0.54
15	0.210	95	8.0	0.960	14.40
30	1.700	90	6.0	5.510	82.65
45	5.350	85	4.0	10.910	163.71
60	11.100	80	4.0	21.310	319.68
75	16.900	75	4.0	30.420	456.30
90	23.650	70	4.0	39.730	595.98
106	31.400	70	3.5	46.160	692.37
120	35.000	70			
Total feed requirement					----- 2,325.63 =====

A. Given values and assumptions:

1. Initial Stock (IS) = 60,000 pcs/ha
2. Total Feed Requirement (TFR) = 2,325.63 kg
3. Final Survival Rate (SRf) = 70%
4. Final Average Body Weight (ABWf) = 35 g
5. Initial Biomass (Bmi) = 0.006 g x 60,000 pcs = 0.36 kg

B. Calculation:

1. Projected Yield (PY) = IS x SRf x ABWf
= 60,000 pcs x 0.70 x 0.035 kg/pc
1,470 kg
2. Projected FCR = $\frac{TFR}{\text{Weight Gained}} = \frac{TFR}{PY-Bmi}$
 $\frac{2,325.63 \text{ kg}}{1,470 \text{ kg} - 0.36 \text{ kg}} = 1.58$

3. Daily Feed Ration (DFR) = IS x SR X ABW x FR

Where: IS Initial Stock
 SR Survival Rate, beginning of the period
 ABW Average Body Weight, beginning of the period
 FR Feeding Rates (% BM), recommended for a particular feed.

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Table 3. A standard feeding time, feeding frequency, feed distribution, and recommended feeding rates

A. FEED TIME, FREQUENCY, AND FEED DISTRIBUTION

Time of feeding (hr)	PL20 - 1 g (1-30 days) Starter	1 - 3 g (31-45 days) Grower	3 - 8 g 46-60 days Grower	8 g - Harvest 61 days-harvest Finisher
0600	40%	30%	25%	20%
1000			20%	15%
1400				10%
1800	60%	40%	35%	35%
2200		30%	20%	20%

Increase feed by 5% the next day if feed is consumed in one hour.

Decrease feed by 10% if feed is not consumed until next feeding.

B. FEEDING RATES

Weight of prawns in grams	Feeding rate (F.R.) (%)
PL - 1.0	8.0 - 12.0
1.0 - 5.0	5.5 - 6.5
5.0 - 10.0	5.0 - 5.5
10.0 - 15.0	4.5 - 5.0
15.0 - 20.0	4.0 - 4.5
20.0 - 25.0	3.5 - 4.0
25.0 - 30.0	3.0 - 3.5
30.0 - 35.0	2.7 - 3.0

Water Management

The periodic change of water is an important management practice which should be observed properly by prawn farmers. In extensive farms water change is made by draining water during low tide then allowing new water to come in during high tide. For the whole period of 5-6 days, total water change can reach as much as 50 to 100%.

In semi-intensive and intensive farms, water change is done in two ways. First, by pumping in new water at the same time draining an equal volume (flow-through system). Second, by draining first a given volume then introducing new water. The latter method provides an effective replacement and dilution due to mixing. Paddlewheel operation is also necessary not only to provide adequate levels of oxygen but also to mix water and prevent stratification. A standard schedule for paddlewheel operation in a one-hectare pond is shown in Table 4.

The total water replacement during the entire culture period varies according to stocking density, water quality, and feeding scheme. Normally, the amount of water replaced for every water change is 20 to 50%. The frequency of change is minimal during the initial period--once or twice a month for the first month, three or four times in the second month. In the third month, water is changed twice a week and in the fourth, every four to five days. The frequency and amount of water change are based on pH levels, salinity, and turbidity.

Control of Pests and Predators

The appearance of pest and predators during the culture period can not be totally avoided. Most common are tilapia, gobies, small crabs (*Varuna litterata*), tarpon (*Megalops cyprinoides*), ten pounder (*Elops hawaiiensis*), sea bass (*Lates calcalifer*), etc. The presence of these unwanted species may create a big problem during the culture period. Tilapia and gobies may occur in large quantity and compete with prawns for feed, space, and dissolved oxygen. Presence of predatory species such as tarpon, ten pounder, and sea bass in large quantities can drastically reduce the population in a short period of time.

Table 4. Standard schedule for paddlewheel operation at stocking density of 20-25/sq m

Days of culture	Operating schedule	Number of hours/ day	Number of paddle- wheels/ha
1 - 15	12 NN 3 PM	11	6
	11 PM 7 AM		
16 - 30	12 NN 3 PM	13	6
	9 PM 7 AM		
31 - 45	12 NN 3 PM	15	6
	7 PM 7 AM		
46 - 60	12 NN 3 PM	16	8
	6 PM 7 AM		
61 - 75	12 NN 3 PM	17	8
	5 PM 7 AM		
76 — Harvest	12 NN 10 AM	22	8

During heavy rains, cloudy, days and water exchange, paddlewheels should be turned on.
During feeding time, aerators may be turned off.

Some growers engaged in extensive culture system try to control the population of tilapia by throwing cast net or allowing some people to fish by hook and line. Gill nets are also utilized to catch bigger tilapia. In the case of gobies, collection by feeding trays or traps is resorted to. The above measures may help but do not completely solve the problem.

Growers engaged in intensive and semi-intensive culture suffer some initial difficulties due to the unavoidable occurrence of gobies and tilapia no matter how they try to filter water. However, a selective pesticide, teaseed powder, has solved the problem. Teaseed powder is an imported by-product

of tea (*Camellia* sp) which contains saponin poisonous to finfishes. Another organic pesticide effective in eliminating ten pounder, tarpon, and other finfishes at levels tolerable to prawns is rotenone. Rotenone is a white odorless crystalline substance which acts as an inhibitor of cellular respiration in fishes (Apud et al 1983). It is extracted from derris root and comes out in powder preparation or in liquid form at a level of 5-8% rotenone.

The possibility of developing techniques for selective elimination using locally available derris root is very promising. A bioassay of powdered derris root (Tumanda 1980) indicated its selective effect. At 5-10 ppm, the powdered material kills tilapia, tarpon, ten pounder, milkfish, and other finfishes but does not affect *P. monodon*.

Harvesting and Post-harvest Handling

Prawn growers engaged in extensive system usually synchronize harvest with the spring tide during new moon and full moon. It has been observed that prawns are active and hard-shelled two or three days after the peak of spring tide. If timing is off, a greater percentage of harvest may be soft-shelled. To avoid this condition, prawns are induced to molt five days before the expected harvest by abruptly changing the pond water from 50-70% to expose them to stressful condition. This is normally practiced in intensive or semi-intensive farms to ensure better quality of prawn product.

Methods of harvesting. There are two ways of harvesting prawns in ponds: partial and total or complete harvesting. Partial harvest is done when there is a wide range of stock sizes in ponds. Harvest gears usually utilized for this purpose are bamboo traps, cast nets, and pond nets. The latter is effective in selecting marketable sizes as smaller prawns easily pass through the net mesh used in the trap (Figure 4).

Total harvest is done using a bag net installed at the drain gate. During draining, prawns tend to go with the water; hence, they are collected inside the bag net. The bag net has an opening at the end portion where the collected prawns are released and transferred to a basket or a net bag. There is some difficulty in getting all the prawns from the pond when pond bottom elevation and slope towards the drain gate are

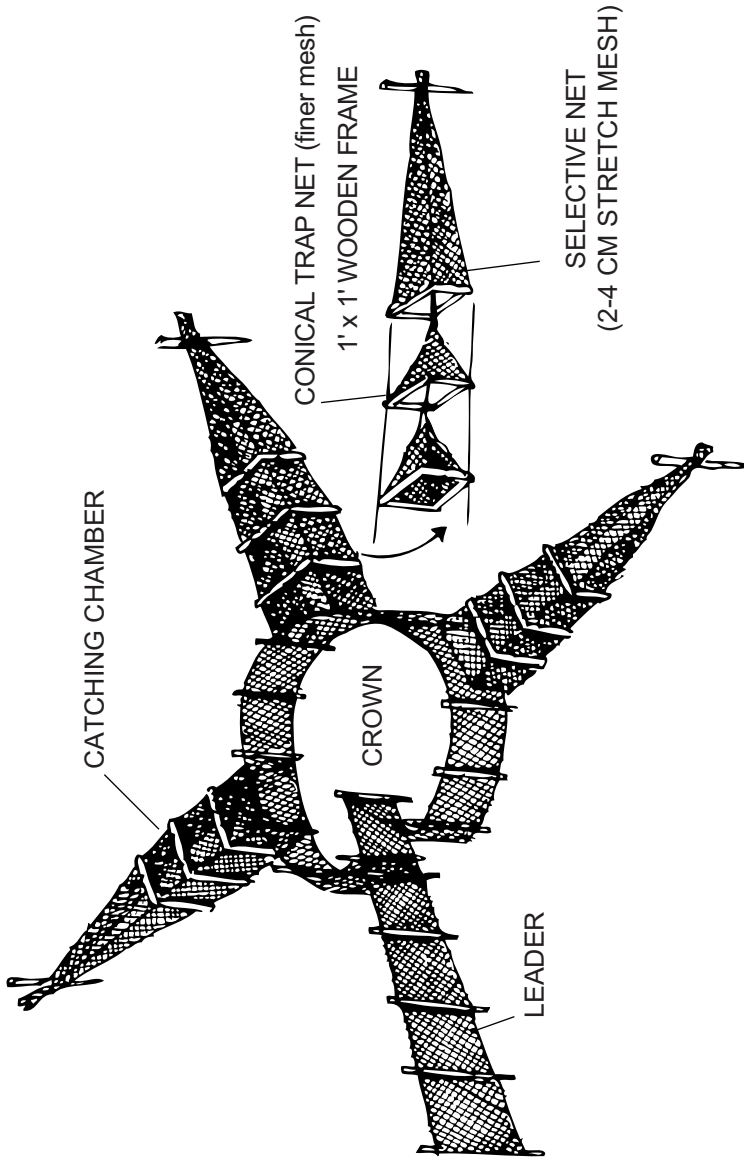


Fig. 4. Selective harvesting net collects only large prawns; undersized stock pass through the net (Suemitsu 1983 in Apud et al 1983)

inadequate. Also, if prawns are not so active or if they are molting, they tend to burrow themselves in the mud. In some cases, farmers resort to handpicking. While it takes much effort and time, prawns harvested this way easily deteriorate and, therefore do not command a good price.

Another method of harvesting prawns is with the use of a large suspension net installed at the discharge portion of the drain gate. Prawns can be accumulated in the net either by allowing them to swim against the water when flooding with tidal water or allowing them to go with the current when draining the pond. This is best suited for a limited volume where prawns can be kept alive for better negotiation in price.

Post-harvest handling. The best care for newly harvested prawns is to wash them thoroughly and immerse them immediately in chilled water (10°C) preferably while still alive. Those that are picked from the mud should be immediately released in clean water to give them the chance of releasing mud and other impurities in the gills prior to chilling. While some farmers are aware of this, many still fail to handle their product properly; hence, they usually do not get a better price.

Depending on the preference of the buyer, prawns particularly *P. monodon*, are classified into different size groups; e.g., 6-18, 19-25, 26-40, and 41 pc per kg and above. All prawns falling under the last category together with the soft-shelled are bought at a much lower price or rejected. Another classification practiced by most buyers in the Visayas is 20 and below, 21-30, 31-40, and 41 pc, and above. The last group and the soft-shelled are also either bought at a much lower price or rejected. Prices fluctuate every now and then reaching its peak in the month of November and part of December. Production results achieved from various farms are shown in Table 5. Average growth rate of prawn at 15-day intervals is shown in Table 6.

PROBLEMS AND PROSPECTS

Problems

While the movement of the industry is shifting into high gear, some problems have developed along the way. Most common among these are the marketing aspect, feed and

Table 5. Production results achieved in various farms at different stocking densities

Location	Stocking density (pcs/m ²)	Survival rate (%)	Ave. body wt.(g)	Yield (kg/ha)	Feed consumed (kg)	Feed conversion ratio
Visayas	4.60	78.00	33.36	1 091.50	1 656.90	1.51
Visayas	5.30	70.00	26.08	1 005.50	1 479.86	1.47
Visayas	10.00	70.00	35.70	2 500.00	4 000.00	1.60
Mindanao	8.00	86.60	30.67	2 255.76	3 492.41	1.55
Mindanao	12.31	84.50	32.27	3 490.11	5 178.81	1.60
Elsewhere	25.97	70.11	34.55	6 292.16	11 955.10	1.90

Table 6. Growth rates of prawns, *P. monodon* at 15-day intervals for both intensive and semi-intensive culture systems

Elapsed time (days)	Farm 1 (g)	Farm 2 (g)	Farm 3 (g)	Average weight (g)
0	0.006 (PL ₂₀)	0.006 (PL ₂₀)	0.006 (PL ₂₀)	
15	0.240	0.210	0.236	0.23
30	1.360	1.700	1.470	1.51
45	3.390	5.350	5.350	4.70
60	10.370	11.100	10.350	10.60
75	15.610	16.900	14.990	15.80
90	21.960	23.650	21.390	22.33
106	27.520	31.400	29.640	29.52
120-130	33.700	37.600	35.800	35.70

feeding, soil and water quality, design and construction, diseases, pest and predator control, seasonal variation, sourcing of inputs, and manpower.

Classification and pricing. Many prawn farmers complain about the wide disparity in the classification and pricing pattern adopted by buyers. Better classification and pricing terms can be offered by buyers depending on the guts and wisdom of the producer during negotiation.

