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Farming freshwater prawns

A manual for the culture of the giant river prawn *(Macrobrachium rosenbergii)*

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by
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PREPARATION OF THIS DOCUMENT

A PREVIOUS MANUAL ON THIS TOPIC was prepared for FAO in 1982 and revised in 1985 but the English edition is now out-of-print. Research has generated considerable benefits on this subject and substantial advances in technology have occurred since the original manual was published. These facts, combined with a revival in interest in expanding the farming of freshwater prawns, have created the need for a new technical manual.

This document has therefore been prepared to provide up-to-date and practical information on freshwater prawn farming. Its emphasis is on techniques for cultivating the major farmed species, namely the giant river prawn (*Macrobrachium rosenbergii*). The manual also contains information of relevance to the farming of other *Macrobrachium* species and to the enhancement of freshwater prawn fisheries.

The document was prepared under contract for the Inland Water Resources and Aquaculture Service, FAO Fishery Resources Division, by one of the authors of the original FAO manual, Michael B. New. It is a synthesis of the personal experience of the author and of his many international friends and colleagues working in this field, who are gratefully acknowledged within the manual text.

The principal targeted audience includes trainers, extension agents, farmers, and students. It is also hoped that the manual will provide background information and reference sources for those embarking on research in this field.

abstract

THE ORIGINAL MANUAL on freshwater prawn farming was published in English, French and Spanish by FAO and translated by others into Farsi, Hindi, and Vietnamese. In the two decades since that manual was written, many technical and practical advances have been made in the rearing of freshwater prawns. Greater farmed production, developing global markets, and the need to ensure that each form of aquaculture is sustainable, have led to an increased interest in the farming of freshwater prawns. A new manual has therefore been prepared, which will be issued in each of the FAO official languages.

This manual provides information on the farming of *Macrobrachium rosenbergii*. Many of the techniques described are also applicable to other species of freshwater prawns that are being cultured. The manual is not a scientific text but is intended to be a practical guide to in-hatchery and on-farm management. The target audience is therefore principally farmers and extension workers. However, it is also hoped that, like the previous manual on this topic, it will be useful for lecturers and students alike in universities and other institutes that provide training in aquaculture.

After a preliminary section on the biology of freshwater prawns, the manual covers site selection for hatcheries, nurseries and grow-out facilities, and the management of the broodstock, hatchery, nursery and grow-out phases of rearing. Harvesting and post-harvest handling are also covered and there are some notes on marketing freshwater prawns. The reference and bibliography section is generally restricted to a list of relevant reviews, as well as other (mainly FAO) manuals on general aquaculture themes, such as water and soil management, topography, pond construction and simple economics. Every attempt has been made to illustrate the management principles described in this manual by photographs and drawings. The manual contains many annexes on specific topics, such as the production of larval feeds, size variation and stock estimation. The final annex is a glossary; this lists not only terms used in the manual itself but also terms which the readers may find in other documents that they may consult.

Key words: *Macrobrachium*, broodstock management, crustacean culture, freshwater prawns, hatchery operation, grow-out procedures, post-harvest handling and marketing, site selection

preface

AN EARLIER FAO MANUAL on freshwater prawn culture was written by the former Co-Managers of the UNDP/FAO Programme for the Expansion of Freshwater Prawn Farming in Thailand, Michael New and Somsak Singholka, which was based substantially on their personal experience. The English version was issued in 1982 (New and Singholka, 1982) and FAO published it in Spanish in 1984 and in French in 1985. A minor revision of the English edition was made when it was reprinted in 1985. With the support of local funding, the manual was also translated and published in Vietnamese in 1990, in Farsi in 1991, and in Hindi in 1996. A number of freshwater prawn manuals by other authors, which were published in English, French, Portuguese and Spanish between 1985 and 1993, are listed in a review of the history of freshwater prawn farming by New (2000a). Many technological advances were made in freshwater prawn culture in the final two decades of the 20th century, and a number of other FAO manuals on general but relevant aquacultural topics were issued during that period (e.g. FAO 1981, 1985, 1988, 1989b, 1992a, 1992b, 1994, 1995, 1996, 1998; Lavens and Sorgeloos 1996; Tave 1996, 1999; Moretti, Pedini Fernandez-Criado, Cittolin and Guidastri 1999).

In the two decades since the original FAO freshwater prawn manual was published, production from the farming of *Macrobrachium rosenbergii* has expanded considerably, mainly in Asia but also in South and North America. Thai farmed freshwater prawn production expanded from less than 250 mt in 1979 (New, Singholka and Vorasayan 1982) to about 3 100 mt in 1984 (FAO 1989a). In 1984, the total global production of farmed *Macrobrachium rosenbergii* was only about 5 000 mt (FAO 1989a). By 2000, official FAO data indicate that global production of *M. rosenbergii* had risen to nearly 119 000 mt, to which Thailand contributed 3 700 mt (FAO 2002). China, which introduced this species in 1976 (New 2000b), produced over 97 000 mt in 2000. The official FAO production statistics for this species are underestimates, because some countries have not yet disaggregated their production from more general statistical categories such as 'freshwater prawns and shrimps nei*' or 'freshwater crustaceans nei*'. In addition, several other freshwater prawn species are now cultured in pilot or full commercial scale, including *M. amazonicum, M. malcolmsonii* and *M. nipponense* (Kutty, Herman and Le Menn 2000) but production data for these species is not yet reported to FAO. Farmed production of *M. nipponense* in China was estimated to be 100 000 mt in 2000 (Miao and Ge 2002), confirming a forecast that total annual production of all freshwater prawn species would reach 200 000 mt early in the new millennium (New 2000a). Some believe that freshwater prawn farming may be more sustainable than marine shrimp farming (New, D'Abramo, Valenti and Singholka 2000).

This renewed interest in freshwater prawn farming provided the stimulus for the preparation of a new FAO manual on the topic. In preparing this manual, the author has drawn heavily on information gained during the editing of a recent academic book on the topic (New and Valenti 2000). The author and the FAO Fisheries Department hope that it will prove useful in further encouraging the culture of freshwater prawns. Translations of the new manual into Arabic, Chinese, French and Spanish will be issued in 2002-2003.

