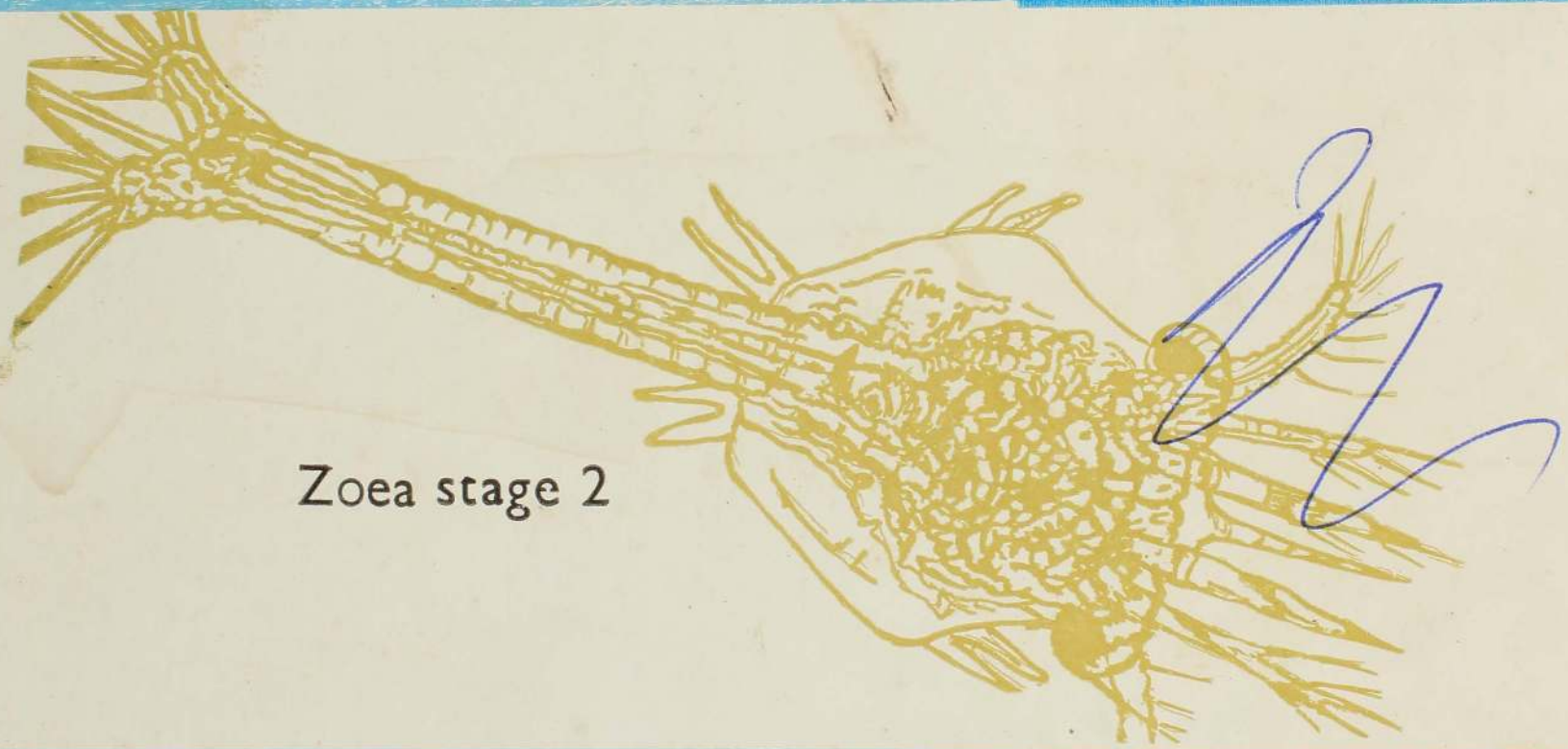
SHRIMP CULTURE

K. Chitravadivelu



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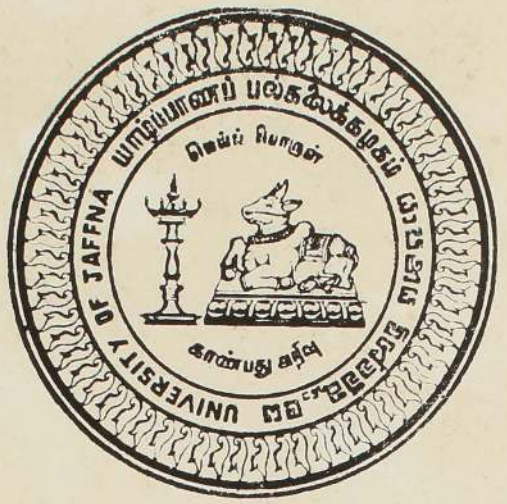

SHRIMP CULTURE

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" ..... but unfortunately, due to lack of an efficient service for collection, translation, compilation, and distribution, much of the valuable knowledge remains either in office files or in some sophisticated publications, both of which are beyond the reach of the people who need them most. Research and experiment have little practical significance unless the results obtained are reduced to simple terms and passed on to the public for application "

— Ling (1972).

FOREWORD

Prof. A. Thurairajah,

B. Sc. Eng. (Sri Lanka), Ph. D. (Cantab),
C. Eng., F. I. E. (Sri Lanka),
F. I. C. E., F. N. A. S. (Sri Lanka),
Vice - Chancellor, University of Jaffna.

University of Jaffna is happy to bring forward this publication **Shrimp Culture** *written by Dr. K. Chitravadivelu, Senior Lecturer in Zoology. The author has utilized the wide knowledge he has obtained through research and field experience over many years, in writing this book.*

Developing of the marine resources in our region will have to be given priority in order to have a sustainable economy for this region. Many industries can be started in this region using the marine resources. This book will be useful for students and research scientists, and to industrialists who would like to venture into this industry.

— 6th August 1993

FOREWORD

Prof. V. K. Ganeshalingam.
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Ph. D. (Lond.),
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University of Jaffna,
Jaffna.

It is claimed by experts that development and intensification of aquaculture offers developing countries in particular greater scope for increasing food production. Large areas of unutilized lagoons and swamps are available in our country and many coastal areas are free from industrial water pollution and therefore suited for brackish water and sea water aquaculture.

Of all marine organisms, shrimps are the most popular target for aquaculture due in large part to their universal popularity, high price and almost unlimited market potential. In a span of less than a decade, shrimp culture has become established in Sri Lanka as a significant source of foreign exchange earning. The financial success of the early adopters has encouraged many others to invest and many more are ready to invest in shrimp culture. The publication of **Shrimp Culture** at this juncture is very timely.

In this book Dr. Chitravadivelu has provided a well integrated and authoritative account by bringing together expert knowledge in different areas of shrimp research. I am certain that this treatise, will serve as an advanced text for researchers, teachers, professionals, students and amateures as well.

I congratulate Dr. Chitravadivelu for producing this excellent contribution and expect more books of this nature to follow.

Let us all work towards developing shrimp culture for the economic development of our motherland.

— 6th August 1993

PREFACE

Dr. K. Chitravadivelu

Shrimp culture is a relatively new field that has generated immense enthusiasm in private and public industry. Shrimp culture technology has now developed to a point that investment in commercial culture can be made with confidence. However, since the requirements of each culture system is unique, the entrepreneur should be cautioned against investing without critical examination of the project.

This hand - book is an attempt to bring recent knowledge in various aspects of shrimps and shrimp culture together and make them available to those "who need them most" and thus serve as a guide.

I have had the privilege of spending my sabbatical, researching in collaboration with Dr. David A. Jones in the Marine Science Laboratories of the University College of North Wales, United Kingdom. The free access to ample, recent literature both personal of Dr. Jones and those in the library of the UCNW, tempted me to embark on this humble task and I hope that my attempt will aid in disseminating basic technical knowledge to both students and shrimp culturists.

I wish to express my sincere thanks to Dr. Jones for his cordiality, generosity, collaboration and guidance.

It is a pleasure to record the assistance and encouragement given to me during the preparation of the manuscript by Dr. Jacob Chacko, Head of the Chemical Oceanography Division, Cochin University of Science and Technology, India who also spent his sabbatical along with me at UCNW.

The information given in this book comes from many sources. These contributions are acknowledged at the end. Acknowledgements of illustrations and tables are made individually beneath each.

I wish to record my sincere thanks to Prof. V. K. Ganeshalingam, Head of the Department of Zoology, for his continuous encouragement and for writing a foreword for this book.

Prof. G. F. Rajendram read the final manuscript; I wish to thank him profusely for his editorial assistance.

My sincere thanks are due to Prof. A. Thurairajah, Vice - Chancellor for inaugurating the Publication Committee and thus making available funds for the publication of this book and for providing a foreword. Thanks are also due to the referees of the Publication Committee for recommending acceptance of this book as a Jaffna University Publication, to the Registar, Mr. K. Parameswaran, Senior Assistant Registrar / Academic, Mr. R. Murugaian, and the Bursar, Mr. M. Alalasundaram, for taking active interest at various stages of this publication.

To Mr. P. Nadarajan who designed the format of the book and did the entire proof reading ungrudingly, I owe a debt of gratitude.

Mahathma Printing Works, Earlalai, Jafffna, Sri Lanka did the printing under the present disturbed conditions in Jaffna. I wish to thank them for their co - operation.

6th August 1993.

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Shrimps are considered a luxury food commodity in international trade (Pedni, 1981). Shrimp fishing is a substantial industry of vital economic importance in at least twenty countries and more nations harvest them than nearly any other kind of marine product (Neal and Maris, 1985). Annual world supply of shrimp was estimated to be about 2.0×10^6 metric tons in 1988, of which 85% was from tropical species. The top four producing countries which contribute to more than 50% of the total are in the Asian region (Fig. 1 (a) and 1 (b) and Table 1). The contribution from aquaculture to the total supply was about 22% in 1988. Increased yields from capture fisheries appear to be unlikely since most major fisheries for shrimp have been discovered and presently being harvested to full or nearly full capacity, that is they have reached their maximum sustainable yield and cannot meet the increasing consumer demand.

Country By Rank (* guesstimate)	Heads - on Production (metric tons)	% of World Production	Hectares in Production	Number of Hatcheries	Number of Farms
China	1000 000	22	100 000	300*	4 000*
Ecuador	70 000	16	100 000	100	1 300
Taiwan	50 000	11	10 000	1 500	3 000*
Indonesia	50 000	11	200 000*	90	6 000*
Other	42 000*	9	80 000*	189*	4 617*
Thailand	40 000	9	50 000	1 000*	5 000*
Philippines	30 000	7	70 000	400*	3 000*
India	30 000	7	50 000	10	4 000*
Vietnam	20 000	4	80 000*	—	—
Central America and Caribbean	13 000	3	15 500	20	150
South America (excluding Ecuador)	5 000	1	10 000	10	150
Totals	450 000	—	765 500	3 619	31 217
Eastern Hemisphere	361 000	80	639 000	3 484	29 597
Western Hemisphere	89 000	20	126 500	135	1 620

Table 1 : *World Shrimp Production in 1988* (*Rosenberry, 1989*) - I

Country Alphabetical (* guesstimate)	Heads on Production (metric tons)	% of World Production	Hectares in Production	Number of Hatcheries	Number of Farms
Africa	0	—	0	2	4
Australia	60	—	350	4	40
Burma	2 000*	—	10 000*	4*	1 000*
Bangladesh	5 000*	1	20 000*	20*	2 000*
France	25	—	20*	5*	20*
Italy	10	—	20	5	10
Japan	3 000	—	600	50	165
Malaysia	3 000*	—	1 000*	20*	250*
Middle East	500*	—	1 000*	5*	10*
North Korea	10 000*	2	10 000*	25*	1 000*
South Pacific	1 000*	—	1 000*	10*	10*
Spain	85	—	700	5	18
Sri Lanka	1 000*	—	4 000*	4*	20*
United States	1 000	—	500	5	20
Other	15 000*	3	30 000*	25*	50*
Totals	41 680	—	79 190	189	4 617
Western Hemisphere	1 000	—	500	5	20
Eastern Hemisphere	40 680	—	78 690	184	4 597

Table 1 : *World Shrimp Production in 1988 (Rosenberry, 1989)* - II

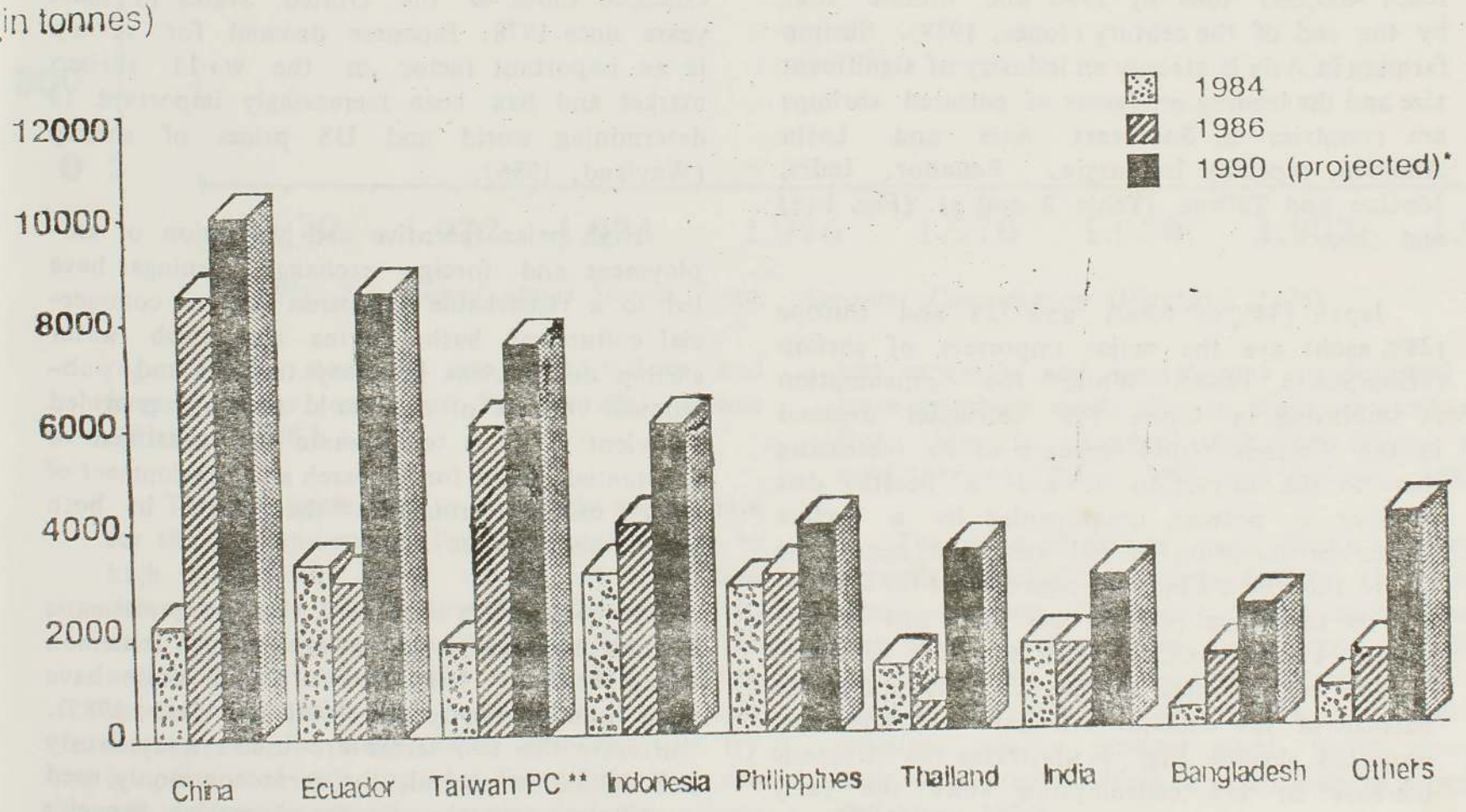
Unit : 1000 metric tons

Country	Estimated production by 2000
Bangladesh	60
Burma	5
China	200
India	50
Indonesia	120
Japan	3
North Korea	15
South Korea	5
Malaysia	8
Pakistan	2
Philippines	100
Singapore	2
Sri Lanka	5
Taiwan	85
Thailand	110
Vietnam	30
Total	800
1985 Total	201

Table 2 : *Potentials of shrimp aquaculture in Asia.* (*Casavas, 1988*)

Country	Average yield (kg/ha)
Bangladesh	108
Burma	173
China	714
India	395
Indonesia	162
Malaysia	553
Philippines	149
Singapore	1476
Thailand	450
Vietnam	260
Average of "extensive" and "semi – intensive" countries	240
Japan	6145
Taiwan	7750
Average of "intensive" countries	7620
Asian average	284

Table 3 : *Average Crustacean yield in As'a (1985) (Casavas, 1988)*



Source : Aquaculture and Capture Fisheries : Impact in U S Seafood Markets, US Department of Commerce, Washington DC, USA. ** Taiwan (Province of China) data from non - FAO source.

Fig. 1 *(a)* **:** *Cultured shrimp production in major producing countries (Rosenberry, 1989)*

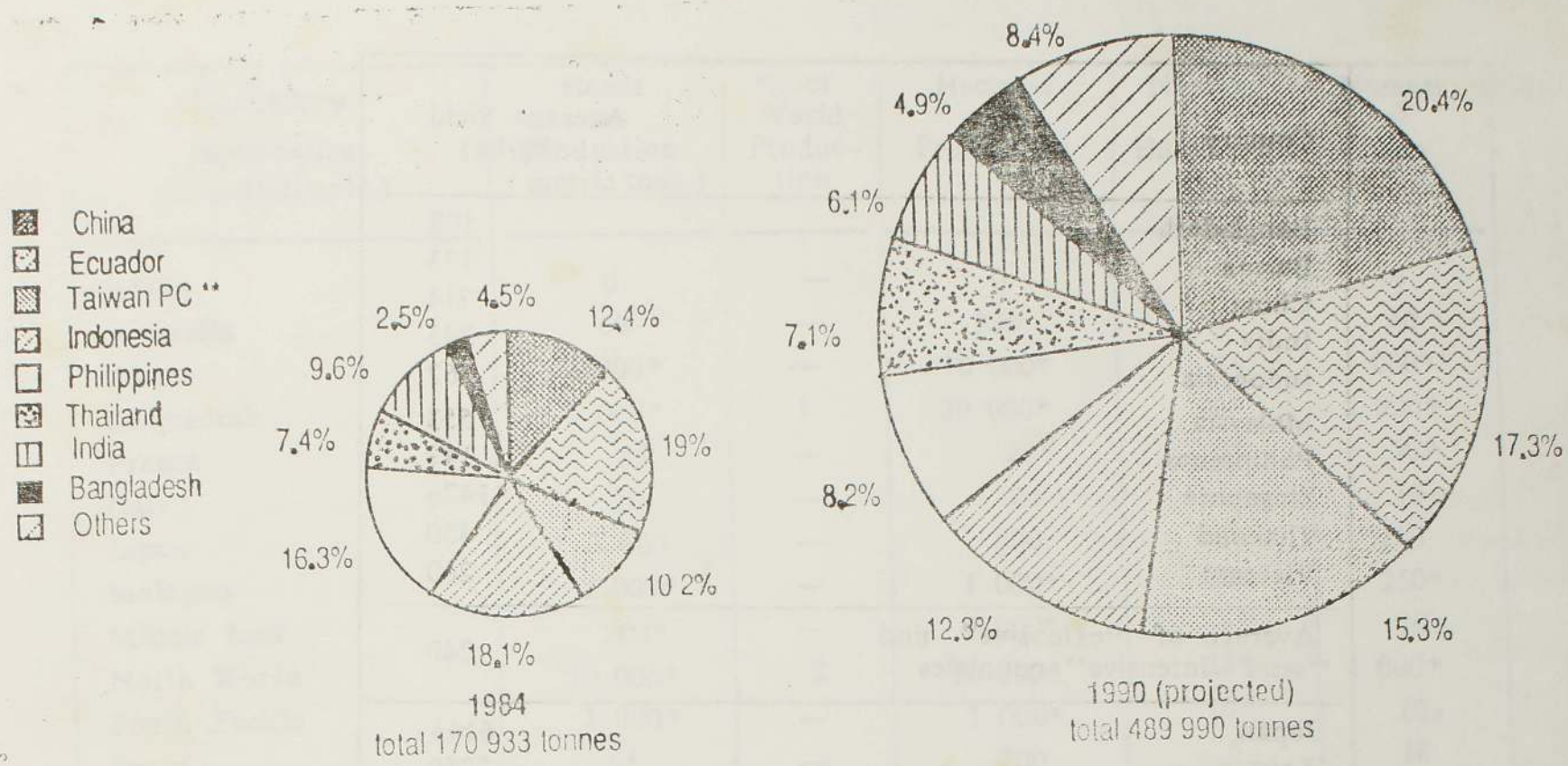


Fig. 1 (b) : *Percentage distribution of cultured shrimp production* (*Rosenberry, 1989*)

But there is considerable potential for increase in aquaclture production which may reach 400,000 tons by 1990 and double that by the end of the century (Jones, 1988). Shrimp farming in Asia is already an industry of significant size and the leading producers of cultured shrimps are countries in Southeast Asia and Latin America, espcially Indonesia, Ecuador, India, Mexico and Taiwan (Table 2 and 3) (Fig. 1 (a) and (b).)

Japan (34% of total) and US and Europe (28% each) are the major importers of shrimp (Sribhibhadh, 1984). While the consumption is stabilising in Japan the consumer demand in the Western World appears to be increasing due to the attraction towards a healthy diet supplied by prawns, accompanied by a decline in the consumption of red meat and eggs. The US is the world's largest single market for shrimp, but its fishermen provide less than half of the country's requirements. With the US resources already being fished to maximum capacity, the balance of the demand will have to come from imported shrimp. Fig. 2 illustrates the dramatic increase in US consumption since the early 1980s. This surge has been attributed largely to an improving US economy. As in US, shrimp is a very popular food in Japan. Japan's consumption in 1984 (Table 4), was an apparent 228,000 M/T, which on a per capita basis is over twice that of US. Japanese imports have exceeded those of the United States in most years since 1978. Japanese demand for shrimp is an important factor in the world shrimp market and has been increasingly important in determining world and US prices of shrimp (Wayland, 1986).

High price incentive and generation of employment and foreign exchange earnings have led to a remarkable expansion in the commercial culture of both marine and fresh water shrimp and parwns in many tropical and subtropical regions of the world and has provided sufficient stimulus to promote the investment of substantial funds for research and development of prawn culture throughout the world in both public and private sector.

It is generally accepted that no systematic distinction can be made between the two common terms "shrimp" and "prawn" and these have been used interchangeably (Neal and Maris, 1985). Currently the two terms are used synonymously and follow in general, the term commonly used in different countries. Species of marine Penaeids are called "prawns" in India, Sri Lanka, Australia and South Africa; "shrimp" in US; while either term used in Japan. In UK small Caridеans

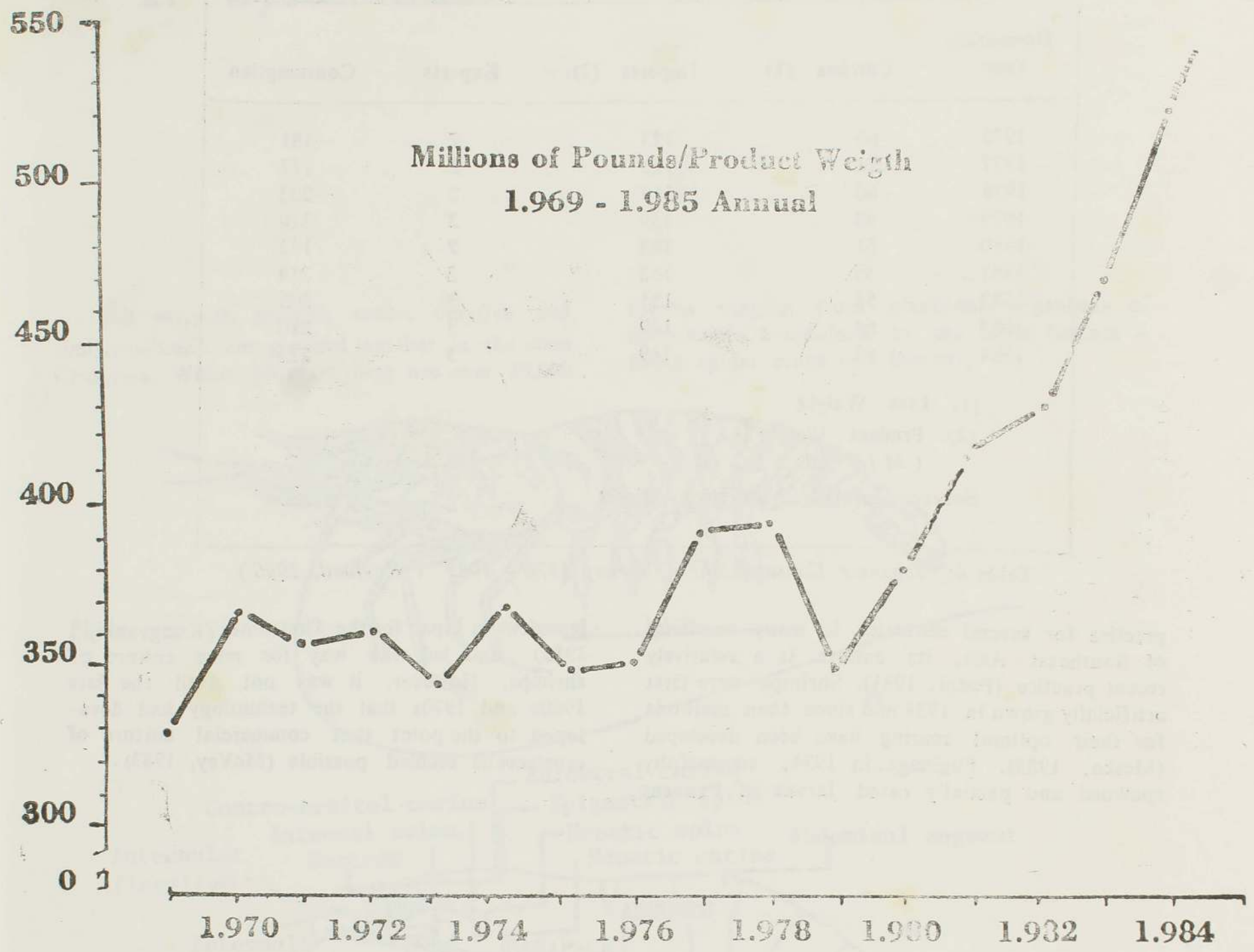


Fig. 2 : *United States Shrimp Usage, Apparent Consumption (Wayland, 1986)*

(eg. **Pandalus montaqui**) are called shrimp and larger species such as **P. borealis**, prawns (Wickins, 1976 b).

Tropical areas seem to be highly appropriate for the development of Penaeid farming, due to high temperature which allows full production throughout the year. The other advantages that exist in the tropics are (i) the tropics are the natural habitat of majority of the fast growing species of Penaeids and thus a supply of gravid females and in many cases abundant wild fry is guaranteed (ii) the tides from 2 to 4 m are not uncommon in the tropics and this allows the filling and draining of tidal ponds without the use of external energy for pumping thus lowering costs (iii) more land is available and less expensive and coastal areas are obtained on lease relatively easily due to State interest and (iv) there is abundant low cost labour and mild taxation (Pedni, 1981 and Aquacop, 1983).

The value of shrimp and shrimp products depends principally on size, quality, origin and species or colour. The shrimp farmer unlike fishermen can control the size of the prawn and time his harvest to meet market requirements. In addition the prawn farmer is able to provide a premium quality product since farms process their own prawns within a short time of capture (Wickins, 1986).

Although trapping and growing Penaeid shrimp in intertidal ponds have been a traditional

Domestic Year	Catches (1)	Imports (2)	Exports	Consumption
1976	60	123	2	181
1977	54	125	2	177
1978	60	144	2	202
1979	53	159	2	210
1980	51	143	2	192
1981	55	162	3	214
1982	58	151	3	206
1983	64	149	3	210
1984	62	169	3	228

(1) Live Weight

(2) Product Weight
(*M / T 000 s*)

Source: Infofish Marketing Digest

Table 4: *Japanese Consumption of Shrimp 1976 - 1982 (Wayland, 1986)*

practice for several centuries, in many countries of Southeast Asia, its culture is a relatively recent practice (Pedni, 1981). Shrimps were first artificially grown in 1934 and since then methods for their optimal rearing have been developed (Meske, 1985). Fuginaga, in 1934, successfully spawned and partially rared larvae of Penaeus japonicus in Japan for the first time (Kungvankiji, 1985) and led the way for mass culture of shrimps. However, it was not until the late 1960s and 1970s that the technology had developed to the point that commercial culture of crustaceans seemed possible (McVey, 1983).

2. Systematics

All shrimps, prawns, crabs, crayfish and similar animals are grouped together in the class Crustacea. Within this class there are over 30,000 species ranging from planktonic organisms of microscopic dimensions to the large bottom – living spider crabs and lobsters.