Nutritional requirement. The nutritional requirement of prawns has not yet been fully understood. Many food sources and feeding practices have been tried for semi-intensive culture, but the results are as varied as the kinds of feed and feeding scheme used. Some farmers are also tempted to buy cheaper prawn pellets just to find that these turn out to be more expensive because of the poor conversion ratio and lower

quality of prawn product. Soft-shelling and bluish prawns have been attributed to nutritional deficiency.

Maintenance of water and soil quality. The high stocking density used in intensive culture system requires high protein feed inputs which result in high metabolic wastes. This condition easily deteriorates the water and soil quality and becomes unhealthful to prawns. The presence of mineral pyrites and organic acids in large amounts in some areas can worsen pond conditions which may result in loss of appetite, disease, and eventually death of prawns.

Design and construction of pond facilities. Some farmers have not followed the design and construction of pond facilities according to the standard requirement and function related to prawn production operations. This aspect has not been seriously studied and fully understood by many prawn farmers such that a number of production failures are still associated with design and construction defects.

Pests, predators, and disease control. Pests and predators still bother many prawn farms. Proper screening can at least minimize but not totally eliminate their presence, especially tilapia and gobies. The application of selective pesticide like teaseed powder and derris root has at least improved the situation; however, this practice may not be economical for the extensive system. Diseases also become a big problem as intensification increases. Disease can be an offshoot of poor pond preparation, poor seed supply, nutritional deficiency, stress due to poor environmental condition, handling, ineffective water management, poor water and soil quality, heavy loading of ponds, and industrial or agricultural pollution or contamination from other farms.

Others. The seasonal variations and other realities in aquaculture are not yet understood by some investors. They tend to program production throughout the year without considering that at certain periods production can be largely influenced by water conditions; supply and quality of fry and other inputs; outbreak of disease; pest and predators; soil and water quality; domestic, agricultural, and industrial runoffs; and deficient manpower know-how and responsibility.

Finally, the excessive use of deepwells for intensive culture makes aquifers vulnerable to sea-water contamination. In some areas artesian wells have started to dry up while adjacent agricultural lands are contaminated by sea-water.

Prospects

The import demand for frozen prawns in Japan and the United States for the last five years has been increasing steadily (Figure 5). In 1983, the importation of each country reached an average of about 150 000 metric tons. In 1987, such importation attained between 220 000 and 250 000 metric tons (van Eys 1987). In effect, the total market potential for frozen prawns in Japan and United States alone reaches about 470 000 metric tons, not including demand from the European market.

The Philippines evidently possesses the right resources in its waters. Prawns have been a common by-product of many milkfish farms. The warm tropical condition and the quality of most of the country's soil and water are favorable for prawn production. Also, the established brackishwater fishpond industry in the country makes it easier to shift to the prawn industry resulting in the dramatic increase of frozen prawn exportation in recent years (Figure 6).

There is also rapid progress in the development of hatchery and broodstock and maturation techniques. Fry production has increased tremendously and once this can be stabilized and wild spawner supply can be adequately backed up by broodstock and maturation techniques, pond production can be a year-round activity.

CONCLUSION AND RECOMMENDATIONS

Despite the massive progress in the development of prawn culture in the Philippines in the last two years, production has yet to be stabilized. Yield per unit area in extensive, semi-intensive, and intensive culture systems vary, depending on numerous factors such as weather condition, fry quality, pond management practices, soil and water quality, technician/caretaker, pond and its support facilities, etc. Intensive farming requires closer and continuous monitoring of pond parameters, including the health condition of prawns and

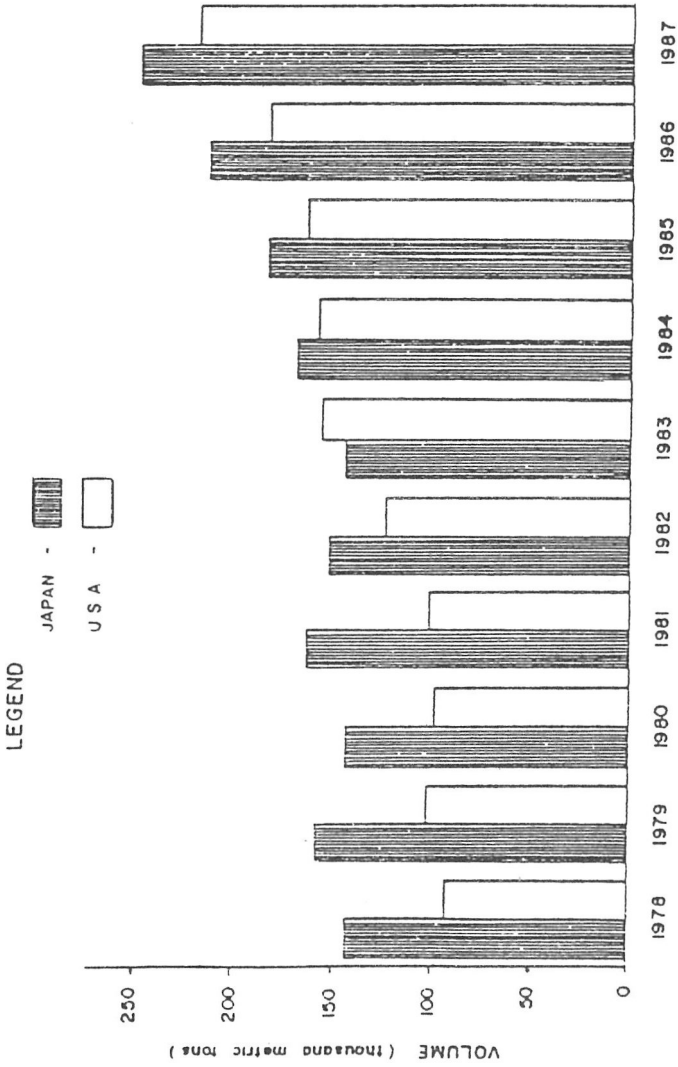


Fig. 5. Japan and U.S. imports of shrimps, 1978-1987 (FAO 1986, van Eys 1987)

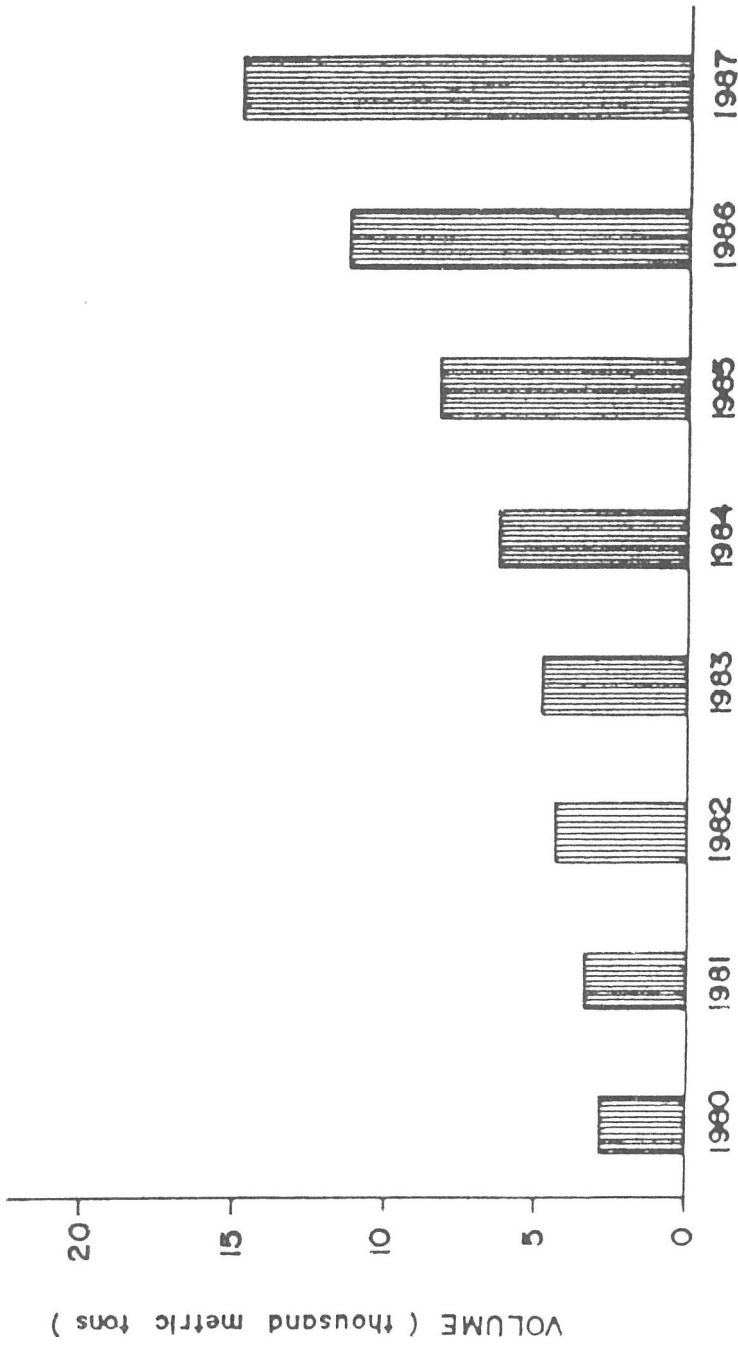


Fig. 6. Total Philippine shrimp exportation, 1980-1987 (BFAR 1980-87)

that of the pond bottom. Early deterioration of the pond bed and late discovery of disease may cause devastating effects on the operation.

Site suitability and pond engineering design are basic considerations that can spell success or failure of the operation. These factors are sometimes taken for granted by some investors who appreciate their importance only after a series of failures because of problems associated with site and pond engineering design and construction.

Pond management practices such as pond preparation, handling, transport and stocking of fry, water management, and feed and feeding management are other key factors in the success of the operation. These are more of an art rather than an exact science; hence, the degree of success can be influenced by the ability of the caretakers and technicians in dealing with these factors.

The market demand for prawns has not been saturated; however, there is a need to develop marketing strategies and postharvest/handling and transport methods to ensure high quality and better price.

There is a great need to improve and standardize the quality of hatchery-bred fry to protect farmers from getting fry in poor condition. Hatcheries should not be too dependent on spawners coming from the wild. Broodstock and maturation techniques should be perfected in order to meet spawner requirements.

The industry generally feels the staggering increase in construction and some operating costs. The capital investment and working capital, particularly for intensive culture, require a sizeable amount so that some investors tend to think twice before investing.

There is a need to further develop support industries such as feed milling and storage; propagation and preparation of organic pesticides; fabrication of blowers, water pumps, paddlewheels, harvesting gears, and maintenance and transport equipment; and processing and storage plants.

The technical, training, and extension services of various consulting firms are prime movers in the development of the

prawn culture industry in the Philippines. The government should therefore continue to provide support to these activities as well as provide credit facilities at low interest rates with minimum and simple loan processing requirements. It should also provide some marketing incentives or protection to prawn farmers.

Prawn growers should form themselves into cooperatives to have better collective bargaining power with the government, suppliers, and exporters. As a group, they can also establish an operational pathology laboratory whose staff can undertake monitoring of prawn health, identify disease if any, and make necessary recommendations. They can also invest in research and development work in order to continuously improve the system and facilities that will ensure stable production.

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Chapter Five

NUTRITION

Felicitas Piedad-Pascual*

Through supplemental feeding of prawns, higher stocking densities and a shorter culture period are possible. Increase in production per crop and in the number of croppings per year results in higher return on investment. Thus fish farmers find feeding artificial diets to prawns to be profitable even if operational cost, which is mainly due to feed, increases by 50-60% over that of the traditional method. There is therefore a need to develop an economical and biologically effective diet for prawns.

In the development of artificial diets for prawns, the practical approach is to simulate their food in the natural environment especially when no data on nutrient requirements are available. Dietary requirements of prawns can be obtained from food intake studies in the natural habitat, since available food in ponds is limited and differs from food in the wild. A study of the nutritional needs of the species is necessary. Based upon experience in the poultry and livestock industry, success in these industries came with acquisition of knowledge of nutrient requirements and the development of feeds that met the nutritional needs of the species.

FOOD AND FEEDING HABITS

Prawns are omnivorous during their early stage of growth. From zoea to mysis they prefer phytoplankton, mainly algae, and shift to zooplankton and crustaceans such as *Artemia* and rotifers from the mysis to post-larval stages (Villaluz et al 1969). At the juvenile stage, crustaceans like small crabs and shrimps, molluscs, fish, polychaetes, ophiuroids, sand and silt, and even debris have been found in their gut. Marte (1980) reported that around 85% of the ingested food of *P. monodon* caught from the wild in Makato, Aklan consisted of crustaceans mainly small crabs, shrimps, and molluscs. Polychaetes, ophiuroids, fish debris, sand and silt composed the remaining

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15%. The transport time for food (95%) from the foregut is around five hours. Prawns feed on slow-moving benthic organisms and crustaceans appear to be the "staple" food while molluscs contribute the largest bulk. Significant monthly variations in feeding activity were shown by the wild prawns caught from the Makato area (Marte 1982).

P. monodon juveniles caught along the Sudanese Red Sea coast were found to feed mainly on algal materials while adults fed on crustaceans, annelids, algae, mud, and unidentified matter (El Hag 1984). Furthermore, El Hag (1984) classified adults as omnivorous but they prefer animal protein. Likewise, the gut of *P. monodon* from the Korapuzha estuary, India had been found to contain crustaceans, molluscs, polychaetes, fishes, and vegetable matter (Thomas 1972).