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* not elsewhere included

table of contents

ABSTRACT iii

PREFACE v

INTRODUCTION xiii

1. Biology 1

1.1 Names, natural range, and characteristics of freshwater prawns 1

Naming freshwater prawns (nomenclature) 1

The natural home of freshwater prawns (distribution) 2

Identifying *Macrobrachium rosenbergii* from other freshwater prawn species 2

1.2 The shape (external morphology) and other characteristics of freshwater prawns 3

1.3 Life history 8

1.4 Sources of further biological information 10

2. Site selection 11

2.1 Hatcheries and indoor nurseries 11

Needs for good quality water 11

Deciding how much water is needed 15

Other requirements for hatchery sites 16

2.2 Outdoor nurseries and grow-out facilities 16

Choosing your site: topography and access 18

Choosing your site: climate 19

Choosing your site: water quality and supply 19

Choosing your site: soil characteristics 24

Choosing your site: power supplies 24

Choosing your site: fry and consumables 25

Choosing your site: labour 26

Choosing your site: sympathetic authorities and technical assistance 26

3. Broodstock 27

3.1 Obtaining and selecting egg-carrying females 27

Obtaining berried females 27

Genetic improvement 28

3.2 Holding your broodstock in temperate zones 30

3.3 Managing your broodstock 30

4. Hatchery phase 35

4.1 Buildings and equipment facilities 36

Basic site and building requirements 36

Equipment and the distribution of water and air 37

4.2 Hatchery management 54

Water treatment 54

Starting your larval batch 55

Routine work 57

Feeding 60

Hygiene, health and management problems 65

Monitoring performance 70

The greenwater system of freshwater prawn culture 73

4.3 Harvesting postlarvae 73

5. Postlarval holding and nursery phases 75

5.1 Basic requirements and facilities 75

Holding tanks 75

Indoor (primary) nursery facilities 75

Outdoor (secondary) nursery facilities 76

Nursery cages 77

5.2 Holding postlarvae before sale 77

5.3 Transporting postlarvae 78

5.4 Managing nurseries 80

Indoor (primary) nurseries 80

Outdoor (secondary) nurseries 82

Other systems 83

6. Grow-out phase 85

6.1 Site requirements and construction 85

Defining the pond 86

Supplying water to the ponds 90

Discharging water from the ponds 95

Aeration 96

Miscellaneous 97

6.2 Management of the grow-out phase 99

Size variation 100

Semi-intensive monoculture in tropical zones 100

Monoculture in temperate zones 108

Polyculture and integrated culture 111

6.3 Feeding and fertilization 114

	Feed type	114
	Measuring feed efficiency	119
	Feeding rate	119
6.4	**Health, predation and disease**	**121**
	Watching for signs of problems	121
	Dealing with problems of predation	122
	Coping with diseases and other problems	123
6.5	**Monitoring performance and record keeping**	**125**
7.	**Harvesting and post-harvest handling**	**129**
7.1	**Harvesting your market-sized prawns**	**129**
	Cull harvesting	130
	Drain harvesting	133
7.2	**Handling your prawns after harvest and ensuring good product quality**	**136**
	Handling prawns to be sold fresh	136
	Handling prawns to be sold frozen	137
	Handling for live sales	138
7.3	**Code of practice for harvesting, processing and handling prawns**	**139**
8.	**Marketing**	**141**
9.1	**Marketing your freshwater prawns alive**	**141**
9.2	**Marketing your freshwater prawns fresh or frozen**	**142**
9.3	**Marketing your freshwater prawns at your farm gate**	**142**
9.4	**International opportunities and general marketing strategy**	**144**

Annexes

1.	**Key to larval stages of freshwater prawns (*Macrobrachium rosenbergii*)**	**145**
2.	**Natural beach filter for seawater**	**147**
3.	**Maturation diets for broodstock freshwater prawns**	**151**
4.	**Source, hatching and enrichment of *Artemia***	**153**
5.	**Production of farm-made larval feeds**	**167**
6.	**Stock estimation**	**169**
7.	**Seine nets**	**173**
8.	**Size management**	**177**
9.	**Farm-made pond feeds**	**185**
10.	**Basic code for introductions**	**191**
11.	**Glossary of terms, abbreviations and conversions**	**193**

FINANCIAL CONSIDERATIONS	**203**
ACKNOWLEDGEMENTS	**205**
REFERENCES	**207**

TABLES

1.	Body segments (somites) in *Macrobrachium rosenbergii* and appendage function	6
2.	Characteristics of water suitable for freshwater prawn hatcheries	15
3.	Artificial brackishwater (12 ppt) for *M. rosenbergii* hatcheries	16
4.	Diluting seawater and brine to make brackishwater for larval freshwater prawn culture	18
5.	Water quality requirements for freshwater prawn nursery and grow-out facilities	20
6.	Example of water requirements for ponds based on various assumptions	23
7.	Relationship between temperature, salinity and dissolved oxygen saturation levels	44
8.	Hatchery feeding schedule	63
9.	Alternative hatchery feeding schedule	64
10.	The major diseases known to affect freshwater prawns, and their exterior symptoms	67
11.	Prevention and treatment of freshwater prawn diseases	68
12.	Water discharge capacity of concrete pipes under various pressure heads	93
13.	Sizes of outlet pipes for ponds with monks	95
14.	Time taken to drain ponds with different drain pipe sizes	96
15.	Oxygen transfer efficiencies of basic types of aerator	97
16.	Lime requirements for treating the bottom of ponds between cycles	105
17.	Average stocking densities and yields in polyculture	112
18.	Examples of major ingredients in grow-out feeds	117
19.	Tentative specifications for semi-intensive freshwater prawn grow-out feeds	118
20.	General recommendations for handling and storing freshwater prawns	143

BOXES

1.	Removal of iron and manganese	14
2.	Flow-through requirements for larval rearing tanks	17
3.	Grow-out water requirements	22
4.	Numbers of berried females required	28
5.	Activating biofilters	53
6.	Treatment of brackishwater	54
7.	Regular monitoring of larval water quality	55
8.	Alternative larval stocking strategies	57
9.	Recommendations for good larval water quality	59
10.	Maintenance schedule for recirculation systems	62
11.	Feeding BSN depends on tank volume, not the number of larvae in it	63
12.	Additional recommendations for recirculation system hygiene	66
13.	Notes on potential disease problems	69
14.	Definitions of farming intensity used in this manual	101
15.	Systems of management in grow-out ponds for freshwater prawns	102-103
16.	Application of rotenone and teaseed cake	104

17.	Measuring soil pH	106
18.	Reasons for not applying organic fertilizers	107
19.	Keeping rooted plants out of your ponds	109
20.	Size grading	110
21.	Polyculture of freshwater prawns with carps	113
22.	Examples of integrated freshwater prawn culture	115
23.	Example of feeding rate for freshwater prawns	121
24.	Examples of freshwater prawn (*M. rosenbergii*) growth and production rates	126

FIGURES

1.	External appearance	3
2.	Large males	5
3.	Sexing juveniles	7
4.	Females with a BC male	7
5.	Male morphotypes	8
6.	Freshwater prawns compared to penaeid shrimp	8
7.	Another way of distinguishing carideans from penaeids	9
8.	Grow-out pond inlets and screens	21
9.	Simple pumps	25
10.	Expensive pumps	25
11.	Berried females	29
12.	Hatching system	31
13.	Airlift pumps	32-33
14.	Small hatcheries	36-37
15.	Partially covered larval tanks	37
16.	Hatchery layout	38
17.	Water flow through a recirculation system	39
18.	Spaces round tanks	39
19.	Cylindrico-conical larval tank	40
20.	Grouping tanks together	40
21.	Shared filter	41
22.	Individual recirculation systems	41
23.	Filter sock	42
24.	Turn-down drains	43
25.	Storage tanks	43
26.	Ring main air supply	45
27.	Tank taps	46
28.	Air blowers and emergency power supplies	47
29.	Water distribution	48
30.	Physical hatchery filters	50
31.	Close-up of a shared biological filter	51
32.	Types of biological filters	52
33.	White board	56
34.	Tank cleaning	60
35.	Reducing losses	61
36.	Observing larval quality	71-72
37.	Additional substrates in holding tanks	76

38. Overhead air and water distribution systems 76
39. Substrates 77
40. Pond with standpipe drain 77
41. Transporting postlarvae 79
42. Substrate in a larval tank 81
43. Large freshwater prawn farm 86
44. Pond bottom profiles 87
45. Improving pond banks 88
46. Angles of pond bank slope 89
47. Erosion 89
48. Grass on pond banks 89
49. Pond banks with integrated agriculture 90
50. Increasing dissolved oxygen levels in incoming water 91
51. Simple gravel filters 91
52. Water distribution system to ponds 92
53. Supplying water by gravity 93
54. Grass minimizes erosion 93
55. Controlling water entry 94
56. Outlet structure 95
57. Cast netting 96
58. Draining 97
59. Screening pond outlets 98-99
60. Long-tail pump 99
61. Long-tail pump being used 99
62. Paddlewheel aerator 100
63. Long-shaft aerator 100
64. Long-shaft aerator in action 101
65. Pond sedimentation 104
66. Tilling the pond bottom 105
67. Juvenile prawns 106
68. Acclimatizing prawns before stocking 107
69. Releasing prawns during stocking 108
70. Weeds invade shallow areas 108
71. Close-up of pond substrate 109
72. Substrates placed vertically 109
73. Substrates placed horizontally 110
74. Integrated freshwater prawn farming 114
75. Catching wild postlarvae 116
76. Feed distribution 120
77. Observing feed consumption 120
78. Measuring transparency 122
79. Simple gravel filter 123
80. Protection from overland predators 123
81. Large BC *Macrobrachium rosenbergii* being measured 127
82. Relationship between total length and weight 127
83. Seining 131
84. Double seining 132
85. Multiple seining 133
86. Sorting prawns 133