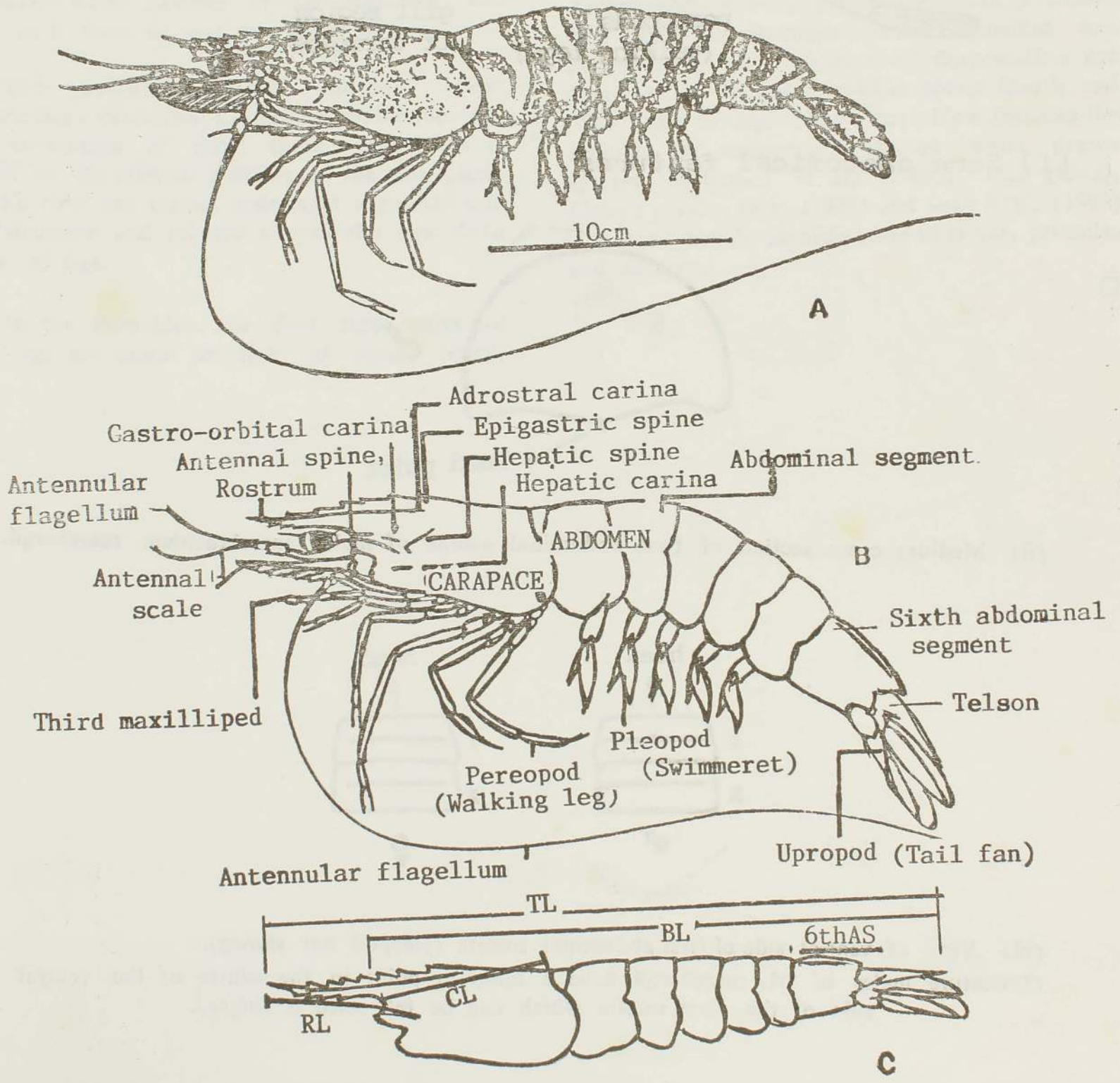
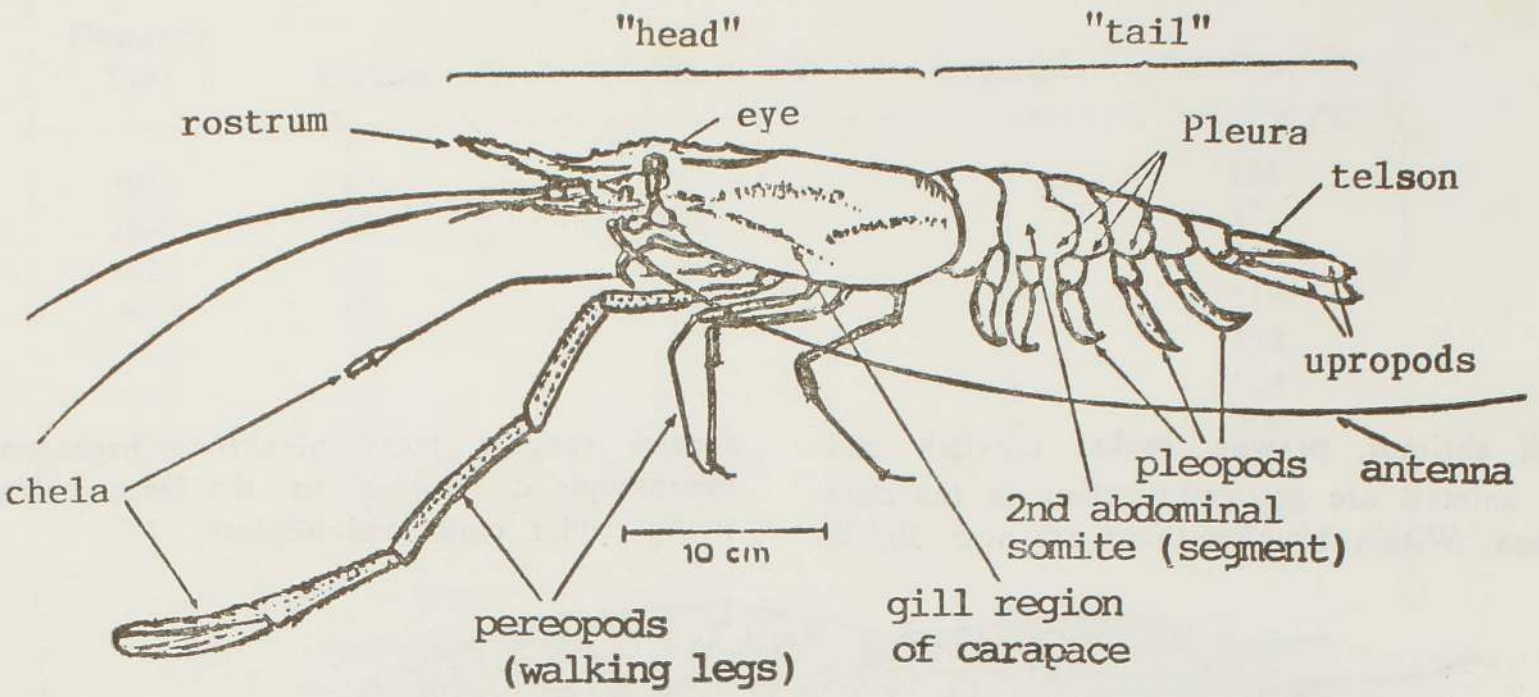
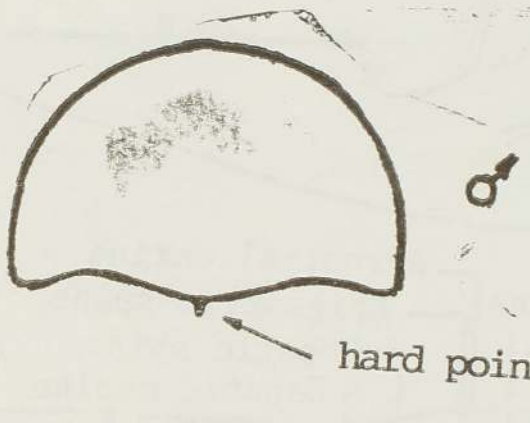


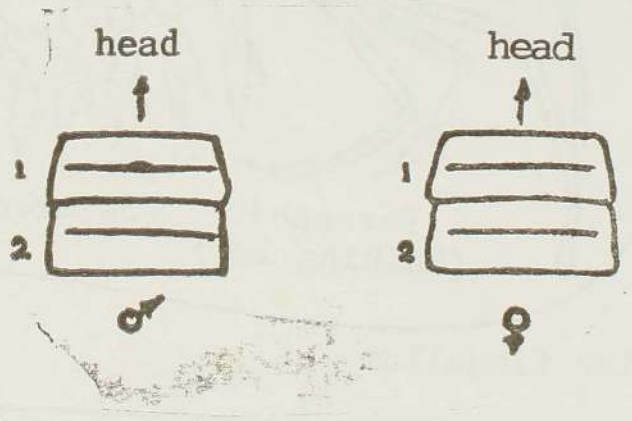
Fig. 3 : *A : Adult female of Penaeus monodon; B : External anatomy of P. monodon ; C : Methods of measurement of P. monodon (RL, rostrum length; CL, carapace length; TL, total length; BL, body length; 6th AS, length of 6th abdominal segment) (Motoh, 1984).*



(i) Some anatomical features



(ii) Medium cross section of first abdominal somite of male Macrobrachium rosenbergii.



(iii) View of ventral side of first abdominal somite (pleopod not shown).
(Immature males of **M. rosenbergii** have a lump or point in the centre of the ventral side of the first somite which can be felt with a finger).

Fig. 4 : *Some anatomical features and sexual differences of* **Macrobrachium rosenbergii**
(Diagrams based on Forster and Wickins, 1972.)

The Crustacean body is characterised by a hard external skeleton which is usually divided into head, thorax and abdomen with a tail piece - the telson. The possession of paired appendages, often especially modified for particular functions such as sensing, manipulating, walking, swimming etc. are also characteristic of Crustacea (Fig. 3 and 4).

Decapoda is one of the several orders within Crustacea and it includes crabs, crayfish, lobsters, prawns and shrimps. All Decapoda have a carapace which encloses the fused head and thorax including the gills and in crabs forms the main part of the animal. Behind the carapace is the abdomen - the edible portion of prawns and lobsters, which consists of six segments and ends in a more or less triangular telson.

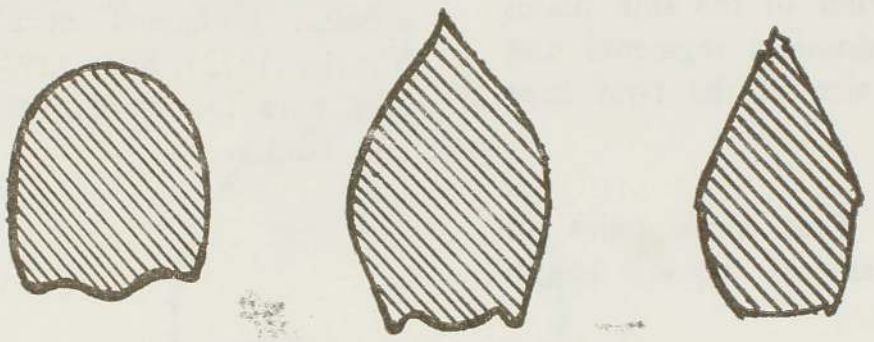
The suborder Natania includes three infraorders - Penaeidea, Caridea and Stenopodidae. The separation of these three infraorders is based on the relative position of the side plates of the first and second abdominal segments and the structure and relative size of the first three pairs of legs.

In the Penaeidea the first three pairs of true legs are more or less of equal length and are chelate, and the side plates of the second abdominal segment do not overlap those of the first. In Caridea, only the first two pairs of thoracic legs are chelate and the side plates of the second abdominal segment overlap those of the first (Fig. 3 and Fig. 5). In Stenopoidea the third pair of thoracic legs is much longer than the first two pairs and all three pairs are chelate. In addition the Caridea and Stenopdidea carry fertilised eggs below the abdominal segments of the female whereas those of Penaeidea are released directly into the sea.

Representatives of the Caridea include fresh and brackish water shrimps and prawns (family Paleaeomonidae) and snapping shrimps (family Alphaeidae). The infraorder Penaeidea is divided into two superfamilies - the Penaeoidea and Sergestoidea. The members of Sergestoidea are characterised by the reduced or absent fourth and fifth pairs of legs. The Penaeoidea includes the majority of commercial shallow water prawn species. Mohamed et al. (1968), Rao (1972), Tirmizi (1972), Silas (1978) and Grey et al. (1983) give keys for the identification of larvae, juveniles and adults. □

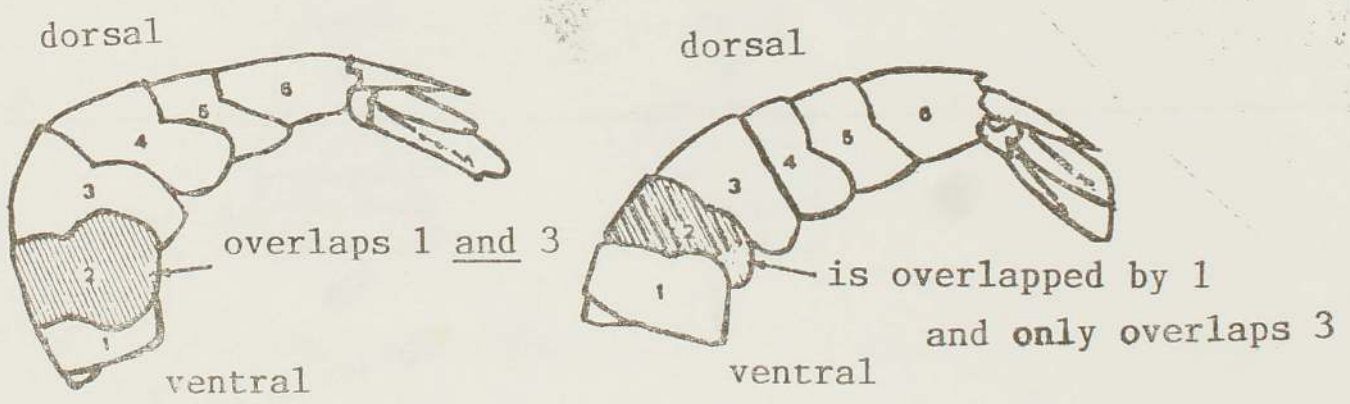
3. Morphology

In *Penaeus monodon* sexes are separate and could be distinguished by the presence of the petasma and a pair of appendix masculina in male and thelycum in female. The petasma is located between the first pleopod and the appendix masculina on the exopods of the second pleopod (swimming legs), while the thelycum is between the 4th and 5th pereopods (walking legs). In the male, a pair of genital openings is situated on the coxae of the fifth pereopods and in the female on the coxae of the third pereopods. Females are relatively larger in size than males (Fig. 6).



(A) M. rosenbergii P. latisulcatus P. duorarum

(i) Cross section of abdominal segment



(ii) Side view of abdomen (head removed ; pleopod not shown) showing difference in overlapping of pleura.

Fig. 5 : *Distinguishing characteristics between* **Macrobrachium** *spp and* **Penaeus** *spp.* (*Fincham and Wickins, 1976*).

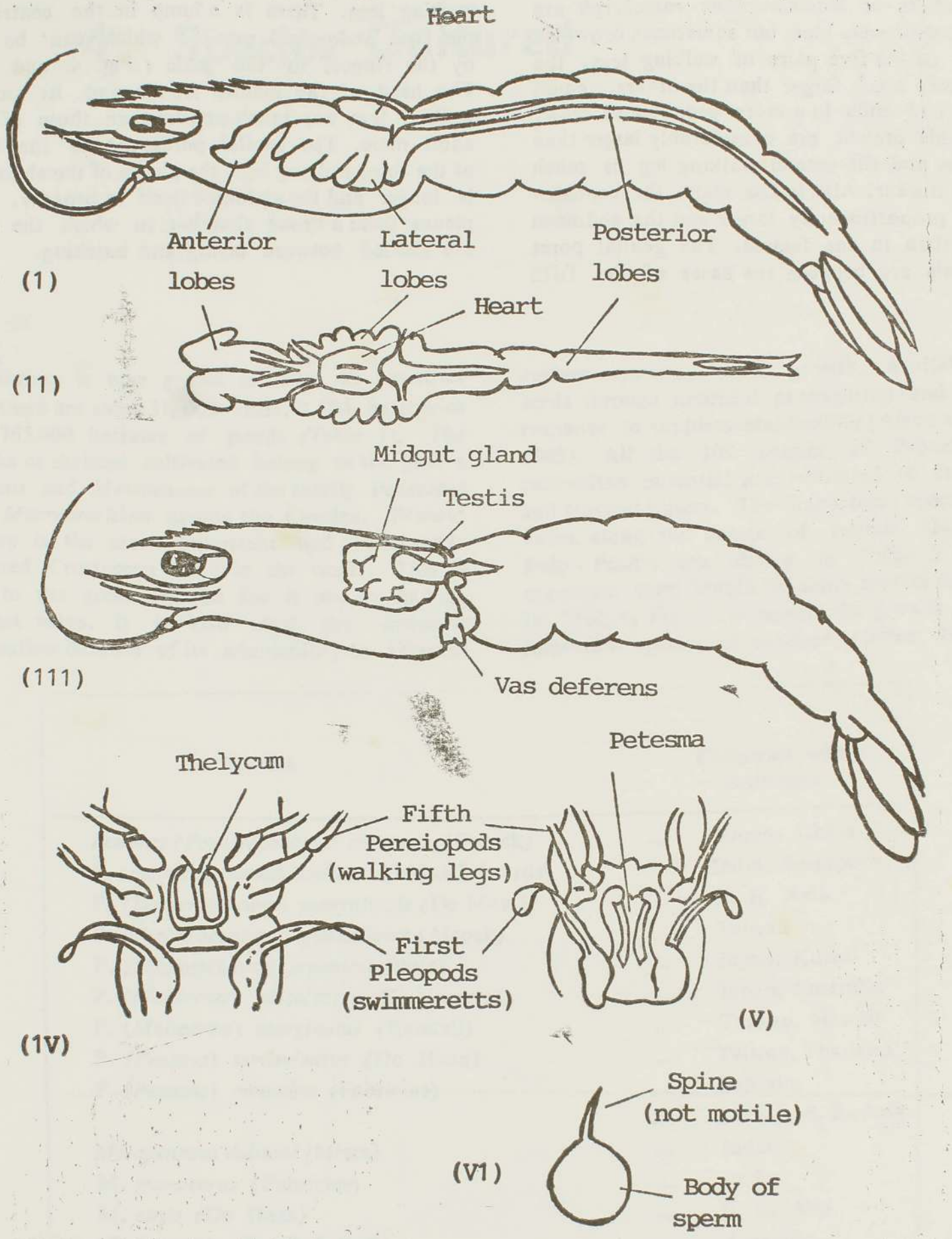


Fig. 6 : *Reproductive structures in a Penaeid prawn. (i) The ovary* **in situ,** *lateral view; (ii) dorsal view showing the ovarian lobes and position of the heart ;* **(iii)** *the testis* **in situ,** *lateral view;* **(iv)** *external genitalia of the female, ventral view;* **(v)** *external genitalia of the male, ventral view;* **(vi)** *one spermatozoa (Wickins and Beard, 1972).*

The adults of *Macrobrachium rosenbergii* are normally distinctively blue, but sometimes brownish in colour. Of the five pairs of walking legs, the second is very much larger than the others, equal in length and ends in a more pronounced claw. Mature male prawns are considerably larger than the females and the second walking leg is much larger and thicker. Also in the male, the cephalothorax is proportionately larger and the abdomen narrower than in the female. The genital pores of the male are between the bases of the fifth walking legs. There is a lump in the centre of the first abdominal somite, which can be felt by the finger, in the male (Fig. 4 and 5). The head of the mature female and its second walking legs are much smaller than those of the adult male. The genital pores are at the base of the third walking legs, the pleura of the abdomen is longer and the abdomen itself is broader. The pleura form a broad chamber in which the eggs are carried between laying and hatching.

4. Species Cultured

Shrimp is now grown in over 40 countries and there are some 31, 000 farms, 3,500 hatcheries and 765,000 hectares of ponds (Table 1). The species of shrimps cultivated belong to the genera *Penaeus* and *Metapenaeus* of the family Penaeidea and *Macrobrachium* among the Caridea. Penaeid shrimp is the most important and extensively cultured Crustacean all over the world. This is due to the great demand for it and to its high market value. It is also ideal for intensive cultivation because of its adaptability to different culture systems, rapid growth, availability of seeds through artificial propagation and positive response to supplemental feeding (Alava and Lim, 1983). All the 109 species of Penaeids with cultivation potential are restricted to subtropical and tropical waters. The important species cultivated along the coasts of Indian Ocean and Indo - Pacific are shown in Table 5 and the maximum total length of some species are shown in Table 6. Fig. 7 compares the growth of some important species of shrimps (Jones, 1988).

Species		Countries where cultivated
Penaeus (Fenneropenaeus) chinensis (Osbeck)	...	Korea, China
P. *(Fenneropenaeus) indicus* (Milne Edwards)	...	India, Singapore
P. *(Fenneropenaeus) merguiensis* (De Man)	...	S. E. Asia
P. *(Fenneropenaeus) penicillatus* (Alcock)	...	Taiwan
P. *(Marsupenaeus) japonicus* (Bate)	...	Japan, Korea
P. *(Melicertus) latisulcatus* (Kishinouye)	...	Japan, Australia
P. *(Melicertus) marginatus* (Randall)	...	Taiwan, Hawaii
P. *(Penaeus) semisulcatus* (De Haan)	...	Taiwan, Thailand
P. *(Penaeus) monodon* (Fabricius)	...	Bahrain,
	...	Kuwait, S. E. Asia
Metapenaeus dobsoni (Miers)	...	India
M. *monoceros* (Fabricius)	...	India
M. *ensis* (De Haan)	...	S. E. Asia
M. *bennettae* (Racek & Dall)	...	Australia
M. *brevicornis* (Milne Edwards)	...	India, Thailand
M. *joyneri* (Miers)	...	Korea, Japan
M. *stebbingi* (Nobili)	...	Bahrain, Kuwait
M. *macleayi* (Haswell)	...	Australia

Table 5 : *Important species of Penaeid prawns cultivated along the coasts of Indian Ocean and Indo - Pacific (Muthu et al., 1982).*

Species	English Name	Maximum total length (cm)	Average Number per kg
Penaeus monodon (Fabricius)	giant tiger prawn	35	5 — 6
P. *merguiensis* (de Man)	white prawn, banana prawn	25	7 — 8
P. *indicus* H. (Milne-Edwards)	white prawn, Indian prawn	22	10 — 12
P. *semisulcatus* (de Haan)	green tiger prawn	23	8 — 9
Metapenaeus ensis (de Haan)	greasy - back prawn	20	13 — 15
M. *brevicomis* (H. Milne Edwards)	yellow prawn	15	45 — 50
M. *affinis* (H. Milne - Edwards)	pink prawn	17	20 — 30

Table 6 : *Species of Penaeidae Widely Distributed in the Indo-Pacific Region that Support Important Fisheries and are Closely Associated with Mangrove Environments (Macintosh, 1982).*

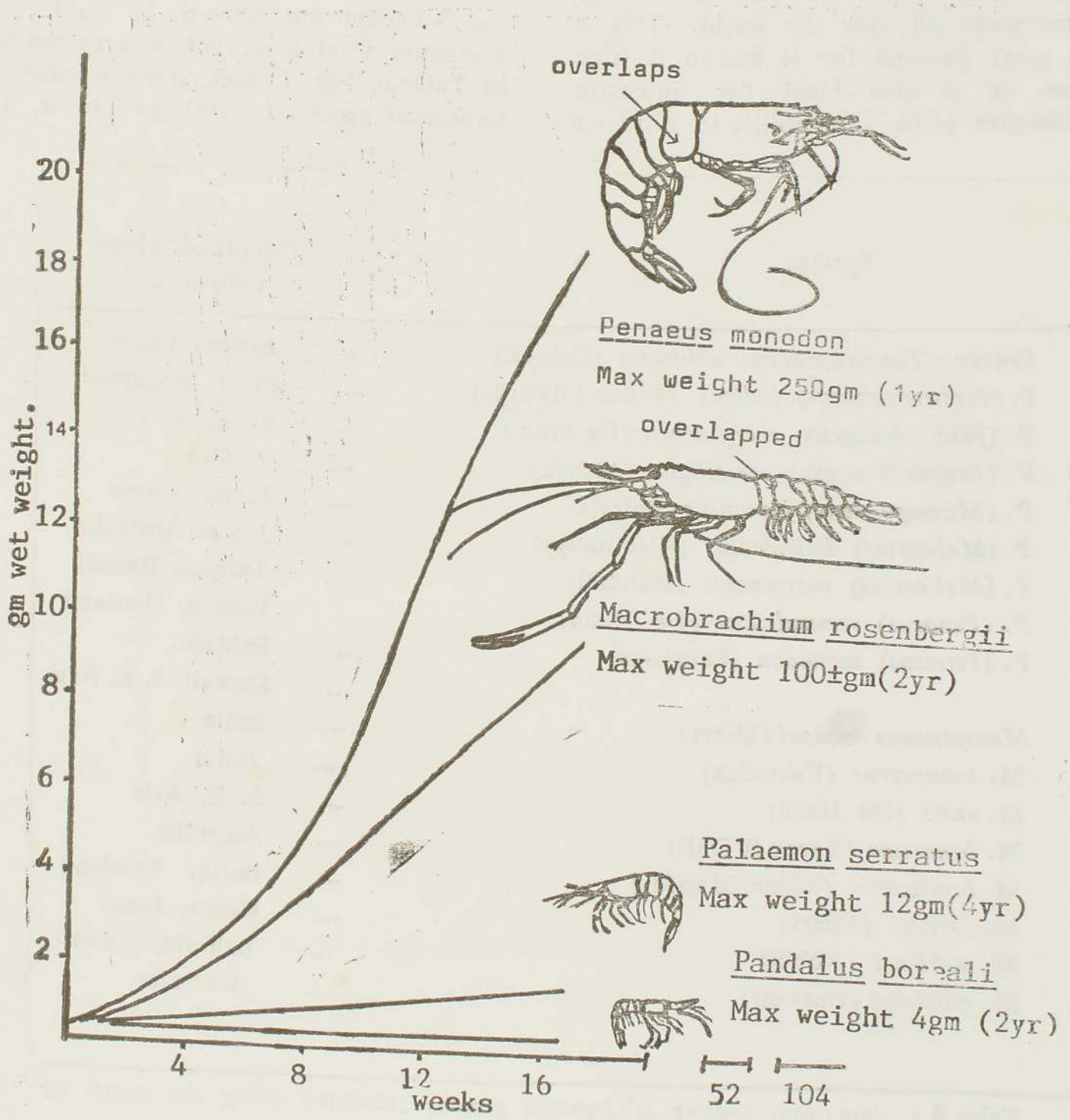


Fig. 7 : *Growth rate of tropical and temperate prawns (Jones, 1988).*

Fig. 8 (a) :

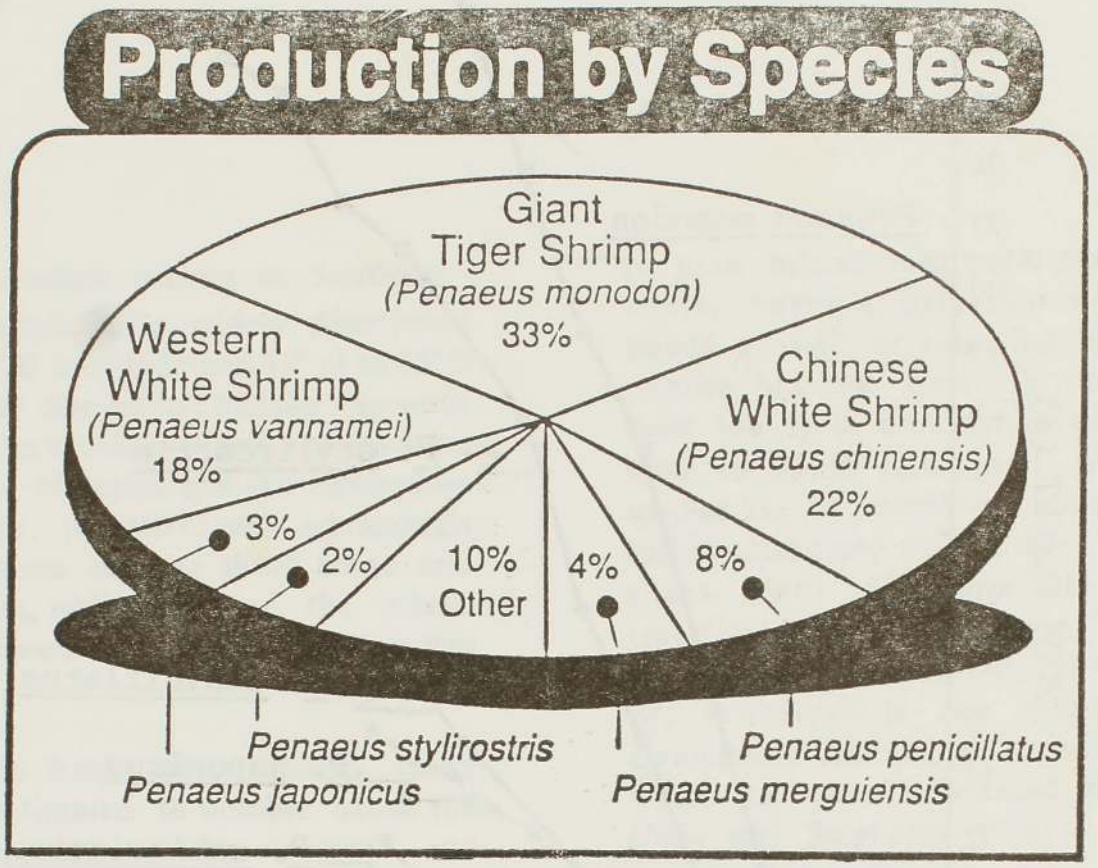
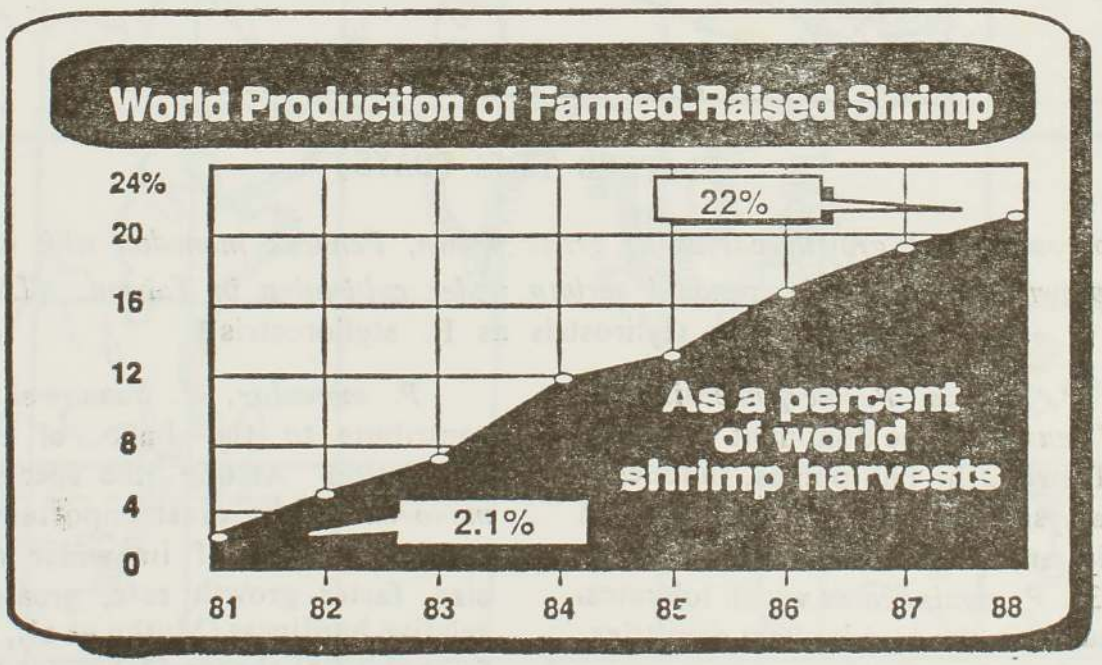