Nezaki (unpubl. 1986a) obtained similar results in a study conducted in the northern coast of Panay Island, Philippines. A monthly survey and monitoring of prawn broodstock showed the gut content to contain crustaceans, molluscs, polychaetes, and detritus as main food items. Development of the ovaries was strongly influenced by the abundance of these prey organisms. Studies on prawns caught from the wild show that they tend to be carnivorous as they grow older (Marte 1982).

During the peak spawning months - March, April, June, August, and December - molluscs occur in the gut more frequently than crustaceans. While in other months (January, March, August) fish remains occur in more prawns. This finding suggests that certain nutrients derived from molluscs and fish may be needed for gonad development.

Prawns are nibblers and slow eaters. They take food with their pincers, bring this to their mouth, and slowly chew on the food. If the feedstuff in the pellet is not homogeneous enough, larger particles are spit out. If the whole pellet is small enough for their mouth, the whole pellet is consumed (Pascual, pers. observation). Cannibalism is caused by factors such as insufficient feed, crowding, poor quality of feed or a nutritionally inadequate ration. Healthy prawns attack and feed on the weak ones. Exuviae are ingested but causes for such are still to be determined. Although they have been found to feed continuously all day, they seem to consume more food at night than during the day.

Apud et al (1980) have observed that *P. monodon* in ponds eat anytime of the day but prefer to bottom-feed when there is light. The prawns move around the perimeter of the pond in the late afternoon and evening, hence the suggestion to give more feed at such time of the day.

NUTRIENT REQUIREMENTS

Very little information on the nutrient requirements of *P. monodon* is available at present. Likewise, there is scarcity of data on the biological availability and apparent digestibility of protein, fats, and carbohydrates. For practical purposes, and in the absence of hard data, prawn feeds have been formulated from what little information there is and values derived from other species. Supplementary feeds in the form of chicken entrails, frog meat, mussel meat, trash fish, worms, and snails are available but problems related to mass production, storage, unpredictable availability, and quality have led to the search for other feedstuff to be incorporated in artificial feed or dry pellets.

Protein and Amino Acids

Protein is primarily necessary for growth, and when there is not enough energy from fat and carbohydrates, it is used to supply heat and energy before it is utilized for growth. High protein diets like algae and *Artemia*, apparently required by larvae for growth and survival, seem to suggest that high amounts of protein are required by the larvae. Alava and Lim (1983) found that *P. monodon* juveniles need around 40% protein. For broodstock, diets containing 50% protein seem to be necessary (Millamena et al 1986). In a recent study by Bautista (1986), protein between 40 and 50% gave the best growth and survival in the presence of 20% carbohydrates and 5-10% lipid. Nezaki et al (1986b) found that 55% protein with 15% carbohydrates in grow-out diets gave the best growth. However, when carbohydrate content is increased to 25% content, a 45% protein diet can give results comparable to those of diets containing 55% protein.

Studies by Wilson (1984) have shown that the closer the essential amino acid pattern of the diet is to that of the species being studied, the more effective is the diet for growth. Amino

acids are building blocks for protein formation and when one essential amino acid is insufficient in the diet, protein synthesis is hampered, resulting in diminished utilization and efficiency of the diet. Not only the amount but also the quality of protein has to be considered.

Ten amino acids have been found essential and have to be included in the diet. The essential amino acids for *P. monodon* are similar to those defined by Deshimaru and Kuroki (1974) for *P. japonicus* and by Shewbart et al (1972) for *P. aztecus*. Several investigators have analyzed the amino acid pattern of *P. monodon* (Catedral and Penaflorida 1977, Kanazawa and Teshima 1981, Coloso and Cruz 1980). Penaflorida (pers. comm.) found that except for arginine, the essential amino acid pattern was similar throughout the life cycle of *P. monodon*.

Coloso and Cruz (1980) found by ^{14}C labelling that *P. monodon* can not synthesize arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, valine, threonine, and tryptophan. Moreover, Pascual and Kanazawa (1986) showed that by following the amino acid pattern of the prawn, a semi-purified type of complete diet provided for good growth and survival. Nezaki et al (1986b) also determined that various diets containing 55% protein were formulated with the use of three sources of protein: defatted prawn flesh, casein, and gelatin. One diet simulated the amino acid profile of *P. monodon* juveniles. The prawns fed the diet that had the most similar amino acid pattern to the prawn muscle, gave the highest percentage weight gain and feed efficiency. Preliminary results on the required amount of arginine and histidine in the diet showed that a level close to the amount found in the tissues of *P. monodon* postlarvae gave the best results (Pascual, in prep.). These studies confirm the results of other researchers that the closer the essential amino acid pattern of the diet, the more effective it is for growth.

Since protein sources are one of the most expensive items in a practical diet, it is necessary to search for locally available potential plant and animal sources. Although semi-purified diets are used for the determination of required nutrient levels, results from such studies have to be translated into practical-type diets for commercial use.

Alava and Lim (1983) used squid meal, fish meal, shrimp meal, casein, and soybean meal as protein sources in diets with protein content ranging from 25 to 60% protein and found 40% protein diet to give the best growth rate. However, comparable results were obtained with shrimps fed 30, 35, and 45% protein diets. In another study by Pascual (1985), diets containing approximately 40% protein from shrimp head meal, fish meal, soybean meal, earthworm meal, and squid meal gave good results.

Lipids and fatty acids

Lipids or fats are necessary for their energy value, polyunsaturated fatty acids (PUFA) and phospholipid content, and vitamin (A, D, E & K) value. Millamena and Qunitio (1985) have shown that for prawn larvae, PUFA are important for growth and enhancement of metamorphosis. In view of the limited capacity of prawns to biosynthesize PUFA, these essential fatty acids have to be provided in the diet to ensure survival and development.

The fatty acid composition of postlarvae is generally related to the fatty acid composition of the diets (Yashiro 1982). Mendoza (1982) found that a diet containing 11.7% lipid gave maximum growth, efficient feed conversion and protein efficiency ratio, and good survival rate in *P. monodon* juveniles. Bautista (1986) also showed that a 10% lipid content in the diet was effective in assuring good growth and survival as long as protein content was between 40 and 45% and carbohydrate was 25%. Catacutan (unpubl.) showed that the best growth of *P. monodon* juveniles was attained with lipid source containing high amounts of highly unsaturated fatty acids of the n-3 series in semi-purified diets for juvenile prawns; thus, 10-11% of this type of lipid may be required.

In a related study by Catacutan and Kanazawa (1985), juvenile *P. monodon* (0.2 to 0.5 g) were fed various types of dietary fatty acids for a period of 35 days. The neutral lipid and polar lipid fractions were analyzed and found to contain high levels of certain polyenoic acids (20:4 n6, 20:5 n3, 22:6 n3), and the sum of n3 series was high in the polar lipid fraction. The component fatty acids of the prawns were correlated with the dietary fatty acid content.

The fatty acid profile of the ovaries, hepatopancreas, and tail muscle of wild *P. monodon* broodstock indicates that there is a predominance of higher long chain polyunsaturated fatty acids --arachidonic (20:4 ω 5), eicosapentaenoic acid (20:5 ω 3), and docosahexaenoic acid (22:6 ω 3) in prawn broodstock (Millamena et al, in press). She further reported (unpubl.) that the inclusion of 5% cod liver oil together with 4% soya lecithin in the diet improved fecundity and egg hatching rate.

Other types of lipids needed by the prawn are cholesterol (Nalzaró 1982) and phospholipids (Pascual 1986). A total cholesterol level of about 1% required for maximum growth, high feed conversion, high protein efficiency and survival rate, and maintenance of a constant level of body cholesterol in prawn juveniles was reported by Nalzaró (1982). However, a practical formulated diet was used and therefore the control diet also contained some cholesterol. Whether 1% cholesterol in the diet would give similar results remains to be confirmed. In addition, Ubal et al (1986) indicated that a level of 0.6 to 1.0% cholesterol in a semi-purified diet containing 6% refined cuttlefish liver oil and soya oil in 3:1 ratio was necessary for good weight gain and feed efficiency in prawn juveniles.

Lecithin which contains 62% phospholipids, phosphatidyl choline, phosphatidyl inositol, and phosphatidyl-ethanolamine has been found necessary in prawn grow-out at around 3% in the diet (Pascual 1986). Furthermore, Nezaki et al (1986c) showed that soybean lecithin levels at around 4% gave the best results compared to those fed greater than 4.6% soybean lecithin levels. Percentage weight gain and feed efficiency increased significantly in prawn juveniles and decreased with increasing lecithin levels beyond 4%. Millamena et al (1986) reported a level of 4% lecithin was necessary for broodstock diets.

Carbohydrates

Carbohydrates in prawn diets are not only useful for their energy value and protein-sparing function but also for their binding properties. Among the carbohydrates that have been studied are sucrose, dextrin, maltose, molasses, cassava starch, cornstarch, sago palm starch, trehalose, glucose (Pascual et al 1983, Alava and Pascual 1987). Sucrose and sago palm starch at 10% of the diet gave better survival rates than the other carbohydrates tested at the same level. However,

histopathological changes in the hepatopancreatic cells were observed (Pascual et al 1983). On the other hand, molasses at 10% of the diet caused mortality within 10 days of culture. In another study by Alava and Pascual (1987), sucrose and trehalose proved to be the better sugars compared to glucose. At 20% of the diet, glucose, a simple sugar, is easily assimilated and remains in the hemolymph for as long as 24 hours and therefore is detrimental to *P. japonicus* (Deshimaru and Yone 1978).

Fourteen-day old postlarvae (2 mg mean body weight) were fed diets containing 10% lipid, protein levels of 25, 35, 45, and 55%, and starch at 10, 20, 30, and 40% to determine the effects of dietary protein and starch levels on growth and survival of *P. monodon*. Growth was not affected by starch levels in the diet but was proportional to the amount of protein content. Survival was affected by the protein/starch ratio (Bages and Sloane 1981).

Energy. The study of Bautista (1986) indicates that prawn juveniles need energy values between 2850 and 3700 Kcal/l kg of diet depending on the protein, carbohydrate, and fat content. The best growth, survival, and feed conversion ratio (FCR) were obtained with 40-50% protein, 5-10% lipid, and 20% carbohydrates.

Vitamins and Minerals

Vitamins and minerals are important for regulating body processes. The B vitamins are necessary for proper utilization of proteins, carbohydrates, and fats while vitamins A and C are important in building resistance to infection. Vitamin D together with minerals, calcium, and phosphorous is necessary for the formation of the exoskeleton or shell. All of these nutrients although needed in minute amounts are necessary for the proper utilization of food by the prawns. It is therefore important that these nutrients be included in complete diets for prawns in their proper amounts. However, up to the present only exploratory, preliminary work on vitamins and minerals have been done on *P. monodon*. Hence, we rely on published data for other species like *P. japonicus* (Deshimaru and Kuroki 1974). Preliminary studies with juveniles under laboratory conditions showed that in practical formulated diets some vitamins may be omitted without decreasing growth and survival. Efficiency of the diets was comparable to the growth

obtained for prawns fed the complete diet (Pascual, unpubl.). Catacutan and Kanazawa (1985) also found similar results with the use of purified diets.

Bautista (in prep.) pointed out the importance of calcium: phosphorous ratios in diets, indicating a 1:1 ratio for *P. monodon* grow-out. A dietary Ca/P ratio of 1:1 was found to be effective in hardening the exoskeleton and preventing soft-shelled disease.

DIET DEVELOPMENT

With some knowledge of the nutritional requirements of the prawn, it is possible to formulate an artificial diet using local indigenous feedstuff and those commonly used in the livestock and poultry industry. Aside from nutritional requirements and sources of the nutrients, there are other factors that have to be considered. There are practical problems related to the physical features of the diet: water stability, attractability, size, shape, density, and texture. The physical characteristics of the diet and factors to be considered would differ from one stage of the life cycle of the prawn to another - from larval stage to grow-out to broodstock.

Larval Diets

Larvae are pelagic and swim continuously in the water column; hence, this characteristic has to be taken into consideration in the development of larval diets. The diet needs to be suspended in water for a certain period. There are so called microparticulate diets which are either microbound or microcapsulated or microcoated. Bautista et al (unpubl.) have formulated a microbound diet that is presently under study. Commercial microencapsulated diets are available in the market for *P. monodon* larvae. The use of non-live feeds is associated with problems of water pollution. With proper management techniques, however, microparticulate diets for larvae offer a potential substitute for traditional algal food.

Quinitio et al (1983) found that soya bean meal is a good substitute for algal food in the larval stages. Likewise, frozen, fresh, and dried *Acetes* sp. were fed to larvae and found to give good survival (Kungvankij et al 1986).

Grow-out and Broodstock Diets

Several formulations have been screened under laboratory conditions and there are four diets that are recommended for different culture or rearing methods (Pascual, in press). The best have been tried under pond conditions and at a stocking density of 25 000 per hectare. There are also several commercial diets imported from Taiwan and Germany.

Knowledge of the characteristics of a good broodstock diet is scanty. Millamena et al (1986) are studying broodstock diets and have used a pelleted feed in bringing prawn to maturity. However, frozen squid or mussel meat has to be fed in combination with this pellet. They reported that the PUFA present in the diet are important for good fecundity, high hatching rate, and healthy larvae (Millamena et al 1986). Food sources like marine worms, molluscs, and crustaceans, used traditionally in shrimp maturation diets, contain high level of PUFA (Millamena et al 1986). The study of Marte (1982) indicated that there are certain nutrients in molluscs and fish which are required for gonad development because during the appearance of spawners, these feeds are found abundantly in the gut of the prawns. Primavera et al (1979) fed broodstock with mussel meat alone or in combination with pellets compared to those that were not offered any mussel meat.