87.	Keeping market-sized prawns alive during harvesting	133
88.	Keeping prawns in peak condition	134
89.	Checking prawn health	134
90.	Internal harvesting sump	134
91.	Harvesting with an internal sump	135
92.	Cull-harvesting	135
93.	Catching the last few prawns by hand	136
94.	Bird predation	136
95.	Kill-chilling harvested prawns	137
96.	Sorting during processing	138
97.	Packaging prawns attractively	138
98.	Recently harvested prawns	139
99.	Advertising freshwater prawns at the farm gate	143
100.	Selling prawns in a supermarket	144

Introduction

THE WORDS 'PRAWN' AND 'SHRIMP' are often used synonymously. Actual use is geographically dependent. For example, animals of the genus *Macrobrachium* are referred to as freshwater prawns in Australia and freshwater shrimp in the United States of America (USA). In its statistical data, FAO refers to the genus *Macrobrachium* as freshwater prawns but also uses the word prawn for many species of marine shrimp, including the banana prawn (*Fenneropenaeus merguiensis*), the giant tiger prawn (*Penaeus monodon*) and the kuruma prawn (*Marsupenaeus japonicus*) (FAO 2001).

This manual is intended to be a practical guide to the farming of freshwater prawns and is meant primarily for extension, rather than research workers. Its contents are a synthesis of practical experience and published information. The manual also has some relevance for the enhancement of freshwater prawn fisheries, since this requires the provision of hatchery-reared animals for stocking purposes. The introduction of *M. rosenbergii* and related species into reservoirs and the enhancement of existing capture fisheries has had some current success, notably in Brazil, India and Thailand. Further developments will require hatchery-reared postlarvae (PL) and juveniles for stocking purposes. Although the new manual is primarily concerned with aquaculture, parts of it (particularly the sections on broodstock, hatchery management and marketing) are also relevant to the enhancement of freshwater prawn fisheries. Further reading on the topic of capture fisheries and enhancement is available in New, Singholka and Kutty (2000). Those interested in the science that supports freshwater prawn farming can find a comprehensive review in New and Valenti (2000).

Although several species of freshwater prawns are currently being cultured, this manual deals exclusively with the farming of the major commercial species (*Macrobrachium rosenbergii*), which is indigenous to South and Southeast Asia, parts of Oceania and some Pacific islands. *M. rosenbergii* has been imported into many other tropical and subtropical areas of the world and is the species most favoured for farming purposes. The use of the words 'freshwater prawns' and 'prawns' in this manual, except where otherwise specifically qualified, refers to *M. rosenbergii*. This species remains by far the major subject of cultivation because a global market for it evolved during the 1990s and is currently being further developed. Other species of *Macrobrachium* are now also being farmed, mainly for domestic consumption, and modifications of the techniques described in this manual can be derived to support this development. Such modifications need to take account of the different environmental requirements of the other species, especially in the larval stages. Reference to the culture of other *Macrobrachium* spp. is contained in Kutty, Herman and Le Menn (2000).

In the previous FAO manual on this topic, the hatchery and pond-rearing techniques described were generally based on those applied in freshwater prawn culture in Thailand in the early 1980s. Only one system of culture, namely the operation of flow-through hatcheries followed by monoculture in ponds, was fully described. This manual broadens the scope by drawing on experience in recirculation hatcheries and monoculture from other countries, notably Brazil and the USA, and by stressing the opportunities for alternative systems of grow-out, including polyculture and integrated culture

After a brief section on the biology of *M. rosenbergii*, the manual deals with the selection of sites for hatchery and grow-out facilities. It then covers the maintenance of broodstock and the management of the hatchery, nursery and grow-out phases. Following a section on harvesting and the post-harvest handling of market-sized prawns, the manual includes a section on marketing, an important topic that was not covered in the previous document. The text of the manual concludes with some references to financial matters and a short bibliography for further reading. Several other important topics, such as the preparation of feed for freshwater prawn larvae, and a glossary, are provided in the annexes. General background information, which should be useful for extension workers and students is provided in the introduction and in Chapter 1. Chapters 2-8 (especially sections 3-6) and the annexes contain the main technical content of the manual, which is of direct relevance for farmers as well as students and extension workers. The different audiences addressed by various parts of the manual are reflected by the writing style chosen for each section. As far as possible, the technical sections that are specific to the hatchery and grow-out management of freshwater prawns (especially the material presented in text 'Boxes' are written in 'cookbook' English, whereas more 'scientific' language is used in Chapter 1 and some of the annexes, for example.

The author and the FAO Fisheries Department hope that you will find the manual useful and stimulating, and would welcome constructive criticism, so that the manual may be improved in future editions.

CHAPTER 1

Biology

THE FOLLOWING NOTES contain background information on the genus *Macrobrachium* and some basic details about the biology of *M. rosenbergii*. This section of the manual has mainly been derived from Holthuis (2000), the work of Ling (1969), and a review by Ismael and New (2000), and is intended to provide basic background information for extension workers and students.

1.1 Names, natural range, and characteristics of freshwater prawns

NAMING FRESHWATER PRAWNS (NOMENCLATURE)

All the freshwater prawns that have been cultured so far belong to the genus *Macrobrachium*, Bate 1868, the largest genus of the family Palaemonidae. About 200 species have been described, almost all of which live in freshwater at least for part of their life.

The giant river prawn, *Macrobrachium rosenbergii*, was one of the first species to become scientifically known, the first recognisable illustration appearing in 1705. The nomenclature of freshwater prawns, both on a generic and a species level has had quite a muddled history. In the past, generic names have included *Cancer (Astacus)* and *Palaemon*. Previous names of *M. rosenbergii* have included *Palaemon carcinus, P. dacqueti*, and *P. rosenbergii* and it was not until 1959 that its present scientific name, *Macrobrachium rosenbergii* (De Man 1879) became universally accepted.

Some taxonomists recognize a western sub-species (found in the waters of the east coast of India, Bay of Bengal, Gulf of Thailand, Malaysia, and the Indonesian regions of Sumatra, Java and Kalimantan) and an eastern sub-species (inhabiting the Philippines, the Indonesian regions of Sulawesi and Irian Jaya, Papua New Guinea and northern Australia). These are referred to as *Macrobrachium rosenbergii dacqueti* (Sunier 1925) for the western form and *Macrobrachium rosenbergii rosenbergii* (De Man 1879) for the eastern form. However, from the perspective of freshwater prawn farmers, exact nomenclature has little relevance, especially because the species *M. rosenbergii* has been transferred within its natural geographical range and been introduced into many other zones where it may become established.

THE NATURAL HOME OF FRESHWATER PRAWNS (DISTRIBUTION)

Species of the freshwater prawn genus *Macrobrachium* are distributed throughout the tropical and subtropical zones of the world. Holthuis (1980) provides useful information on the distribution, local names, habitats and maximum sizes of commercial (fished and farmed) species of *Macrobrachium*.

They are found in most inland freshwater areas including lakes, rivers, swamps, irrigation ditches, canals and ponds, as well as in estuarine areas. Most species require brackishwater in the initial stages of their life cycle (and therefore they are found in water that is directly or indirectly connected with the sea) although some complete their cycle in inland saline and freshwater lakes. Some species prefer rivers containing clear water, while others are found in extremely turbid conditions. *M. rosenbergii* is an example of the latter.

There is a wide interspecific variation in maximum size and growth rate, *M. rosenbergii*, *M. americanum, M. carcinus, M. malcolmsonii, M. choprai, M. vollenhovenii* and *M. lar* being the largest species known. *M. americanum* (Cauque river prawn) is found naturally in western watersheds of the Americas while *M. carcinus* (painted river prawn) is found in those connected with the Atlantic. *M. choprai* (Ganges river prawn) is found in the Ganges and Brahmaputra river systems. *M. lar* (Monkey river prawn) is native from East Africa to the Marquesas Islands of the Pacific (and was introduced into Hawaii). *M. malcolmsonii* (monsoon river prawn) is found in the waters of Bangladesh, India and Pakistan. *M. rosenbergii* (giant river prawn) is indigenous in the whole of the South and Southeast Asian area as well as in northern Oceania and in the western Pacific islands. *M. vollenhovenii* (African river prawn) is naturally distributed in West Africa, from Senegal to Angola.