Fig. 8 (b) :



(*Rosenberry 1989*)

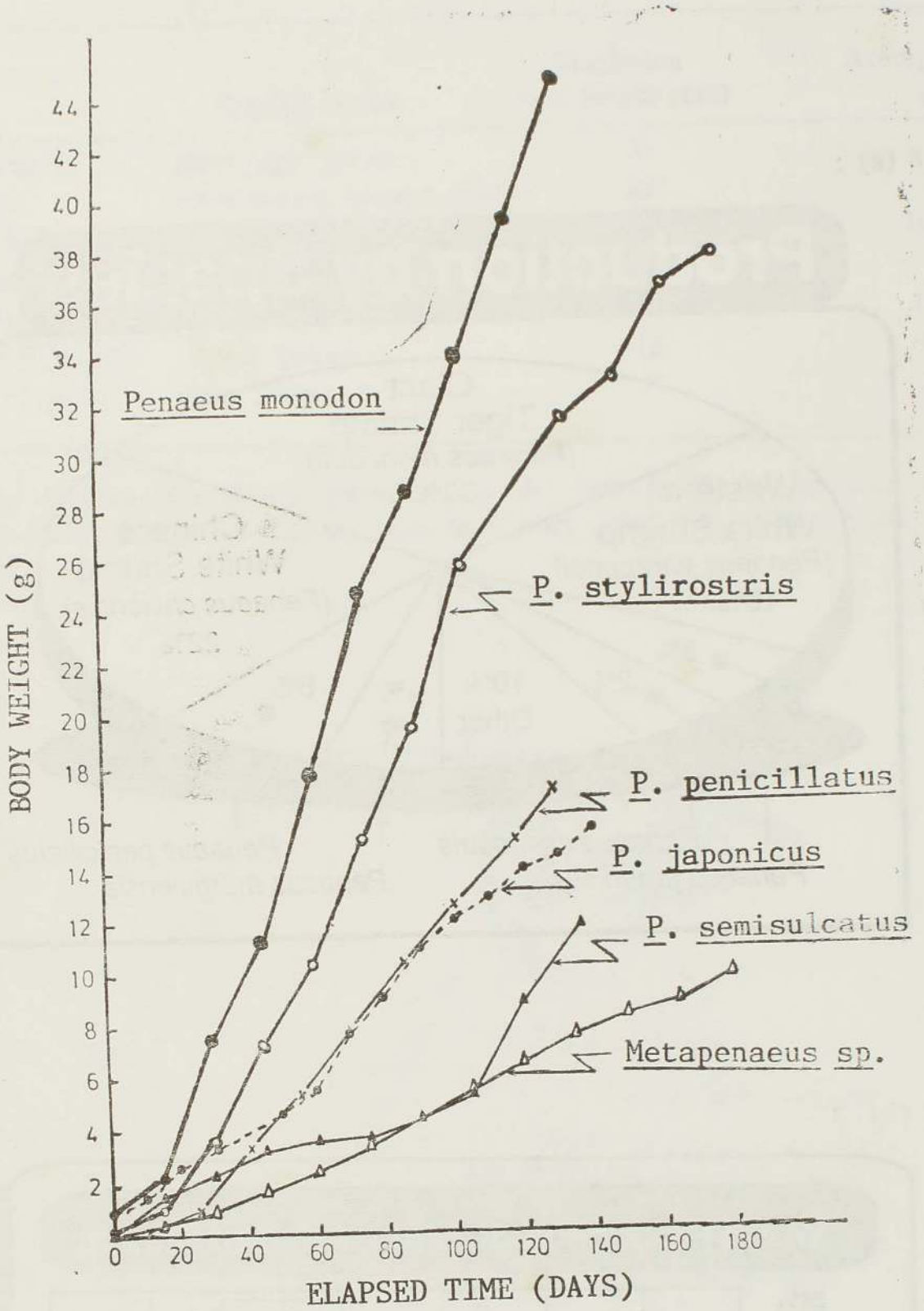


Fig. 9 :*Comparison of growth curves of grass prawn, Penaeus monodon with another four Penaeid prawns and one Metapenaeid shrimp under cultivation in Taiwan. (Liao, 1984)*
(Read P. stylirostris as P. styliorostris)

P. monodon, *P. indicus*, *P. merguniensis*, *M. monoceros* and *M. ensis* are the dominant cultured species in India, Taiwan, the Philippines, Indonesia, Thailand and Malaysia. In Ecuador and Panama the cultured species are *P. vannamei* and *P. stylirostris* (Pretto, 1983). *P. semisulcatus* which tolerates, high salinity is reared in the Middle East countries. The best species for the temperate waters are *P. japonicus*, *P. oriantalis* and *P. setiferus* which are mainly cultured in Japan, Korea and US respectively (Aquacop, 1985).

P. monodon, *P. vannamei* and *P. japonicus* contribute to the bulk of the current world production. Among the species of *Penaeus*, *P. monodon* is the most important as a candidate species in view of its wider distribution, larger size, faster growth rate, greater fecundity and relative hardiness (Muthu et al., 1982) and accounts for a third of the world harvest (Fig. 8 and 9). But Expansion of farming in China is bringing up the Chinese white shrimp *P. chinensis* which follows the *P. monodon* with 22%. In the third place is the Western white shrimp *P. vannamei* (Rosenberry, 1989) Fig. 8.

□

5. Distribution

P. monodon occurs mainly in Southeast-Asian waters, though it is widely distributed from 30° E to 155° E longitude and 35° N to 35° S latitude. However, the main fishing grounds are mostly located in tropical countries, particulary in Indonesia, Malaysia and the Philippines (Fig. 10). The fry, juveniles and adolescents inhabit surface waters such as shore areas and mangrove estuaries, while most of the adults inhabit waters down to about 160 meters (Motoh, 1984).

Species of the fresh water prawn genus *Macrobrachium*, estimated to number about 100 are distributed throughout the tropical and subtropical zones of the world. They are found in most inland fresh water areas including lakes, rivers, swamps, irrigation ditches, canals and ponds as well as estuarine areas. Most species require brackish water in the initial stages of their life cycle although some complete their cycle in inland saline and fresh lakes. Some species like *M. rosenbergii* are found in extremely turbid conditions while others prefer clear water rivers. Many *Macrobrachium* sp. have been transferred from their natural location to other parts of the world, initially for research purposes. *M. rosenbergii* is the species most used for commercial farming and consequently is the one which has been introduced to more countries (New and Singholka, 1985).

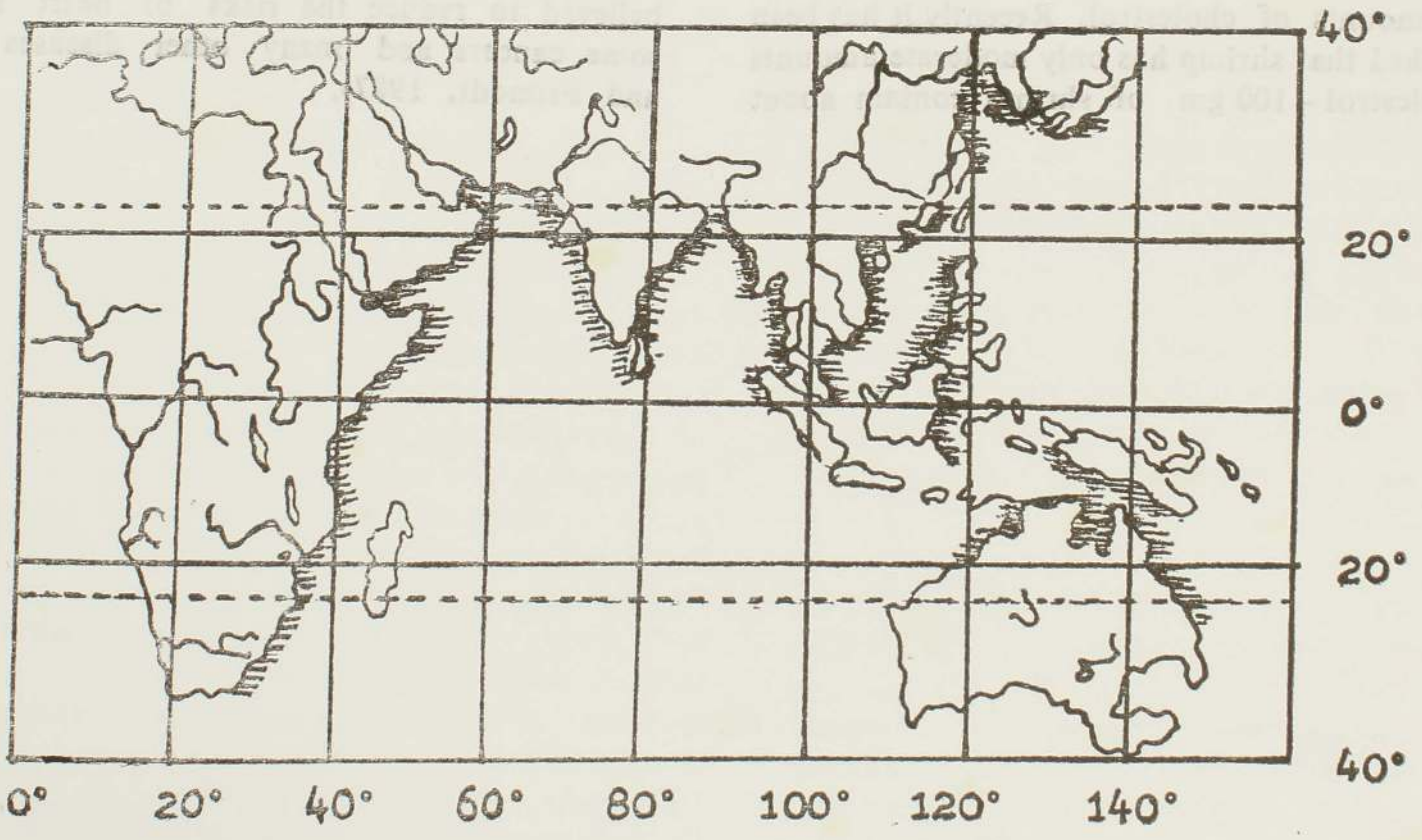


Fig. 10 : *Geographical distribution of* **Penaeus monodon** *(Based on Grey et al., 1983)*

6. Nutritional Value

In shrimps, with exception of parts of the ovaries and straight gut, which can be easily removed, the major internal organs are located in the cephalothorax. In Penaeids, the abdomen is primarily muscle tissue, constituting 60% of the entire body weight (Bayagbona et al., 1971). The exoskeleton which forms a firm, protective covering around the tail, prevents damage during handling and resists entry of bacteria that would cause spoilage (Kurian and Sebastian, 1976). The exoskeleton, together with the fact that shrimp flesh freezes well, facilitates handling and processing. The almost universal acceptability and demand for shrimp as a food item is a result of their unique flavour, texture and versatility (Neal and Maris, 1985).

Shrimp was at one time thought to contain large amounts of cholestrol. Recently it has been established that shrimp has only moderate amounts of cholestrol - 100 gm of shrimp contain about 100 mg of cholestrol which is about one third the amount in one egg. Though the cholestrol levels in shrimps are higher than in most sea foods, it is still lower than in most other animal protein foods. The content of essential minerals, calcium and phoshorus is also high. Shrimp also contains good amounts of other minerals and vitamins.

On an average, shrimp contain about 20% of protein, very small amounts of carbohydrates (0 — 2. 7%) and between 0.4 and 1. 2% of fat. There are about 90 — 100 calories in 100 gm of shrimp. Shrimp is a high protein food, low in fats and is exceptionally nutritious. The fat is predominantly polyunsaturated with useful amounts of omega - 3 fatty acids which help to reduce cholestrol levels in the blood and are believed to reduce the risks of heart attacks, some cancers and many other diseases (Dore and Frimodt, 1987).

□

7. Longevity and Sex Ratio

The longevity of *P. monodon* is estimated to be about one and a half years for males and about two years for females. This estimate is based on data from pond rearing experiments and size compositions of wild specimens (Motoh, 1984).

Initial stocking of *P. monodon* in maturation tanks and pens at a 1 : 1 ratio has been based on an assumed safety factor rather than on experimental data. In a study on different sex ratios, the 1 male : 2 female ratio produced the highest % of spawnings, highest average fecundity and the greatest total number of eggs. Stocking at an initial 1 male : 2 female ratio has been found to be economical because it maximises the number of females per tank. □

8. Maturation

Within the last decade, two important advances in brood stock management have occurred with promise to reduce the reliance in wild stocks. They are (i) the ability to artificially induce maturation and spawning in most Penaeid species (ii) the development of techniques for artificial impregnation of the most important culture species.

In Penaeid prawns mating and spawning are independent processes. Spawning can take place in the absence of the male, the female herself releasing the sperms from the thelycum at the time of oviposition. The female should be impregnated for obtaining fertilised eggs. But in captivity an unimpregnated female can be induced to mature and spawn after eyestalk ablation, but the eggs will not be fertilised. To avoid this, ablation of eyestalk should be done on impregnated females only. Maturation and ovulation by captive *P. monodon* were achieved through eye - stalk ablation by Liao (1973), Arnstein and Beard (1974) and Alikunhi et al. (1975). However, these workers failed to obtain fertilised eggs. Santiago (1977) was the first to obtain viable eggs of *P. monodon* through eye-stalk ablation. He reared fry of *P. monodon* from wild adult stock in brackishwater ponds, transferred them to marine pens, unilaterally ablated them and succeeded in breeding them (Halder, 1978).

Liao and Chen (1983) lists the following nine different methods employed in the ablation of the female: 1. Pinching the eyestalk or crushing the eyeball between the fingers. 2. Ligating the base of the eyestalk. 3. Cutting the eyestalk with surgical scissors. 4. Severing the eyestalk prior to cauterizing with a soldering iron. 5. Severing the eyeball with a razor. 6. Squeezing the eyestalk tissue. 7. Crushing the eyestalk after emptying the eyeball through an incision. 8. Removing the eyestalk with hot surgical clamps and 9. Penetrating the eyeball with a lancet. Muthu and Laxminarayana (1977) observed that cautery prevented bleeding and produced little mortality in *P. indicus* and *P. monodon*. Browdy and Samocha (1985) attributed good survival of ablated *P. semisulcatus* partly to the use of electro - cautery which prevented bleeding and infection. Makinouchi and Primavera (1987) using different ablation methods found that eyestalk cautery and ligation give significantly higher female survival and mean hatch rates compared to pinching in *P. indicus*.

Although the ablation technique provides the culturists greater scope for extending the natural breeding season and for culturing certain species outside their natural geographic range, the operation usually results in reduced longevity, fecundity and egg - hatch rate by comparison with naturally maturing females (Wickins, 1986).

The success with which courtship and impregnation occurs in some captive species varies widely, but the reasons for this are not well understood. They may be associated with environmental factors such as tank size, illumination, disturbance and the general condition of the females. *M. rosenbergii* and some species of open thelycum Penaeids have been artificially impregnated. *P. monodon* and *P. japonicus* with enclosed thelycum have also been artificially impregnated by implanting electro - ejaculated spermatophores from males into newly moulted soft shelled females. Spermatophores could be induced to protrude half way out of the terminal ampoules of males by applying short alternating current discharges (5 V) at the bases of the fifth pair of periopods. They could then be extracted completely using surgical tweezers to grasp them at the level of the chitinous lamellae. By using electric current it is thus possible to avoid causing any permanent damage to the terminal ampoules. The

terminal ampoules take on a blackish colour, probably due to cell lysis, when subjected to manual squeezing (Lumare, 1981).

If the eyestalk ablation is done on healthy animals no mortality occurs. To follow each famale individually in a tank, each female is double tagged. A coloured elastic silicone ring bearing a label is inserted around the remaining eyestalk and another label with a number is glued on the cephalothorax. The first tag stays on the animal after moulting while the other is found on the discarded carapace (Aquacop, 1983).

Eyestalks of Decapod Crustaceans are known to have an X-organ, secreting a moulting inhibiting hormone (MH) and a gonad inhibiting hormone (GIH). Eyestalk ablation reduces hormonal production of gonad - inhibiting hormone and accelerates vittellogenesis (Liao and Chen, 1983). The removal of eyestalks that contain the X-organ - sinus gland complex which produces and stores gonad inhibiting hormones in Decapod Crustaceans has become a well recognised technique for inducing gonadial maturation (Adiyodi and Adiyodi, 1970). Idyll (1971) and Caillouet (1973) applied this method first on *Penaeus duorarum*. Maturation of ovaries is said to be stimulated by the gonad stimulating hormones secreted by the brain and thoracic ganglia and inhibited by the gonad inhibiting hormone of the eyestalk. But the very fact that, in nature, the prawn is able to mature and spawn with both eyes intact suggests that the antagonism of eyestalk principle may be reduced by a decline in the titre of the GIH as the prawn grows and moves into an environment suitable for spawning and the final spawning act may be triggered by a stimulus, either visual or hormonal, originating in the eyestalk. In the unilateral eyestalk ablation the titre of GIH is artificially lowered and this appears to stimulate vitellogenesis (Muthu and Laxminarayana, 1982).

□

9. Brood Stock and Mating

The availability of quality prawn seeds as and when required by culturists is one of the basic requirements for proper planning of the culture operations. The distribution pattern and abundance of prawn seeds in the coastal lagoons, estuaries and brackish water areas fluctuate widely due to biological and physical factors and therefore the supply of post-larvae from the wild is extremely unpredictable (Fig. 11). Inadequate supply of prawn seeds forms a major

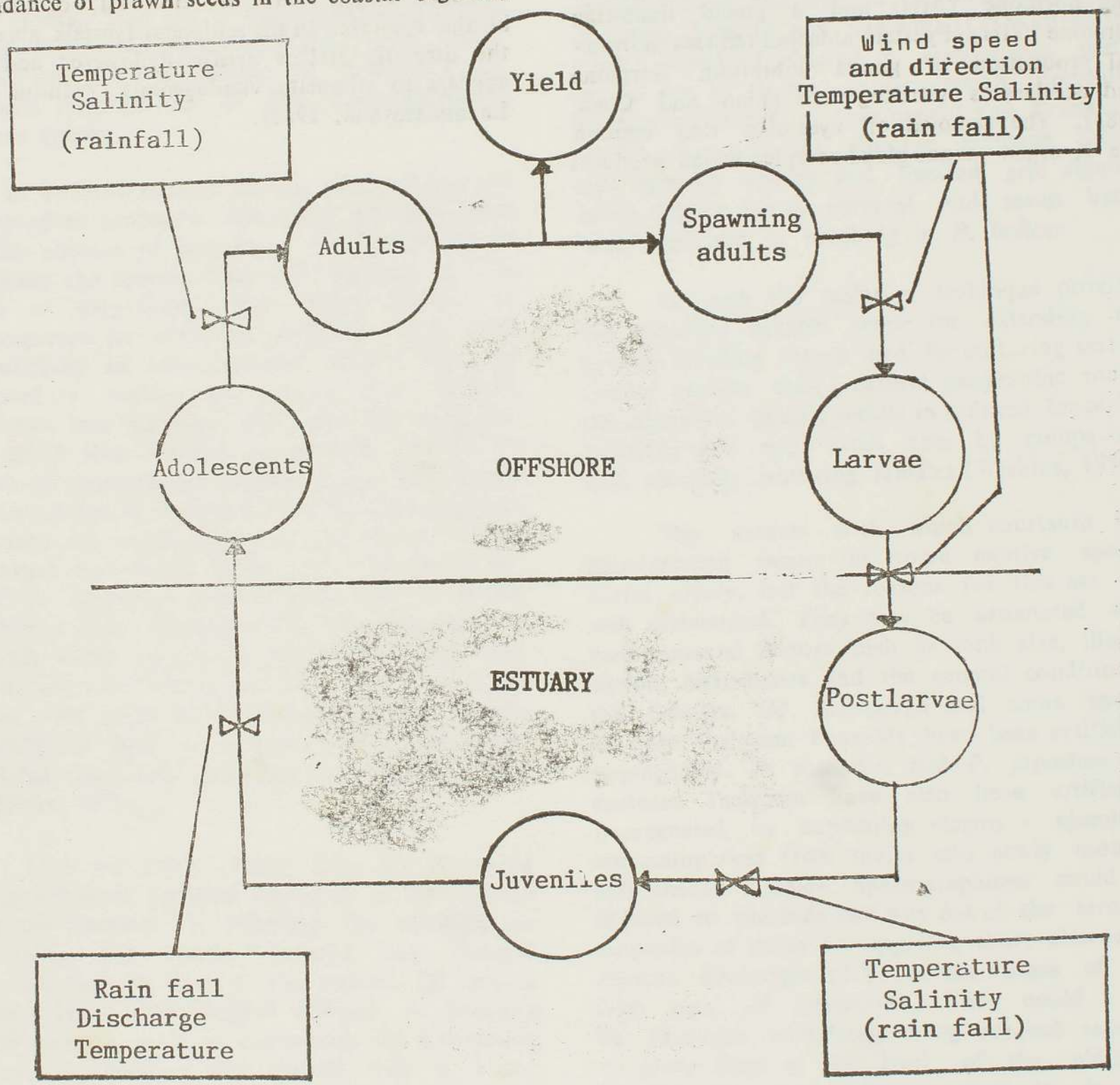


Fig. 11 : *Life history diagram of a Penaeid shrimp showing factors influencing yearly fluctuations in catch.* (*Vance et al., 1983.*)

constraint in the development of prawn culture. To overcome this, hatchery propagation of Penaeid prawns under controlled conditions has been perfected in Japan, Korea and Taiwan and is being developed in other countries of the region such as the Philippines, Indonesia, Australia, Thailand, Hawaii, Malaysia, India, Bangladesh, SriLanka, Bahrain and Kuwait (Primavera, 1982).

The biggest constraint in hatchery production of post-larvae is the non-availability of an adequate number of spawners of the desired species as and when required. Apart from Japan where there is a well organised trade in the capture and transport of live adult *P. japonicus* from the sea, the securing of ripe spawners for hatcheries is an uncertain and costly operation.

Macrobrachium matures and breeds easily in captivity and therefore poses no problems in the production of post-larvae while the female Penaeid prawn rarely undergoes natural ovarian maturation away from the sea, hence the high price paid for wild spawners.

The males use the petasma to transfer the sperm sac to the thelycum of the female. A female with a closed thelycum must be soft shelled before she can mate because the sperm sac is placed in the thelycal chamber by the male. The tips of the thelycum can only be parted while they are soft. Females with an open thelycum are presumably capable of mating at any time. (Fig. 6).

P. monodon is a Penaeid with a closed thelycum and therefore moulting of the female is a prerequisite to mating because insertion of the spermatophores can only take place when the thelycum is soft. The newly moulted female attracts upto three males who follow her a round, but only one male is able to position himself directly below the female. As the pair swims, the male turn ventral side up trying to align his thorax with that of the female. Once successful the male turns perpendicular to the female, curves his body in a U-shape around her and flicks head and tail simultaneously up to three times in a row, all these steps in quick succession. The whole process may take 30 minutes to three hours (Primavera, 1979) (Fig 12).

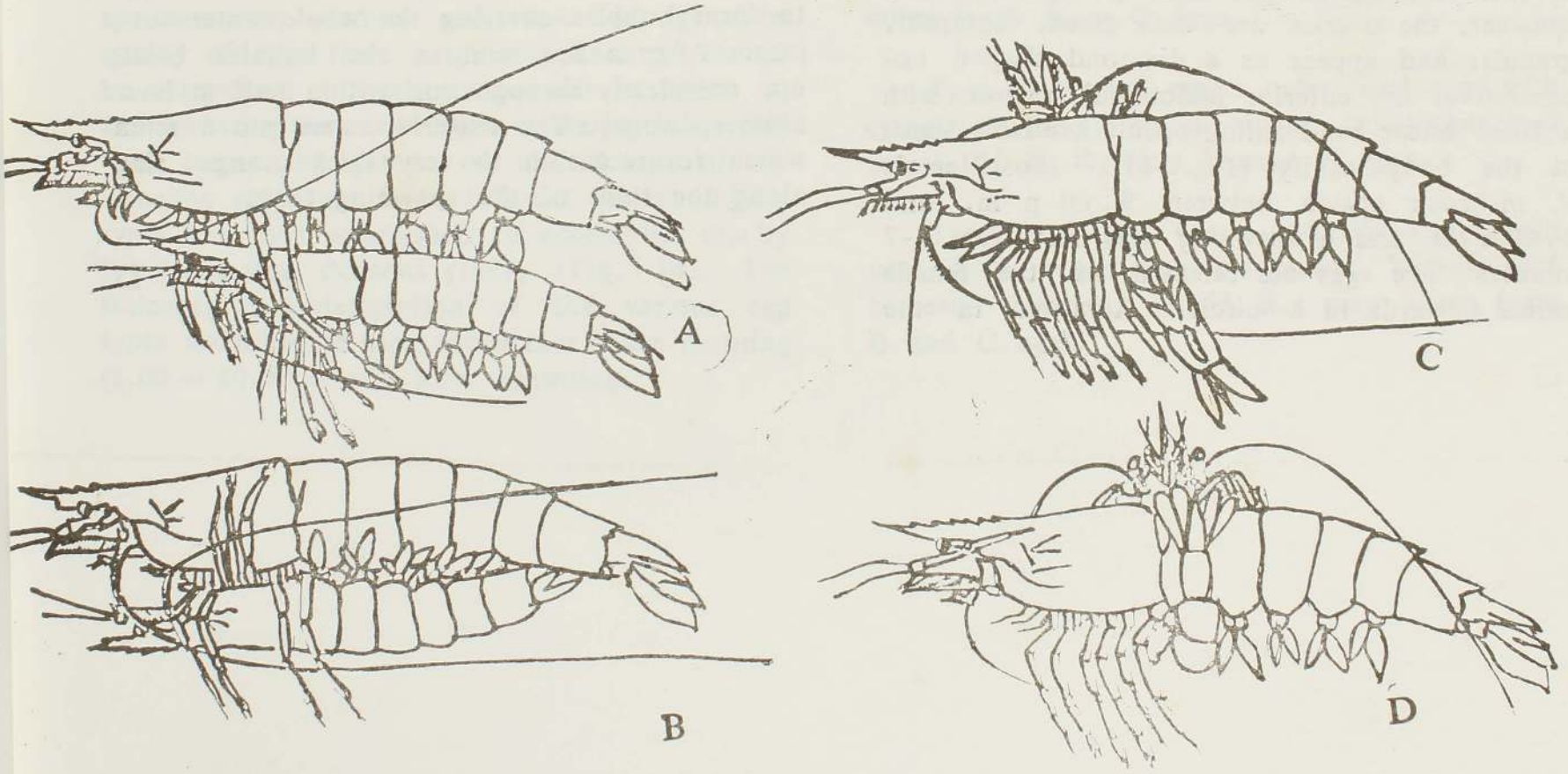


Fig. 12 : *Courtship and mating behavior of Penaeus monodon. A : Female above, male below in parallel swimming (phase 1). B : Male turns ventrol side up and attaches to famale (phase 2). C : Male turns perpendicular to female (phase 3a). D : Male curves body around female and flicks head and tail simultaneously (phase 3b) (Primavera, 1979).*

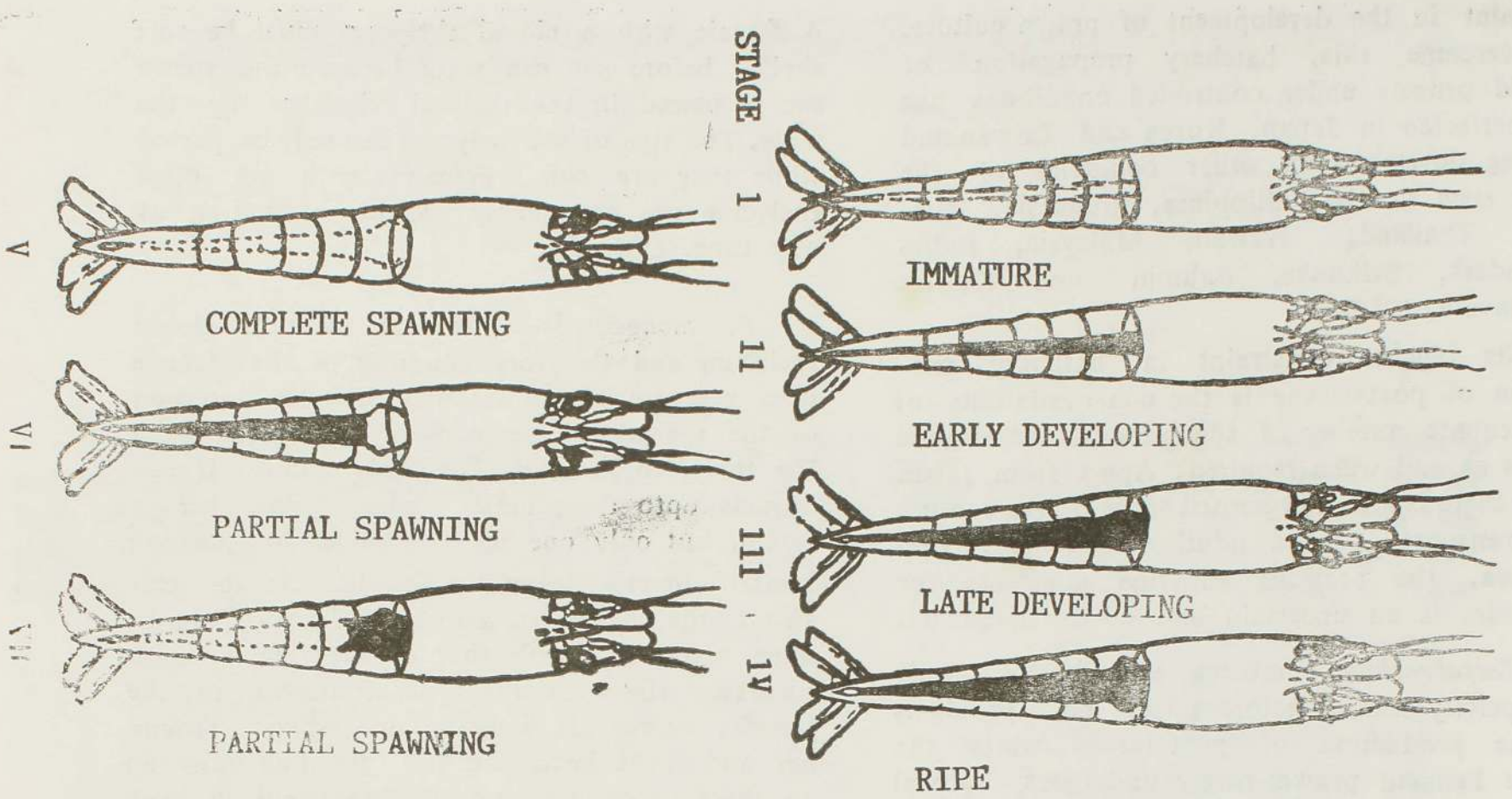


Fig. 13 : *External appearance of the ovaries of P. monodon at* **different stages of** *maturity as seen through the dorsal exoskeleton (Primavera, 1983).*

The stage of maturity of the spawners could be seen holding a light laterally. In a mature spawner, the overies are dark green, compact, granular and appear as a diamond shaped expansion at the anterior abdominal region with a thick linear band filling up all available space in the body cavity (Fig. 13). Most female *P. monodon* spawn between 9.00 p.m. and 2.00 a m. and a spawning may last from 2-7 minutes. The eggs are released, as the female swims upwards in a circle Aeration in the spawning tank causes the ovarian material released in to the water together with the eggs to form bubbles covering the whole water surface. After a few minutes, the bubbles break up, completely disappearing within half an hour after spawning. The material turns into a scum which forms a thin to very thick orange ring along the tides of the spawning tank.