PHYSICAL CHARACTERISTICS OF PELLETS

All types of diets have to be properly bound and attractive to the organism. Hence, finely ground feedstuff and a good binder with an attractant are necessary in the development of a feed. Antioxidants and anti-mold agents may also be necessary especially in the tropics where relative humidity is generally high during the rainy months. A good packaging material also has to be developed to avoid fungal growth.

Sweet potato starch, cassava starch, extract of shark fins, *Gracilaria*, gum arabic, alginate, glutinous rice, carboxymethylcellulose, carrageenan, corn starch, polymethylolcarbamide, and sago palm starch (Pascual et al 1978; Pascual and Tabbu 1979; Murai et al 1981; Pascual and Sumalangcay 1982; Pascual, unpubl.; Lim and Destajo 1979) have all been studied for their possible use as binders in both

practical and semi-purified diets. Sweet potato starch at 5% has poor binding capacity and allows growth of molds easily. Other binders are either too expensive or not commercially available. Sago palm starch, cornstarch, alpha potato starch, and carboxymethylcellulose are good but relatively expensive binders for commercial use in the Philippines. Polymethylolcarbamide at 0.5 to 1% has been found to be of help in practical diets but not in semi-purified diets that do not contain gelatin (Pascual, unpubl.). Steaming the diet has been found to further increase water stability of the pellet.

Attractiveness is another characteristic of a prawn diet that has to be considered. Several attractants have been tested by incorporating shrimp, mussel, squid, fish and mussel extracts in purified diets (Pascual 1980, Murai et al 1983) while krill meal, earthworm meal, glycine, sucrose, and mussel water have been used as attractants in a practical diet. Addition of krill meal, earthworm meal, and sucrose improved attractability to a certain extent while glycine supplement and mussel significantly improved attractability. Furthermore, dietary groups supplemented with any type of attractant showed better mean weight gain than those fed the diet without attractants. Prawns fed the diet with earthworm meal gave the best growth rate and feed conversion (Murai et al 1983). Hence diet attractability, per se, may be a vital factor in determining the quality of compounded feed for prawn.

ANTI-NUTRITIVE FACTORS

The efficiency of raw feedstuffs is improved by processing. Pascual (1985) found that earthworm meal when incorporated in the diet in the fresh-frozen state rather than in the dried meal form gave poor survival. According to Stafford and Edwards (1983) there is a heat-labile toxic substance in the coelomic fluid excreted by the choriogenic cells of the worms.

Heat-labile trypsin inhibitors are found in soybean meal therefore the latter has to be cooked before it is incorporated in the diet. Defatted soybean meal with low content of trypsin inhibitor should be the choice meal (Akiyama 1988).

Leucaena (ipil-ipil) leaves are a potential source of protein but because of the mimosine content, can not be used unless the mimosine is removed. Vogt et al (1986) found that

the hepatopancreatic cells (R-cells in particular) are damaged in the presence of mimosine. Damage to new cells occurs before growth, and survival is affected. Soaking ipil-ipil leaves in fresh water for 24 hours and air drying thereafter removes around 95% of the mimosine (Pascual and Penaflores 1979). However, the method is not practical for commercial use.

The use of electron microscopy as a method for detecting early pathological changes in the midgut gland of *P. monodon* fed various types and levels of nutrients, protein, fats, and carbohydrates has been demonstrated by Storch et al (1984) and Vogt et al (1985, 1986). Starved prawns showed pathological changes which were irreversible when starvation lasted for 5 days (Vogt et al 1985).

FEED AND FEEDSTUFF RESOURCES

A diet is generally composed of protein source--animal and plant; lipid source--animal and plant; carbohydrate source; binder; attractant; vitamins; minerals; additives such as attractants; antioxidants; fungicides; and sometimes hormones, etc. The amino acid pattern of the protein source and fatty acid profile in lipid source are important considerations in choosing the feedstuff to be incorporated in the diet.

Protein Sources

Feedstuffs considered as protein sources usually contain more than 20% protein on a dry matter basis. There are two principal sources of protein: animal and vegetable. Squid meal, shrimp meal, mussel meat, fish meal, shrimp head meal and earthworm meal have been found to be good animal protein sources (Lim et al 1979, Pascual and Destajo 1979, Pascual 1985).

Shrimp, earthworm, squid, and mussel meals are not only excellent sources of protein but also provide attractants and contain essential amino acids and fatty acids needed by the prawn. Shrimp meal and other crustacean meals contain astaxanthin that gives the bright red color to the prawn when cooked (Benjamin 1982). Generally, a combination of two or more protein sources is better than just one. Ipil-ipil leaf meal of not more than 10% in the diet may substitute for part of the

animal protein source (Pascual and Catacutan, unpubl.). Recently, Pascual et al (unpubl.) found that soybean meal at 35 to 45% of the diet gave similar results in terms of growth and survival to those of diets with lower soybean content (15 or 25%) when fed to prawn juveniles for a period of four months in earthen ponds.

The amino acid pattern of the protein source is an important factor in the choice of protein sources. Penaflorida (unpubl.) who is screening for other potential animal and vegetable protein sources found that the common limiting amino acid in both types of feedstuffs is arginine.

Lipid Sources

The effect of various oils like corn oil, soybean oil, beef tallow, pork lard and fish oil on growth of *P. monodon* juveniles has been studied by Mangalik (1979). Fish oil is the best, followed by beef tallow, soybean oil, copra oil, and pork lard, in descending order. Likewise, Mangalik (unpubl.) tried different lipid sources in prawn diets and found that cod liver oil followed by beef tallow and pork fat gave good growth and survival. Structure of hepatopancreatic cells of prawns fed cod liver oil was similar to the control. A 1:1 ratio of cod liver oil and soybean oil, preferably the crude degummed soya oil if available, is suggested (Pascual 1986). Coconut oil does not contain the essential polyunsaturated fatty acids needed by the prawn, hence has not been used in prawn diet.

Some carbohydrate sources are wheat flour (bread flour), rice flour, cassava flour, potato starch, sago palm starch, "tiki-tiki" or the very fine type of rice bran, corn meal, and copra meal.

In the absence of hard data on the vitamin-mineral requirements of *P. monodon*, a vitamin-mineral premix recommended for *P. japonicus* by Deshimaru and Kuroki (1974) and by Catacutan and Kanazawa (1985) are used in both practical and semi-purified diets.

Apparent Digestibility

Apparent digestibility of the feedstuff is important for it is useless if it is not digestible and utilized by the prawn. Catacutan has analyzed the apparent digestibility of some protein sources for male *P. monodon* with weights of approximately 30 grams. Both full fat and defatted soybean meal were equally digestible while fish meal was poorly digested. Further work has to be done to confirm these results (Catacutan, unpubl.).

FEEDING PRACTICES

Feeding trays are used under pond conditions to be able to see whether the prawns are feeding or not. Automatic and semi-automatic feeders are available. However, under Philippine conditions where labor is relatively cheap and where unemployment is high, food could be broadcast around the pond twice, thrice, or even five times a day. About 10% of the total daily feed ration is placed in trays in order to observe if the animals eat.

A feeding scheme for grow-out is in the chapter on culture techniques.

Feed Storage Requirements

Feeds have to be properly stored to prevent bacterial and fungal growth. The presence of these in feeds can cause diseases and mass mortality. Rancidity and destruction of nutrients can be caused by improper storage. Feeds should be stored in a cool, airy but not humid environment. Waterproof sacks prevent moisture from spoiling the feed. Aflatoxin, a carcinogen, is present when *Aspergillus* molds grow in the feed. Hence, feeds should be stored properly. Rodents and cockroaches should be avoided. Plastic-covered containers kept in a cool place will help prevent rodents from attacking the feed.

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Chapter Six

DISEASES

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The great losses suffered by the industry due to diseases attest to the need to focus more attention on this aspect of aquaculture. Prawn diseases have been the subject of many reports from various culture facilities in the Philippines (Villaluz 1975, Gacutan 1979, Vicente et al 1979), Taiwan (Liao et al 1977), Thailand (Ruangpan 1982), and Mexico (Lightner et al 1984). Reviews of diseases causing significant losses in penaeid shrimp and prawn culture have been made by Lightner (1983, 1985) with special emphasis on more recent trends and developments. The present review deals specifically with diseases of the giant tiger prawn, *Penaeus monodon* Fabricius, including the diagnosis and pathology of disease or disease agents involved and their prevention and control.

VIRAL DISEASES

Perhaps because of the specialized methods of diagnosis involved in the study of viral diseases, reports on these are relatively recent. A group of scientists led by Dr. Donald V. Lightner of the University of Arizona, U.S.A. first identified and reported the occurrence of viruses in *P. monodon*. At present, three types of viruses have been found in *P. monodon*: the *monodon* baculovirus or MBV, the infectious hypodermal and hematopoietic necrosis virus or IHHNV, and the hepatopancreatic parvo-like virus or HPV.

P. monodon **Baculovirus (MBV) Disease**

In 1980, Lightner et al reported a disease which wiped out a whole population of adult *P. monodon* in Mexico. The mortalities were suspected to be due to the destruction of hepatopancreatic tubule epithelium or to secondary bacterial septicemias (Lightner et al 1984). The disease agent was found to be a singly enveloped, rod-shaped, presumed DNA virus of

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the genus *Baculovirus* subgroup A (Brock et al 1983, Lightner et al 1983b). *P. monodon* baculovirus (MBV) occurs free or within proteinaceous polyhedral occlusion bodies in the nucleus, with nucleocapsids measuring 42 ± 3 nm x 246 ± 15 nm and enveloped virions measuring $75 + 4$ nm x 324 ± 33 nm (Lightner et al 1983b).

MBV has been found in *P. monodon* coming from Taiwan, the Philippines, Malaysia, French Polynesia, Hawaii (Brock et al 1983), and Kenya (Colorni et al 1987), Mexico, Singapore (Lightner 1985), and Indonesia (Baticados, unpubl.). It affects the hepatopancreatic tubule and duct epithelium of postlarvae, juveniles, and adults as well as the anterior midgut epithelium of the very young postlarvae (Lightner 1983, Lightner et al 1983b). The pathogenesis of MBV disease in the prawn hepatopancreas starts with the presence of slightly hypertrophied hepatopancreatocyte nuclei and few completed virions and eventually ends up with cell necrosis and cytolysis, releasing the virus and occlusion bodies into the gut lumen (Lightner et al 1983b). Shrimp populations affected by MBV reach up to 70% cumulative mortality among older stages (juvenile to adults) in tanks and raceways (Brock et al 1983). Younger stages (PL₅ and PL₁₀) examined had low incidence and severity, making it difficult to diagnose the disease until the shrimp were 20-30 days old (Lightner et al 1983b). A case of multiple infection with MBV, a reo-like virus, rickettsia-like organisms, and bacteria was recently reported in extensively cultured *P. monodon* juveniles in Malaysia (Anderson et al 1987). About 61% of all shrimp examined showed the typical intranuclear MBV occlusion bodies. Anderson and his co-workers (1987) believe that the MBV and the reo-like virus may have facilitated the initial rickettsial infection or may have become patent after shrimp had been weakened from rickettsia and secondary bacterial infections.

The reservoir of infection for MBV is believed to be feral *P. monodon* as indicated by its enzootic nature in Taiwan and Philippine hatcheries using wild-caught broodstock (Brock et al 1983). The same report suggests that patently infected prawns may be the source of infection in culture settings, as MBV virions contained in occlusion bodies shed in feces may remain intact for years and could be a potential source of infection to susceptible shrimp (Brock et al 1983).

The presence of MBV in prawn may be detected through direct microscopic examination of wet mounts of infected tissue stained with 0.1% aqueous solution of malachite green to demonstrate one or more bright green spherical occlusion bodies in hypertrophied nuclei of hepatopancreatic or midgut epithelial cells (Lightner 1985). A more sensitive method is the histological preparation of tissues from prawns with enhanced infections, enhancement being accomplished by crowding in small tanks to increase the prevalence and severity of infection especially among late postlarvae (Lightner et al 1983b, in press a in Lightner 1985). Although not specific for MBV, Brown and Brenn's gram stain intensely dyes the occlusion bodies, making them visible in light microscopy; otherwise, histological sections are processed and stained with uranyl acetate and lead citrate for transmission electron microscopy (Lightner and Redman 1981, Lightner et al in press b in Lightner 1985). MBV has never been grown in cell culture so diagnosis using serologic or immunologic procedures are not available for distinguishing MBV viral antigens (Brock et al 1983).

Observing the gross appearance of the prawn may sometimes aid in the diagnosis of suspected MBV infections. Moderately to severely infected postlarvae are usually much smaller and darker in color (pale bluish-grey to dark blue-black) than are less affected or unaffected postlarvae (tan or buff base) (Lightner et al 1983b). General signs of severe infections are lethargy, loss of appetite, decreased preening activity, and therefore greater susceptibility to surface and gill fouling by benthic microorganisms (Lightner et al 1983b).