Many *Macrobrachium* species have been transferred from their natural location to other parts of the world, initially for research purposes. *M. rosenbergii* remains the species most used for commercial farming and consequently is the one which has been introduced to more countries. Following its import into Hawaii from Malaysia in 1965, where the pioneer work of Ling (1969) was translated into a method for the mass production of postlarvae (PL) by Fujimura and Okamoto (1972), it has been introduced into almost every continent for farming purposes. *M. rosenbergii* is now farmed in many countries; the major producers (>200 mt) are Bangladesh, Brazil, China, Ecuador, India, Malaysia, Taiwan Province of China, and Thailand (FAO 2002). More than thirty other countries reported production of this species in the year 2000. Viet Nam is also a major producer, according to New (2000b). In addition, there are also valuable capture fisheries for *M. rosenbergii*, for example in Bangladesh, India, and several countries in Southeast Asia.

IDENTIFYING *MACROBRACHIUM ROSENBERGII* FROM OTHER FRESHWATER PRAWN SPECIES

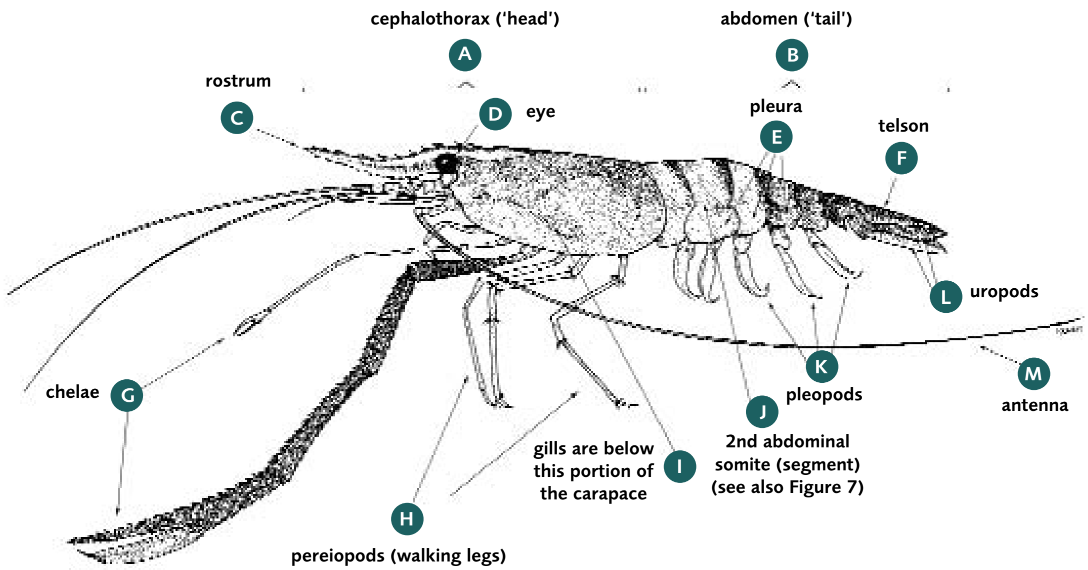
Macrobrachium rosenbergii (Figure 1) can be distinguished from other species in the genus by the following characteristics (the morphological terms used below are explained in the glossary – Annex 11):

- it has a very long rostrum, with 11-14 dorsal teeth and 8-10 ventral teeth (the ventral characteristics are especially important);
- the tip of its telson reaches distinctly beyond the posterior spines of the telson;

FIGURE 1

The external features of *Macrobrachium rosenbergii*

NOTE: OTHER CARIDEAN PRAWNS HAVE SIMILAR CHARACTERISTICS BUT SOME (E.G. *PANDALUS*, *CRANGON*, *PALAEMON*) ARE MARINE



SOURCE: EMANUELA D'ANTONI

- the adult male has very long second chelipeds in which all segments are elongate and have blunt spines;
- the movable finger of the second chelipeds of the adult male is covered by a dense velvet-like fur (except the extreme tip) but this fur is absent from the fixed finger and the rest of the cheliped; and
- it is the largest known of all Macrobrachium species, adult males having been reported with a total body length of up to 33 cm, and adult females of up to 29 cm.

1.2 The shape (external morphology) and other characteristics of freshwater prawns

The following information deals with the general external anatomy of the freshwater prawn *M. rosenbergii*, and provides some notes on the function of various major parts of the body. Internal morphology (circulatory, respiratory, digestive, excretory, reproductive and nervous systems) is not covered in this manual, which concentrates on farming, but further information is available in the references cited in the introduction to this section.

Freshwater prawn eggs of this species are slightly elliptical, with a long axis of 0.6-0.7 mm, and are bright orange in colour until 2-3 days before hatching when they become grey-black. This colour change occurs as the embryos utilize their food reserves.

Most scientists accept that the larvae go through 11 distinct stages (Uno and Kwon 1969) before metamorphosis, each with several distinguishing features which are described and illustrated in Annex 1. However, from stage VI onwards their size is variable, which has led to some workers, notably Ling (1969) to describe only eight stages. Stage I larvae (zoeae) are just under 2 mm long (from the tip of the rostrum to the tip of the telson). Larvae swim upside down by using their thoracic appendages and are positively attracted to light. By stage XI they are about 7.7 mm long. Newly metamorphosed postlarvae (PL) are also about 7.7 mm long and are characterized by the fact that they move and swim in the same way as adult prawns. They are generally translucent and have a light orange-pink head area.

The body of postlarval and adult prawns consists of the cephalothorax ('head') and the abdomen ('tail'). The bodies of freshwater prawns are divided into twenty segments (known as somites). There are 14 segments in the head, which are fused together and invisible under a large dorsal and lateral shield, known as the carapace. The carapace is hard and smooth, except for two spines on either side; one (the antennal spine) is just below the orbit and the other (the hepatic spine) is lower down and behind the antennal spine. The carapace ends at the front in a long beak or rostrum, which is slender and curved upwards. The rostrum extends further forward than the antennal scale and has 11-14 teeth on the top and 8-10 underneath (Figure 1). The first two of the dorsal (top side) teeth appear behind the eye socket (orbit).

The front portion of the cephalothorax, known as the cephalon, has six segments and includes the eyes and five pairs of appendages. The final three of these six segments can be seen if the animal is turned upside down and the appendages of the thorax (see below) are moved aside. The cephalon segments therefore support, from the front of the animal:

- the stalked eyes;
- the first antennae, which each have three-segment peduncles (stalks) from which three tactile flagella emerge;
- the second antennae, which each have five-segment peduncles and a single, long flagellum;
- the mandibles, which are short and hard and are used to grind food;
- the first maxillae, which are plate-like (lamelliform), hidden below the second maxillae, and used to transfer food into the mouth; and
- the second maxillae, which are similar to the first maxillae but have an additional function. Part of these appendages are constantly beating, thus producing a current of water through the gill chamber to promote the respiratory function of the latter.

The two pairs of antennae are the most important sites of sensory perception; the peduncles of the first antennae contain a statocyst, which is a gravity receptor. The mandibles and first and second maxillae form part of the six sets of mouthparts (see below).

The rear portion of the cephalothorax, known as the thorax, consists of 8 fused segments which have easily visible pairs of appendages. These appendages consist of 3 sets of maxillipeds and 5 pairs of pereiopods, as follows:

- the first and second maxillipeds are similar to the first and second maxillae and function as mouthparts (see above);
- the third maxillipeds, which are also mouthparts but look rather like legs;
- the first and second legs (pereiopods), which have pincers (chelae). These pincer-ended legs are also called chelipeds. The first legs are slender but the second pair bear numerous small spines and are much stronger than any other leg. The second chelipeds are used for capturing food, as well as in mating and agonistic (fighting) behaviour; and
- the third, fourth and fifth legs (pereiopods), which are much shorter than the second cheliped, have simple claws (not pincers), and are sometimes called walking legs.