□

10. Fecundity and Egg Quality

Extremely high fecundity is characteristic of penaeids and a female may spawn from several thousand to one million or more eggs depending on the species and shrimp size (Neal and Maris, 1985). The number of eggs produced in a complete spawning ranges from 200,000 to 1,000,000 with an average of 500,000 eggs for *P. monodon* spawners caught in the wild. The range for ablated females is 100,000 to 800,000 with an average of 200,000 for ablated pond stock and 300,000 for ablated wild stock. Female prawns of *M. rosenbergii* are reported to lay from 80,000 to 100,000 eggs during one spawning when fully mature.

In *P. monodon*, both wild and ablated spawners may produce good and bad eggs. The quality of eggs from a given spawning should be determined as early as possible in order to avoid wasting time and efforts in rearing inherently weak larvae. A system of classification of *P. monodon* eggs into five different morphological types has been established to accomplish this by Primavera and Posadas (1981) (Fig. 14). The following is a description of the various egg types according to their appearance in the morning (8.00 — 10.00 a. m.) after spawning.

Type A_1 or good eggs : nauplius undergoing normal development with distinct setae (only the morula or many - celled stage may be visible if the female spwned late, e. g. 5-00 a. m.) : mean hatching rate (H. R.) 58%; larvae strongly phototactic, i. e they actively swim towards a source of light.

Type A_2 or not so good eggs : development of embryo either delayed or abnormal in comparison to A_1 eggs belonging to the same batch; mean H. R. 32%; newly - hatched naupli may be weak.

Type B or bad eggs : unfertilised eggs showing irregular cytoplasmic formations; 0% H. R; may come from A or C eggs.

Type C or bad eggs : unfertilised eggs with cytoplasm remaining a single undifferentiated mass; 0% H. R; may become B eggs.

Type D or bad eggs : unfertilised eggs with very little remaining cytoplasm because of bacterial invasion; 0% H. R.; may come from B and C eggs.

□

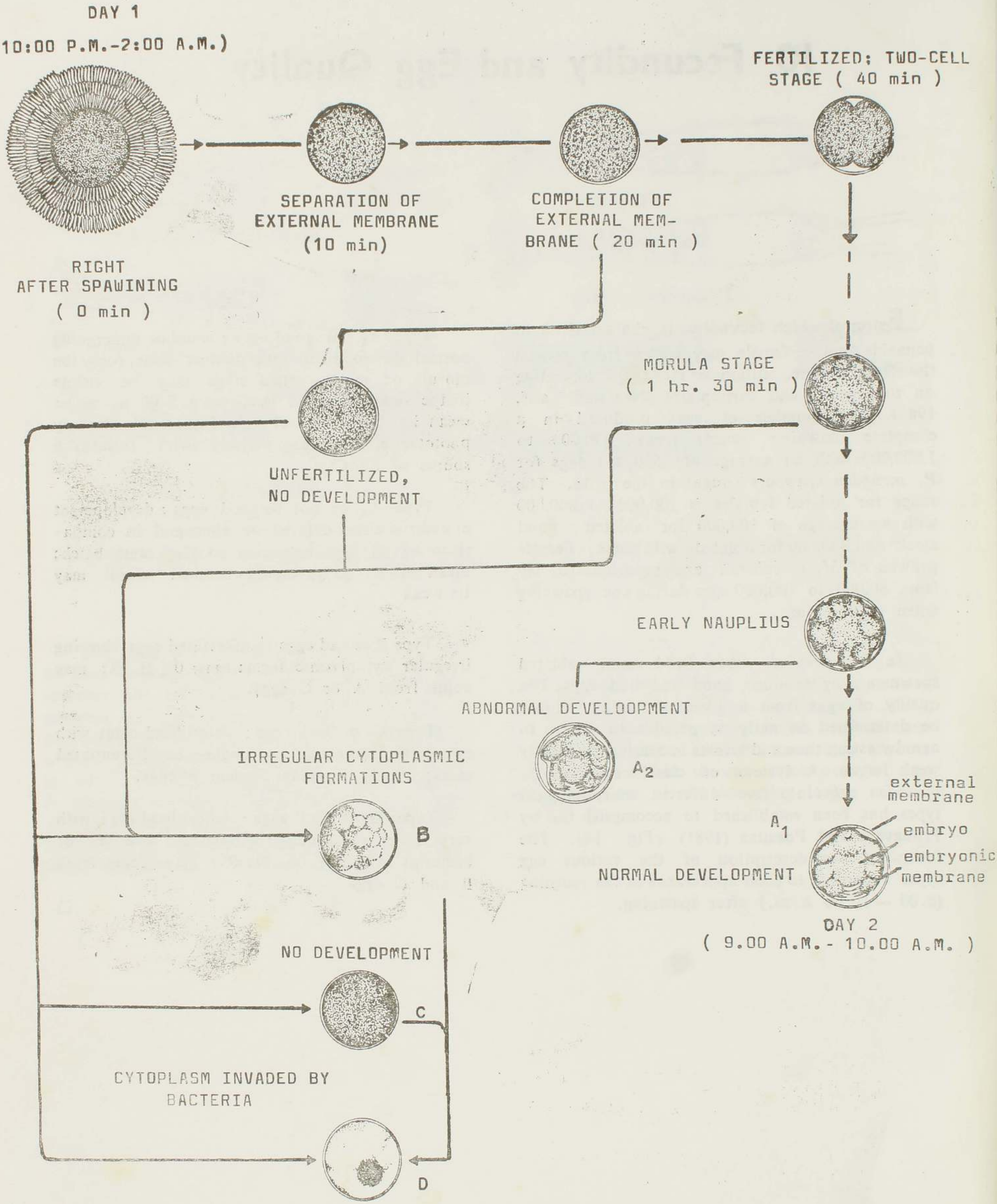


Fig. 14: *Development of different egg types of* **Penaeus monodon** *from immediate post – spawning (between 10-00 p. m. and 2-00 a. m.) to the following morning (9-00 to 10-00 a. m.) (after Primavera and Posadas. 1981).*

II. Life Cycle

Species of prawns are found in a variety of habitats ranging from the ocean depths to inland streams and lakes and from tropics to the sub - polar region. In spite of their diversity of habitat, prawns show many similarities in their biology (Foster and Wickins, 1972).

The development of Penaeidae larvae differs from that of the Caridea (Fig. 15). Penaeid prawns spend much of their life in coastal waters burrowing in shallow muddy substrates during day and feeding at night on benthic invertebrates. They migrate into deeper waters at the onset of maturation and spawning by releasing up to 500,000 small pelagic eggs. Fig. 16 shows the various embryonic developmental stages of *P. monodon*.

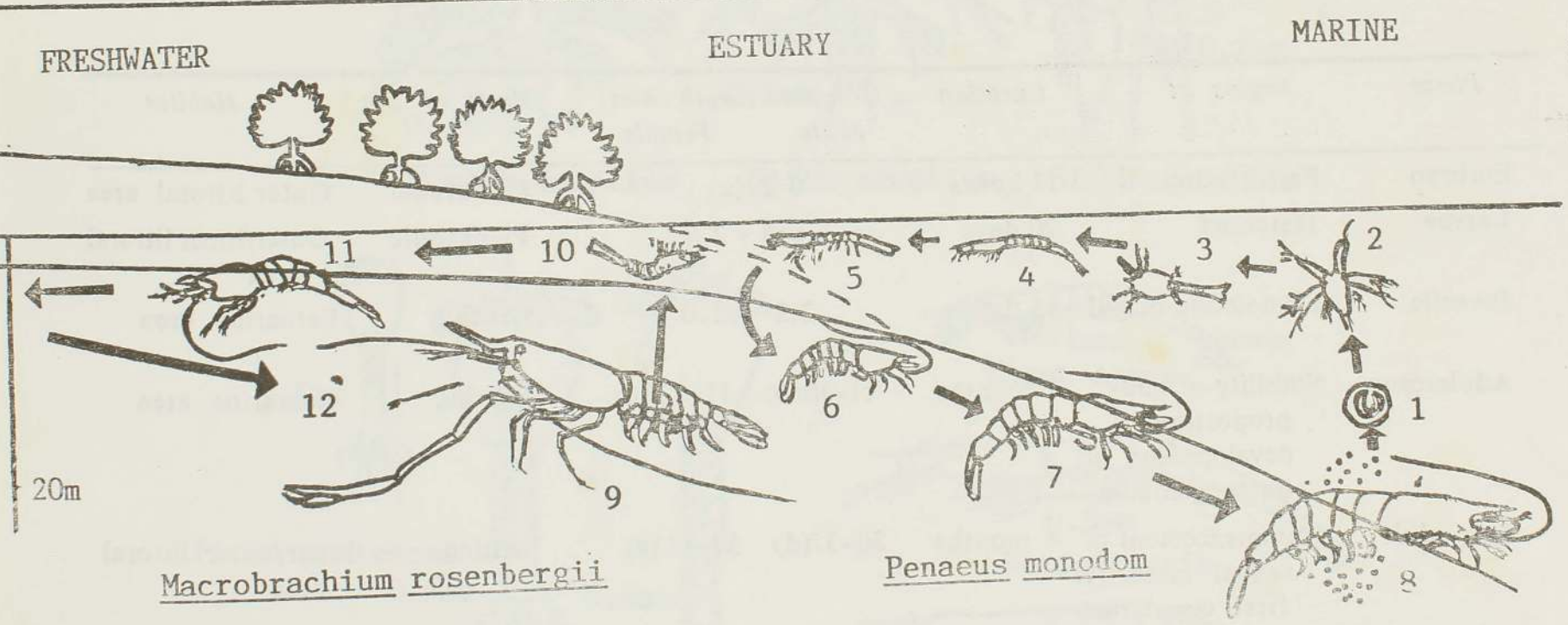


Fig. 15 : *Life cycles of Penaeid prawns and Macrobrachium rosenbergii. 1. fertilised egg; 2. nauplius (6 stages) ; 3. protozoea (3 stages) ; 4. mysis (3 stages) ; 5 post larva ; 6. juvenile ; 7. immature adult ; 8. fertilised female spawning ; 9. female Macrobrachium brooding eggs ; 10. zoea (11 stages) ; 11. juvenile migrating to freshwater ; 12. adult migrating back to estuary for breeding. (Jones, 1988).*

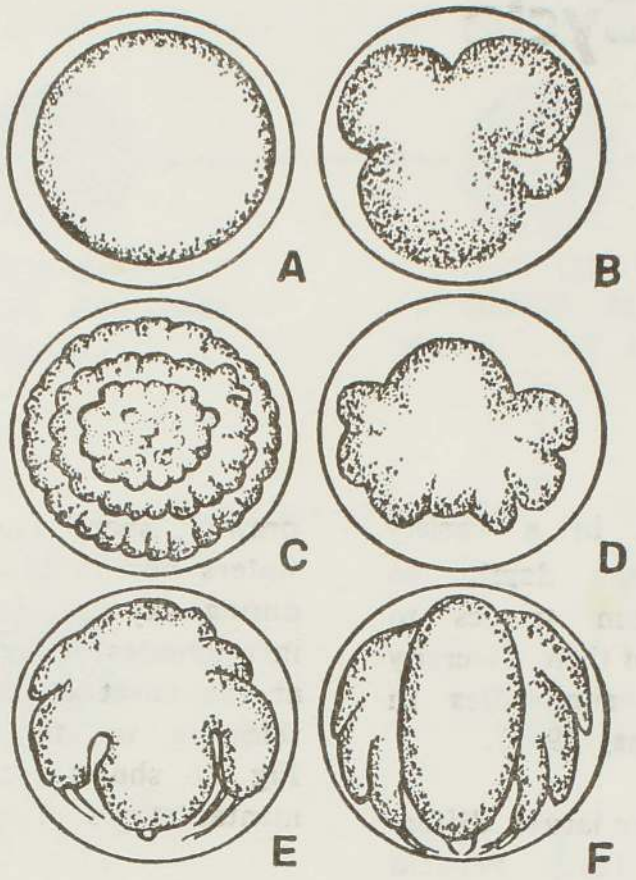


Fig. 16 : *Eggs of* **Penaeus monodon** *at various embryonic developmental stages. A : newly spawned egg. B : 4-cell stage (about 1 hr. after spawning) : C : morula stage (about 1.8 hr. after spawning). D : early embryonic nauplius. E : late embryonic nauplius. F : embryonic nauplius immediately before hatching (Motoh, 1984).*

Phase	*Begins at*	*Duration*	*Carapace length (mm)* *Male*	*Female*	*Mode of life*	*Habitat*
Embryo	Fertilization	12 hours	0·29(a)		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(b)	11-37 (c)	Benthic	Estuarine area
Sub-adult	Commencement of sexual maturity, first copulation	4 months	30-37(d)	37-47 (e)	Benthic	Inner/outer littoral area
Adult	Completion of sexual maturity	10 months	37-71 (f)	47-81 (f)	Benthic	Outer littoral area

(a, Egg diameter, (b)Minimum size with jointed petasma, (c)Minimum size with adult-like thelycum, (d)Minimum size with spermatozoa in terminal ampoules, (e)Minimum size with spermatozoa in thelycum, (f)Maximum size ever found.

Table 7(a) : *Life history phases of the giant tiger prawn,* **Penaeus monodon**

Species ↓	stage → Egg mm	length in mm Nauplius N1 – N6	Zoea Z1 – Z3	Mysis M1 – M3	Post - larva PL1
P. monodon	0.24	0.32 — 0.53	1.02 — 2.75	3.40 — 4.37	5.01
P. semisulcatus	0.26	0.33 — 0.53	1.02 — 2.71	3.38 — 4.74	5.22
P. monoceros	0.22	0.28 — 0.41	0.82 — 1.91	2.40 — 3.30	3.47
P. japonicus	0.25	0.32 — 0.50	0.92 — 2.50	2.83 — 4.34	4.90

Table 7 (b) : *Comparison of the size of eggs and larvae (Liao and Huang, 1972).*

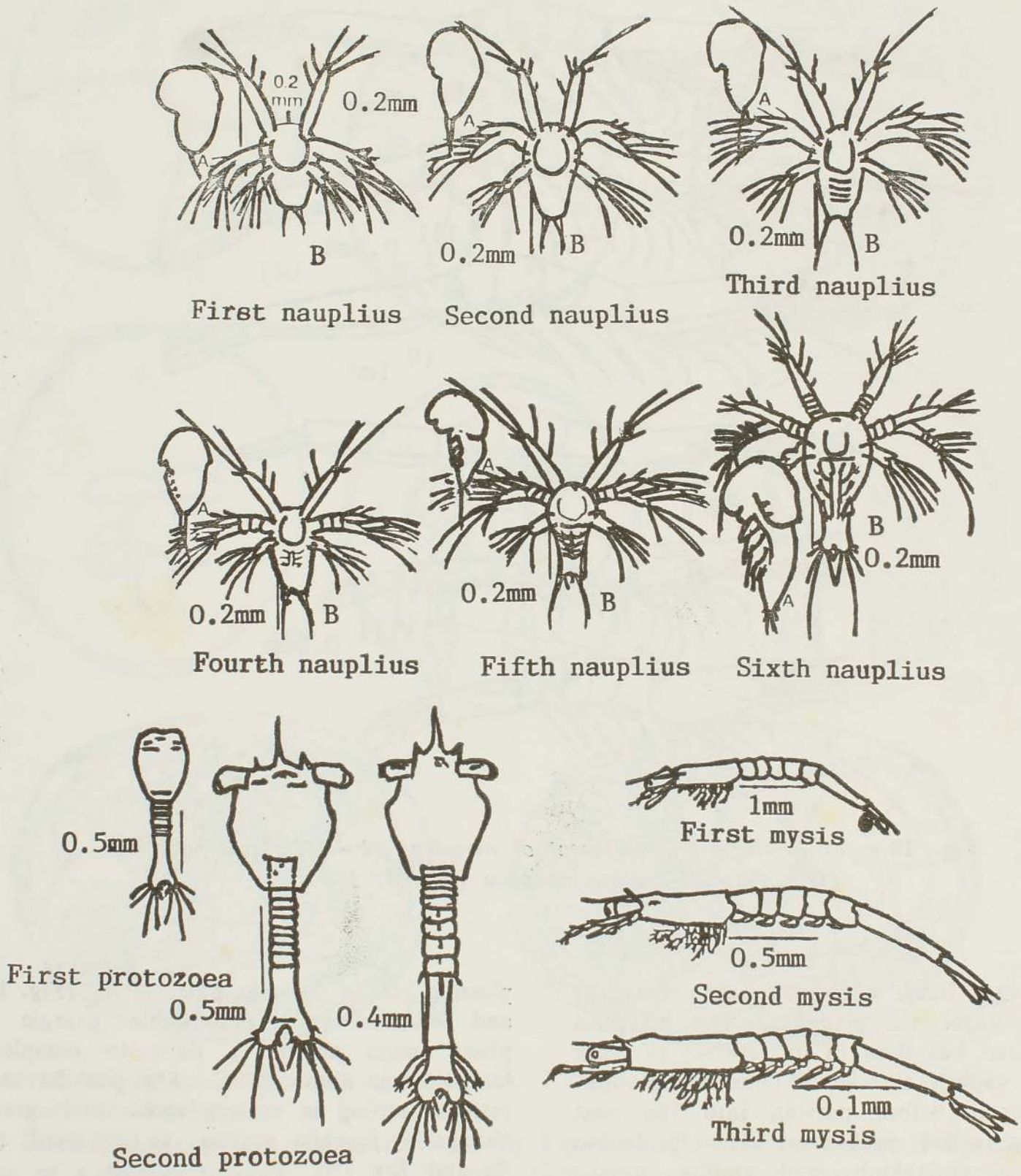


Fig. 17 : *Larval stages of* **Penaeus monodon.** *A : lateral view ; B: ventral view (Motoh, 1984).*

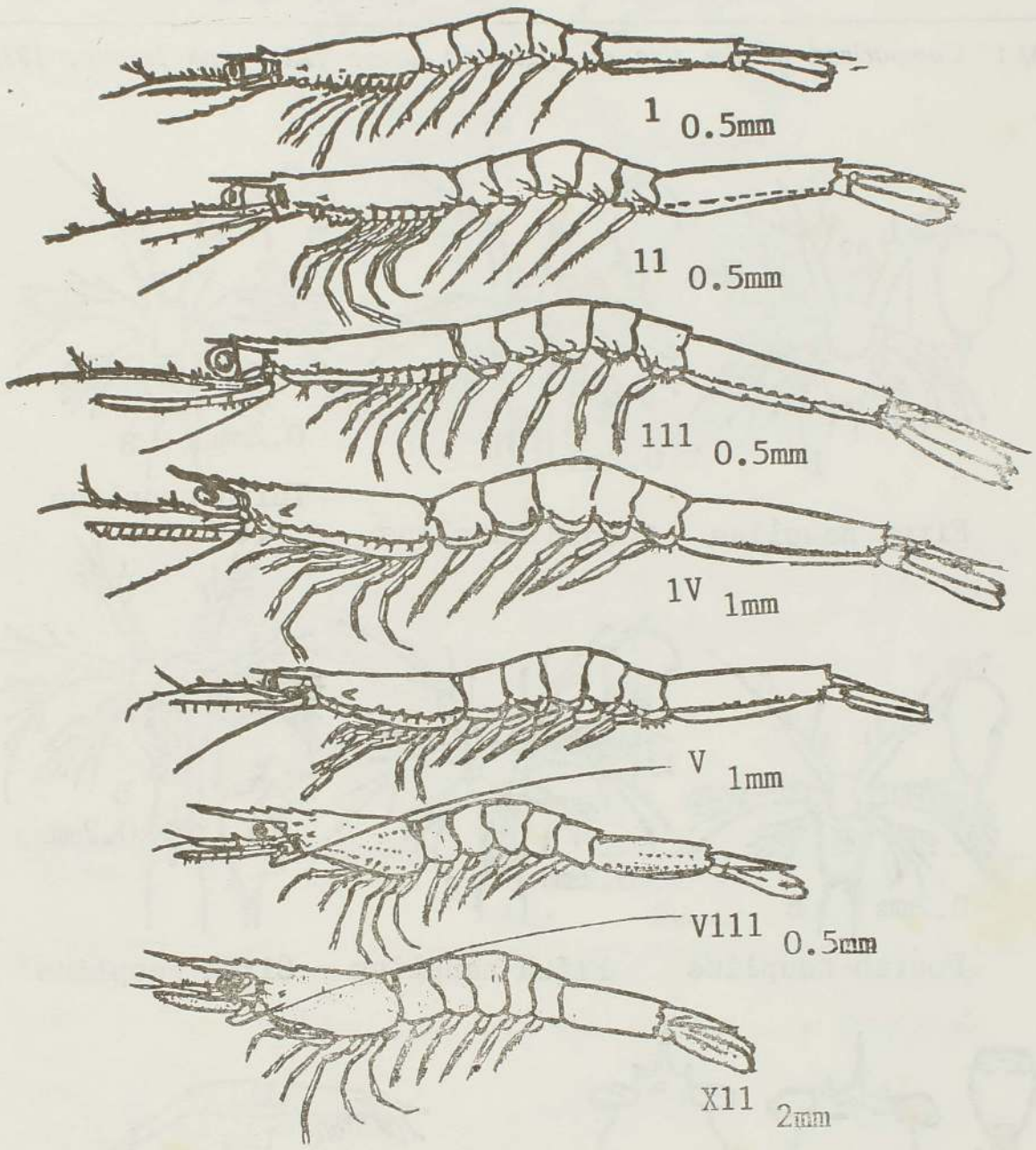


Fig. 18 : *Morphological development of megalopa (1 - 111) and juvenile (IV - XII) of* **Penaeus monodon** *(Motoh, 1984).*

These eggs hatch within 36 hours into the first larval stage, the nauplius. The nauplius does not feed but lives in its reserves of yolk and passes rapidly through a number of moults- usually 5 or 6 - before passing into the next larval form called protozoea. The protozoea feeds on phytoplanktons and moults usually three times, before passing into the final larval form called a mysis which feeds on zooplankton and itself moults three times before metamorphosing into a benthic post larva (Fig. 15, 17 and 18). The whole remarkable pelagic larval phase takes about 11 days to complete at temperatures above 28° C. The post larvae drift inshore, setting in nursery areas and gradually change to juvenile prawns, as they moult (Table 7a and 7b).

The eggs of *M. rosenbergii* at various stages of embryonic development are shown in Fig. 19.

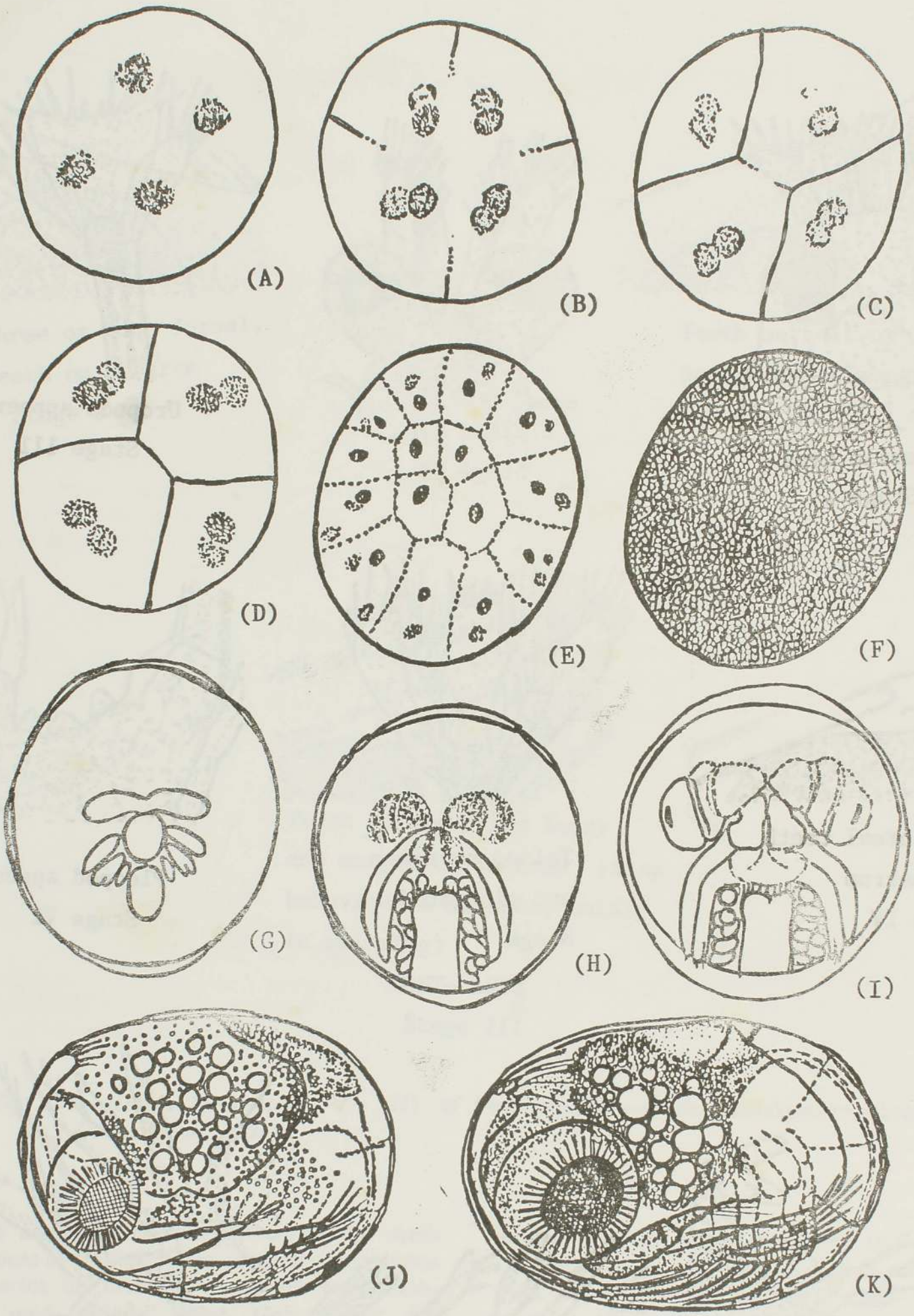
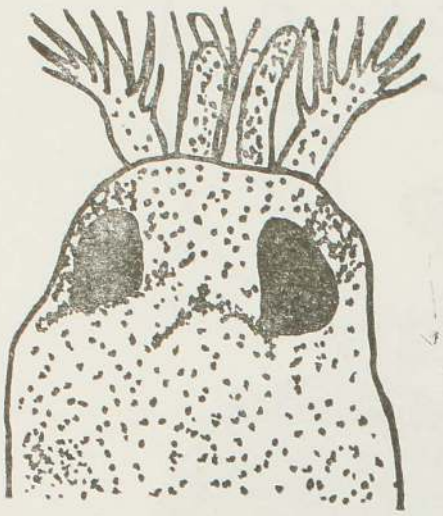


Fig. 19 : **Macrobrachium rosenbergii,** *segmentation and embryonic development. Times refer to period since fertilization.*

(A) 7 h - completion of second nuclear division. (B) 8 h 45 min-third nuclear division nearly completed, appearance of 4 cleavage furrows. *(C)* 8 h 55 min - third nuclear division completed, tips of the 4 cleavage furrows have met at 2 points from which the median furrow is developing. (D) 9 h - complete formation of 4 quadrants (blastomeres). *(E)* 14 h - 32 nuclei. *(F)* 24 h - completion of segmentation. *(G)* 6 days - formation of caudal papilla. (H) 7 days - formation of optic vesicle. *(I)* 9 days-eye pigment developed. *(J)* 14 days - larva fully formed. (K) 19 days - larva ready to hatch (Ling, 1967)