MBV infections may be prevented only through avoidance, i.e., by using MBV-free stages of prawn (Brock et al 1983), quite a difficult feat particularly when dealing with younger stages (e.g., PL₂₅) where the incidence and severity of infection are low and thus not easily diagnosed (Lightner et al 1983b). Crowding stress, cannibalism of dead prawns, or ingestion of free virus or occlusion bodies with virus from tank sediments are believed to increase the prevalence and severity of MBV infections (Lightner et al 1983b). Good and sanitary husbandry practices as well as proper nutrition, therefore, must always prevail in the culture facility to control such infections (Lightner et al 1984, Brock et al 1983). Antibiotic therapy, i.e., by using medicated feeds could also control secondary bacterial infections (Lightner et al 1984). Otherwise, eradication would be the only alternative left, particularly in highly prevalent and

severe infections in cultured prawn populations (Brock et al 1983).

Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) Disease

The infectious hypodermal and hematopoietic necrosis virus is an unclassified, probable picornavirus (Lightner 1985). The virions are icosahedral and small, 17-28 nm, and the inclusions or polyhedra are eosinophilic, intranuclear, single, and basophilic (Brock et al 1983, Lightner 1983, Lightner et al 1983a).

IHHNV has been found in the United States, South America, Southeast Asia, and Israel (Brock et al 1983). Its extensive range may have resulted from contaminated shipments of live *P. stylirostris* and *P. vannamei* from South or Central American countries (Bell and Lightner 1983 in Brock et al 1983) which could be the natural geographic range of IHHNV (Brock et al 1983). IHHNV was detected in histological samples coming from *P. monodon* reared in Ecuador, Guam, Tahiti, the Philippines, and Hawaii (Bell and Lightner 1983), Singapore, and possibly Taiwan (Lightner 1985).

Lightner (1983) reported 80-90% cumulative mortalities within two weeks from onset of IHHNV in 0.05-1 g *P. monodon*. This virus could cause epizootics in cultured prawn populations (Bell and Lightner 1983), particularly among postlarvae and juveniles (Lightner 1983). The target organs or tissues are the cuticular hypodermis, hemocytes, hematopoietic organs, and connective tissues (Lightner 1983, Lightner et al 1983a). It may be present in larval stages as a latent or inapparent infection (Brock et al 1983).

The incubation period for IHHNV is 5-14 days after exposure to the virus based on experimental infection (Bell and Lightner 1983a in Brock et al 1983). The virus may be transmitted via parenteral infection, direct contact, indirect contact with contaminated water, or by *per os* exposure (Bell and Lightner 1983b in Brock et al 1983). In culture, *P. monodon* was shown to develop clinical IHHNV disease and harbor IHHNV as a latent carrier (Brock et al 1983).

IHHNV may be detected through histological preparations of tissues having the characteristics Cowdry type A intranuclear inclusion bodies (Lightner et al in press a) and direct samplings for microscopic examination of wet mounts (Lightner et al in press b in Lightner 1985). Enhancement of infection (through crowded and stressful conditions) or bioassay of a suspect shrimp population with a sensitive indicator species (i.e., juveniles or 0.05-4 g *P. stylirostris*) may also be done, followed by sampling and histopathology (Lightner et al in press b in Lightner 1985). Direct sampling and histopathology have limited sensitivity because they demonstrate only prawns with acute/subacute infections in populations with higher prevalence of the disease. Enhancement of infection, on the other hand, is more sensitive but is not suitable for demonstration of IHHNV in asymptomatic carriers (Lightner et al in press b in Lightner 1985).

Prevention of IHHNV disease consists only of avoidance, i.e., by preventing the introduction of IHHNV-infected prawn into the culture area while control would mean eradication of the virus through depopulation of infected or exposed prawns and disinfection of contaminated areas (Brock et al 1983). There should also be absolute quarantine of all live prawns (Brock et al 1983).

Hepatopancreatic Parvo-like Virus (HPV) Disease

Another virus reported by Lightner and Redman (1985b) infected the hepatopancreas of *P. monodon* in Malaysia, appearing as aggregations of 22-24 nm diameter, basophilic, PAS-negative, Feulgen-positive, intranuclear inclusion bodies in necrotic and atrophied hepatopancreatocytes. The same workers examined samples coming from a private company in the Philippines and referred to the virus as HPV for hepatopancreatic parvo-like virus.

Prawns with HPV exhibited poor growth rates, anorexia, reduced preening activity, increased surface fouling, and occasional opacity of tail musculature. The incidence of HPV (1 juvenile) was relatively lower than those of IHHNV infections (6 juveniles and adults) and MBV infections (69 juveniles) within the same batch of 114 prawns examined. The non-specific signs of the disease were accompanied by mortalities during the juvenile stages after apparently normal development

through the larval and post-larval stages (Lightner and Redman 1985b).

P. monodon adults imported by Israel from Kenya were also found to be infected with HPV during quarantine so the entire stock was destroyed (Colorni et al 1987).

Available data on the viral diseases of *P. monodon* are summarized in Table 1.

BACTERIAL DISEASES

Like many other pathogens, bacteria may always be present in the water and are "opportunistic" organisms. They affect prawns both as primary and secondary invaders, and

Table 1. Viral diseases of *Penaeus monodon*

Disease Agent	Stages Affected	Target Organ/Tissues	Geographic Distribution	Diagnostic Method
MBV	PL ₅ to adults	Hepatopancreatic tubule and duct epithelium; anterior midgut epithelium	Taiwan, Indonesia, Philippines, Malaysia, Singapore, French Polynesia, Mexico, and Hawaii	Microscopic examination of wet mounts of infected tissue Histological examination of infected tissues under light and electron microscopy
IHHNV	Post-larva (0.05-1g) to juveniles	Cuticular hypodermis, hemocytes, hematopoietic organs and connective tissues	Singapore, Philippines, Guam, Tahiti, Hawaii, USA, Israel, Ecuador, and other South/Central American countries, and possibly in Taiwan	Microscopic examination of wet mounts Histological examination Enhancement of infection or bioassay of sensitive indicator species followed by sampling and histopathology
HPV	Juveniles	Hepatopancreas	Malaysia, Philippines and Kenya	Microscopic examination

infections develop usually as a result of adverse changes in the environment which easily stress the prawn and thus lower its resistance. A number of these bacterial diseases have been reported to occur in different stages of *P. monodon*.

Necrosis of Appendages

Larvae and young postlarvae (PL₁₀) of *P. monodon* may be affected by a bacterial disease causing necrosis of the appendages, with postlarvae relatively more resistant than the younger stages (Aquacop 1977, 1979; Vicente et al 1979). In protozoae, the disease starts with the liquefaction of gut contents. Necrosis begins as a "browning" of the exoskeleton or tip of the appendage, e.g., uropods in protozoa III or pleopods in mysis, spreads towards the base and finally appears as an

Morphology	Pathology/ Signs	Prevention/ Control	References
Singly enveloped; free or with polyhedral occlusion bodies; intranuclear; nucleocapsids 42±3 nm X 246 ± 15 nm; enveloped virions 75±4 nm X 324 ± 33 nm	Necrosis and cytolysis of hepatopancreatic epithelial cells and anterior midgut epithelium, up to 70% mortality, post-larvae small and dark, lethargy, loss of appetite, reduced preening activity	Prevention through avoidance, sanitation and proper nutrition Eradication through depopulation and disinfection	Lightner 1983, 1985 Lightner and Redman 1981 Lightner et al 1983b, 1984 Brock et al 1983, Colorni et al 1987, Anderson et al 1987
Probable picornavirus; virions icosahedral, small 17-28 nm; inclusions, eosinophilic intranuclear, single	80-90% cumulative mortalities, latent infection in larvae possible	Prevention through avoidance Eradication through depopulation and disinfection and quarantine of all live prawns	Bell and Lightner 1983 Brock et al 1983 Lightner 1983, 1985 Lightner et al 1983a
Aggregations of 22-24 nm dia., intranuclear, basophilic inclusion bodies	Necrosis and atrophy of hepatopancreaticocytes but very low incidence, poor growth rates, anorexia, reduced preening activity, occasionally opaque tail, mortalities		Lightner and Redman 1985a Colorni et al 1987

erosion of affected areas (Aquacop 1977, Gacutan 1979, Vicente et al 1979). Affected mysis and postlarvae have twisted antennae, broken setae, deformed abdomen, opaque and eroded appendages, and exhibit incomplete molting (Aquacop 1977, Vicente et al 1979). Gacutan (1979) suggested that mortalities were due to secondary bacterial infection after cuticular injury or breakdown, or to the inability of larvae to molt. This infection played a minor role in SEAFDEC AQD hatchery mortalities (Gacutan 1979) but wiped out the whole larval population at the MSU-IFRD hatchery in 24 hours (Vicente et al 1979). The disease has also been observed in Indonesia, Malaysia, Singapore, Taiwan and Thailand (Baticados, unpubl.).

The use of antibiotics to control bacterial infections has been instituted against necrosis of larvae and heavy mortalities (Aquacop 1983). Aquacop (1977) has tested and used prophylactic/therapeutic drugs, namely, erythromycin phosphate at 1 ppm active product (from the second day of protozoa II), streptomycin-bipenicillin at 2 ppm AP (2 UI/ml), tetracycline chlorhydrate at 1 ppm AP, sulfamethazin at 3 ppm AP, and Furanace at 0.1 ppm AP. The drug is applied every other day until the post-larval stage is reached. Treated larvae resume feeding, recover quickly, and lose any trace of necrosis after regenerating new appendages at the next molt (Aquacop 1977). More recently, chloramphenicol has been used in hatcheries at 1 ppm every 3 days for prophylactic treatment (Sunaryanto 1986) and found to be most effective at prophylactic levels of 2-6 ppm every 2 days or therapeutic levels of 2-10 ppm with variation adjusted according to the larval stage (Aquacop 1983).

Vibrio Disease

The bacterial species *Vibrio* has also been observed to affect the protozoal stages and to cause heavy mortalities of up to 80% in hatcheries (Ruangpan 1982, PCARRD 1985). The disease is asymptomatic but occurred primarily during the period December to February in Thailand's Phuket Fishery Station (Ruangpan 1982). Ruangpan (1982) believed that perhaps *Vibrio* preferred to grow in colder temperature while Delves-Broughton and Poupard (1976 in Aquacop 1977) suggested that the *Vibrio* disease observed in *P. monodon* may have been due to the prevailing environmental conditions.

Luminous Bacterial Disease

Luminous bacteria were recently isolated from larval and post-larval sediments and water samples from hatcheries in Panay Island, Philippines. The bacteria were recovered in dominant proportions from weak and dead prawns and rearing water samples and were isolated from sediments and sea-water samples indicating its occurrence in the natural environment (Pitogo, pers. comm.). The luminous bacteria were classified as predominantly *Vibrio harveyi* and a few isolates as *V. splendidus* (Pitogo, pers. comm.). Heavily infected larvae were moribund and luminescent in the dark due to the large numbers of motile bacteria in the tissues. The bacteria were also isolated from apparently active larvae in low numbers. Mass mortalities were often encountered during heavy infection. The disease is also a serious problem in Indonesia, Malaysia, and Thailand (Baticados, unpubl.).

Several luminous bacterial isolates were tested and found to be resistant to many of the more commonly used antibiotics such as erythromycin, penicillin, streptomycin, and sulfadiazine (Baticados, unpubl. data). Screening of other chemicals and drugs that could control luminous bacteria is being conducted and tolerance of the larvae and postlarvae to effective levels of the chemicals is being investigated at SEAFDEC AQD. It appears that resistance of the bacteria to certain drugs depended on the kind of antibiotic commonly used in a particular area (Baticados, unpubl. data).

Rigid sanitary practices which include chlorination of the rearing water, removal of the wastes and sediments from the tank bottom, and more frequent water change (flow-through twice daily) were observed to reduce mortalities due to luminous bacteria.

Filamentous Bacterial Disease

The filamentous bacterial species *Leucothrix mucor* has been found to occur as an ectocommensal of *P. monodon* larvae and postlarvae particularly during the months of October to December (Gacutan 1979). The bacteria attach themselves to the gills, setae, appendages, and body surface of the prawn and flourish particularly in waters rich in organic and inorganic substances such as phosphates and nitrates (Gacutan 1979).

When present in large numbers, the bacteria can cause mortalities due to hypoxia and impairment of the molting process (Gacutan 1979, Lightner et al 1984). Losses in the prawn population may also occur in conjunction with stressful conditions resulting from crowding, molting, or low oxygen levels (Lightner et al 1984). The disease occurs in the Philippines, Indonesia, and Malaysia (Baticados, unpubl.).

The disease may be controlled by Cutrine-Plus, a copper compound, given upon onset of the disease at 0.1 mg Cu/l for 24 h 0.25-0.5 mg Cu/l for 4-8 h (Lightner et al 1984).

Shell Disease

Juveniles and adult prawns from grow-out earthen ponds in the Philippines, Indonesia, Malaysia, Taiwan, and Singapore are affected by a shell disease or erosion of the exoskeleton (Villaluz 1975, Chong and Chao 1986, Baticados, unpubl.). Affected juveniles exhibit eroded and brownish dorsal shell surface which may be eliminated when the prawn molts except when the underlying membranes or tissues are already damaged by the bacteria (Villaluz 1975). Chitinolytic forms of *Vibrio* and *Aeromonas* species have been isolated from shell lesions of pond-grown prawns, and the disease was observed during experimental infection when accompanied by mechanical injury of the shell (Baticados et al 1986). Most of the isolates from the haemolymph of adult *P. monodon* with eroded uropods and carapace lesions were of the species *Vibrio alginolyticus* (Chong and Chao 1986). *Vibrio* and *Aeromonas* are very common in sea water and may also be part of the natural flora of the prawn so that the disease could be a result of secondary infection after mechanical injury or trauma of the shell and the underlying membranes.