Eggs are extruded from oval gonopores in the base of the third pereiopods of females, which are covered with a membrane. In males, sperm is extruded from gonopores which are covered by flaps, situated in the base of the fifth pereiopods.

The pereiopods include chemoreceptor cells, which are sensitive to aqueous extracts of food and to salts (and may therefore be involved in migratory and reproductive processes). The left and right second legs (chelipeds) of *M. rosenbergii* are equal in size, unlike some other *Macrobrachium* spp. In adult males they become extremely long and reach well beyond the tip of the rostrum. Some extreme examples are shown in Figure 2.

The tail (abdomen) is very clearly divided into 6 segments, each bearing a pair of appendages known as pleopods or swimmerets (as this name implies, they are used for swimming, in contrast to the walking legs). The first five pairs of swimmerets are soft. In females they have attachment sites for holding clusters of eggs within the brood chamber (see below). In males, the second pair of swimmerets is modified for use in copulation. This spinous projection is known as the appendix masculina. The sixth pair of swimmerets, known as uropods, are stiff and hard. The telson is a central appendage on the last segment and has a broad point with two small spines which project further behind the point. The telson and the uropods form the tail fan, which can be used to move the prawn suddenly backwards.

Figure 2
These very large *Macrobrachium rosenbergii* males were obtained from a fisheries enhancement programme (India)

SOURCE: METHIL NARAYANAN KUTTY

A summary of the segments and the functions of each appendage is provided in Table 1.

Postlarval prawns are usually a greenish-brownish grey and sometimes blue. Normally there are irregular brown, grey and whitish longitudinal streaks on the body. Orange spots may be visible where the tail segments bend. The lateral ridge of the rostrum may be red. The antennae are often blue. The chelipeds are generally blue but the second chelipeds may also be orange (see below). The colour of the bodies of prawns tends to be brighter in younger animals and generally darker and blue or brownish in older prawns (they become red when cooked).

Mature male prawns are considerably larger than the females and the second chelipeds are much larger and thicker. The head of the male is also proportionately larger, and the abdomen is narrower. As noted above, the genital pores of the male are between at the base of the fifth walking legs. The head of the mature female and its second walking legs are much smaller than the adult male. The female genital pores are at the base of the third walking legs. An alternative technique for sexing juvenile prawns is shown in Figure 3. The pleura (overhanging sides of the abdomenal segments) are longer in females than in males, and the abdomen itself is broader. These pleura of the first, second and third tail segments of females form a brood chamber in which the eggs are carried between laying and hatching. A ripe or 'ovigerous' female can easily be detected because the ovaries can be seen as large orange-coloured masses occupying a large portion of the dorsal and lateral parts of the cephalothorax.

TABLE 1 Body segments (somites) in *Macrobrachium rosenbergii* and appendage function

BODY SECTION	SOMITE #	APPENDAGE NAMES (PAIRS)	FUNCTIONS OF APPENDAGES AND RELATED STRUCTURES
Cephalon *front portion of the cephalothorax*	1	embryonic segment (not visible in adults)	
	2	1st antennae	tactile and sensory perception (statocyst)
	3	2nd antennae	tactile
	4	mandibles	cutting and grinding food
	5	1st maxillae (maxillulae)	food handling
	6	2nd maxillae	food handling; water circulation through the gill chamber (scaphognathite)
Thorax *rear portion of the cephalothorax*	7	1st maxillipeds	feeding/food handling
	8	2nd maxillipeds	feeding/food handling
	9	3rd maxillipeds	feeding/food handling
	10	1st pereiopods (chelipeds)	food capture
	11	2nd pereiopods (chelipeds)	food capture; agonistic and mating behaviour
	12	3rd pereiopods	walking; female gonophores between base of legs
	13	4th pereiopods	walking
	14	5th pereiopods	walking: male gonophores between base of legs
Abdomen	15	1st pleopods (swimmerets)	swimming
	16	2nd pleopods (swimmerets)	swimming; copulation in males
	17	3rd pleopods (swimmerets)	swimming
	18	4th pleopods (swimmerets)	swimming
	19	5th pleopods (swimmerets)	swimming
	20	uropods	propulsion, together with the central telson

SOURCE: DERIVED FROM PINHEIRO AND HEBLING (1998)

Female prawns are sometimes referred to as virgin females (V or VF), berried (egg carrying) females (BE or BF) and open brood chamber (spent) females (OP). Egg-carrying females are shown in Figure 4. There are three major types of freshwater prawn males and a number of intermediate forms, which were not fully described in the original FAO manual. All three major types of males are illustrated in Figure 5. The ability to distinguish between these forms is important in understanding the need for size management during the grow-out phase of culture (Annex 8). The first type consists of blue claw males (BC), which have extremely long claws. The second type of males, sometimes known as runts, have small claws and are now called small males (SM). Although this type is similar in size

FIGURE 3

How to sex juvenile *Macrobrachium rosenbergii*

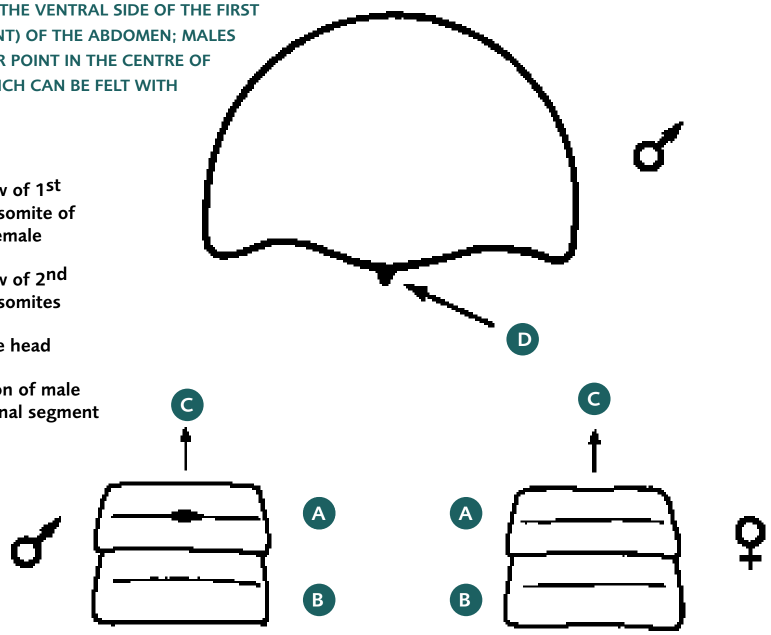
NOTE: EXAMINE THE VENTRAL SIDE OF THE FIRST SOMITE (SEGMENT) OF THE ABDOMEN; MALES HAVE A LUMP OR POINT IN THE CENTRE OF THE SOMITE WHICH CAN BE FELT WITH THE FINGER