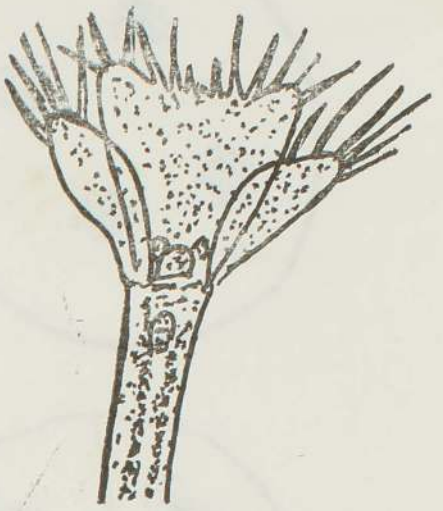


Sessile eyes

Stage 1

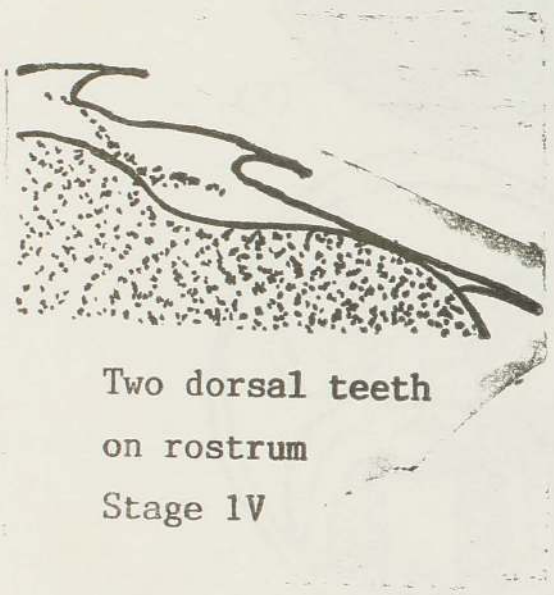
Stalked eyes

Stage 11



Uropods appear

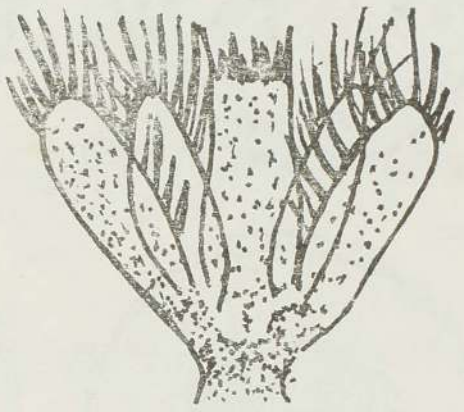
Stage 111



Two dorsal teeth

on rostrum

Stage 1V



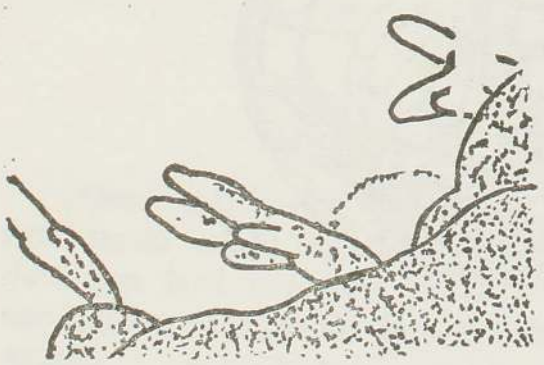
Telson narrower

and elongated

Stage V

Pleopod appear

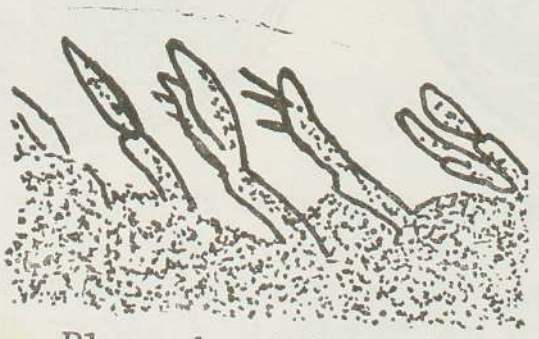
Stage V1



Pleopods biramous

and bare

Stage V11



Pleopods with setae

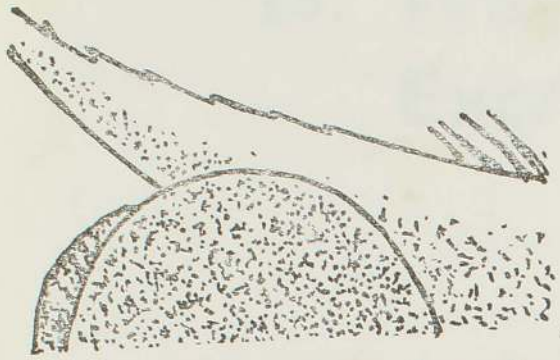
Stage V111

Endopods of pleopods with

appendices internae

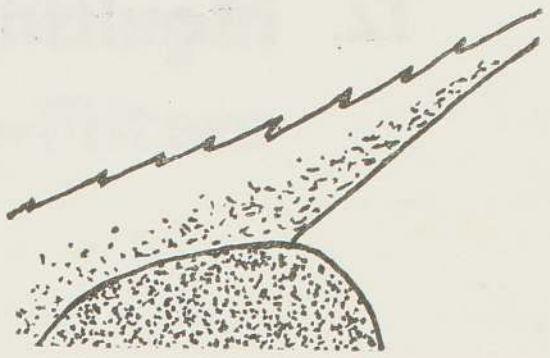
Stage 1X

Fig. 20 (Continued)



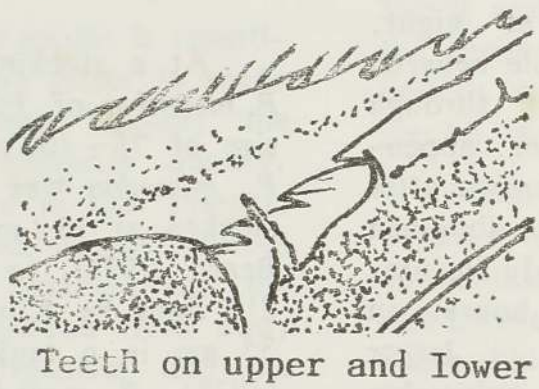
Three or four dorsal, teeth on rostrum

Stage X



Teeth on half of upper dorsal margin

Stage X1



Teeth on upper and lower and margin of rostrum (also behavioural changes, mainly in swimming)

POST-LARVA

Stage X11

Fig. 20 : *Key to larval stages (I - XII) of fresh water prawn* **Macrobrachium rosenbergii** *(Uno and Soo, 1989).*

The adult *M. rosenbergii*, occupying fresh water zones of tropical rivers, migrate downstream to estuarine or brackish waters of approximately 12 o/oo salinity where their larvae are released. Larval zoeae are voracious carnivores throughout their 30 day planktonic existence, during which time they undergo some 9 - 12 moults (Fig. 20) before returning to the benthos as post - larvae. At this stage they actively seek fresh water, migrating back up - stream to complete their life - cycle (Fig. 15). □

12. Moulting and Growth

The rate of growth in prawns is a function of the frequency with which they moult and the increase in size at each moult and vary according to species, age or size, sex, population density, season, temperature, food and other environmental factors (Neal and Maris, 1985). Though the moulting can occur at any time, if frequently takes place at night. Moulting commences within the cuticle between the carapace and intercalary sclerite, through which the cephalothorax and anterior appendages are carefully withdrawn. The prawn after a pause then rapidly menoeuvres its abdomen out of the old shell with a single body flexure. The new cuticle takes from a few hours, in small prawns, to one or two days, in larger animals, to harden. The prawns are vulnerable to attack from predators and its fellows during this time. The main events in the moult cycle are (i) accumulation of mineral and organic reserves (ii) removal of material from the old "shell" and formation of the new exoskeleton (iii) ecdysis, accompanied by an uptake of water (iv) molecular strengthening of the exoskeleton by rearrangement of organic matrices and deposition of inorganic salts and (v) replacement of fluid by tissue growth. There are considerable changes in the composition of haemolymph in particular as skeletal calcium and protein are mobilised, water and salts are absorbed and as the metabolism changes to provide for mobilisation or accumulation of reserves. Hormones secreted from paired organs in the cephalothorax (the Y organ) control moulting (Wickins, 1976 b).

At a stocking density of 5,000 / ha. fry of *P. monodon* of 3.0 cm have been grown to a size of 75 - 100 gm in 5 months in ponds. *P. monodon* was grown to 25 gm in a tank stocked at 15 / m² in 16 weeks, by Forster and Beard (1974), to 42 gm in earthen ponds in 210 days by Kungavankiji et al. (1976) and to 35 gm in a tank stocked at 15 / m² by Liao (1977). *P. monodon* reaches the minimum market size at 10 gm wet weight within 10 - 12 weeks and under ideal conditions may go on to reach a maximum weight of 250 gm within an year (Jones, 1988) (Fig. 7).

The intermoult period varies between species, within species with size and, in normally growing individuals, with age. Young Penaeid larvae may moult two or three times in a day. Some aspects of the life history of *P. monodon* and *M. rosenbergii* (Wickins, 1982) are given below:

species	Incubation period days	length larval life days	age at first maturity months	size at first maturity gm +	interval between spawning
P. monodon	none	12 — 14	08 — 10	60 - 80	3 — 4 days
M. rosenbergii	19 — 21	34 — 44	07 — 08	25 — 30	3 — 4 months

+ live Weight

13. Water Systems, Nitrogen Excretion and Bio-Filters

Two categories of systems used to provide water suitable for rearing shellfish are the (1) open and (ii) semi-open or closed systems.

In open systems, the water supply is essentially continuous and little or no effort is made to maintain water quality, because initially the incoming water must be of adequate quality. After a minimal residence time in the system, the culture medium is discharged, usually without treatment. Advantages of this systems are the potentially rapid flow rates, that can flush away metabolites from the culture organism and the limited expense involved in the maintenance of water quality. The disadvantages are the possible introduction of contaminants in the water supply of uncertain and usually highly variable quality and the increasing limitations on discharge of environmentally undesirable effluents. However the advantages of the open system may outweigh the disadvantages for commercial scale culture except in special circumstances.

In the semi-open or closed systems there is some modification of the water quality during capture time and usually some amount of recycling before discharge. As the reuse of water approaches 100%, the classification approaches that of a closed system. In closed systems a very high proportion of the culture medium is retained and recycled; the incoming water is only necessary to replenish the loss by evaporation or very limited discharge losses or both (Provenzano, 1985). Closed systems thus present an alternative to open systems where a satisfactory water supply is not available. The use of recirculated water systems has been reviewed by Wickins (1982) for Crustaceans in particular and by Muir (1982) for aquaculture generally.

Beard et al. (1977) has described the culture of *Penaeus merquiensis* through 3 generations in the laboratory recirculation systems where only 50% of the water was renewed each week and Mevel and Chamroux (1981) have shown that the shrimp, *P. japonicus* can live for long periods up to one year in recirculating experimental tanks where the water was never renewed.

Natural water may be drawn from surface supplies or from wells. Surface waters may be contaminated by industrial or agricultural chemicals injurious to Crustaceans, even in very dilute concentrations. Spores, eggs or fry of Crustacean disease organisms or predators are some of the biological contaminants in natural waters. Well water on the other hand is usually free of bilogical contaminants and hence more desirable for culture if obtainable in adequate quantity. Occasionally well water may be low in oxygen content but if it is otherwise suitable, oxygen level could be restored by simple mechanical means. High quality water is required for larval rearing than for pond culture. Generally high quality water means freedom from nitrogenous wastes as well as other contaminants.

Captive water will begin to undergo various physical and chemical changes within moments after entering a culture system, particularly one in which animals are being grown or maintained. These changes will render it unsuitable for culture use, if these changes are not controlled. The main features to be controlled are oxygen level, temperature, salinity, where applicable, dissolved organics, pH and concentration of nitrogenous wastes.

Nutrient leaching and breakdown of uneaten diet adds to prawn ammonia excretion estimated at 0 021 kg / kg prawns per day. Wickins

(1976 a) demonstrated the toxicity of ammonium salts, especially the NH_3-N fraction, to prawns and found a maximum acceptable level of 100 µg / l. Nitrite released as an intermediate through nitrification of ammonia is far more toxic and prawns especially during larval and early post - larval stages are sensitive to concentrations below 100 µg / l.

Ammonia is the most important soluble waste in aquaculture systems and could be removed most economically by biological filteration. Several types of biological filters such as percolating and up flow filters, activated sludge filters (Meske, 1985), and biological sedimentation filters (Short, 1973) are used in aquaculture. Activated sludge and biological sedimentation filters are more complex to operate, though more efficient and occupy less space. Percolating filters are preferred to the other types because they have a number of inherent fail - safe features in their operation.

A percolating biological filter has a bed of gravel or purpose made plastic rings which provide a large surface area on which nitrifying micro - organisms grow. Soluble wastes like ammonia, amino acids, amines and bicarbonates are utilised by the nitrifying micro - organisms for their growth and metabolism. The end products which include nitrates and carbondioxide are not harmful to the prawns until they reach levels many times higher than those in natural sea water. Some of the changes that occur in sea water used in culture of prawns is given in Table 8 (Wickins, 1972).

Day	Operations (two vessels are employed and stocked on alternate weeks)
1.	20,700 newly hatched nauplii are stocked in 166 lit. of clean sea water at 35 ppt and 28° C in a culture vessel.
2.	Cultured Tetraselmis are added to give a density of 30 — 40 cells / µl. The algae provide food for the first protozoea stages.
3.	Freshly cultured algae are added further to raise the density to 70 — 80 cells / µl, when most of the larvae would have developed to the protozoea.
4.	About 80 lit. of water are siphoned out through a 200 µm screen sufficiently slowly so that larvae are not forced against the mesh. The vessel is refilled with clean sea water with a salinity of 3 — 5 ppt below that of the residual water. Algae cells are added to maintain a concentration of 70 — 80 cells / µl.
5,	The concentration of unutilised algae is determined and made up, if required to 70 — 80 / µl. 10 — 12 gm of *Artemia* eggs in two litres of sea water are vigorously aerated.
6.	As 4th day. The hatched nauplii of *Artemia* are added to give a concentration of 1 *Artemia* / ml in the culture vessel.
7.	With newly hatched nauplii, the concentration of *Artemia* is increased to 2 — 5 / ml and a further batch of eggs set to hatch. At this stage most of the larvae are mysis I.
8.	As 4th day but no algae are added. The concentration of *Artemia* is assessed and made up, if necessary to 2 - 5/ml with newly hatched nauplii.
9.	The concentration of *Artemia* is determined and brought up if necessary to 2 — 5 / ml. A fresh batch of *Artemia* eggs are set to hatch.
10.	As 8th and 9th days. Some post - larvae may be noticed.
11. & 12.	As 9th day. The proportion of post - larvae (PL'S) prevent can be determined by taking ten ml samples from the vessel. The culture could be continued for upto 2 days if necessary until 90% are post larvae.
13.	The vessel is drained completely and cleaned in preparation for the next culture.

Table. 8 : *A scheme for the culture of Penaeid larvae (Wickins and Beard, 1972).*

Acid is produced during biological filtration and care must be taken in densely stocked marine culture systems to ensure that the water remains adequately buffered against a decrease in pH. Production of carbondioxide and consequent lowering of pH tend to decrease the toxicity of ammonia, because lower pH shifts the equilibrium towards the less toxic ionized ammonium NH_4+. However, the carbondioxide itself is detrimental and aeration, in addition to supplying oxygen, tends to remove carbondioxide. Reduced amounts of oxygen, as a result of high biomass or organic decomposition in ponds or both, is another commonly encountered problem and perhaps the most frequent cause of large scale mortality in Crustacean culture (Provinzano, 1985). Ammonia and nitrate nitrogen from sea water removed by many marine algae and algal "filters" have been used in marine recirculation systems in attempts to control the levels of nitrate and phosphate (Kinne, 1976). But little is known of their effectiveness and cost of the necessary illumination for proper functioning in tropical marine systems. The following three main factors are involved in the design of biological filters suitable for intensive Crustacian culture (Wickins, 1973):

i) *Biological load* : The rates of nitrogen excretion in tropical prawns based on approximate measurements range from 1 mg total ammonia nitrogen per gm of prawn per day (1 mg total NH_4-N / gm / d) in small prawns up to 5 gm live weight to (0.5 mg total NH_4-N/ gm / d) in 10 — 20 gm animals. The quantity and type of solids and solubles leached from the food and converted by micro - organisms in the water to ammonia depends on (i) the composition of the diet (ii) the efficiency of the binding agent and (iii) the time the food remains in the tank.

ii) *Tolerance of prawns to ammonia, nitrite and nitrate* : Levels of ammonia, nitrite and nitrate nitrogen which reduce their growth to 50% of that of prawns in normal sea water after three weeks but which did not kill them are : (a) ammonia : 0.45 mg un-ionised NH_3N /l (approx. 10 mg total NH_4-N / l at pH 8.0 and 100 mg total NH_4N / l at pH 7.0) (b) nitrite: 6 – 10 mg NO_2-N/l (c) nitrate : no reduction of growth was detected after 3 — 5 weeks exposure of *P. monodon* to nitrate concentration up to 200 mg NO_3-N / l.

M. rosenbergii seems more susceptible to nitrite and nitrate than the marine Penaeids and suffered 50% mortality in three weeks after exposure to 15 mg NO_2 -N and 160 mg NO_3 -N / l.

iii) *Carrying capacity of the filter* : The oxidation of the amount of ammonia and hence the number and weight of animals a nitrifying filter can (a) ammonia input concentration (b) specific surface area of filter medium (c) filter volume (d) hydrolic load (e) pH, temperature, salinity and oxygen levels.

Experiments with model filters (Forster, 1974) containing 1 - 2 cm gravel chips with a specific surface area of 150 - 120 m^2 / m^3 showed that when the input concentration was approximate 1 mg total NH_4 -N / l and the hydrate load was 20 - 250 m^2 / m^3 / day then the nitrification rate was 0.25 – 1.0 gm total NH_4 -N/m^2 of specific surface / day. These figures provide the basis for the calculations of filter size on costs.

A flow diagram of a recirculation system for the culture of prawns (Wickins and Beard, 1972) is shown in Fig. 21.

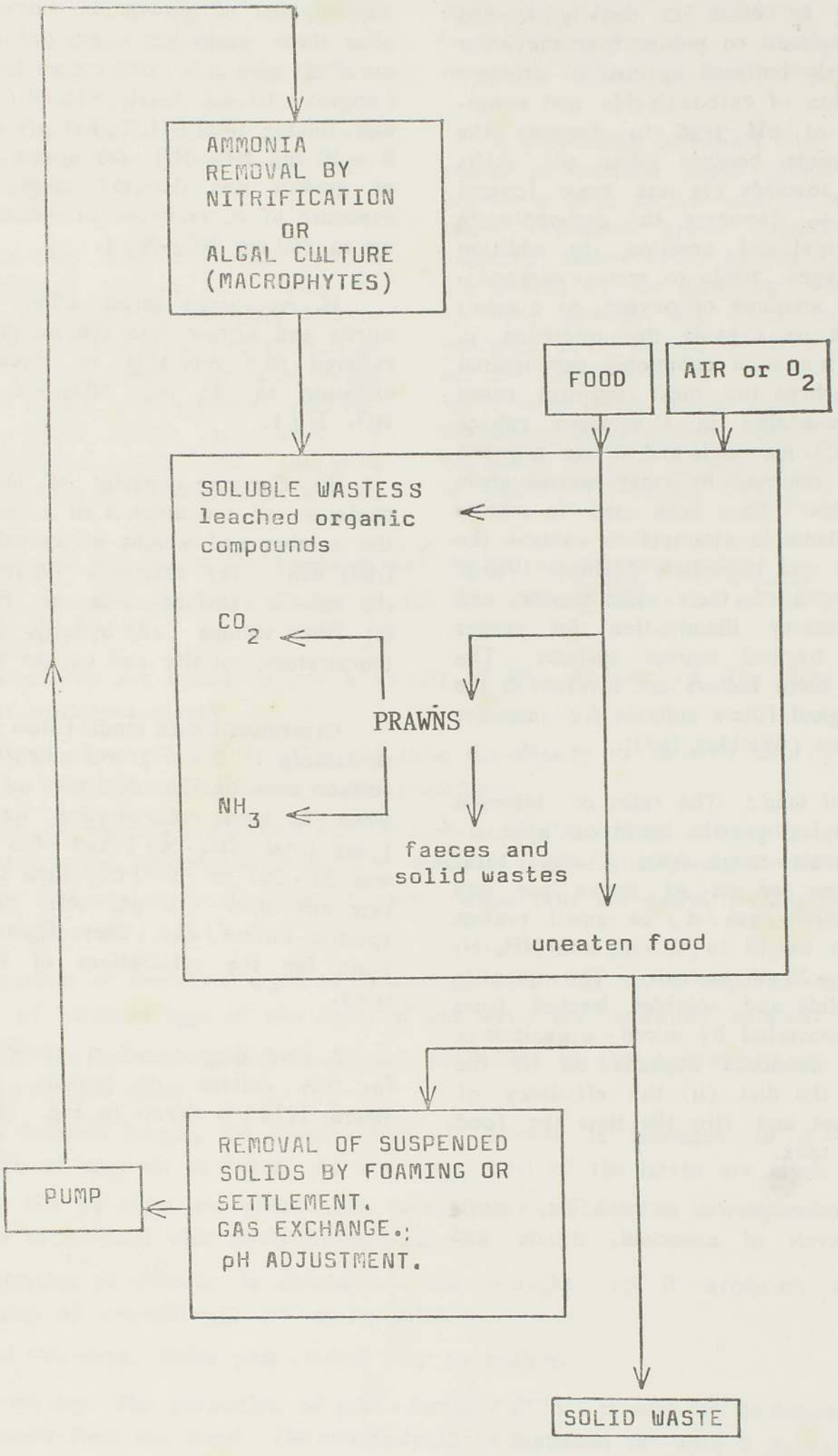


Fig. 21 : *A flow diagram of a recirculation system for the culture of prawns (Wickins and Beard, 1972).*

14. Water Quality Acceptable Limits

The acceptable limits of water quality for shrimp culture, based on the data for oceanic waters with abundant shrimps are given below:

pH value 8.0 — 8.5 Temp. 25° C — 35° C Salinity 20 — 40 0/00
Alkalinity 50 — 200 as $CaCO_3$ Carbondioxide 15 ppm Max.

DO larvae	0.54	ppm	NO_2 — 100	ppm	Max.
post larvae	0.81	ppm	NO_3 — 200	ppm	Max.
juvenile	0.64	ppm	NH_3 — 0.1	ppm	Max.
adult	0.76	ppm	H_2SO_4 — 0.1	ppm	Max.

Aluminium	5.0 ppb	Arsenic	2.3 ppb
Cadmium	0.05 ppb	Cobalt	0.02 ppb
Chromium	0.6 ppb	Copper	3.0 ppb
Iron	3.0 ppb	Mercury	0.05 ppb
Magnesium	2.0 ppb	Molybdenum	10.0 ppb
Nickel	2.0 ppb	Lead	0.03 ppb
Antimony	0.2 ppb	Selenium	0.45 ppb
Tin	0.01 ppb	Vanadium	1.5 ppb
Zinc	6.0 ppb	Tri Butyl Tin	1

Bacteria no *E. coli*
Pesticide etc. No trace.

15. Larval Culture and 'Green Water' Systems

Larvae are reared in prawn hatcheries from hatching through to size where they can be introduced into a pond (Fig 22). Hatcheries operate as a separate business in most countries (Table 1) and their numbers have increased repidly to keep pace with the demand for seed prawns. In Taiwan alone over 1,500 hatcheries exist and in 1985 these supplied 3 billion post - larvae which ultimately produced 31,000 tonnes of marketable prawns (Jones, 1988). Soon after spawning and hatching, the late stage non - feeding nauphi larvae are concentrated at light and stocked at 50 - 200 per litre in rearing tanks filled with filtered and ultra - violet sterilised sea water. Filtration is done by passing the sea water through three cartridge filters of 10 micron, 5 micron and 0.2 micron. Nauplii larvae on metamorphosis to the protozoea, feed on unicellular algae. As the larvae develop into the mysis stage, live zooplankton in the form of *Artemia* nauplii are provided as the main larval feeds. The culture of *Macrobrachium* also depends on *Artemia* to feed the carnivorous prawn larvae, although *Chlorella* is often supplied to remove toxic ammonia and nitrate wastes. A scheme for the culture of Penaeid larvae suggested by Wickins and Beard (1972) is shown in Table 8.

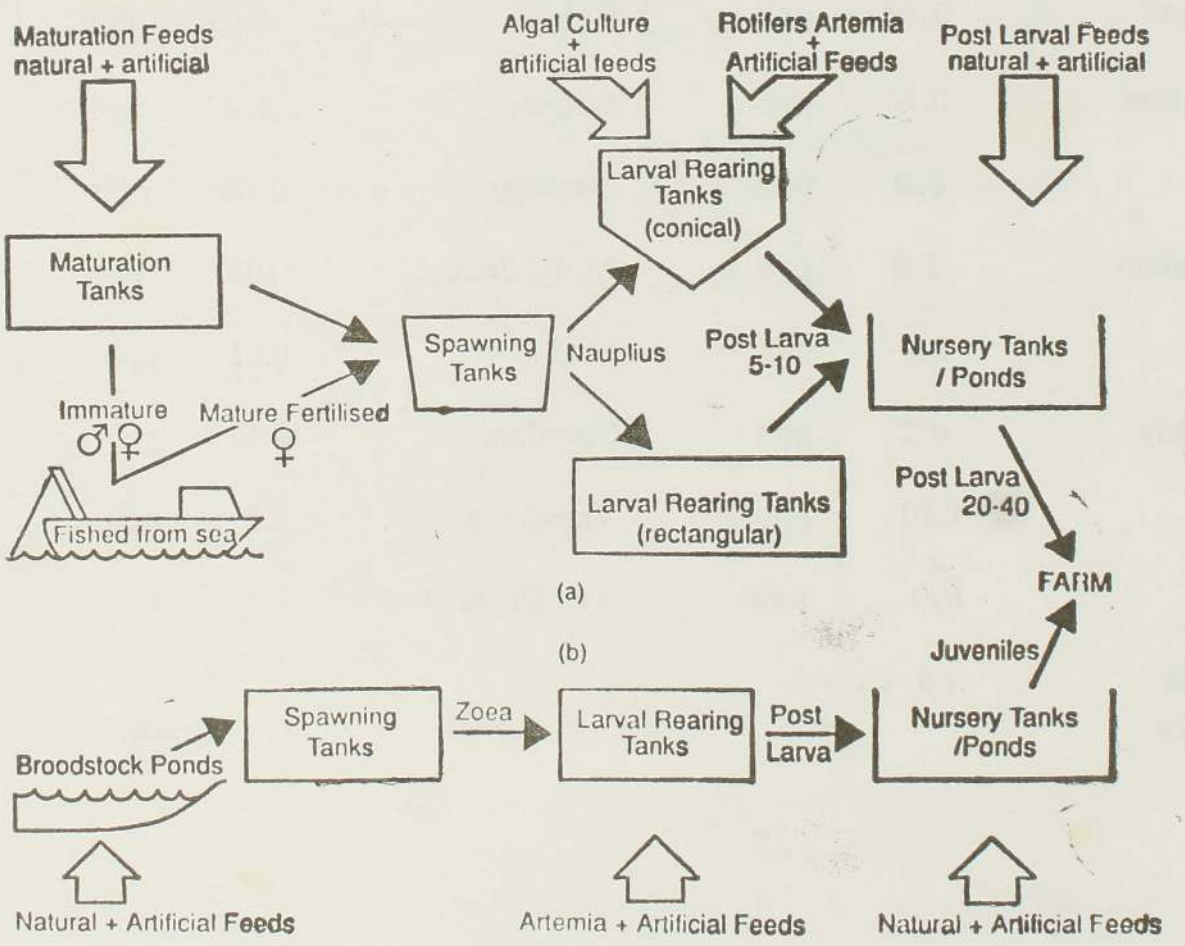


Fig. 22 : *Flow chart for (a) Penaeid hatchery and (b) Macrobrachium hatchery (Jones, 1988).*

Culturing of *M. rosenbergii* juveniles to maturity in fresh water in outdoor ponds is a relatively simple technique. However, hatchery operation of the larval stages to post – larvae requires brackish water and involves more complex technique and management. Since the pioneering work by Ling (1969), post – larvae of *M. rosenbergii* have been successfully produced. The methods involved range from simple backyard hatchery using low level technology to more complex and intensive hatchery management such as recirculated water systems of frequent water changes and cleaning of larval tanks to ensure good sanitation (Mavel and Chamroux, 1981). These methods are labour intensive and involve wastage of sea water. Use of "green water" to overcome the above problems have been demonstrated by Maddox and Manzi (1976), Cohen et al. (1976) and Ang and Cheah (1986). These investigators have indicated that "green water" is an efficient system of removing toxic metabolites such as ammonia from the culture medium. The "green water" in actual fact functions as a biological filter and consists mainly of unicellular algae such as *Chlorella* sp. and *Scenesdesmus* sp. The roles algae could play in this culturing system are: (i) provide nutrients via accidental or active ingestion by the *Macrobrachium* larvae (ii) detoxify the larviculture medium by assimilating or neutralising inhibitory materials (iii) improve the nutritional value of *Artemia* which serve as the primary food source (iv) secrete into the medium metabolic products which facilitate larval growth and / or development. Cohen et al. (1976) has shown that *Macrobrachium* larvae do not ingest algae and that the primary role of algae is that of detoxification, specifically, removal of ammonia from the medium.

□

16. Nursery Systems

After five to fifteen days, post - larvae prawns are usually moved from larval rearing systems to nursery ponds and stocked at 50 - 600 / sq. m. These ponds or tanks are often provided with a natural muddy sand substrate both to prevent cannibalism and allow production of some natural food and are usually shallow with a large bottom area. The young prawns are weaned from larval foods on to a mixture of natural and specially prepared crumbles of granulated feeds, during the next 20 - 60 days They are initially fed at up to 40 times body weight. Artificial feeds must contain at least 40% protein and 3 - 4% PUFA rich lipid to sustain the rapid growth that allows juveniles to reach 0.5 - 2.0 gm by the end of the nursery period for *P. monodon* and other Penaeids (Jones, 1988). As the exact biomass can be calculated on transfer, this nursery period allows accurate stocking of grow - out systems, enables prawns to acclimatise to local environmental conditions and protects them from predators (Fig. 23).