Shell disease was also reported to affect wild adult prawns caught with cast or drag nets off the Cochin backwaters of India (Gopalan et al 1980). Prevalence, though, was quite low with only 6 out of 155 specimens of 7.9-8.8 cm length (Gopalan et al 1980).

General control procedures for bacterial diseases. Bacterial infections may be reduced by frequently changing the water during the protozoal stages to keep water quality at an optimum level (Vicente et al 1979). Sanitary measures like

drying, cleaning, and disinfection of culture tanks could also considerably minimize the occurrence of bacterial diseases in larvae and postlarvae (Lightner 1983).

Chemotherapy of bacterial infections may be done through direct addition of antibiotics to culture tank water during hatching, larval, or post-larval rearing while for older stages, incorporation of antibiotics in the diet could prove a better method (Lightner 1983). Liao et al (1981 in Liao 1984) suggested the use of furazolidone, glutaraldehyde, and oxolinic acid to prevent the spread of cholera from imported spawners.

Table 2 summarizes information on bacterial diseases of *P. monodon*.

FUNGAL DISEASES

Among the fungi attacking *P. monodon*, *Lagenidium* has been considered to be the most prevalent and pathogenic in the larval and early post-larval stages. As a result, it was also the most frequently reported and most extensively studied. It has occurred under the same conditions as *Haliphthoros* and *Sirolopidium* which belong to the same group of aquatic fungi, the Phycomycetes (Gacutan 1979, PCARRD 1985).

Larval Mycosis

Lagenidium. In 1977, a fungus which caused heavy mortalities among larvae and postlarvae at the SEAFDEC AQD hatchery was isolated, identified as *Lagenidium callinectes*, and grown in culture media (Baticados et al 1977b, Gacutan and Baticados 1979). *In vivo* and *in vitro* observations of the sporulation process left no doubt as to its reproductive capacity. The hyphal system extends from inside (intramatrical) the body of the prawn to the outside (extramatrical), developing short discharge tubes. A vesicle forms at the end of the discharge tube with sporogenic cytoplasm coming from the hyphal system in 5-10 min. Spore formation proceeds for 10-20 min and spores start to move slowly inside the vesicle, after which numerous motile spores become active and are released 10-15 min later to infect other prawns (Baticados et al 1977b). The fungus has a wide range of tolerance for temperature, pH, and salinity and appears to have the same growth and sporulation conditions as

Table 2. Bacterial diseases of *Penaeus monodon*

Diseases	Agent	Stages Affected	Pathology/Signs
Necrosis of appendages	Bacteria	Zoea, mysis, post-larva	Necrosis of appendages, twisted antennae or broken setae, "browning" of exoskeleton or tip of appendages, liquefaction of gut contents in zoea.
<i>Vibrio</i> disease	<i>Vibrio</i>	Zoea	Heavy mortalities up to 80%
Luminous bacterial disease	<i>Vibrio harveyi</i> <i>V. splendidus</i>	Nauplii, zoea, mysis, post-larva	Prawn luminiscent in the dark, heavy mortalities
Filamentous bacterial disease	<i>Leucothrix mucor</i>	Larvae, post-larvae	Bacteria on gills, setae, appendages and body surface; mortalities due to hypoxia; and impaired molting
Shell disease	<i>V. alginolyticus</i> <i>V. parahaemolyticus</i> <i>Aeromonas</i>	Juveniles, adults	Erosion of exoskeleton

for larval rearing (Gacutan 1979). *Lagenidium* spp. have also been observed (Vicente et al 1979) and isolated from *P. monodon* eggs and protozoa (Bautista 1983) at the MSU-IFRD Hatchery in Mindanao, Philippines.

Lagenidium attacks eggs, larvae, and postlarvae of *P. monodon* and has been the cause of mass mortalities in many hatcheries. Infected eggs appear opaque white and do not hatch while larvae become weak, lose equilibrium, respire irregularly, twitch their appendages, and appear either whitish (Bautista 1983) or reddish (Vicente et al 1979). In all cases, the fungal hyphae fill the eggs, replace the tissues of the larvae/postlarvae, and may cause 100% mortality (Villaluz 1975, Aquacop 1977, Baticados et al 1977b, Gacutan 1979, Gacutan and Baticados 1979, Ruangpan 1982). The signs of the disease, however, are apparent only when it is already widespread (Gacutan 1979).

Prevention/Control	References
Erythromycin phosphate 1 ppm, Streptomycin-bipenicillin 2 ppm, Tetracyclin chlorhydrate 1 ppm, Sulfamethazine 3 ppm, Furanace 0.1 ppm, every other day; Chloram- phenicol, 1 ppm every 3 days or 2-6 ppm every 2 days (prophylactic) or 2-10 ppm (therapeutic)	Aquacop 1977, 1979, 1983 Gacutan 1979 Vicente et al 1979 Sunaryanto 1986
	Aquacop 1977 Ruangpan 1982 PCARRD 1985
Chlorination of rearing water, removal of bottom sediments, and more frequent water change	
Citrine Plus, 0.1 mg Cu/l, 24 h or 0.25 to 0.5 mg Cu/l, 4-8 h	Gacutan 1979 Lightner et al 1984
None reported	Villaluz 1975 Gopalan et al 1980 Baticados et al 1986 Chong and Chao 1986

The disease develops very fast, within 1-2 days, especially in younger stages (Aquacop 1977, Ruangpan 1982). In a case in Thailand, the infection occurred in 20% of the larvae (late protozoa to early mysis) but disappeared at the post-larval stage (Ruangpan 1982). *Lagenidium* infection is likewise a problem in Indonesian hatcheries (Baticados, unpubl.).

At SEAFDEC AQD, *Lagenidium* attacked larvae in 35 out of 51 hatchery runs in 1976 (Gacutan 1979) and 12 out of 31 in 1977 (SEAFDEC 1977). It was observed that when the initial infection rates were higher than 10%, the fungus multiplied rapidly and the larvae did not recover (SEAFDEC 1977). Of the 35 runs affected in 1976, 22 were serious and had to be discarded. The prevalence rate was considerably reduced to 9 out of 43 hatchery runs in 1978 because of safeguards instituted against the fungal infection (Gacutan 1979).

In cases where the incidence rates were quite low (1-5%), siphoning of sediments and dead larvae as well as water management (e.g., 30-min flow-through and replenishment of water) every 4 h proved to be effective in controlling *Lagenidium* infections (Vicente et al 1979, Vicente 1981 in PCARRD 1985). Other precautionary measures include the reduction of stocking density and faster water circulation (Ruangpan 1982).

Several chemicals have been screened to combat *Lagenidium* spp. isolated from *P. monodon*. Lio-Po et al (1982) determined the sensitivity of *Lagenidium* isolates to 34 antifungal compounds and found the mycostatic levels of malachite green at 0.1-0.5 ppm, Treflan at 0.1-5 ppm, trifluralin (the active ingredient of Treflan) at 0.005-10 ppm, formalin at 10 ppm, and detergent (Tide) at 5-50 ppm. The mycocidal levels of Tide (50-100 ppm), formalin (50 ppm), and potassium permanganate (100 ppm) could be used for disinfection (Lio-Po et al 1982). The mycostatic levels of the fungicides were then tested on the prawn eggs and larvae and based on the experiments conducted, only Treflan and trifluralin could be safely used for the eggs, larvae, and postlarvae at therapeutic levels up to 0.2 ppm for 24 h, while a 20 ppm Tide bath for 2-4 h followed by complete water change before hatching could be used for disinfection of eggs (Lio-Po and Sanvictores 1986). Spawners may be disinfected with a high concentration of Treflan R (5 ppm) for 1 h, followed by an equal duration of thorough rinsing (Gacutan 1979). Aquacop (1983) preferred to use Treflan R at 5 ppm as continuous preventive treatment against attacks of *Lagenidium* as trifluralin is very volatile and drifts away with tank aeration (Aquacop 1977). Because of these characteristics, it is believed that a combination of the single dose treatment and continuous dosing regimes might be more effective than only either of the two methods, i.e., a single dose producing an effective 0.01-0.1 ppm trifluralin level followed by a continuous application at a rate that will compensate for a 20-30% loss per hour (Williams et al 1986). Considered economical and easy to use, trifluralin gave consistent results without secondary effects (Vicente et al 1979). Malachite green is fungitoxic at 0.006 ppm (Ruangpan 1982) but is safe only for the mysis stage (Lio-Po et al 1978). This chemical is also reported to have potential carcinogenic and teratogenic properties (Bailey 1983). Another chemical, 2,4-D (2,4-dichloro-phenoxy-acetic acid), is well tolerated, has a 96-h

LD50 of 0.6 ppm for M_I, and is also effective in arresting *Lagenidium* infections (Gacutan 1979).

Sirolopidium. Another fungus attacking prawn larvae is *Sirolopidium* (Gacutan 1979, Aquacop 1983, Bautista 1983). At the MSU-IFRD hatchery, this fungus was found to be as pathogenic as *Lagenidium* sp. (Bautista 1983). This fungus does not produce vesicles, has very short discharge tubes, and small numerous zoospores which may enter through the anus, mouth, or wounds (Bautista 1983). *Sirolopidium* infections exhibit the same signs as in *Lagenidium* infections.

Preventive measures include disinfection of equipment and tanks, filtration of water, chemical treatment of spawners, environmental sanitation, proper disposal of infected larvae and contaminated tank water, and occasional siphoning of debris and dead larvae (Bautista 1983). Treflan at 5 ppm may also be used continuously against *Sirolopidium* infection (Aquacop 1982b).

Haliphthoros. A new species, *Haliphthoros philippinensis* was found and isolated from mysis of *P. monodon* at the SEAFDEC AQD hatchery (Hatai et al 1980). It grows in culture media at wide ranges of temperature (13.5-36.3°C), sodium chloride concentration (0.3-7%), and pH (5-11) (Hatai et al 1980). The fungus also replaces the tissues of the prawn larvae.

Lio-Po et al (1985) tested a number of fungicides against *H. philippinensis* and found that for therapeutic purposes the following could be used because they inhibit the growth of and kill the fungus within a 24 h exposure: Furanace (10% active product) at 0.2-1 ppm, malachite green at 0.01-1.3 ppm, formalin at 6-30 ppm, and potassium permanganate at 10 ppm. For disinfection purposes, the detergent Tide (100 ppm),/calcium hypochlorite (200 ppm), and Resiguard (200 ppm) may be used (Lio-Po et al 1985). Furanace was found to have a 24-hour LD50 of 1.6 ppm for protozoa II and 2.0 ppm for mysis (Gacutan and Llobrera 1977). Protozoa II may be safely exposed to a furanace bath of 1 ppm for 6 h; overdosage could result in morphological changes and necrosis (Gacutan et al 1979b), reduced swimming activity, loss of appetite, and weak gill movements (Gacutan and Llobrera 1977). The same level of 1 ppm, however, significantly reduced the algal food *Chaetoceros* populations after a 6-h exposure (Baticados and Gacutan 1977) but did not have considerable effect on the rotifer *Brachionus*

populations (Baticados et al 1977a). Likewise, the use of malachite green, potassium permanganate, and formalin may not be wise, since the fungitoxic levels of the first two chemicals are also possibly toxic to the larvae while formalin is tolerated by larvae and postlarvae only at 5 ppm for 24 h (Lio-Po and Lavilla in Lio-Po et al 1985).

Fusarium Infection

Fusarium, a fungus which produces oval-shaped microconidia and boat-shaped microconidia, was reportedly isolated from nauplius and protozoa of *P. monodon* at the MSU-IFRD hatchery (Bautista 1983). The fungus has scanty white cottony strands of hyphae which attach to the larvae and hinder their movement (Bautista 1983). In adult prawns, *Fusarium* caused the black gill disease in a private prawn farm in Thailand (Ruangpan 1982). About 50% of the prawn population had black gills, reduced feeding activity, and gill tissues destroyed by the fungal mycelium, resulting in large losses of the stock (Ruangpan 1982).

The black gill disease was controlled by harvesting all the prawns and treating the pond with chlorine (Ruangpan 1982).

Other Fungal Diseases

Another fungal species, *Hyphomyces* sp., was isolated from cultured prawn nauplii and protozoa at the MSU-IFRD hatchery. Affected larvae moved sluggishly (Bautista 1983).

In India, adult prawns were found to be infected with two species of fungi - *Saprolegnia parasitica* and *Leptolegnia marina* (Gopalan et al 1980). The hyphae of *L. marina* were found to be older than those of *S. parasitica* in the prawn, indicating that the prawn may have been infected with the former (a marine form) in the sea and later on with *S. parasitica* (a predominantly freshwater form) in the estuary. *L. marina* has mostly intramatrical, long, delicate, densely interwoven, microscopic hyphae with terminal sporangia containing a row of smaller spores while *S. parasitica* has straight, simple, cottony, long filaments with terminal clavate sporangia and motile zoospores. The fungi attack primarily the calcified layer of the

shell, with *L. marina* producing wider and more necrotic lesions. Infection with *L. marina* starts as tiny brownish dots which later fuse to form deeply pitted irregular patches. Affected prawns were generally sluggish, very weak, exhibited gradual mortalities in 32 days, molted irregularly, and had dark brown necrotic lesions all over the body (Gopalan et al 1980).

These reports on fungal diseases of prawn are summarized in Table 3.

PROTOZOAN DISEASES

Protozoans which can cause diseases in prawns may be classified as either ectocommensal or parasitic. The first group consists of opportunistic organisms which cause disease only when present in large numbers. The second group comprises gregarines and microsporidians, endoparasites of the prawn, which may do little harm but could also be fatal to the prawn.