A ventral view of 1st abdominal somite of male and female

B ventral view of 2nd abdominal somites

C towards the head

D cross section of male 1st abdominal segment



SOURCE: EMANUELA D'ANTONI, AFTER MARIO PEDINI

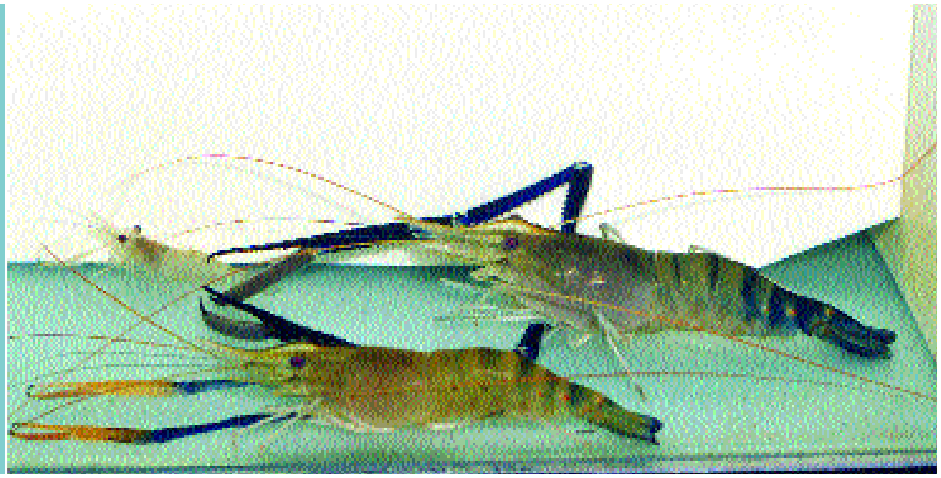
to younger juveniles, the prawns are much older. The third type of males are known as orange claw males (OC). OC males have golden coloured claws, which are 30 to 70% shorter than the claws of BC males. The three major types of males can generally be distinguished by sight. However, more reliable ways of determining which type males are can be found in Karplus, Malecha and Sagi (2000). As mentioned, a number of intermediate male forms have also been recognized, including weak orange claw (WOC), strong orange claw (SOC) and transforming orange claw (TOC) males. The relationship and transformation of these various male types, and their importance in size management is covered later in this manual (Annex 8).

Many people find it hard to distinguish between *Macrobrachium* and penaeid (marine) shrimp, once they have been harvested and the heads have been removed. If the 'tail' still retains its shell there are, in fact, two easy ways of distinguishing them (Fincham and Wickins, 1976). Firstly,

Figure 4 Notice that the abdominal pleura of the two females with this BC male *Macrobrachium rosenbergii* are enlarged to accommodate eggs (Brazil)

SOURCE: EUDES CORREIA

Figure 5
The major male morphotypes of *Macrobrachium rosenbergii* are called blue claw (BC), orange claw (OC), and small male (SM) (Israel)



SOURCE: ASSAF BARKI, REPRODUCED FROM NEW AND VALENTI (2000) WITH PERMISSION FROM BLACKWELL SCIENCE

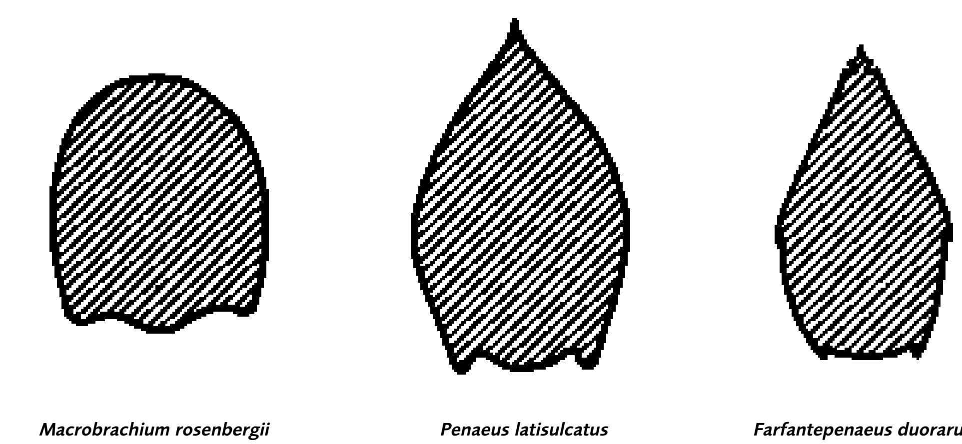
Macrobrachium spp., have a smooth rounded dorsal surface to the abdomen while penaeids have a simple or complex ridge at the dorsal apex of the abdomen (Figure 6). Secondly, the second pleuron of the abdomen (or tail) of *Macrobrachium* (in common with all caridean prawns, including some marine shrimp such as *Crangon* spp., *Pandalus* spp., and *Palaemon* spp.) overlaps both the first and the third pleuron. In penaeids the second pleuron overlaps the third pleuron only and is itself overlapped by the first (Figure 7).

1.3 Life history

All freshwater prawns (like other crustaceans) have to regularly cast their 'exoskeleton' or shell in order to grow. This process is referred to as moulting and is accompanied by a sud-

FIGURE 6

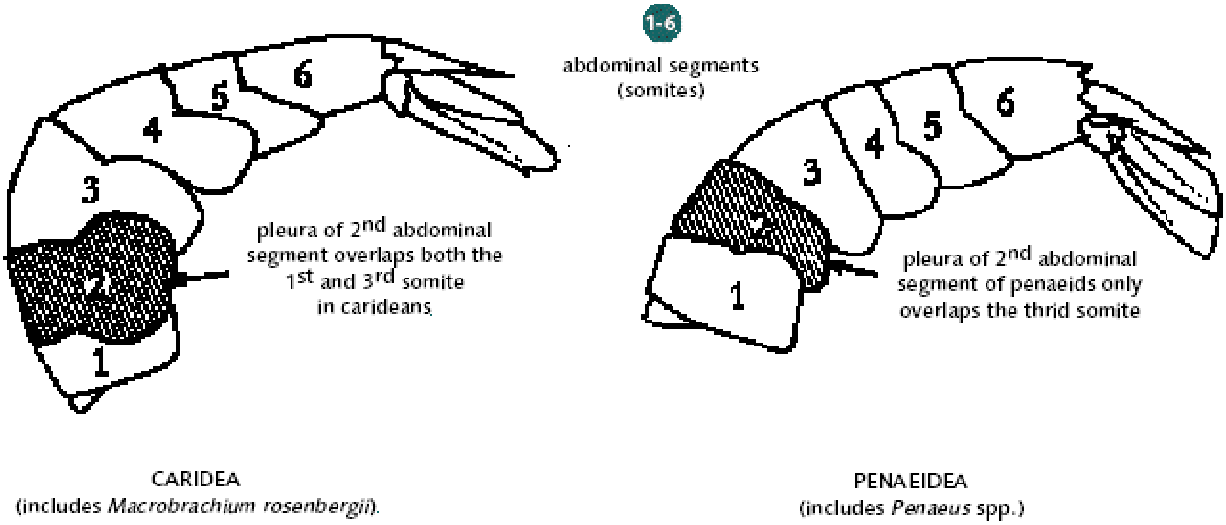
The body shape of freshwater prawns (*Macrobrachium rosenbergii*) is different to that of penaeid shrimp, as these cross sections of the 5th abdominal segments show



SOURCE: EMANUELA D'ANTONI, AFTER FINCHAM AND WICKINS (1976)

FIGURE 7

Freshwater (caridean) prawns can also be distinguished from penaeid shrimp by looking at the second pleura on the abdomen (see arrow)



SOURCE: EMANUELA D'ANTONI, AFTER FINCHAM AND WICKINS (1976)

den increase in size and weight. There are four distinct phases in the life cycle of the freshwater prawn, namely eggs, larvae, postlarvae (PL) and adults. The time spent by each species of *Macrobrachium* in the different phases of its life cycle (and its growth rate and maximum size) varies, not only specifically but according to environmental conditions, mainly temperature.

The life cycle of *M. rosenbergii* can be summarized as follows. The mating (copulation) of adults results in the deposition of a gelatinous mass of semen (referred to as a spermatophore) on the underside of the thoracic region of the female's body (between the walking legs). Successful mating can only take place between ripe females, which have just completed their pre-mating moult (usually at night) and are therefore soft-shelled, and hard-shelled males. All of the various types of males are capable of fertilising females but their behaviour is different (see Annex 8). Detailed descriptions of the mating process are given in Ismael and New (2000) and Karplus, Malecha and Sagi (2000). Under natural conditions, mating occurs throughout the year, although there are sometimes peaks of activity related to environmental conditions. In tropical areas these coincide with the onset of the rainy season, whereas in temperate areas they occur in the summer.