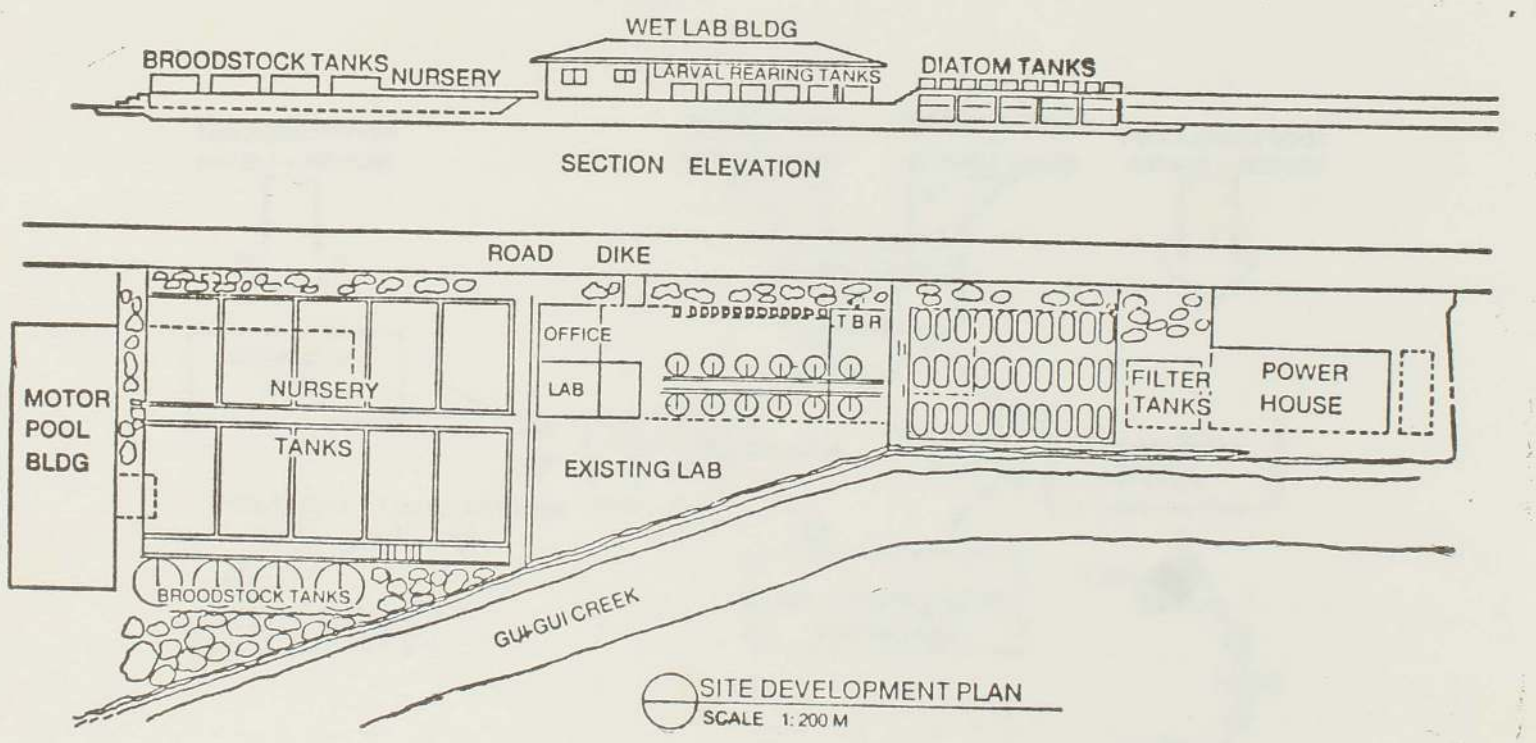


Fig. 23 (a) : *Lay - out of medium scale hatchery (Kungavankiji, 1984).*

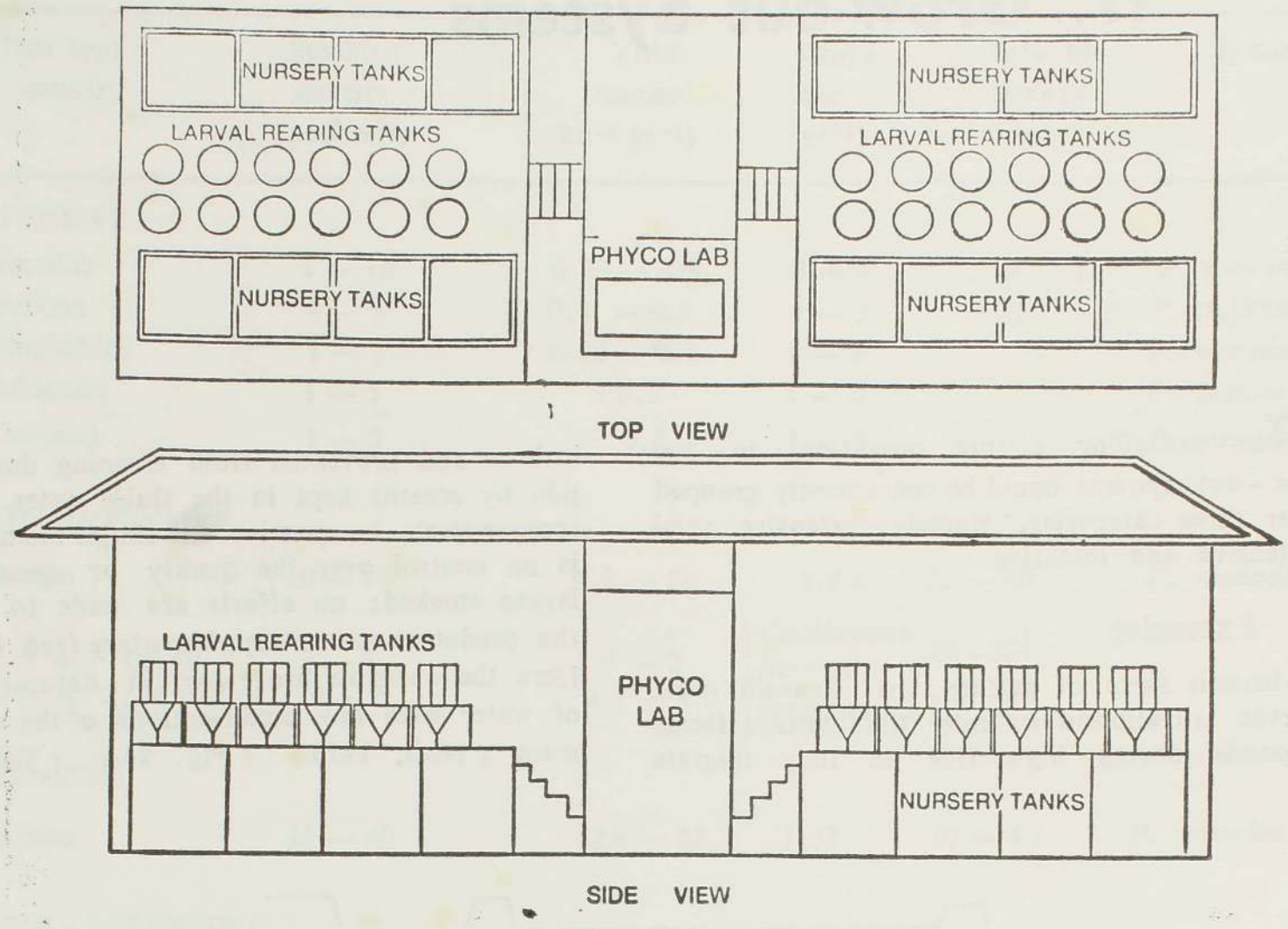


Fig. 23 (b) : *Lay - out of combined hatchery system (Kungavankiji, 1984).*

Since larger juveniles take less time to reach market size, the introduction of a nursery system between the hatchery and grow - out system, makes available larger juveniles for stocking and allows more crops to be obtained per year (Wickins, 1986).

□

17. Grow-out Systems

The prevailing culture operations in the grow - out systems could be conveniently grouped under three categories, namely - extensive, semi - intensive and intensive.

(i) Extensive

In this form of culture the Penaeid post - larvae are allowed to enter the culture fields or ponds during high tide as they migrate inshore and prevented from escaping during low tide by screens kept in the sluice gates. In this comparatively inexpensive and simple method there is no control over the quality or quantity of larvae stocked; no efforts are made to control the predators and no supplementary feed is given. Here the shellfish are raised in natural bodies of water with few modifications of the environment (Neal, 1973) (Fig. 24) (Table 9).

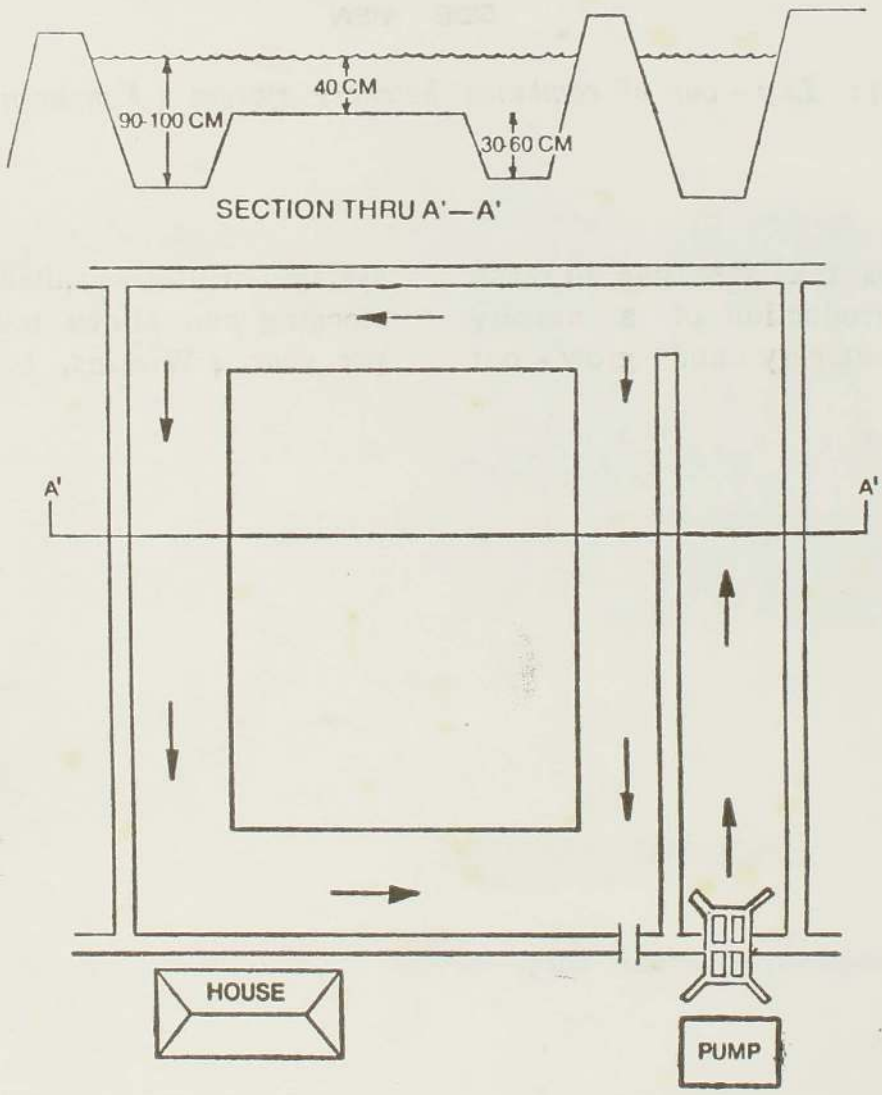


Fig. 24 : *Typical extensive pond in Thailand (Kungavankiji, 1984).*

Culture type and country	Stocking density (no / m^{-2})	Yield (tonnes ha^{-1} yr^{-1})	Crops (no yr^{-1})	Size of prawns (g)	Species
EXTENSIVE					
Ecuador	1 — 10	0.72 — 4.8	3 — 4	19 — 22	*P. vannamei*
Panama	4 — 5	0.4 — 0.9	1 — 3	20	*P. stylirostris*
Bangladesh	1 — 5	0.08 — 0.1	1 — 2		*P. monodon*
Indonesia	1 — 5	<0.2	1 — 2		*P. indicus*
Thailand	1 — 5	0.4	1 — 2		*P. merguiensis*
SEMI - INTENSIVE					
Taiwan	10 — 15	4.2 — 11	1.5 2	30 — 40	*P. monodon*
U.S A., Hawaii	2 — 6	1.5 — 2	Continuous harvesting	20 — 30	*M. rosenbergii*
U.S.A. S., Carolina	4 — 6	0.7 — 1.2	for 6 months	20 25	
INTENSIVE					
Taiwan	15 — 40	12.6 — 27.4	1.52	30 — 40	*P. monodon*
SUPER - INTENSIVE					
Japan	100 — 250	4.5 — 24	1	17 — 20	*P. Japonicus*
U.S.A., Hawaii	?	25 — 70	2.5	?	*P. stylirostris*
					P. vannamei

Table 9 : *Production Examples from Different types of Prawn Farm (Data from various sources) (Wickins, 1986).*

Though low yields varying from 45 - 1000 kg / ha / a are obtained by this method, this is still a wide spread farming practice, as costs are minimal. The recent trends in improving the yield from this type of culture involve supplementing the naturally available food by fertilisation with animal manure or chemical fertiliser elimination of predators and competitors by tea seed cake (containing saponin) or derris root powder (containing retenone) (Terazaki et al. 1980), stocking at higher densities with fast growing species, providing aeration and controlling water exchange. Janssen et al. (1986) giving supplimentary feed of 60% trash fish, 30% rice bran, ground nut oil cake, broken rice and 10% tapioca, maida as feed binder have reported a production rate of 300 kg / ha / crop in four and a half to five months in ponds, in Polekurru, Andhra Pradesh, India.

(ii) Semi - Intensive

In semi intensive culture, the culture ponds are selectively stocked with fast growing species from the wild or hatchery and are fed artificial feeds. The water exchange through sluice gates is only to maintain the water quality in the ponds and not for stocking. Tidal and pumped water exchange of up to 30 — 40% per day are carefully managed, often with supplementary aeration. Pond sizes vary from 0.2 to 2.0 ha. and yields varying from 1000 - 10,000 kg/ha/a are obtained from two crops per year (Wickins, 1986) (Fig. 25).

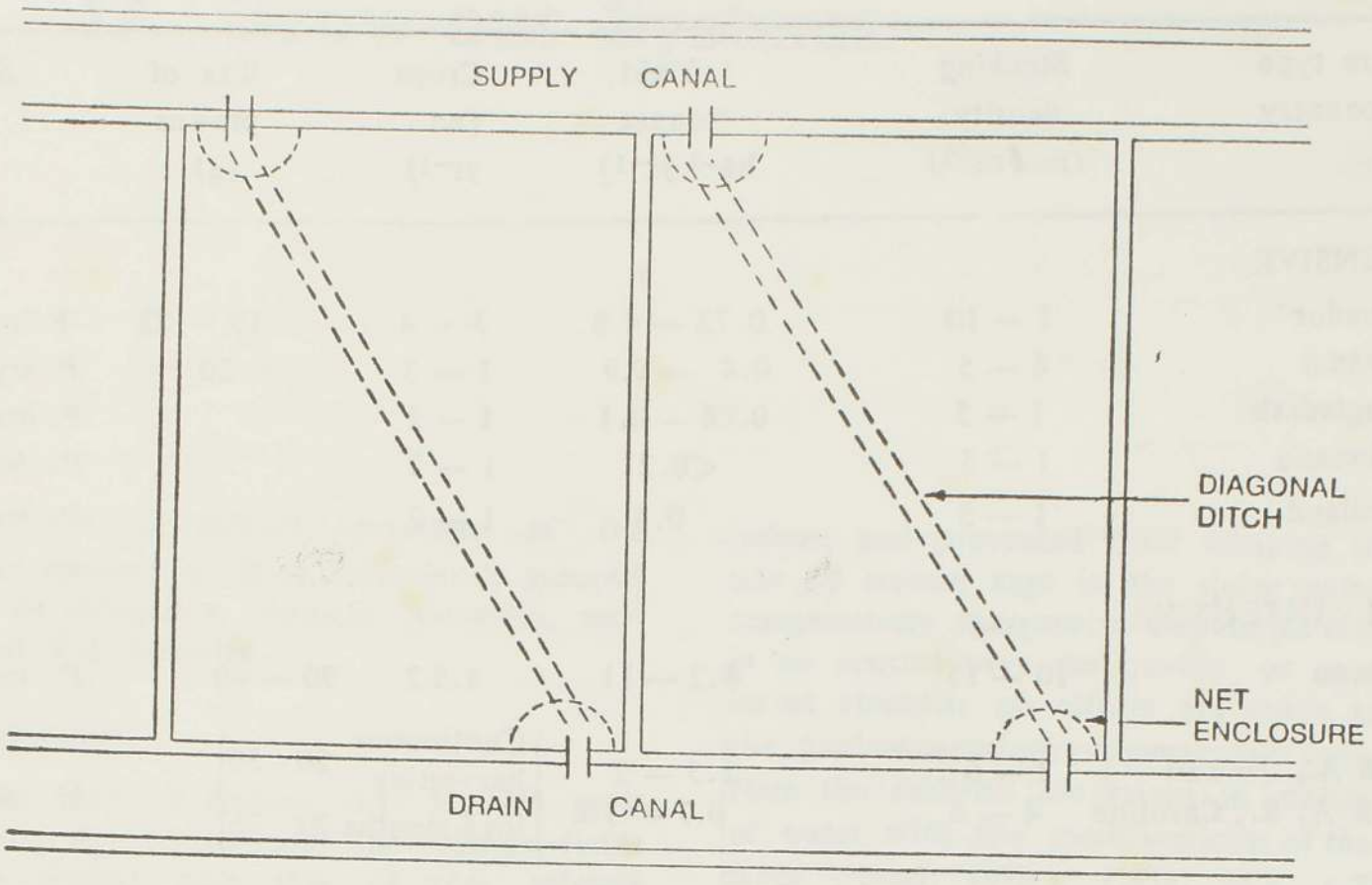


Fig. 25 : *Typical semi - intensive pond (Kungavankiji, 1984).*

(iii) Intensive

In this high density culture method, initially started in Japan, raceways or tanks with air lift circulation, continuous flow of sea water with exchange generally over 30% per day along with precise controlled intensive feeding are involved. Hatchery reared, nursed juveniles are stocked at specific densities. The problems posed by the accumulation of unused food and moults of prawns led to the development of circular

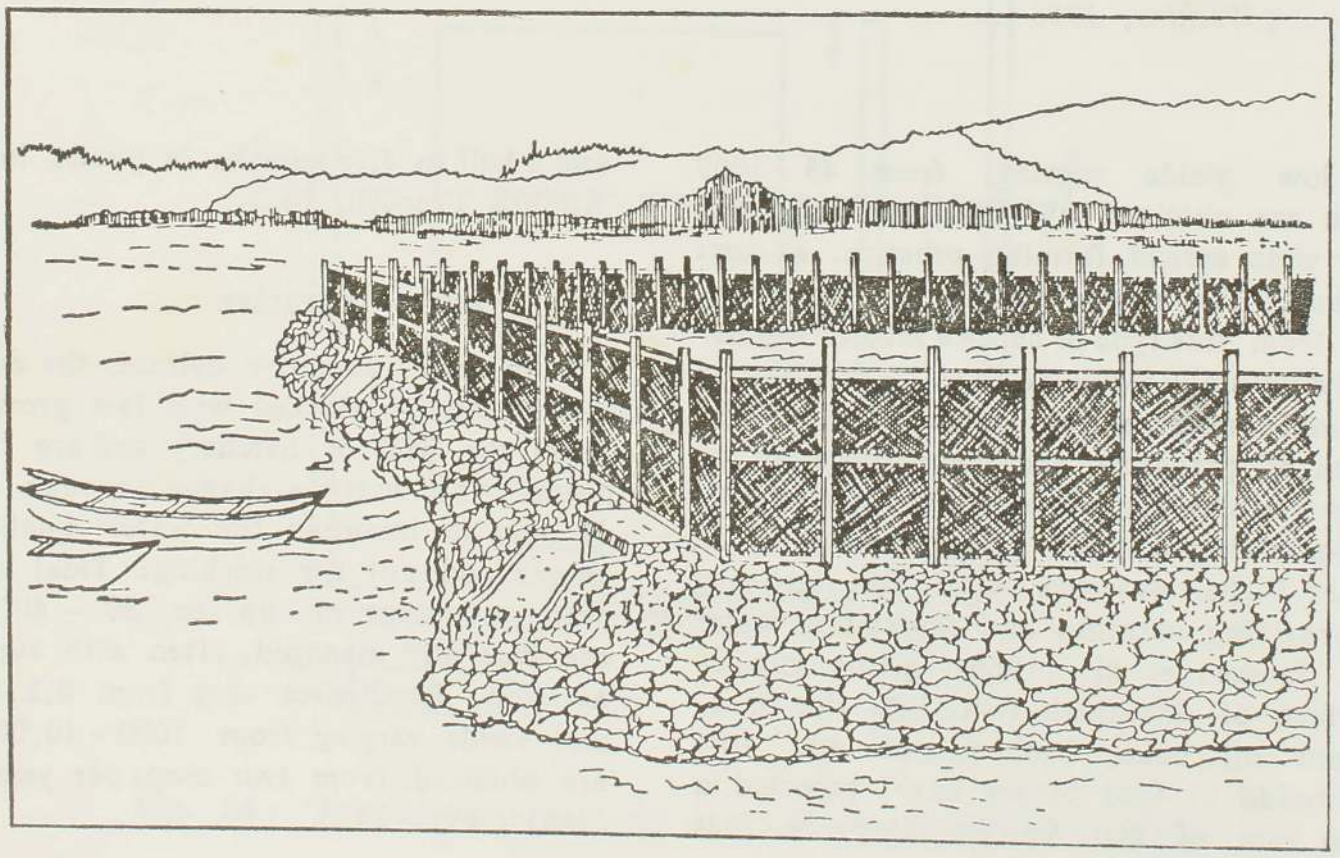


Fig. 26 : *Amakusa type shrimp farm in Japan (Kungavankiji, 1984).*

self cleaning tanks by Shigueno (1975). False bottom and central drain pipe are special features of these tanks. Also constant supply of fresh sea water is sprayed into the tank in such a way that a circular motion is imparted to the water in the tank. This drives the debris towards the middle of the tank from where they are evacuated through the central drain. Raceways and tanks range in size from 0.03 to 0.2 ha and yields over 10,000 kg / ha / y two to four crops per year are obtained. The construction of specialised tanks, providing such a large volume of running sea water and the complete dependence on pelletised feeds requiring a high capital investment which could be found economical only in Japan where land and labour costs are high and the live prawns fetch an unusually high market price as a luxury food. The high density culturing is also greatly vulnerable to disease and to large scale mortalities due to mechanical failures even for a short duration (Muthu et al., 1982). Over 1,000 tonnes per year of *P. joponicus* are produced by intensive methods (Meske, 1985) (Fig. 26 and 27).

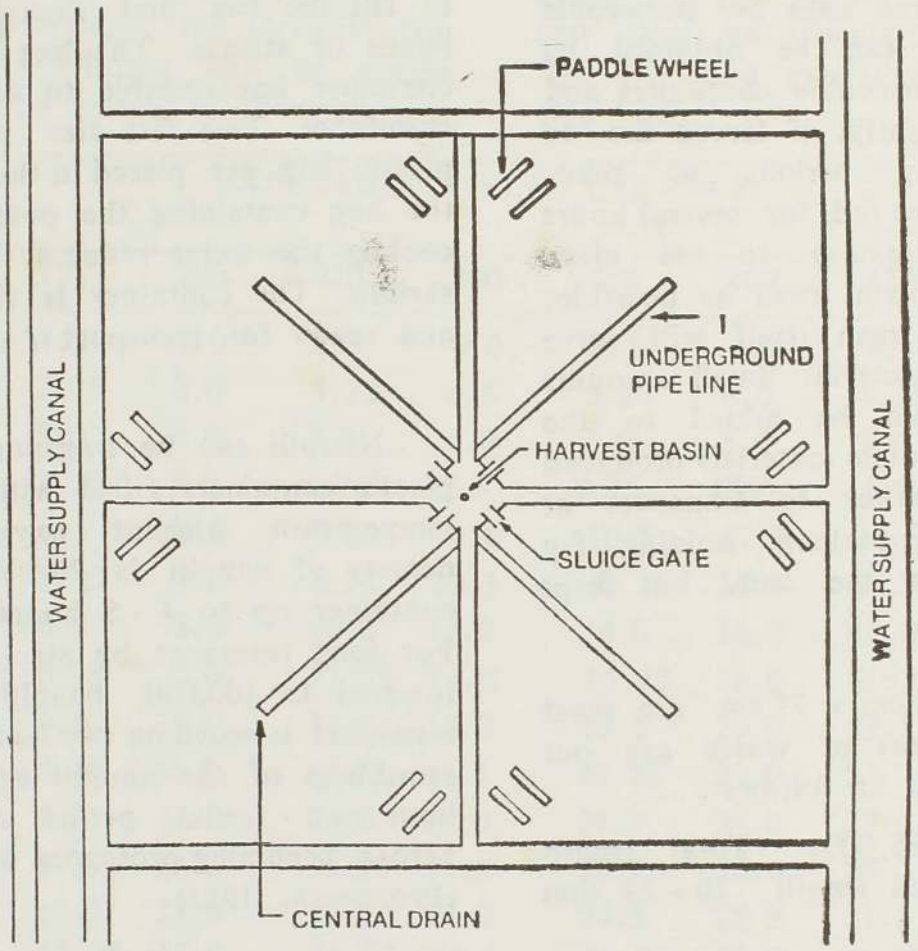


Fig. 27 : *Intensive pond (earthen with concrete dikes after Liu and Mancebo, 1982).*

In Japan and Taiwan, intensive systems predominate while extensive systems predominate throughout much of southeast Asia, especially in areas where mariculture is a long established adaptation by small scale producers (Bailey, 1988). Table 9 (Wickins, 1986), indicates the types of culture systems operating in different countries.

□

18. Fry Transport

Shrimp fry is most commonly transported in double plastic bags filled with oxygenated water. Since thin polythene bags are permeable to oxygen, better results can be obtained by placing the bags in impermeable containers and sealing the containers tightly, if larvae are to be transported for long periods of time. Post – larvae should not be fed for several hours before packing. It is necessary to use clean water and eliminate as much trash as possible, as the decomposition of trash itself will serve as nutrients for harmful bacteria. Small amounts of activated charcoal could be added to the bags to absorb harmful waste materials produced by the shrimp. It is better to transport at night. In day time the containers holding fry should not be exposed to the sun, but kept in the shade.

Polythene bags of 50 cm × 75 cm are most commonly used. 5 – 6 litres of water are put into the bag and stocked as follows :

Total length 10 mm – 15,000; Total length 17 – 18 mm – 5,000; Total length 20 – 24 mm - 3,000

Soft twigs can be placed inside the bag for the post - larvae to attach; then they do not group together on the bottom. The bag is closed down to the water level, sufficient oxygen is added to fill the bag and then sealed with elastic bands or strings. The bag is then placed in a container impermeable to oxygen, preferably of styrofoam. Two fist size pieces of ice in a plastic bag are placed in the container alongside the bag containing the post larvae. The ice by cooling the water reduces the metabolism of the shrimp. The container is then sealed with tape and ready for transport (Anonymous, 1978).

Nauplii can be transported, packed in 20-L plastic containers filled with sea water at ambient temperature without oxygenation. Maximum density of nauplii is 20,000 / L or 400,000 / container up to 4 - 5 hours transport overland. For long transport by air stocking should be lowered to 100,000 nauplii / container. Nauplii transport is based on two factors : (i) the relative sturdiness of the nauplii and (ii) the long 36 hour non - feeding period in the nauplius stage, before becoming protozoea which requires feeding (Primavera, 1983).

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19. Stocking Rate

Depending on the management capability of the culturists, type of management, costs of inputs and marketing strategy, the stocking rate can be calculated. A culturist has to decide what size of shrimp he wants to harvest and estimate how many kg / ha he can produce per crop. The number of post larvae to be stocked can then be calculated from the Table 10. The estimated mortality must then be added to this figure.

Size at harvest	EXPECTED YIELD (kg / ha)										
(No. / kg)	100	150	200	250	300	350	400	450	500	550	600
10	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
15	1.5	2.75	3.0	3.75	4.5	5.25	6.0	6.75	7.5	8.25	9.0
20	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
25	2.5	3.75	5.0	6.25	7.5	8.75	10.0	11.25	12.5	13.75	15.0
30	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0
35	3.5	5.25	7.0	8.75	10.5	12.25	14.0	15.75	17.5	19.25	21.0
40	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0
45	4.5	6.75	9.0	11.25	13.5	15.75	18.0	20.25	22.5	24.75	27.0
50	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30 0
55	5.5	8.25	11.0	13.75	16.5	19.25	22.0	25.75	27.5	30.25	33.0
60	6.0	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0
65	6.5	9.75	13.0	16.25	19.5	22.75	26.0	29.25	32.5	35.75	39.0
70	7.0	10.5	14.0	17.5	21.0	24.5	28.0	31.5	35.0	38.5	42.0
75	7.5	11.25	15.0	18.75	22.5	26.25	30.0	34.75	37.5	41.25	45.0
80	8.0	12.0	16.0	20.0	24.0	28.0	32.0	36.0	40.0	44.0	48.0
85	8.5	12.75	17.0	21.25	25.5	29.75	34.0	38.25	42.5	46.75	51.0
90	9.0	13.50	18.0	22.50	27.0	31.50	36.0	40.50	45.0	49.50	54.0
95	9.5	14.25	19.0	23.75	28.5	33.25	38.0	42.75	47.5	52.25	57.0
100	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0
110	11.0	16.5	22.0	27.5	33.0	38.5	44.0	49.5	55.0	60.5	66.0

Table. 10 : *Stocking rates of post-larvae (in thousands) needed to obtain various yields at different size at harvest, assuming no mortality (Anonymous, 1978).*

If a culturist estimates that he can produce 350 kg of shrimp with a size of 40 / kg, then from the Table 10, it can be seen that this requires a stocking rate of 14,000 post larvae per hectare. Suppose the estimated mortality is 30%, then 30% of 14,000 ie. 4,200 is added to 14,000, to obtain a stocking rate of 18,200 post larvae per hectare. If the estimated mortality is 50%, then stocking will have to be at a rate of (14,000 + 7,000 =) 21,000 per hectare in order to harvest the desired final weight of 350 kg of shrimp (Anonymous, 1978).

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20. Larval Feeds

Success in shrimp hatchery production depends on the timely supply of the needed food organisms in sufficient quantity. Though much research is underway to find artificial replacement diets, natural food still remains the major food in shrimp larval rearing operations. The non-feeding nauplii larvae on metamorphosis to the protozoea stage feed on unicellular algae. The larvae on transfer to the mysis stage, require live Zooplankton in the form of rotifers and *Artemia* nauplii for mysis and post-larval stages. The larvae of *Macrobrachium* feed on *Artemia* and inert food preparations throughout their pelagic phase. Most hatchery operations, therefore, require the culture of two to four types of living food organisms. Majority of the hatcheries usually have algae cultures and Zooplankton areas to maintain pure stocks of the needed live food such as *Chaetoceros*, *Skeletonema*, *Tetraselmis*, *Chlorella* and *Brachionus*. The nauplii of *Artemia* are most conveniently hatched as required from commercially available drought resistant cysts which can be stored dry for up to five years. These feeds are often difficult to culture and maintain, are often nutritionally variable and deficient in essential polyunsaturated fatty acids (PUFA) and are costly (Jones, 1988).