Ciliate Infestation

Several species of protozoans attach to the eyes, gills, appendages, and shell or body surface of prawns, causing respiratory and locomotory difficulties when present in large numbers. These include the peritrichs *Epistylis*, *Vorticella*, and *Zoothamnium*, and suctorians *Ephelota gemmipara* and *Acineta* which are often seen on prawn larvae and postlarvae (Gacutan et al 1977, Gacutan 1979). Among these, *Epistylis* is commonly observed in the Philippines (Gacutan 1979, Vicente and Valdez 1979, Vicente et al 1979) and Taiwan (Liao et al 1977, Chen 1978, Liao and Chao 1983, Liao 1984). *Epistylis* grows well when there is stratification of dissolved gases, particularly with minimal aeration (Vicente et al 1979). *Zoothamnium* is as prevalent among prawns in Thailand (Ruangpan 1982), Indonesia, Malaysia, and Taiwan (Baticados, unpubl.), and among juveniles and adults particularly soft-shelled ones, in the Philippines (Baticados et al 1986). Less often observed was *Ephelota gemmipara* which nevertheless caused heavy mortalities in several runs at the SEAFDEC AQD hatchery in 1976 (Gacutan 1979). *E. gemmipara* primarily attached to broad and relatively immobile parts of the larvae, e.g., body segments, carapace, and uropods (Gacutan et al 1979a). Larvae infected with this suctorian kicked violently, possibly to shake off the

Table 3. Fungal diseases of *P. monodon*

Disease Agent	Stages Affected	Pathology/Signs
<i>Lagenidium</i> (<i>L. callinectes</i> , <i>Lagenidium</i> sp.)	Eggs, larvae, early post-larvae	Fungus replaces internal tissues of prawn, eggs do not hatch, larvae weak, up to 100% within 1-2 days
<i>Sirolopidium</i>	Larvae	Same signs as above
<i>Haliphthoros philippinensis</i>	Zoea, mysis	Same signs as above
<i>Fusarium</i>	Nauplius, zoea, juvenile to adult	Scanty white cottony strands attach to larvae; may cause blackening of gills of 50% of pond stock; destroyed gill tissues; mortalities
<i>Hyphomyces</i>	Nauplius, zoea	Larvae move sluggishly
<i>Saprolegnia parasitica</i> and <i>Leptolegnia marina</i>	Adults	Attack shell of prawn; affected prawn sluggish, weak, gradual mortalities for 32 days, irregular molting, necrotic dark lesions on body

Prevention/Control	References
<p>Water management; reduction of stocking density Treflan or trifluralin at 0.2 ppm, 24 h treatment Disinfection of spawners with Treflan R, 5 ppm, 1 h Malachite green, 0.006 ppm, only for mysis Disinfection of eggs with Tide, 20 ppm, 2-4 h</p>	<p>Villaluz 1975 Aquacop 1977, 1983 Baticados et al 1977b SEAFDEC 1977 Lio-Po et al 1978, 1982 Gacutan 1979 Gacutan and Baticados 1979 Vicente et al 1979 Ruangpan 1982 Bailey 1983 Bautista 1983 PCARRD 1985 Lio-Po and Sanvictores 1986 Williams et al 1986</p>
<p>Disinfection of equipment and tanks; filtration of water; chemical treatment of spawners with Treflan, 5 ppm, 1 h; sanitation; disposal of infected larvae</p>	<p>Gacutan 1979 Aquacop 1983 Bautista 1983</p>
<p>Furanace, 1 ppm, 6 h</p>	<p>Baticados and Gacutan 1977 Baticados et al 1977a Gacutan and Llobrera 1977 Gacutan and et al 1979b Hatai et al 1980 Lio-Po et al 1985</p>
<p>Harvest affected pond-reared prawns and treat pond with chlorine</p>	<p>Ruangpan 1982 Bautista 1983</p>
<p>None reported</p>	<p>Bautista 1983</p>
<p>None reported</p>	<p>Gopalan et al 1980</p>

pathogen which might have resulted in larval weakening and loss of appetite (Gacutan et al 1979a).

Heavy infestations of these ciliates, particularly *Zoothamnium*, may result in the formation of a mat-like material on the shell and gills of juvenile and adult prawns (Baticados 1988, Villaluz 1975). Increase in their populations may come as a result of the deterioration of the culture water, i.e., high nutrient load, heavy siltation and turbidity, and low oxygen tension. These ciliates do not cause any mechanical damage but do harm to the prawns through immobility, starvation, and hypoxia (Villaluz 1975, Vicente and Valdez 1979, Ruangpan 1982).

Peritrichous ciliates attacking juveniles in nursery tanks were controlled by applying chloroquin diphosphate at a rate of 1.1 ppm for 2 days, the ciliates dying after 3 treatments (Yang 1979). *Zoothamnium* infestation was treated with a 50-100 ppm formalin bath for 30 min (Ruangpan 1982). Pond-reared juveniles with *Epistylis* infestation were exposed to 30 ppm formalin which effectively controlled the disease (Chen 1978). The same concentration was applied in natural food culture tanks before feeding the food organisms to the larvae (Vicente et al 1979). Formalin at 30 ppm did not have any effect on the alga *Chlorella* and the rotifer *Brachionus* but was found to be the LC_{50} for larvae at 12 hours and to kill mysis and postlarvae after an 8-hour exposure (Vicente and Valdez 1979). A higher dose, 40 ppm, resulted in coarsening of the shell and weakening of pond-reared juveniles (Chen 1978).

Gregarine Disease

Gregarines are among the common microorganisms associated with *P. monodon* larvae (Gacutan 1979). Microscopic examination of the larvae would show the motile stage, the trophozoite, gliding about or attached to the digestive tract (Baticados 1984). Large numbers of this protozoan in the filter apparatus could interfere with particle filtration to the hepatopancreatic ducts or through the gut (Baticados 1984) and could cause heavy mortalities in prawn hatcheries. Gregarines were observed to occur together with luminous bacteria in protozoa I, resulting in mass mortalities within 2 days (Cruz and Pitogo, pers. comm.). In Thailand, two species of gregarines

were found in the gut of 94% of the prawns from a private farm (Ruangpan 1982).

Gregarines utilize a molluscan bivalve as intermediate host so that one way of controlling them is by eliminating this host.

Microsporidiosis

Parasitic infection of the female reproductive organ may result in sterility, weakness, and greater susceptibility to other environmental stresses (Villaluz 1975, Baticados 1984, PCARRD 1985). The disease microsporidiosis has been observed in *P. monodon* spawners and is manifested by the whitening of the ovaries due to the presence of spores and other stages of the parasite which have replaced the ovarian tissues. Microsporidiosis may be diagnosed through gross examination of the ovaries coupled with microscopic examination of fresh squashes or Giemsa-stained smears from infected tissue or histological examination of suspected tissue samples (Baticados 1984).

Microsporidiosis may be prevented or controlled by isolating or destroying infected individuals, avoiding contact of infected spawners with non-infected individuals, and disinfecting culture systems with commercial bleach or disinfectants containing iodine (Baticados 1984).

Table 4 summarizes the information on protozoan diseases of *P. monodon*.

DISEASES CAUSED BY OTHER ORGANISMS

Other organisms may also be present in prawn as ectocommensals or parasites. The damage done by ectocommensals usually depend on their number while damage due to parasites may depend on their pathogenicity/virulence as well as their quantity. There are no reported control measures for these organisms. In any case, however, rigid water management and sanitation would help considerably.

Table 4. Protozoan diseases of *Penaeus monodon*

Disease	Agent	Stages Affected	Pathology/Signs	Prevent/Control	References
Ciliate infestation	<i>Epistylis</i> <i>Vorticella</i> <i>Zoothamnium</i> <i>Ephelota</i> <i>Acineta</i>	All stages	Respiratory and locomotory difficulties, loss of appetite, sometimes form fuzzy mat on shell	Chloroquin diphosphate, 1.1 ppm, 2 days For <i>Zoothamnium</i> : formalin, 50-100 ppm, 30 min. For <i>Epistylis</i> : formalin, 30 ppm, for juveniles but not for larvae and post-larvae	Villaluz 1975 Liao et al 1977 Gacutan et al 1977 Chen 1978 Gacutan 1979 Vicente and Valdez 1979 Vicente et al 1979 Yang 1979 Ruangpan 1982 Liao and Chao 1983 Liao 1984 Baticados et al 1986
Gregarine disease	Gregarines	Larvae	Interferes with particle filtration to hepatopancreatic duct or through gut, rate of infection up to 94%	Eliminate molluscan intermediate host	Gacutan 1979 Ruangpan 1982 Baticados 1984
Microsporidiosis	Microsporidia	Female spawners	Whitening of ovaries, microsporidian spores, and other stages of parasite replaced ovarian tissues	Isolation and destruction of infected individuals, disinfection of culture system with commercial bleach or disinfectants with iodine	Villaluz 1975 Baticados 1984 PCARRD 1985

Dinoflagellates

A major cause of loss in prawn hatchery production in Singapore is the red vein disease of postlarvae caused by a peridinin dinoflagellate related to *Haematodinium* sp., a crab pathogen in temperate waters (Chong and Chao 1986). Moribund prawns are luminescent at night and microscopic examination revealed the presence of numerous red-pigmented microorganisms filling the entire ventral sinus and hemolymph spaces as well as spreading to various appendages (Chong and Chao 1986).

In another case in Taiwan, ponds with prawn juveniles infested with *Epistylis* were characterized by brownish water resulting from the presence of the dinoflagellate *Pyrocystis* sp. and the diatom *Pleurosigma* (Chen 1978).

Algae

Pond-grown prawn may sometimes exhibit ectozoic algal growth resulting in sluggishness, inactivity, or during heavy infestation, death (Liao et al 1977, Liao 1984). Also found on mysis and postlarvae in hatcheries is the algal species *Schizothrix calcicola* (Gacutan et al 1977) which attaches to the prawn and does harm when present in large numbers.

Helminths

An unidentified nematode has been implicated in many mass mortalities among postlarvae. In one case, the nematode was found in low numbers in PL₅ and PL₈ and mass mortality occurred after two days in indoor tanks (Gacutan et al 1977). In another case, nematode infestations caused heavy mortalities among M_{II} and M_{III} within two days following use of non-chlorinated water (Baticados, unpubl.). Nematode infestations have also been observed in Indonesia, and Malaysia (Baticados, unpubl.).

A nematode has also been found in the gut of adult *P. monodon* caught in Andaman Sea (Ruangpan 1982) but no apparent effect on the prawn was reported.

Copepods

A crustacean ectoparasite, *Caligus epidemicus*, was observed to parasitize the pleopods and tail of 72% of adult *P. monodon* in a Thai farm (Ruangan 1982). The rate of parasite burden, however, was quite low (Ruangan 1982).

NUTRITIONAL, TOXIC AND ENVIRONMENTAL DISEASES

Prawns may be adversely affected by deficiencies in their diet, toxins or pollutants in the water, or other environmental factors like temperature extremes and oxygen depletion. Their responses to these factors may vary from slight changes in morphological or histological make-up to mortalities within a few hours.

Chronic Soft-shell Syndrome

One of the disease problems which is largely responsible for low prawn production in ponds is the chronic soft-shell syndrome. The chronic soft-shell syndrome is a condition in which the prawn exoskeleton remains persistently soft for several weeks, thus making the prawn weak, more susceptible to cannibalism, and low-priced upon harvest (Baticados et al 1986). The syndrome affects juveniles and adults of *P. monodon*. The cuticular layers of the hard shell, particularly the exocuticle and endocuticle, are considerably thinner, often have a rough or wrinkled surface and are usually disrupted and separated from the epidermis, while those of the hard shell are thicker, generally intact, and attached to the epidermis (Baticados et al 1987). The condition was found to be caused by nutritional deficiency, pesticide contamination in the water, and poor pond water and soil conditions. Because of the significant differences in tissue calcium and phosphorus levels of soft-shelled prawns from those of hard-shelled ones, Baticados et al (1986, 1987) also believed that mobilization of calcium and phosphorus from the storage organ, the hepatopancreas, to the exoskeleton where they are needed for shell formation and hardening, could have been impaired. The disease also occurs among tank-reared prawns and in ponds in Indonesia, Malaysia, and Thailand (Baticados, unpubl.).

The disease may be prevented or controlled through environmental and dietary manipulation, i.e., by providing favorable pond water and soil conditions for shell formation and hardening and by adequate nutrition. Reversal of soft-shelling, general improvement of shell quality, and best growth and survival rates were obtained after feeding prawn juveniles with frozen mussel meat at 14% of the body weight, compared with those fed 2% and 8%. Some management practices like good water management through regular water change and proper storage or use of good quality feeds could also prevent the occurrence of the chronic soft-shell syndrome (Baticados et al 1986).