Within a few hours of copulation, eggs are extruded through the gonopores and guided by the ovipositing setae (stiff hairs), which are at the base of the walking legs, into the brood chamber. During this process the eggs are fertilized by the semen attached to the exterior of the female's body. The eggs are held in the brood chamber (stuck to the ovigerous setae) and kept aerated by vigorous movements of the swimmerets. This is in contrast to penaeid shrimp, whose fertilized eggs are released into the sea, where they hatch. The length of time that the eggs are carried by female freshwater prawns varies but is not normally longer than three weeks. The number of eggs which are laid depends also on the size of the female. Female prawns of *M. rosenbergii* are reported to lay from 80 000 to 100 000 eggs during one spawning when fully mature. However, their first broods, (i.e. those which are produced within their first year of life), are often not more than 5 000 to 20 000. Females normally become mature when they reach 15-20 g but berried females have been observed as small as 6.5 g (Daniels, Cavalli and Smullen 2000). Under laboratory conditions, where a breeding stock of both males and females was kept, it has been noted that egg incubation time averaged 20 days at 28°C (range 18-23 days). Ovaries frequently ripened again while females were carrying eggs. Pre-mate intermoults were separated by as little as 23 days (i.e. females on some occasions hatched two batches of eggs within a one-month period). It is unlikely that this would happen under natural conditions but it does show the potential fecundity of the animal.

As the eggs hatch, a process which is normally completed for the whole brood within one or two nights, the larvae (free-swimming zoeae) are dispersed by rapid movements of the abdominal appendages of the parent. Freshwater prawn larvae are planktonic and swim actively tail first, ventral side uppermost (i.e. upside down). *M. rosenbergii* larvae require brackishwater for survival. Those which hatch in freshwater will die unless they reach brackishwater within a few days. There are a number of microscopically distinct stages during the larval life of freshwater prawns, which lasts several weeks (Annex 1). Individual larvae of *M. rosenbergii* have been observed, in hatchery conditions, to complete their larval life in as little as 16 days but reaching this stage may take much longer, depending on water temperature and other factors. The importance of this observation is fully discussed later in the manual. Larvae eat continuously and, in nature, their diet is principally zooplankton (mainly minute crustaceans), very small worms, and the larval stages of other aquatic invertebrates.

On completion of their larval life, freshwater prawns metamorphose into postlarvae (PL). From this point onwards they resemble miniature adult prawns and become mainly crawling rather than free-swimming animals. When they do swim it is usually in a normal (dorsal side uppermost) way and in a forward direction. Rapid evasive movement is also achieved by contracting the abdominal muscles and rapid movement of the tail fan. Postlarvae exhibit good tolerance to a wide range of salinities, which is a characteristic of freshwater prawns.

Postlarvae begin to migrate upstream into freshwater conditions within one or two weeks after metamorphosis and are soon able to swim against rapidly flowing currents and to crawl over the stones at the shallow edges of rivers and in rapids. They can climb vertical surfaces and cross land, provided there is abundant moisture available. In addition to using the foods available to them as larvae, they now utilize larger pieces of organic material, both of animal and vegetable origin. Postlarval freshwater prawns are omnivorous and, as they grow, their natural diet eventually includes aquatic insects and their larvae, algae, nuts, grain, seeds, fruits, small molluscs and crustaceans, fish flesh and the offal of fish and other animals. They can also be cannibalistic. Further reading on this topic may be found in Ling (1969).

1.4 Sources of further biological information

The polymorphism of male prawns, which is particularly relevant to the management of prawn farming, is covered in Annex 8 of this manual. However, the internal morphology, reproductive physiology, and osmo-ionic regulation of freshwater prawns and the nature of ecdysis (moulting), autotomy (shedding of parts of the body) and the regeneration of appendages, are topics that are beyond the scope of this manual. New and Valenti (2000) have provided a review of these subjects.

CHAPTER 2

Site selection

A STUDY OF THE POTENTIAL market for the product and careful selection of suitable sites for prawn culture, whether it be for the larval (hatchery) or grow-out phases, is an essential prerequisite for successful farming. Failure to realize this before any project is commenced is likely to cause the ultimate downfall of the enterprise, which not only has unfortunate consequences for the farmer and investor(s) involved but may also cause serious damage to the image of prawn farming, both nationally and even internationally. Marketing is covered later in this manual.

The current section of the manual contains a brief description of the essential characteristics of good sites for freshwater prawn farming. More detailed information is available in a review by Muir and Lombardi (2000). You are also strongly recommended to obtain and study the FAO manuals on topography (FAO 1988, 1989b), soils (FAO 1985), and water (FAO 1981), as well as the section on site selection in FAO (1995)[1].

2.1 Hatcheries and indoor nurseries

The site requirements for hatcheries and indoor nurseries, which are normally associated with each other, are similar. In this section of the manual, reference to hatcheries therefore includes indoor nurseries.

NEEDS FOR GOOD QUALITY WATER

Although the larval stages of freshwater prawns require brackishwater for growth and survival, hatcheries do not have to be located on coastal sites. Prawn hatcheries can be sited on inland sites. There, the necessary brackishwater can be obtained by mixing locally available freshwater with seawater or brine (and sometimes artificial seawater) which has been transported to the site. Two decades ago, when the original FAO manual was written,

1 These manuals are not specific to freshwater prawns. They are relevant to many forms of fish and crustacean farming and are designed for advanced extension workers.

most hatcheries operated on flow-through systems. Many still do so but the establishment of inland hatcheries, the costs of obtaining and transporting seawater or brine, and increasing concerns about the discharge of saline water in inland areas have encouraged some operators to minimize water consumption through partial or full recirculation systems. Inland hatcheries have the advantage that they can be sited wherever suitable freshwater is available and their market (namely outdoor nurseries and grow-out facilities) is close by. Where to site a hatchery is therefore not only a technical but also an economic consideration. This involves balancing the costs of transporting seawater and brine, or using recirculation, against the advantages of an inland site. Prawn hatcheries, regardless of type, require an abundant source of freshwater as well as seawater or brine. The quality of intake water, whether it be saline or fresh, is of paramount importance for efficient hatchery operation. Water quality is thus a critical factor in site selection. Hatchery sites should preferably be far from cities, harbours and industrial centres, or other activities which may pollute the water supply.

Due to the extra problems and dangers involved, it is generally recommended that freshwater prawn hatcheries should not be sited where the only source of water is surface water. However, this guidance has not always been observed. The minimum requirement during site evaluation should be to carry out watershed surveys and water analyses, especially for pesticides and oil spill residues. In coastal areas, it may be possible to draw good quality water from sub-surface layers, usually with freshwater overlying more saline water. The ideal site, where wells sunk to different depths provide both freshwater and seawater, is rare, although it is sometimes possible to make good use of groundwater sources, which are usually cleaner and less liable to become contaminated. The quality of water depends on the soil materials. In coastal areas with underlying coral rock, hatcheries can often get good quality seawater, free of pollution or harmful protozoa and bacteria. If sites with borehole seawater are not available, direct access to a sandy beach with mixed sand particle size can be selected. On this type of site a shallow beach filter of the type described in Annex 2 can be utilized. Muddy areas are not so suitable, but a larger filter may be used, provided it can be cleaned out periodically.

Many freshwater prawn hatcheries utilize surface supplies for both freshwater and seawater. Often, seawater can be drawn from areas where the salinity is 30 to 35 ppt, usually through a rigid pier off-take in the sea or a flexible buoyed system. Crude screening can be used to prevent the entry of the larger flora and fauna but this alone is not sufficient to protect the larvae from disease and parasitical problems. The use of unfiltered water will almost certainly result in disaster, so additional filtration is essential. Brine, sometimes used instead of seawater for inland hatcheries to minimize transport costs, can be obtained from salt evaporation pans. The brine, which is often between 80-100 ppt salinity but can be as high as 180 ppt, can be diluted with freshwater to form brackishwater (in theory, the higher the salinity of the brine used, the better; this is because the sudden osmotic shock which occurs when brine and freshwater are mixed together may reduce the numbers of bacteria and parasites present in the original supplies). Some hatcheries obtain freshwater pumped or fed by gravity from surface supplies such as rivers or irrigation canals. This practice exposes the hatchery to severe variations in water quality and particularly to water contamination from agricultural chemicals.