Research during the last decade has provided the hatchery industry with a number of techniques capable of improving hatchery performance and reliability. Firstly, the nutritionally good species of algae and strains of *Artemia*, and the ways of enhancing the gross biochemical composition of algae, rotifers and *Artemia*, by altering their nutrient or food source and culture conditions have been identified. Secondly, problems of contamination and fouling with products released during the hatching of *Artemia* have been substantially reduced by decapsulation and disinfecting the cysts prior to hatching. Decapsulation is done by dissolving the drought resistant outer shell of the cyst in a solution of sodium hypochlorite. The decapsulated cysts are then washed and stored in concentrated brine, hatched in warm sea water or fed directly to larvae or post - larvae (Wickins, 1986). The most recent development is the use of technique of microencapsulation to produce diets for Penaeid larvae. This is the most significant advance in recent hatchery technology.

The aquaculture industry has been aiming to replace natural foods with artificial nutritionally balanced diets, because live foods are difficult and expensive to culture, may introduce pollutants and disease and are of variable nutritional quality (Jones et al., 1974 and Jones & Kurmaly, 1987). The costs of algal production have been estimated to be approximately $ 360 Kg^{-1} dry weight. The search for artificial alternatives to live foods has intensified in recent years. Though in theory it should be possible simply to grind pelleted foods, designed for the adults of that species, in practice this is rarely successful. High concentrations of food particles in suspension at all times are required for filter feeding larvae like that of shrimp and this may be as high as 50 - 100 000 algal cells of 3 - 20 μm size ml^{-1}. When the pellets are ground finely enough, dissolution of soluble nutrients together with unprotected diet particles lead to rapid blooms of bacteria resulting in pollution of water and collapse of the culture. The differing particle size and chemosensory preferences displayed by each larval species and even larval stages within the same species are additional problems. Information available on essential nutritional requirements of most larvae is also scanty at present.

Animals, unlike plants, require unsaturated fatty acids in the diet for development and optimum growth. There is evidence that in

shrimp (Penaeidae) and certain marine fish there is dietary requirement for a long chain fatty acid of 22 carbon atoms in length with 6 double bonds in a certain configuration identified by a w number, namely 22 : 6w 3. New (1976 ; 1980) has reviewed the dietary studies of shrimp and prawns and documented a bibiliography.

There are now three main types of artificial larval feeds designed to replace live feeds thus simplifying larval culture systems and optimising growth and survival of the prawn larvae. They are freeze - dried or otherwise processed natural products, microparticulate diets and microencapsulate diets (Jones and Kurmaly, 1987). Langdon et al. (1985) give a review of microparticulate feeds for marine suspension feeders.

(1) *Processed natural products* : Natural products are mostly based on dried algae or yeasts. The advantage of these is that natural products still retain the correct particle size range for many first feeding herbivorous larvae, although this excludes the use of such feeds for later stage carnivorous larvae. Cell contents are subjected to leaching once the cells are dead and the cell wall may break down rapidly, reducing nutritional quality and stimulating bacterial growth in the culture water. Many of the original cell cultures will be of variable nutritional quality as with live foods and unless these are enhanced with approximate additives such as PUFA's for marine larvae, they will be of little value.

(ii) *Microparticulate feeds or microbound feeds* : Microparticulate feeds have been produced by incorporating dietary ingerdients into gels of carboxymethyl cellulose, calcium alginate, gelatin, carrageen, agar or zein (Langdon et al., 1985). Alginate diets are gelled either by adding calcium chloride or carrageen by heating, freeze - drying and powdering or zein by pH changes or gelatin by curing with formaldehyde. It has been shown by laboratory trial, that carrageenan - bound diets may support larval development. *P. japonicus*, *Chanos chanos* and *Pleuronectes platessa* have all been reared on gelatin - bound diets, although heavy mortalities were met with. Rapid leaching of water soluble ingredients, particle breakdown due to poor stability and tank pollution are the major problems encountered with these formulations. In addition, acceptable particle sizes available to larvae may be rapidly reduced by clumbing due to bacterial action. When using these diets strict attention must be paid to feeding levels, to avoid culture collapse due to over feeding. There does not appear to be any microparticulate product which has yet been used successfully as a total replacement for live feeds on a commercial scale although there are many products based on one or other process in the market.

(iii) *Microencapsulated feeds* : By encapsulating diets within a protective membrane, the solution to the problem of bacterial degradation was first demonstrated by Jones et al., (1974) using crosslinked nylon - protein microcapsules prepared by interfacial polymerisation of dietary amine groups by an acid chloride. Since the initial application of microencapsulation techniques to solve larval feeding problems, research in this field has grown widely with groups now working in the United States, Europe and Japan employing a variety of methods (Jones et al., 1989) (Table 11). Widespread commercial use has so far been restricted to the cross - linked capsule, although a number of other encapsulation techniques have been developed for nutritional research.

The early nylon - protein capsule delivery system has now been replaced by an X linked protein walled capsule which eliminates the nylon precursors, uses part of the diet to form the wall and can be dried for storage before rehydration as a larva feed. This process developed in collaboration with Frippak Feeds (Basingstoke, UK) and patented, is now under full commercial production. The capsule range currently designed for Penaeid shrimp larval culture is produced in the size ranges of 5-30 μm for zoeal stages, 90 μm for mysis and 90 - 150 μm for post - larval stages.

Rusults of commercial shrimp hatchery trials in Ecuador and Taiwan have shown that these encapsulated feeds are successful in preventing tank pollution and enhancing larval survival when fed as a 50% replacement for algae and *Artemia*. Further studies in the feeding biology by Jones et al., (1987) and Jones (1988) on *P. monodon* larvae have enabled adjustments to capsule size, diet formulation and wall digestibility to be made part of a continuous development programme. These have facilitated laboratory trials in which over 90% survival for *P. monodon* to post larval stage (PL_5) was attained on microencapsulated feed which replaced all live feeds.

	Method	Source	Modified by
1.	*Interfacial polymerization*		
	Diaminohexane – sebacoyl chloride	Chang et al. (1966)	Jones et al. (1974) Jones (1978) Clark et al. (1982)
	Diaminohexane – dichlorodiethyl ether	Suzuki et al. (1968)	Clark et al. (1982)
	Protein – terephthaloyl chloride	Kondo et al. (1976)	Clark et al. (1982)
2.	*Coacervation*		
	Gelatin – acacia	Green and Schleicher (1957)*	Gatesoupe and Luquet (1977a) Langdon and Waldock (1981) Holland and Jones (1981)
	Ethyl cellulose	Vrancken and Claeys (1970)*	Langdon and Waldock (1981)
	Zein – alcohol	Brynko and Bakan (1963)*	Gatesoupe and Luguet (1977a)
3.	*Microglobules*		
	Zein – coated diets	Bayliss (1975)* Gatesoupe and Luquet (1977a)	Clark et al. (1982)

* Patents

Table 11 : *Microencapsulation Methods Used for Marine Larval Feeds (Jones et al., 1984).*

Growth of *P. monodon* larvae in microencapsulated feeds was similar to life fed controls, but when 50% replacement of algae with capsules was fed for the first five days, growth exceeded that recorded for wild caught post – larvae. Though laboratory studies with artificial feeds have demonstrated potential to increase survival and growth of larvae beyond limits possible with live foods, total replacement of all conventional live foods in commercial hatcheries could emerge only through more research.

Recent trials with diets prepared with processed algae and algal extracts, have indicated better growth and survival than live algal food itself, in *P. monodon* larvae, indicating that some active factors in algae could be responsible for this enhanced growth (Amjad et al., 1989).

Microencapsulated diets have now become a standard tool for the study of Crustacean larval and post - larval nutritional requirements and have been extended to the nutritional studies of bivalves and fish larvae (Jones, et al., 1984). The current target of research in Penaeid larval nutrition of an efficient hundred percent artificial diet seems attainable in the near future. This would mean a more profitable shrimp culture that would expand to meet the increasing world demand for shrimps (Chitravadivelu, 1992).

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21. Feeding and Digestion

Cephalic appendages, antennae, mandibles, maxillules, maxillae and maxillipeds are used in feeding by most suspension feeding Crustaceans. The traditional concept of filter feeding in small Crustaceans such as Copepods has been challenged and recent research has shown that the setal rows of feeding appendages create currents which draw particles into the mouth region, rather than acting as simple filters (Koele and Stickler, 1981; Gerritsen and Porter, 1982). Most species display variable feeding strategies which allow optimal utilisation of available food resources and may grasp large particles individually. Yule and Crisp (1983) claimed that there is evidence to suggest that many planktonic Copepods and larvae assess the concentration of suspended food particles in the surrounding medium by chemical and other methods and adjust feeding rates accordingly.

Commercially important Crustacean species such as shrimps, lobsters, and crabs possess planktonic, suspension - feeding larval stages. Penaeid shrimps have some herbivorous larval stages while some species such as lobsters have carnivorous larval stages. Species of microalgal food, used in the culture of herbivorous Crustacean larvae, generally are less than 20 μm in diameter so that they are ingestible by the larvae. For the capture or filtration of the particles by Crustaceans, food particles must be of the correct size and shape.

Chance encounter feeding behaviour has been shown by many predatory Crustacean larvae, grasping any particle which they encounter and visual and chemical clues appear unimportant. Both chemical and textural stimuli become important on contact with the mouth parts and unless the correct stimuli are provided, the particles are rejected (Moller et al., 1979). Therefore, if maximum diet utilisation is to be achieved for many predatory species, chemical attractants normally associated with natural foods must be incorporated into artificial diets (Ache, 1983; Wales, 1982). Feeding rates could be optimized by the controlled release of these attractants from food particles (Roseman and Mansdrof, 1983).

Herbivorous or omnivorous larvae such as that of *P. japonicus*, appear far less selective and will acccpt a wide range of non-living and living particulates (Jones et al., 1979).

A gastric mill in the cardiac stomach of the majority of Crustaceans mechanically grinds ingested food particles. The triturated particles then pass through a complicated filter apparatus. The fine particles enter the pyloric stomach and digestive diverticula where further digestion occurs. The gastric mill is reduced or abesnt in prawns and the mandibles, armed with sharp teeth, enable the animals to chew the food before ingestion. Digestion in Crustacea is generally extracellular and takes place in the stomach and tubules of the digestive diverticula (Gibson, 1983).

Clark et al. (1986) have demonstrated that the protozoeal stages of *P. monodon* show both particle size selection and chemosensory behaviour when feeding. With larval stages of *P. monodon* using suspended carbon particles, in laboratory feeding trials, they found that the zoeal stages ingest only a narrow range rarely exceeding 10 μm and a median particle size (mps) of 3.5 — 4.9 μm. With the moult to the omnivorous mysis stage the range of mps is 9 — 15 μm (Fig. 28).

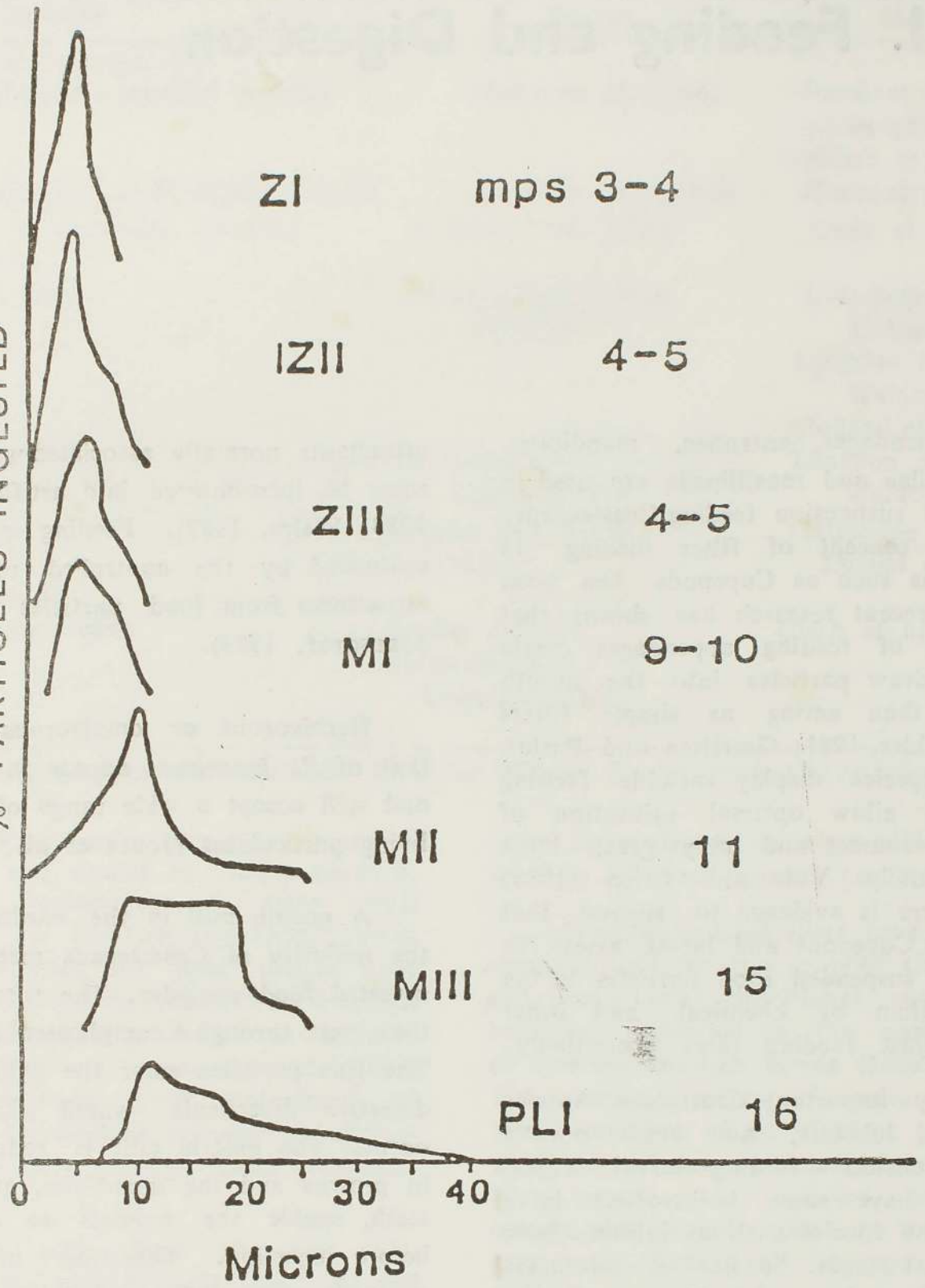

Fig. 28 : *Range of particle sizes accepted by the different larval stages of* **P. monodon** *(mps = median particle size) (Clark et al., 1986).*

Modification of Frippak encapsulated diets to reduce particle size and enhance retention of water soluble ingredients has led to patterns of ingestion and faecal pellet production which are similar to those observed for larvae feeding on conventional prey items such as algae and *Artemia*. To achieve further improvement in growth and survival rates on Frippak encapsulated diets for the Penaeid larvae it has been necessary to study the functional changes in the gut during larval development together with the process of digestion.

Though data on larval assimilation rates are not adequate as yet, preliminary measurements indicate that *P. monodon* protozoea assimilate 50 — 60% of ingested algae. Remarkable changes have been shown in gastroevacuation rates according to larval stages; with protozoea (PZ_1) clearing the gut in 7 — 12 minutes, mysis (M) taking double this time and post-larvae (PL_1) up to one hour; juveniles show a mean time of three hours (Table 13). Allowance must be made for short residence time and relatively low

Stage	Energy per stage	Ingestion Algae	rate (1) *Artemia*	Respiration rate (R)	Exuvia (Ex)	Growth (G)	Egestion and excretion (E)
PZ1	0.13	0.746		0.014	0.0052	0.1	0.627
pZ2	0.33	0.884		0.030	0.0132	0.095	0.746
PZ3	0.52	1.462		0.051	0.0208	0.185	1.205
M1	0.89	1.917		0.080	0.0356	0.090	1.711
M2	1.07	2.073	1.28	0.118	0.0428	0.105	1.411
M3	1.28	2.210	1.65	0.120	0.0512	0.180	1.579
PL1	1.64	1.350	1.74	0.136	0.0656	0.178	1.165

Table 12 : *Daily energy budget for the larval development of* **Penaeus monodon** *(all figures in joules individual - 1 (Karim et al., 1989).*

assimilation efficiencies when designing artificial feeds for early Penaeid larvae (Jones and Kurmaly, 1987).

At PZ_1 when first fully operational, the fore gut lacks the mastigatory and filter apparatus present in the juvenile. Since the gut ossicles are functional only from M_2 it appears unlikely that breakdown of food by mechanical trituration is imortant before this larval stage. Jones and Kurmaly (1987) have suggested that the primary method of food breakdown during protozoeal stages is enzymatic and is conducted by the anterior diverticulae of the midgut which regress during later larval stages. This is in conformity with the finding of Galgani and Benjamin (1985) who report maximal trypsin and protease activity during PZ stages.

Stage	Feed	Gastro Evacuation Rate (Mins.)	Assimilation Efficiencies %
Protozoea I	Microencapsulated diet	7 ± 2	
	Algae (Tetraselmis)	12 ± 2	16.0
	Charcoal particles	7 ± 2	
Protozoea III	Microencapsulated diet	8 ± 2	
	Algae (Tetraselmis)	12 ± 2	17.6
	Charcoal particles	8 ± 2	
Mysis I	Microencapsulated diet	20 ± 5	
	Algae (Tetraselmis)	15 ± 5	10.7
	Charcoal particles	25 ± 5	
Post-larva I	Microencapsulated diet	60-300	32.0
	Frozen mysid		65.0
Adult (12g)	Artificial pelleted diet	280-360	76.0

Table 13 : *Gastroevacuation rates and assimilation efficiencies for different larval stages of the prawn* **P. monodon** *fed on inert particles, natural and artificial diets (Jones, 1988).*

Jones and Kurmaly (1987) suggest that early larval strategy to maximise energy uptake is to process large quantities of small sized abundant particulate material rapidly with a low assimilation efficiency but with a high turnover rate. Only with the development of a functional gastric mill and filter press can energetic requirements be met in late mysis stage by switching to animal prey. More efficient mechanical trituration coupled with longer gut residence times results in higher assimilation efficiencies which balance increased energy expenditure in

the search for less abundant prey. These larval feeding strategies have important implications for the design of encapsulated feeds. These feeds for protozoeal stages must be of the correct size, fed at high density and have a wall which is readily digestible by enzymatic activity. The feed must also be nutritionally balanced, of a high calorific value and contain nutritional ingredients in an easily assimilable form.

Kurmaly et al. (1988) determined the ingestion rates and respiration rates for different larval stages of *P. monodon* over a range of temperatures and used these data together with assimilation and growth rates to compute preliminary energetic requirements for larvae (Table 12, 13 and 14). The dry weights of algae and microencapsulated CAR feed required to produce 10^6 PL *P. monodon* were calculated using the value for total ingested energy required. The dry weight of algae required to produce 10^6 PL is 0.9 kg and 1.1 kg Frippak CAR or CD feeds.

Ingested	Growth	Moult	Respiration	Excretion
18.78	1.69	0.403	0.962	15.72

As algae, *Tetraselmis chuii* has 22.05 J mg dry wt^{-1}, 0.852 kg algae is required to culture 10^6 post-larvae.

As microencapsulated feed has 18.78 J mg dry wt^{-1}, and similar assimilation, 1.02 kg encapsulated feed is required to culture 10^6 post larvae.

Table 14: *An energy budget (joules) for the total development of a* **Penaeus monodon** *larva (Jones, 1988).*

Kurmaly et al. (1988) have demonstrated that an effective diet must be captured, ingested, assimilated and provide appropriate metabolites; consequently the size, shape, attractiveness and nutritional content of an artifcial diet must be optimised to achieve adequate growth and survival. Particle size experiments suggest that *P. monodon* protozoea able to ingest spherical particles of up to 15 μm diameter, and that later mysis stages progressively ingest larger particles of up to 25 μm (Fig. 28). From PZ_2, the larvae can efficiently handle prey items up to 100 μm in length. Visual observations suggest, however, that prey items have to be 8 μm to enter the midgut diverticulum. It appears that the main feeding mechanism during the PZ_1 stage is suspension feeding and that from PZ_2 the larvae may also feed raptorially.

22. Food Requirement

Food supplies the energy shrimps require for movement and all other activities in which they engage. Shrimps are cold blooded aquatic animals and therefore do not have to utilise energy to maintain steady body temperature and tend to be more efficient users of food than other farm animals. Their rate of metabolism, however, depends very largely on the temperature of the water in which they are living and differs for each species. Within the range of temperatures of which they are tolerant, metabolic rate and the need for food increase as the optimum temperature is reached. The energy available for biological activity and growth after satisfying the energy requirements for maintaining body temperature, which is not necessary for shrimps, is the free energy. Excess energy is dissipated as heat. Many species of Penaeids are usually active in the night and burrow into the substrate when not feeding, thus conserving energy and reducing predation (Fuss and Ogren, 1966; Kutty and Murugapoopathy, 1967).

The most economically important thing from the point of view of the shrimp farmer is the quantity and cost of energy which is available for the growth of the culture animal. The requirements of food of different species vary in quantity and quality according to the nature of the animal, its feeding habits, its environment and its reproductive state (New, 1987).

The gross energy of a food, that is the total energy containing in it is not available in full to the animal. Different components of the diet have different energy availabilities. The energy available for growth is what remains after the energy for metabolism, reproduction etc. Small animals like shrimps grow faster than large ones in terms of percentage increase in weight per day. Thus the feed requirements of shrimp are different to those of large animals and require a higher feeding rate. However, at a certain body size, growth rate starts to decline rapidly. It is at this point the optimum marketable size of an aquaculture species like shrimp normally occurs, unless the market factors dictate otherwise.

Prawns like other living organisms need proteins, fats, carbohydrates, vitamins and minerals to provide for growth, maintain life and provide resistance to disease. Since all these nutrients are so interrelated, they have to be incorporated in the diet in proper amounts if they were to be fully utilised by the body.

Proteins and amino acids :

Animals cannot synthesise proteins which are large complex organic compounds. Unlike plants, animals cannot synthesise them from simple inorganic materials and have to rely on receiving them through their diet or on their synthesis by gut bacteria. Protein is an energy source as well as a tissue builder. Proteins are composed of mostly amino acids linked with peptide bonds and cross - linked between chains with sulphydral and hydrogen bonds. The major amino acids are twenty in number. The amino acid composition of proteins varies widely from different sources. Some proteins have none of certain amino acids. Animals can synthesise some amino acids. Those amino acids that connot be synthesised are called essential amino acids (EAA) (New, 1987). The optimum protein levels in diets for shrimps are different among species (Kanazawa, 1984).

Lipids and fatty acids :

The two main functions of dietary lipids are (i) as a source of energy and (ii) as a source of its component fatty acids, some of which are

essential (and cannot be synthesised by animal itself) dietary components for the growth and survival of the recepient animal. Those fatty acids which have their first double bond on the third carbon atom are known as the " W-3 " series or the " linolenic " series after the name of the fatty acid in the series with 18 carbon atoms in its chain. Similarly those which have their first double bond on the sixth carbon atom are known as the " W-6 " series or the " linoleic " series.

Saturated fatty acids are those without any double bonds. Monosaturated fatty acids are those with only one double bond, while those with more than one double bond are known as poly - unsaturated fatty acids (PUFA). The " W-3 " series and " W-6 " series fatty acids are all members of the group known as poly - unsaturated fatty acids, because they have more than one double bond. These are referred to as PUFA's. Members of this group which have many (4 or more) double bonds are sometimes referred to as higher unsaturated fatty acids (HUFA's).

The essential fatty acid (EFA) requirements of different species vary but are not yet fully understood. Aquatic animals have a higher requirement for W-3 series of fatty acids than terrestrial animals, for which the W-6 series is more important. EFA deficiencies are more noticeable in seawater than in fresh water conditions. Thus salinity affects EFA requirements. Shrimps and prawns have a requirement for the W-3 series and the W-3 : W-6 ratio is important (New, 1987). The levels of either type of PUFA's can be detrimentally high in a feed. Knowledge of the specific requirements of a species is therefore constantly being sought to optimize formulation practices. Although many vegetable lipids are high in PUFA's, the best sources of the W-3 HUFA's are marine lipids. Vegetable oils tend to have high levels of W-6 series (New, 1987).

The unique aspect of lipid nutrition in Crustaceans is that they require dietary sources of sterol for normal growth and survival because of the absence of their sterol - synthesising ability from acetate and mevalonate.

Carbohydrate :

Starches, sugars, cellulose and gums contain only the elements carbon, hydrogen and oxygen and are all carbohydrates. These are usually the cheapest source of energy in foods and feed. Shrimps vary in their ability to digest carbohydrates, their efficiency varies according to source and the ability to digest specific sources of carbohydrates also varies between species (New, 1976). Carbohydrates are important in the Kreb's cycle, in glycogen storage, in chitin synthesis and in the formation of steroids and fatty acids.

Minerals and vitamins :

Mineral elements provide strength and regidity to the exoskeleton of Crustacea. In body fluids they are involved mainly with the maintenance of osmotic equilibrium with the aquatic environment and in the nervous and endocrine systems. They are components of enzymes, blood pigments and other organic compounds. Essentially they are involved in the metabolic processes concerned with energy transport. Apart from absorbing minerals from the digestion of food, Crustaceans can also absorb them through the ingestion of sea water and through exchange from their aquatic environment across body tissues such as skin and the gill membranes. Probably minerals are not so important a component of the diet of shrimp as they are in that of other animals (New, 1987).

Vitamins are complex organic compounds required in trace amounts for normal growth, reproduction, health and general metabolism. Vitamin deficiencies are much less likely to occur in extensive systems of culture, in ponds where natural food is also available. Though the understanding of the role of vitamins in shrimp nutrition is incomplete, widely divergent quantities of individual vitamins have been contributed to diets by supplementation. The application of vitamin mixtures to shrimp diets without knowledge may not only be economically wasteful but dangerous as well because excess of some sorts of vitamins may be toxic. Vitamin deficiency may be fulfilled by the prawn itself from the natural productivity of the water (New, 1976). Fisher (1960) has discussed the metabolic functions of vitamins in Crustacea.

Generally, minerals and vitamins are added to artificial diets, but there is little data on the quantitative requirements for each of the vitamins and minerals for Penaeid prawns. Supplementing the diets with phosphorus, magnesium, potassium and copper improves growth somewhat while

iron and manganese inhibited growth slightly. Most of the B group vitamins are required in Crustacean diets, in addition to vitamins C and E. Vitamin D may be partly ingested in the diet but can be synthesised from ergosterol. Vitamin K may even be antagonistic to some species of Crustacea. The quantitative requirements for phosphorus, magnesium, iron, copper, thiamine, pyridoxine, inositol, choline and ascorbic acid have been investigated but the necessity for other minerals and vitamins for Penaeids is unknown (Fisher, 1960; Kanazawa, 1981 and 1984).

□

23. Artificial Diets

The development of artificial diets for Crustaceans is complicated by the need to bind the feed ingredients into water stable form, to avoid disintegration from exposure to water and manipulation process of the animal during ingestion (Mayers and Zein - Eldin, 1972). Knowledge of how to bind feeds to prevent distintegration in water has become increasingly important, with the increased interest in aquaculture, especially intensive shrimp farming. The feed particles need to be bound tightly enough to prevent undue wastage during the mastication process and to ensure that ingestion of a diet can continue for at least several hours after introduction. Mayers *et al.* (1972) has referred to a range of substances avilable for binding aquatic diets and has given details of methods of preparation for shrimp diets bound with sodium alginate - calcium complex or with propylene glycol alginate. Agar, alginates, carrageen, guar and locust bean gums, gelatins and cellulose are some of the ingredients that have been tested for their binding ability. The large scale production of diets bound with any of the above additives is limited by costs, availability and machinery which can be readily utilized in the manufacturing process (Balazs *et al*, 1973).

Jones *et al.* (1989) and Amjad et al. (1989) have evaluated the performance of leading types of artificial larvae diets under controlled conditions with *P. monodon* larvae. They have concluded that if total replacement of all live feeds in shrimp larval culture is to be achieved, feed process technology must concentrate on production of stable low leach diets.

The possession of chemoreceptors sensitive to amino acids and / or other nitrogenous compounds of low molecular weight is characteristic of all marine Arthropods that have been studied to date using either behavioural procedures or electrophysiological techniques (Carr and Gurin, 1975). To induce location and feeding in cultured animals, artificially compounded diets should be chemically attractive and in addition, small quantities of chemo - stimulants might increase ingestion rates, improve growth and food conversion. However, the use of these attractants or ingestants may or may not be advantageous to the aquaculturist in terms of finance though addition of these may improve growth, survival and food conversion

Dietary requirements, particularly with respect to protein level, appear to vary quite widely from species to species. Generally marine shrimps

species	moisture	crude protein	crude lipid	crude ash
		% by weight		
P japonicus	12	55	9	20
P. monodon	12	35 — 40	2.8 — 3.3	18 — 21
P. vannamei	8	36 — 38	6	15
P. merquiensis	10	43	2.5	4
P. setiferus	10	28 — 32	4	10 — 20
Macrobrachium	10 — 15	23 — 35	5 — 10	15

Table 15 : *Analysis of commercial grow - on feeds for different tropical prawn species (Jones, 1988).*

require high levels of animal protein (particularly marine), whereas freshwater prawns are more omnivorous. Pascual (1983) has shown that *P. monodon* juveniles require 35 — 40% protein depending on the source protein, 10 — 12 % fat, 40% carbohydrates, 0.5 — 1.0 % cholestrol, vitamins and minerals. Approximate dietary protein / lipid ratios have been established for most commercial species and are given in Table 15.

The following factors should be considered in developing and preparing diets : (i) nutritional requirements of prawn (ii) availability and cost of ingredients (iii) ease of preparation (iv) acceptability and attractability to the prawn and (v) effectiveness of the diet (Pascual, 1983).

Formulations of certain grow - out feeds are given in Table 16.