Red Disease

Red disease was first reported by Liao et al (1977) among prawn juveniles and adults in Taiwan. Affected prawns exhibited reddish discoloration of the cuticle, gill fouling, internal tissues with foul odor, and pale hepatopancreas and heart which eventually led to heavy mortalities (Liao et al 1977, Liao and Chao 1983, Liao 1984). Lightner and Redman (1985a) much later observed red disease among 3-15 g pond-reared juveniles and 40-60 g wild-caught adults. The same disease was also observed among 55-104 g *P. monodon* in broodstock tanks (Baticados et al, unpubl.) and among 10-15 g prawns in ponds in the Philippines (Gacutan and Billiones, unpubl.), Malaysia, and Thailand (Baticados, unpubl.). Aside from the reddish bodies, the prawns also had reddish gills and pleopods (Lightner and Redman 1985a, Baticados et al, unpubl., Gacutan and Billiones, unpubl.) In ponds, juveniles stocked at PL₄₀ to PL₅₀ exhibited reddening about a week after stocking, became very sensitive to handling stress, and showed gradual mortalities in a period of three months, eventually reaching 98% (Gacutan and Billiones, unpubl.). Histopathological examination of the samples revealed atrophy and necrosis of hepatopancreas, intense cellular inflammatory response, and less commonly, melanized cellular inflammatory lesions in antennal gland, mandibular organ, midgut, and gills (Lightner and Redman 1985a). The degree of reddening of the prawn broodstock appeared to be directly related to the degree of atrophy and necrosis of the hepatopancreas (Baticados et al, unpubl.). Destruction of the hepatopancreas resulted in the release, distribution and deposition of the stored carotenoids into the tissues which then become reddish (Lightner 1985). It is believed that the disease

might be due to microbial toxins (e.g., mycotoxins) in rancid or spoiled diets or in detritus of ponds rich in organic matter (Liao et al 1977, Lightner and Redman 1985a). Gacutan and Billiones (unpubl.) also observed unusually high inputs of lime during pond preparation (4 tons/ha) and very high levels of carbon dioxide (30-60 ppm) in affected ponds.

Fatty Infiltration of the Hepatopancreas

In Texas, Mexico, and Hawaii, prawn juveniles and adults, particularly those which were extensively cultured, exhibited excessive deposits of lipid in the hepatopancreatic tubule epithelium (Lightner 1983). It was believed that this disease might have developed from improper dietary lipid levels, improper caloric-lipid balance, or dietary toxins (Lightner 1983).

Blue Disease

The "blue disease" or the soft blue shell syndrome (Aquacop 1984b) was first observed in 1978-79 when prawn broodstock in Tahiti were affected, resulting in large mortalities (Aquacop 1984a). Affected prawns are lethargic and had a rough cuticle surface and a pale blue discoloration of the often thin and soft cuticle. Both juvenile and adult stages from the ponds are affected (Lightner 1983, Aquacop 1984b, Baticados 1988). The disease was thought to be mainly due to a nutritional deficiency but a probable viral etiology was not discounted (Lightner 1983, Aquacop 1984b). Blue prawns have been found to have very low levels of the carotenoid astaxanthin, the major pigment responsible for the color in prawns (Chiu, pers. comm.). Histological observations on the hepatopancreas of blue prawns also revealed a disruption of the hepatopancreatic tubules (Fernandez and de la Cruz, pers. comm.). Bluish discoloration has likewise been observed in Indonesia, Malaysia, Taiwan and Thailand (Baticados, unpubl.).

To control "blue disease" among breeders, Aquacop (1984a) instituted new procedures for broodstock production from postlarvae based on the principles of low density, high quality food, and frequent change of pond water.

Cramped Tails

Cramped tails or "body cramp" has been reported in Taiwan (Liao et al 1977, Liao 1984) but also occurs in the Philippines (Baticados 1988), and Indonesia (Baticados, unpubl.). Juveniles and adults exhibit flexed, rigid abdomen which may be due to a sudden increase in temperature, e.g., during handling of prawns in air relatively warmer than the rearing water (Liao et al 1977).

Prawns which have just had "body cramp" could still recover by putting them back into well-aerated culture water and straightening the bodies back to their normal shape, which is practical only for the more expensive stages, like spawners or experimental animals (Baticados 1988). Handling of prawns during hot weather conditions should be avoided to prevent the disease.

Hemocytic Enteritis

Blooms of blue-green algae belonging to the family Oscillatoriaceae caused hemocytic enteritis in primarily young juveniles as well as subadult prawns in the Philippines (Lightner 1985). The algal endotoxin released in the gut resulted in necrosis and considerable hemocytic inflammation of mucosal epithelium of the midgut and its caeca as well as necrosis and degeneration of hepatopancreas. Deaths were due to osmotic imbalance, poor absorption of nutrients, or secondary bacterial infections (e.g., *Vibrio alginolyticus*) in septic hemolymph (Lightner 1985).

Growth of the filamentous blue-green algae may be prevented by "shading out" these benthic mats with typical plankton blooms maintained at sufficient density and water depth (Lightner 1988a).

Heavy Metal Poisoning

The presence of heavy metals in the water was proven to be harmful to 2.3-cm long *P. monodon* in bioassay experiments (Chen 1979). Among the metals tested (mercury, copper, cadmium, and zinc), mercury was the most toxic followed by copper, cadmium, and zinc. Cadmium toxicity was found to be the most rapid (Chen 1979).

In a separate case, cadmium and copper poisoning were suspected to be the cause of mortalities in hatchery farms in Taiwan in 1980-81 (Kuo et al 1984). The heavy metals came from the waste water discharged by nearby industries. Signs of poisoning in protozoa and mysis included the presence of a fog-like substance on the dorsal surface of the prawn body, enlarged and laterally curled carapace, irregular chelae and palps, loss of appetite and swimming ability, presence of bubble-like processes on uropod edges which became orange swellings when prawns got worse, and sometimes, red spots on the body (Kuo et al 1984). Mortalities occurred within 6 h to 2 days after signs were observed (Kuo et al 1984). Heavy metals generally damage gill tissues and inhibit the enzyme system (Chen 1979). The 48-h LC50's of copper sulfate on protozoa_I, mysis_I, and postlarva were shown to be 0.225, 0.350, and 0.125 ppm, respectively (Canto 1977).

Mortality rates in larvae poisoned by heavy metals (particularly cadmium and copper) may be reduced by substituting clean sea water for culture (Kuo et al 1984).

Black Gill Disease

The black gill disease in prawns has been reported to accompany many other syndromes such as viral/bacterial/fungal/protozoan infections, black death or shrimp scurvy, and contamination of toxic pollutants like cadmium, copper, potassium permanganate, ozone, ammonia, and nitrate (Lightner 1985). Black gill disease in *P. monodon* takes the form of reddish, brownish to black gills. Adult *P. monodon* reared in ponds in a Thai farm were found to have black gills during fungal (*Fusarium*) infections (Ruangpan 1982). Red discoloration of gills was also manifested in prawns with red disease (Lightner and Redman 1985b). Examination of affected prawns from some farms in the Philippines also revealed that the black gill disease might also be due to *Zoothamnium* infestation as well as to accumulated soil particles in the gills during heavy siltation (Baticados 1988). The disease may cause respiratory difficulties and mortalities. The disease has been observed also in Indonesia, Malaysia and Taiwan (unpubl.).

Avoidance of the primary causes of the disease is the best way to prevent it. Pond conditions must always be kept at the optimum and the exact cause of the disease must be

identified so that proper treatment could be implemented (Baticados 1988).

Muscle Necrosis

All penaeid species may be affected by a condition called "muscle necrosis" which is characterized by whitish opaque areas in the muscles, particularly in the posterior portion of the abdomen (Lightner 1985). The disease has been associated with stressful environmental conditions like low oxygen levels, temperature or salinity shock, overcrowding, and severe gill fouling. The chronic and infected form of the disease when affecting the distal portion of the abdomen is the more commonly observed "tail rot" (Lightner 1985). Prawns with tail rot have tails that are necrotic, eroded, and reddish to black. Tail rot is highly prevalent in intensive culture farms where environmental conditions are often very poor because of very high stocking densities (Baticados 1988). The disease may cause mortalities if large areas of the abdomen are affected (Lightner 1985). Tail rot is a common problem in Indonesia, Malaysia, Taiwan, Thailand (Baticados, unpubl.) and the Philippines (Baticados 1988).

Control of the disease consists of avoiding possible causes and, when already present, improving the environmental conditions (Baticados 1988).

Gas-bubble Disease

Gas-bubble disease may affect all penaeids (Lightner 1988b). The disease is due to supersaturation of seawater with atmospheric gases and oxygen (Lightner 1983). Gas bubbles appear in the gills, under the cuticle (Lightner 1988b) or in the gut and prawns that die from it float (Baticados 1988).

Supersaturation of gases must be avoided and once the disease is present, mechanical aeration should immediately be done to reduce dissolved oxygen levels (Lightner 1988b).

Available reports on these diseases are summarized in Table 5.

Table 5. Nutritional, toxic and environmental diseases of *Penaeus monodon*

Disease	Agent	Stages Affected
Chronic softshell syndrome	Nutritional deficiency; pesticide contamination; poor pond water and soil conditions (high soil pH, low water phosphate, and low organic matter content)	Juveniles, adults
Red disease	Possibly microbial toxins (mycotoxins) in rancid or spoiled diets or in detritus of ponds rich in organic matter	Juveniles, adults
Fatty infiltration of hepatopancreas	Possibly nutritional; improper dietary lipids or caloric lipid balance or dietary toxins	Juveniles, adults
"Blue disease" or soft blue shell syndrome	Possibly nutritional deficiency or viral etiology	Broodstock Juveniles, adults
Cramped tails or "body cramp"	Temperature shock (e.g., handling of prawns in air relatively warmer than culture water)	Juveniles, adults
Hemocytic enteritis	Endotoxin blooms of blue green algae	Young juveniles and subadults
Heavy metal poisoning	Cadmium and copper contamination	Larvae, post-larvae to young juveniles
Black gill disease	Viral/bacterial/fungal protozoan infections; black death; Cd, Cu, KMnO_4 , ozone, ammonia and nitrate contamination; heavy siltation	Juveniles to adults
Muscle necrosis	Associated with poor environmental conditions like low oxygen levels, temperature or salinity shock, severe gill fouling, overcrowding	Juveniles to adults
Gas-bubble disease	Supersaturation of seawater with atmospheric gases	All stages

Pathology/Signs	Prevention/Control	References
Shell is thin and persistently soft for several weeks; prawns weak, more susceptible to cannibalism	Environmental and dietary manipulation	Baticados et al 1986, 1987
Reddish cuticle, gills and pleopods; gill fouling; internal tissues with foul odor; pale hepatopancreas and heart; atrophy and necrosis of hepatopancreas; mortalities; intense cellular inflammatory response	None reported	Liao et al 1977 Liao and Chao 1983 Liao 1984 Lightner and Redman 1985b
Excessive deposits of lipid in hepatopancreatic tubule epithelium	None reported	Lightner 1983
Blue discoloration of thin, soft cuticle; rough cuticle surface; lethargy	Maintain low stocking density, high quality food, frequent changes of pond water	Lightner 1983 Aquadrop 1984a, 1984b Baticados 1988
Rigid flexure of abdomen	Early stages may be reversed by replacing prawn in water and straightening them back to normal; avoid handling during hot weather	Liao et al 1977 Liao 1984 Baticados 1988
Necrosis and hemocytic inflammation of mucosal epithelium of midgut and caeca; necrosis and degeneration of hepatopancreas; deaths due to osmotic imbalance; poor nutrient absorption; and secondary bacterial infections	"Shade out" benthic blue-green mats with typical plankton blooms	Lightner 1985, 1988a
Morphological deformities, gill damage and inhibition of enzyme system, mortalities	Water change	Canto 1977 Chen 1979 Kuo et al 1984
Gills become reddish, brownish to black; respiratory difficulties, mortalities	Avoid causes, maintain good pond conditions	Lightner 1985 Baticados 1988
Whitish opaque areas on abdominal segment, distal portion of abdomen may become infected and develop into tail rot.	Avoid possible causes, improve environmental conditions	Lightner 1985 Baticados 1988
Gas bubbles in gills, under the cuticle or gut; gills appear whitish and prawn exhibits erratic swimming behavior	Mechanical aeration to reduce dissolved oxygen levels once disease is present	Lightner 1983, 1988b Baticados 1988

OTHER ENVIRONMENTAL STRESS FACTORS

Adverse changes in the environment could cause harm to the prawns either directly or indirectly. Ghosh and Nanda (1985) observed that 8-10.5 cm long *P. monodon* subjected to thermal shock (about 10°C higher or lower) suffered cytomorphological changes in the eye and brain which considerably altered their secretory function.

The build-up of organic wastes and toxic gases due to overcrowding (Villaluz 1975) and excess food (Ruangpan 1982) coupled with improper sanitation deteriorate water quality and contribute to mortalities in hatchery (Villaluz 1975) and broodstock (Primavera et al 1978) tanks.

In ponds, heavy rains could lower the salinity of the surface water and cause oxygen depletion on the lower layer because of water stratification. Mortalities may occur because of the benthic nature of prawns in ponds. Turbid water due to suspended mud particles during periods of high temperature could also be fatal to prawns (Villaluz 1975). Poor quality of the pond bottom has also been associated with rolled up gills and carapace (Aquacop 1984).

PROBLEMS AND PROSPECTS

Even with the available information on the diseases of *P. monodon*, many gaps still exist but could be bridged through a more intensive research program. Viral infections, for instance, are difficult to identify particularly in very young stages (larvae) which appear normal but may have latent viral infection. Diagnostic methods must be improved and simplified to facilitate the identification of viral infections. More effective methods of prevention and control are very much needed to combat not only viral diseases, but bacterial, protozoan, fungal, and non-infectious diseases as well.

It should be noted that not all cases of disease outbreaks are reported--one reason why researches on some disease problems are not conducted. A major hindrance is the prawn farmer's or technician's inability to distinguish or diagnose diseases and to prevent or control them. Training programs in aquaculture should include the study of diseases to alleviate this problem. In addition, disease diagnostic centers in prawn

culture areas could facilitate the identification of prawn diseases and recommend preventive and control measures as needed.

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