(A) *Marine Shrimp (Penaeus monodon) :* (Malaysia)

	Grow-out Feed	
	Semi-moist	Dry
	(%)	(%)
Fish Meal (55% CP)	10.0	16.0
Shrimp Head Meal	15.0	24.0
Wheat Pollards	36.75	58.0
Vitamin Mix No.3	1.25	2.0
Water	37.0	—
	100.00	100.00

Source : Chow, 1984

(B) *Freshwater Prawns :* (Indonesia)

	Dry Pellets
	(%)
Shrimp Head Meal	30.0
Soybean	4.0
Rice Bran	35.0
Coconut Oil Cake	20.0
Tapioca	9.0
Agar	1.0
Pfizer Premix A (1)	1.0
	100.0

Source : *Manik, 1976*
(1) No details available

(C) *Freshwater Prawns: :* (Malaysia)

	Grow – out feed	
	Semi – Moist	*Dry*
	(%)	(%)
Fish Meal (55%) (CP)	8.00	13.0
Wheat Pollards	30.00	47.0
Rice Bran	11.75	19.0
Soybean Meal	12.00	19.0
Vitamin Mix No. 3	1.25	2.0
Water	37.00	—
	100.00	100.0

Source : *Chow, 1984*

Table 16 : *Composition of premixes for prawns (New, 1987).*

(D) *Marine Shrimp (Penaeus monodon)* :	Dry Grow - out Pellets	(Indonesia)
Squid Head Meal	10.0	
Fish Meal	20.0	
Soybean Cake	34.0	
Shrimp Meat	24.0	
Wheat Flour	8.0	
Aquamix (Vitamin Mix) (1)	2.0	
Kelco Alginate	2.0	
	100.0	

Source : Manik *et al.*, 1980

(1) No details available

(E) *Marine Shrimp (Penaeus mondon P. merguiensis)* ;	*Dry Pellets* (%)	(Malaysia)
Fish Meal	27 0	
Meat & Bone Meal	10.0	
Soybean Meal	15.0	
Exp. Sesame Cake Meal	5.0	
Exp Groundnut Meal	5.0	
Maize	4.0	
Coconut Cake	10.0	
Extracted Rice Bran	10.0	
Leaf Meal	5.0	
Tapioca	8.0	
Vitamin Mix No. 4 (+BHT 0.02% and Ethoxyquin 0.015%)	1.0	
	100.0	

Source : *Kanazawa, 1984.*

(F) *Marine Shrimp* :	*Practical Pond Diet (2)* %	(USA)
Fish Meal (61 % CP)	15,0	
Ext. Soybean Meal	36.0	
Shrimp Waste Meal	10.0	
High - Gluten Wheat Flour	20.0	
Rice Bran	12.0	
Fat (1)	2.0	
Binder (Hemicellulose or Lignin Sulphonate : by - products of wood processing)	2.0	
Vitamin Mix (1)	0.5	
Trace Mineral Mix (1)	0.5	
Dicalcium Phosphate	1.0	
Coated Vitamin C	0.038	

Source : *NRC, 1983.*

(1) No details available (2) Diet does not add to 100%

Table 16 *Composition of premixes for prawns (New, 1987)* (Continued)

(G) *Marine Shrimp (various spp)* : *Moist / Dry Pellets (1)* (Bangladesh)

	1 (%)	2 (%)
Animal viscera	60	—
'A' grade fish meal	—	40
Rice bran	20	35
Wheat flour	20	25
	100	100

Source : *Karim, 1986*

(1) These moist diets were fed moist or sun - dried, stored and used later. This was the pioneer shrimp, feed in Bangladesh.

(H) *Freshwater Prawns* : *Dry Pellets* (Thailand)

	1 (%)	2 (%)
Fish oil	3.0	3.0
Shrimp Meal	25.0	10.0
Fish Meal	10.0	4.0
Peanut meal	5.0	2.0
Soybean meal	5.0	2.0
Broken Rice	25.5	39.0
Rice Bran	25.5	39.0
Guar Gum	1.0	1.0
	100.0	100.0

Source : *New and Singholks, 1982*

(I) *Freshwater Prawns* : *Dry Pellets* (Indonesia)

	(%)
Fish Meal	20.0
Soybean Meal	9.0
Rice Bran	45.0
Coconut Oil Cake	20.0
Tapioca	5.0
Pfizer premix A (1)	1.0
	100.0

Source : *Manik, 1976*

(1) No details available.

Table 16 : *Composition of premixes for prawns (New, 1987)* (Continued)

(J) *Freshwater Prawns :* Ingredients	*Dry Pellets*			(Hawaii)
	Waldron's Broiler Starter (%)	*Waldron's Game - cock Pellets* (%)	*Waldron's Prawn No. 1* (%)	*Waldron's Prawn No.2* (%)
Alfalfa	—	—	4.00	4.00
Corn	53.25	50.25	56.75	56.75
Cotton seed Meal	10.00	15.75	—	—
Soybean Meal	24.25	20.50	27.00	25.00
Meat and Bone Meal	7.00	7.00	11.00	8.00
Tuna Meal	—	—	—	5.00
Vitamin Mix (1)	1.25	1.25	1.25	1.25
Mineral Mix (1)	1.25	1.25	—	—
Molasses	3.00	4.00	—	—
	100.00	100.00	100.00	100.00

Source : Corbin *et al., 1986*

(1) No details available

Table 16 : *Composition of premixes for prawns* (*New. 1987*). (Continued)

A formulated diet for prawn larvae made out of ingredients available locally in India designated as NPCL - 17 (Narakkal Prawn Culture Laboratory), modified with ingredients available in Sri Lanka and partially tested (Anonymous, 1986) is given in Table 17. Karim and Bose (1985) has used supplementary feed consisting of 50% animal matter (squid offal, octopus, clam meat, trash fish), 30 — 40% plant matter (Ground nut oilcake, de-oiled rice bran) and 10% polished wheat flour and tapioca powder as feed binders in the culture of shrimp in the back waters of Killai, Tamil Nadu.

NCPL-17 Ingredients	Composition	Locally made formulated feed ingredients	Composition
Dried prawn head powder	25%	Dried prawn head powder	25%
Dried mantis prawn powder	25%	Dried mantis prawn powder	25%
Groundnut oil cake powder	37.5%	Soybean Powder	37.5%
Fish meal	12.5%	Fish meal	12.5%
Multivitamins and minerals	trace	Multivitamins and minerals	trace
Tapioca powder	20% of feed base	Wheat flour (binder)	22% of feed base

Preparation procedures for micro - encapsulated whole egg larval diet (Adapted from "Fish Feed Technology" ADCP / REP / 80 - 11-p 360) (Anonymous, 1986).

Table 17 : *Artificial larval feeds used at the Carsp backyard hatchery. Ingredients of NPCL-17 and of the locally - made formulated feed.*

In semi-intensive experimental shrimp farming, in ponds in Polekkru, Andhra Pradesh, India, (Janssen *et al.*, 1986) gave supplementary feed, with the following approximate composition :

60% trash fish (silver belly, ribbon fish, squilla, small shrimp), clam meat.

30% rice bran, ground nut oil cake, broken rice.

10% tapioca, maida as feed binder.

The food was prepared by thoroughly washing and cleaning the required quantity of fish, mincing in a hand mincer, mixing with rice bran, broken rice and soaked ground nut oil cake. The binding agent was boiled till it became sticky and was thoroughly mixed with the prepared food material until the whole mass turned into a sticky dough. This was then divided into smaller lumps and distributed to various ponds as per the determined feeding rate. The feed was given in mud plates, placed at a margin of 30 cm depth of the pond bottom at places marked with long sticks. Feed was served in these trials at 5 — 10% of the body weight of shrimps in ponds.

Karim (1986) in brackish water semi-intensive shrimp culture in Bangladesh has used feeds made in hand grinders using the following combinations where wheat flour acted both as a source of carbohydrate and binder.

- animal viscera (60%), rice bran (20%) and wheat flour (20 %)

- 'A' grade fishmeal (40%), rice bran (35%) and wheat flour (25%).

Pellets were dried in the sun. Dry or half dry pellets were thrown along the edges of the grassy berm sometime before sunset when shrimp became active and started grazing.

Food conversion ratios of 1.8 to 3.3 have been reported for prawn feeds and these ratios could be improved by studies on digestive enzyme activities in conjunction with factors controlling assimilation in prawn (Jones, 1988).

There is no unanimous view regarding the optimum time and feeding frequency for marine shrimps. There are some which burrow during the day and feed most actively at night; while others feed in shallow parts of pond, avoiding these areas in daylight when the temperatures are highest. It would be best to feed these species in the late afternoon or early evening. Most farms feed once, or at the most twice a day, usually first thing in the morning and last thing in the afternoon (New, 1987).

□

24. Natural Food

In ponds the availability of natural foods may be increased by organic or inorganic fertilization, which results in higher planktonic and benthos productivity and this is the least expensive method of increasing food supply. The natural foods called ' lab - lab ' and 'lumut' by Filipinos are algal complexes which form a dense mat over the pond.

(i) "Lab - lab" :

This micro-benthic complex is composed of blue - green algae, diatoms with many other forms of plants and animals associated with it and contribute to its nutritional value. "Lab-lab" requires water levels from 5 to 40 cm and grows best in salinities of 25 ppt or higher. The high salinity requirement of "lab-lab" is not compatible with optimum growing conditions for *P. monodon* which is reported to grow best at slightly low salinities (10—25 ppt). " Lab-lab " is well suited for *P. indicus* or *P. merguiensis*.

A high clay (42% — 50%) content in soils supports the best growth of "lab - lab". The pond bottom should be levelled, made firm enough to serve as a hold fast for the algae but not hard. The amount of organic matter present in the soil also affects the growth of " lab - lab ". 9-16 % of organic matter supports the growth of algae. Fertilizer, chicken or other manure is applied to the dry pond bottom at the rate of 350 kg. / ha, to increase the amount of organic matters in the soil. The chicken manure should not be treated with insecticide and should be dried. Inorganic fertilizer can be used if no manure is available; at the rate of 50 - 100 kg of 18 — 46 — 0 (N - P - K) or 100 - 150 kg of 16 — 20 — 0 per ha. 3 — 5 cm of water is let into the pond, immediately after fertilization. The same amount of fertilizer is applied after one week and the water level raised to 10 — 15 cm. After the second week, the fertilization is repeated and the level is raised to 20 — 25 cm.

(ii) " Lumut " :

This is a complex composed primarily of filamentous green algae such as *Chaetomorpha* spp. and *Entromorpha* spp. Many other forms of life are associated with these algae and contribute to the nutritive value of " lumut ". Water depth of 40 to 60 cm and a range of salinity of 25 ppt and below are most favourable. " Lumut " is not suitable for nursery ponds because the post-larvae become intangled in it and die. It is recommended that some fish such as milk fish, mullet or rabbit fish be stocked in the pond to eat the " lumut " and keep the growth down as its heavy growth can even be harmful to adult shrimp.

" Lumut " grows favourably in soft mud bottoms of pH 6.8 — 7.5. Bottoms with a pH less than 6.5 should be treated with lime. For " lumut " culture also the pond bottom must be dried. Sufficient water is let in to moisten the soil, after the bottom has been dried and the pond bottom is seeded by sticking a portion of the filaments of very young plants or light green ends of older plants into the mud. The pond is flooded to a depth of 20 cm after the seeding and fertilized with 16 — 20 — 0 (N-P-K) at the rate of 18 - 20 gm / m^3 of water. The water level is raised to 40 cm after one week. Weekly application of fertilizer, starting with the second week at the rate of 9 — 10 gm / m^3 of water is continued until 6 weeks before the crop is to be harvested. Organisms which attach to the algae such as bacteria, protozoans, diatoms, nematodes, small Crustaceans, etc, also increase in number as a result of the addition of fertilizer and serve as food for the shrimp.

(iii) Phytoplankton :

When phytoplankton is grown in a pond, the zooplankton as well as pieces of organic material in the pond also serve as food. Phytoplankton is not directly fed on by the shrimps. Shrimps feed on the zooplanktons that eat the phyloplankton or on bacteria that grow on the dead phytoplankton cells which accumulate on the bottom. At a water level of 70 cm. or more phytoplankton is better, though it has been grown in shallower ponds. Types of phytoplankton which give the water a yellow - green or yellow - brown colour are claimed to be good.

The conditions suitable for shrimp growth at all life stages are well suited for growing phytoplanktons.

Fertilization causes a good growth of phytoplankton; various micro - organisms feed on the phytoplankton and the shrimps feed on the micro - organisms. Growths of shrimp in ponds in which the most common types of algae are true diatoms have been reported to be better than those in ponds in which phytoflagellates dominate. Nitrogen (N) to Phosphorous (P) ratios of 20 or 30 to 1 have been found most suitable for diatoms and ratio close to 1 : 1 most suitable for phytoflagellates in laboratory and tank cultures (Annonymous, 1978).

25. Disease

Often a major cause of disease in prawns is stress induced by poor management, particularly during the hatchery and nursery stage and in intensive culture systems where transmission and development are enhanced. Many of the organisms causing disease are opportunistic pathogens which form part of the normal microfauna and flora of the sea and fresh water (Jones, 1988). These include bacteria, phycomycete fungi and peritrich protozoans. *Vibrio* bacteria infect the cuticle, appendages or gills and appear as black or brown spot, due to melanin produced by hemocytes involved in the inflammatory process. Shrimps affected by this bacteria also typically off-feed and therefore, lack faecal strands and have empty guts. The filamentous bacteria *Leucothrix* and *Flexibacter* appear as filamentous growth on the body surfaces, especially on the cuticular setae of the appendages. Though these do not cause demonstrable pathology to cuticular surfaces to which they attach, they foul the larvae and post-larvae so that respiration, feeding, locomotion and moulting become seriously impaired. resulting in slower growth, retarded development and eventually death (Lightner, 1988).

The phycomycetomus fungi *Lagenidium* and *Sirolpidium* are responsible for high mortalities in the hatchery. These fungi cause progressive mycosis and are most severe in the protozoeal and mysis stages. Affected larvae contain an extensive, non - septate, highly branched fungal mycelium throughout the body and appendages. They are occasionally observed in nauplii but only rarely do they produce active infections in early post-larvae. Infection of individual shrimp invariably results in death.

Another form of gill disease that may occur alone or with *Leucothrix* is due to the infestation of the gills by one or more species of the peritrich protozoans, *Zoothamnium sp.*, *Epistylis* sp. and *Vorticella* sp. These organisms, when abundant on the surface of the gills, can cause hypoxia and death.

The use of anti - bacterial chemotherapeutics such as formalin, malachite green and methylene blue has been reported to be effective in controlling these organisms. Increasing use of powerful antibiotics such as chloramphenicol, especially as prophylactics, is unfortunately leading to resistant strains of bacteria (Jones, 1988).

In extensive culture systems disease problems are encountered less frequently than in intensive systems. Feeding prepared diets and crowding contribute to disease. Apart from chemical treatment through feed additives, treatment can also be accomplished by changing the water quality to kill parasites and removing the animals from the water for treatment. Prophylactic measures can be taken in intensive systems but are not feasible for extensive cultures (Neal, 1973).

□

26. Predators, Competitors and Pests

The following have been identified as causing problems in shrimp culture :

Predators : Fish, crabs, birds, man, insects, snakes.
Competitors : Snails, fish, crabs, shrimps.
Pests : Crabs, burrowing shrimp *(Thallassina)*, organisms which degrade wood, mud worm egg cases, shells.

Methods of control of fish and crabs

I. Fish

A. Prevention :

Prevention is the most effective method of control. Fish will not ordinarily be a problem during the culture period if proper precautions are taken in maintenance and pond preparation.

(i) Proper pond maintenance : Predators and competitors can enter the pond through crab holes and other leaks in the dikes. Post - larvae shrimp can also escape from the ponds through the holes. Regular maintenance should be performed to stop all leaks in the dikes.

(ii) Drying the pond bottom : Drying the pond bottom thoroughly before stocking will eliminate the fish.

(iii) Poisoning before stocking : Fish poisons can be used before the pond is stocked, if a pond cannot be completely drained. Rotenone or derris root is recommended, 4 to 5kg dry root for a one - hectare pond with water depth of 5cm. " Bux 300 " may be suitable for use as a pretreatment at the recommended dosage, as it degrades in one week.

(iv) Screening water as it enters the pond: All the water let into the pond is screened, after the fish are eliminated from a pond. The mesh size of the screen should be fine enough to prevent entry of fish eggs and larvae as well as adult fish.

B. Selective poisoning :

The most effective method to get rid of a large number of fish in a pond is by the use of selective poisons. The natural products such as tea seed cake or derris root could be used. They are not harmful to man in small amounts and they break down and lose their toxicity shortly after application and are therefore safe.

Because of their long term residual effects, use of the chlorinated hydrocarbon group chemicals (DDT, Endrin, Chlordane, Gamma BHC, etc.) is not recommended. The amount of water in a pond must be estimated, to apply the correct dose of a chemical.

(i) Saponin is the best known compound to poison fish selectively without damaging the shrimp or food organisms in the pond. Saponin is 50 times more toxic to fish than to shrimp and so it is safe to use, while shrimpsare in the pond. It does not affect rotifers and copepods at the recommended dosage. Saponin is biodegradable and after a short time, probably 2 or 3 days, loses its toxicity. Tea seed cake, a residue from the processing of oil from the seeds, of *Camelliais* the most commonly used source of saponin. The effectiveness of saponin decreases with decreasing salinity. The recommended level of application is :

Salinity above 15 ppt = 12 gm tea seed cake m^{-3} of water
Salinity below 15 ppt = 20 gm tea seed cake m^{-3} of water
(Anonymous, 1978)

Tea seed cake is dried in an oven to make it brittle and ground up. The required weight of the ground cake is soaked in water for 24 hrs. to extract the saponin. After filtration, the water containing saponin is applied to the pond water. Since the tea seed cake residue acts as a fertiliser, it is not essential to filter the water.

The level of water in the pond should be lowered as much as possible, without causing damage to the shrimp by increased temperature, when using tea seed cake or any other chemical control. The best method is to lower the water level in the late afternoon or evening, and then apply the chemical. Water level in the pond could be raised in the morning before the sun heats up the shallow pond water. The amount of oxygen in the water decreases somewhat when saponin is applied. This however, is not serious, but saponin should not be applied to a pond in which the level of oxygen is low.

(ii) Rotenone has been used selectively to kill fish but not shrimp. Since the difference between the lethal limit for fish and shrimp is small, great care should be taken when using it. Rotenone is most effective in fresh water and works better in low salinity water than in high salinity water.

(iii) Sodium pentachlorophenate (PCP-Na): This widely used agro - chemical, kills fish at treatment levels which do not kill shrimp. The recommended level of treatment is 0.5 ppm. Before application, the pond water should be reduced to as low a level as practicable. The required amount of PCP-Na dissolved in fresh water is then evenly spread around the pond. Fresh water should be let into the pond to dilute the concentration of PCP-Na, as soon as the fish are killed.

As PCP-Na is toxic to man in large doses, care should be taken in its use. Fish killed with PCP-Na should not be eaten.

(II) Carbs

The most destructive pest in a shrimp pond is the crab. Crabs of the family Portunidae (swimming crabs) especially are violent predators of shrimps. With fish with firm meat such as those of catfish of shark , the crabs be removed from the pond by trapping. Trash fish, snake meat, toads and uncooked bones are other suitable baits. Shrimps will also be attracted to the bait and killed by the crabs if they are caught in the trap. (This can be prevented by constructing the trap with mesh large enough for the escape of the shrimp).

" Sevin " — a widely used insecticide is effective in killing crabs. " Sevin " is relatively safe for domestic animals and humans.

27. Indicators of Problems

1. Presence of dead shrimp.

2. A die - off of algal growths which sometimes cause milky coloured water.

3. A bloom of phytoplankton which can cause oxygen depletion.

4. Active swimming of shrimp around the edge of the pond during day light hours, indicating a lack of food in the pond.

5. Water colour changes abruptly. Clear water indicates an accumulation of organic matter on the pond bottom.

6. Smell of rotten egg caused by hydrogen sulphide, indicating accumulation of organic matter on the pond bottom.

7. Heavy concentration of rotifers like *Branchionus* or other zooplankton indicates a build up of organic matter resulting from decomposition of other food organisms or a heavy growth of bacteria.

8. Gills appear black due to disease or shrimp burying mud which has become black by decomposition.

9. White discolouration appears on the tails caused by disease or by the stress of low oxygen concentration and high temperature.

10. Papery shells are caused by lack of food.

11. Presence of a large number of chironomid worms and nothing else in the bottom mud indicates pollution.

12. Black spots on the shrimps are caused by bacterial disease, usually associated with water which has a high organic content.

13. Abrupt lowering of salinity and rise of temperature above 32° C.

14. Low pH and low levels of dissolved oxygen.

(Anonymous, 1978)

□

28. Remedial Action

1. A general preventive or remedial measure is to change the water for most of the conditions listed above. This introduces new oxygen, dilute waste products or phytoplankton that may have built up too high; introduces new organisms, trace minerals and organic and also dilutes disease causing organisms.

2. Water could be mixed to supply oxygen by using mechanical agitators or windmills.

3. Addition of potassium permanganate could be a remedy for low dissolved oxygen levels.

4. Stop or postpone feeding or fertilization when shrimps appear to in stress, until the situation is corrected.

5. Dead ones should be removed as soon as possible.

6. When a large percentage of shrimp in a system are diseased or die from bad pond conditions and there is no way to remedy the situation, as a last resort, total harvesting could be done.

29. Harvesting

The following behavioural characteristics of the shrimp could be used to advantage during harvest : (i) move around the pond at night looking for food (ii) attracted to light (iii) stimulated by movement of water (iv) when water is let into a pond, the shrimps become active, swimming around the pond and often gather near the sluice gate (v) larger ones have a natural tendency to migrate to deeper water offshore, so they swim out of a pond with water when water is discharged (vi) most species of shrimp are more active during new and full moon (vii) periods of greatest activity are usually shortly after sunset and again shortly before sunrise (Anonymous, 1978).

In some types of manegement systems where only the large shrimps are to be caught and the smaller ones left in the pond to grow larger and in polyculture where the farmer wants to harvest shrimp and retain the fish, partial harvesting is useful. Some individuals grow much faster than others because of different growth rates. The large individuals could be selectively harvested before the main crop. Barrier traps set around the edge of a pond, cast nets, lift nets and drag nets could be used to partially harvest the shrimp (Chitravadivelu and Arudpragasam, 1983).

In Taiwan, China, a hand - held electric gear is used to harvest shrimp. The unit consists of an accumulator and two bamboo poles , one of which has a metal tip and the other a steel ring with a net attached. The metal tip is connected by wires to the anode of the accumulator in a backpack or on a small raft. An electric field is formed between the two poles when the gear is switched on. The shrimps jump out of the water on receiving an electric stimulation and are caught in the net. The gear has also been used to harvest large ponds totally (Anonymous, 1978).

A bagnet placed in the sluice gate can be used to harvest shrimp effectively by catching the shrimp as they swim from the pond with the outflowing water. Night, during the new moon or full moon, is the best time to do this type of harvesting. Draining water from the pond very slowly until water remains only in the peripheral canals or a harvest basin is a method of total harvest particularly useful for *P. monodon*.

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30. Feasibility Study

The following is a brief outline of the data required to make a feasibility study for shrimp culture.

1.0 Economic criteria :

The size and types of farming operations will be largely determined by land price, labour costs, feed availability and cost, together with investment available (Gerbardsep, 1976). As these will determine the scale and type of operation (tidal pond, enclosure pumped pond, receway, intensive, semi - intensive) which in turn will affect decisions on biological factors such as species choice, these need to be determined at an early stage.

However, it is possible to investigate the physical and biological potential of the area for shrimp farming before the above are known. As it is extremely unlikely that sufficient seed can be obtained from the wild, any farming operation will require both hatchery (to raise the seed) and grow-out facilities. Thus a preliminary physical and biological site survey should include a study of the requirements for a hatchery which will be more stringent, than for the grow-out phase.

2.0 Physical criteria :

Information on the following must be collected either from published or local sources or by direct measurement.

2.1 Geology of site :

Land elevation above mean sea level, substratum type, depth and type of soil, subtidal sea bed depth and substratum type, sand bar formation, long shore drift etc.

2.2 Climate :

Annual and monthly air temperature range, daily maximum and minimum, wind and rainfall data, storm occurrences etc.

2.3 Sea :

Temperature ranges, annual, monthly and daily; tidal range, daily, seasonal, annual maximum and minimum; wave action, mean maximum and minimum; storm surges over last 100 years; salinity ranges - as for tides above, currents.

2.4 Fresh water :

Availability, quality, source and quantity.

2.5 Sea water :

Quality testing for a wide range of parameters ranging from pH and dissolved gases to nitrate, nitrite, ammonia and pollutants such as heavy metals.

2.6 Inshore lagoon or pond :

Benthos substrate type, oxygen levels, pH, BOD etc.

3.0 Biological criteria :

3.1 Sources of seed and broodstock :

Seasonal data on availability of mature and juveniles of the culturable species.

3.2 Water quality :

Biological, bacterial loading, potential competitors, predators (plankton survey).

3.3 Benthos :

Inshore benthic fauna or flora potential as food for young shrimp - particularly sea grass or mangal occurrence.

3.4 Inshore and lagoon or pond :

Phytoplankton production (seasonal and annual).

3.5 Sources of feed :

Availability or cost of hatchery feeds (algae, *Artemia*); nursery feeds (pellets, trash fish). Availability locally or imported.

3.6 Biodata on potential cultured species :

Growth rates, survival, tolerance limits, market prices, availability seasonally etc.

4.0 Legal and economic criteria :

4.1 Regulation restricting planning and water utilisation, construction, access to site, sea and fresh water; treatment of effluent from farm.

4.2 Access to :

Electricity supply, road conditions, transport to market, processing plant, cold storage, feed suppliers, broodstock supply, plus costs of the above.

4.3 Staffing :

Availability, level of training and experience to cover management, site engineering and maintenance, disease control and general husbandry plus costs for above.

4.4 Feed and brood stock costs:

Modern aquaculture is an emerging technology and each year scientists make technical advances in their desciplines which push husbandry and management of aquatic animals to new limits. The continuous stream of new information requires flexibility in the engineering and operation of all facilities for the culture of aquatic animals to avoid immediate or future obsolescence. The planning and design of these facilities therefore require thoughtful integration of many technical skills in order to obtain the most economic return on capital investment. An integrated systematic approach (Brown and Nash, 1988) to the planning and design of aquaculture facilities seems very appropriate. The integrated systematic approach to the planning and design of aquaculture facilities establishes effective communication between the many professional and non - professional individuals who can be involved, such as :

(i) *Planners, administrators and developers* : Who are concerned with investments which are economic and profitable in the use of all resources.

(ii) *Engineers and design specialists* : Who are concerned with the interpretation of biological and technical data into workable and reliable production systems and

(iii) *Biologists and technicians* : Who are concerned with technological and environmental concepts and their constraints for the welfare of the captive aquatic animals and plants.

This systematic approach streamlines the planning and design process. It also reduces the period of time between conceptualizing and commissioning of the completed facility and invariably saves capital investment and effort. Often it makes the difference between economic success or failure of a project, irrespective of its purpose (Brown and Nash, 1988).

❑

31. Concerted Action

Important problems of shrimp farming which require concerted action are :

(I) Research :

1. Finding suitable local, cheap, natural food material;
2. Development of efficient artificial feeds;
3. Reduction of mortality while increasing rate of growth under culture;
4. Finding optimum stocking rate and stock manipulation for mono – culture or culture in combination with fish;
5. Knowing the biology and habits of organisms to be cultured.

(II) Technical :

1. Formulating criteria for selection of site;
2. Planning of farm lay – out;
3. Construction and maintenance of farms;
4. Formulation of cultural practices;
5. Technical training to personel of all levels.

(III) Finances :

Establishment of organised loan and credit systems and co – operative efforts to finance the construction of ponds, water drainages and supply systems, purchase of equipment, seed, fertilizers and feeds and payment of operational expenses.

(IV) Institutions :

Countries having the same general climatic and geographical conditions, flora and fauna and socio – economic backgrounds, should group together to establish international or group country research and training centres (Ling, 1972).

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32. Scope for development in Sri Lanka

There appears to be no history of shrimp farming in Sri Lanka but interest in its development is currently very active (New and Rabnal, 1985). Of the 121, 400 ha of coastal brackish water areas in Sri Lanka, one third is composed of shallow lagoons, mangrove swamps, tidal flats and marshes (Jayasekera, 1982). The total land area adjoining, lagoons, available for shrimp farming in Sri Lanka is about 15,000 acres according to preliminary estimates of the Inland Fisheries Division of the Ministry of fisheries (Samaranayake, 1986).

This is made up as follows :

Puttalam	3000	Acres
Hambantota	1000	Acres
Galle	500	Acres
Batticaloa	4000	Acres
Mannar	2000	Acres
Jaffna	1000	Acres
Trincomalee	1500	Acres
Mullaitivu	2000	Acres
	15,000	Acres

Sri Lanka exported 2088 t year^{-1}, on an average from 1979 to 1981 and the export value of US $ 13.4 million in 1981 represented 74% of all fish exports and the bulk of the export (85%) of shrimps was to Japan and the USA. The quantity of shrimp exported in 1984 was 2606.5 metric tons, according to the Export Development Board of Sri Lanka. This mainly consisted of captured shrimps from the wild (Samaranayake, 1986).

As in other parts of the world, in Sri-Lanka, shrimp mariculture development has captured the imagination of national policy makers, international development assistance agencies, and private sector investors ranging from small scale producers to multinational corporations. Serendib Sea Foods (SSF), Marine Resources Asia (MRA) and Lever Aquaproducts Ltd. are three shrimp farms of significant scale among many others. Apart from these the World Bank and ADB have offered aid programmes to promote small holders. If all these developments are realised, Sri Lanka has the potential to produce atleast 2000 tonnes year^{-1} of farmed shrimp by 1990 (New and Rabanal, 1985).

The Inland Fisheries division of the Ministry of Fisheries initiated work in rearing Penaeid shrimps using some of the existing facilities at their Coastal aquaculture Station at Pitipana with partial support from the Bay of Bengal Programme of the FAO in 1986. This was carried out mainly to test the technical feasibility of producing shrimp seeds under local conditions and demonstrate the operation of a small scale shrimp larvae production unit. Shrimp spawners for these trials were collected from among shrimps captured in the usual commercial operation of shrimp trawlers.

Post - larvae of *P. monodon*, *P. indicus*, *P. merguiensis*, and *P. semisulcatus* were produced in the hatchery, with the highest survival of 66 6% recorded form nauplius to PL$_5$ (Amandakoon *et al.*, 1986).

The current boom in large - scale coastal aquaculture development in Sri Lanka augurs well for the future, since the infrastructure for aquaculture exists and suitable sites are available (Funegaard, 1985).

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'..... There is however, a specific need for specialised research and education and training and, in many areas, aquaculture demonstration farms and realistic extension service should be established. For the small aquaculturists, in particular, it would be very useful if provision could be made for a package containing both technical advice, assistance in organising supplies of construction materials and, not least, institutional credit on reasonable terms both for investment and operational purposes. This will mean restructuring and upgrading the advisory agencies so that they may carry new knowledge to fish culturist" - Gerhardsen (1976).

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— Liao, 1988,

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