In all cases, water supplies need careful analysis during site selection, to determine their physical, chemical, and biological characteristics, and the extent to which these may vary daily, seasonally, or through other cycles. Special care is needed where hatcheries are situated in or near areas where the use of pesticides, herbicides, and fertilizers is intensive. Ideally, freshwater should be obtained from underground sources, though some of these may be unsuitable because of high levels of iron and manganese, which are lethal to prawn larvae. Methods of reducing the levels of these ions are provided later in this section of the manual. City tap water is also normally suitable, provided it is vigorously aerated for 24-48 hours before use to remove residual chlorine, but may be too expensive to use. Well water should also be aerated, by cascading for example, to bring its dissolved oxygen level up to, or near to saturation point.

The brackishwater derived from the mixture of seawater, brine or artificial sea salts with freshwater for use in *M. rosenbergii* hatcheries should be 12-16 ppt, have a pH of 7.0 to 8.5, and contain a minimum dissolved oxygen level of 5 ppm. Water of various levels of salinity is also required for hatching *Artemia* as a larval food (Annex 4); the ideal hatching salinity depends on the source of cysts. The use of estuarine water, which would theoretically limit the need to balance freshwater and seawater to obtain the optimum salinity, is possible. However, the salinity of estuarine water varies, both diurnally and seasonally, making management difficult. In addition, although estuarine water can be utilized if its salinity is above the hatchery operating salinity, its use is not recommended because the levels of micro-organisms and potential pollution may be high.

Both freshwater and seawater must be free from heavy metals (from industrial sources), marine pollution, and herbicide and insecticide residues (from agricultural sources), as well as biological contamination (e.g. as indicated by the presence of faecal coliforms, which can be common in residential and agricultural areas). The analyses of water found suitable for use in freshwater prawn hatcheries are given in Table 2. Not much is known about the tolerance of larvae to toxic materials but it can be assumed that larvae are at least as (probably more) susceptible to pollution and toxicity as juveniles. As safe and lethal levels of specific substances are not yet fully understood, it is inappropriate to provide a summary of current research in this manual. Those who wish to know more about this topic are recommended to consult Boyd and Zimmermann (2000), Correia, Suwannatous and New (2000) and Daniels, Cavalli and Smullen (2000).

If seawater or freshwater is drawn from surface supplies, some form of treatment is essential, as discussed later in this manual. Both freshwater and seawater used for hatchery purposes should have a pH and a temperature as close as possible to the optimum range. Hydrogen sulphide and chlorine (e.g. from tap water) must be absent. High levels of nitrite and nitrate nitrogen must be avoided. Seawater should have as little diurnal or seasonal variation as possible. Very hard (reported as $CaCO_3$ level) freshwater should be avoided. The levels of iron (Fe) and manganese (Mn) should be low; copper (Cu) toxicity may also be a problem, especially after larval stage VI. However, some iron and manganese can be precipitated from well water by aeration; the resultant floc can be removed by sand filtration, or by biofiltration and settling (Box 1).

High levels of heavy metals, such as mercury (Hg), lead (Pb) and zinc (Zn), should also be avoided - these are most likely to be caused by industrial pollution. In general, especially where surface water is used, hatcheries should not be sited where their water supplies are endangered by pollution from tanker discharge, oil refineries, tanning, agricultural pesticides and herbicides, or chemical factories. In practice, an 'ideal' water supply might be difficult to define, but a summary of the characteristics of water found suitable for use in freshwater prawn hatcheries is provided in Table 2.

Artificial seawater has been used in some recirculation systems, especially in research. The stimulus for such work is that its use may reduce the problems caused by water pollution, parasites, and the presence of prawn competitors and predators in larval rearing tanks. Many formulations for artificial seawater exist and commercial preparations are sold in the aquarium trade. However, not all have been found suitable for fresh-

BOX 1

Removal of iron and manganese

WELL OR BOREHOLE water is often high in iron and manganese but low in dissolved oxygen (DO_2). Aeration provides a source of DO_2, which will convert iron and manganese from their ferrous and manganous forms to their insoluble oxidized ferric and manganic forms. 1 ppm iron (Fe) needs 0.14 ppm DO_2 for oxidation; 1 ppm of manganese (Mn) requires 0.27 ppm DO_2. Thus, aeration provides a means of removing iron and managanese from water, since the insoluble precipitates formed by converting them to their insoluble forms can be settled or filtered out. Additionally, aeration also helps to strip out the volatile organic compounds and the hydrogen sulphide (H_2S) also found in this type of water source.

DO_2 should be supplied in an aeration tank, using fine bubble air diffusers. The water must spend at least 10 minutes under aeration (10 minutes residence time). The water should then be circulated through another tank containing biofiltration media. Once this filter has been developed (i.e. run for some time), the iron and manganese particles will tend to fall out of solution and accumulate on the surface of the biofiltration media. In large-scale systems the water is then passed through a pressure filter. However, passing it into a third (settling) tank, where most of the rest of the Fe and Mn precipitates will settle out, should provide water sufficiently low in Fe and Mn for use in your hatchery. It is suggested that the water be allowed to remain in the settling tank for 24 hours before the water is pumped (without disturbing the sediment) into the hatchery for use.

Obviously, the biofiltration media will have to be regularly washed; placing the plastic media within stainless steel or plastic cages makes it easy to remove it from the filtration tank for this purpose. The settlement tank will also need to be cleaned out. The dimensions of the equipment you use depend on the quantity of water you need to treat.

SOURCE: FURTHER DETAILS ON FLOW-THROUGH SYSTEMS FOR STRIPPING WELL WATER AND OTHER TYPES OF WATER TREATMENT ARE AVAILABLE FROM WATER INDUSTRY SUPPLIERS. THIS BOX WAS DERIVED FROM A WWW.GOOGLE.COM LINK TO THE WEBSITE OF DRYDEN AQUA (WWW.DRYDENAQUA.COM), WHICH IS GRATEFULLY ACKNOWLEDGED.

water prawns and many are complex and expensive. The exact and specific ionic composition that is optimum for freshwater prawns is not yet known. The formula for a simple preparation which has been used in *Macrobrachium rosenbergii* hatcheries is given in Table 3. This contains the essential ions sodium, potassium, chloride, bromide, carbonate and sulphate, together with the correct ratio of calcium and magnesium. This preparation may not be complete, and there is some evidence that its use increases oxygen consumption after larval stage V, but it (and variations of the formula) have been used in research and a few commercial cycles in Brazil. The unit cost, even for such a simple formula, is high (e.g. US$ 75/m^3 in Brazil in 2000). However, not much is required because evaporative losses can be made up with freshwater alone and, if properly handled and processed, the same brackishwater can be used for two consecutive larval cycles without affecting production. The productivity of systems using artificial seawater is reported to be as high as 40 PL/L but the larval cycle may take about 10% longer than when natural seawater is used. Due to its cost and the uncertainty about its effectiveness, the use of artificial seawater is not recommended in this manual. Whenever possible, the use of natural seawater or brine is recommended.

DECIDING HOW MUCH WATER IS NEEDED

The quantity of freshwater and seawater required for a freshwater prawn hatchery depends not only on the proposed scale of operation but also on the type of management utilized (flow-through, recirculation, use of brine). Flow-through systems obviously require the maximum quantities of water. All other systems will either require less seawater or, in the case of those which utilize brine or artificial seawater, none. It is therefore not possible in this manual to define the exact quantities of water needed, as these are scale, site and management system dependent. An example of the water requirements for a flow-through system using seawater that includes ten 5 m^3 larval tanks, each capable of producing 50 000 postlarval prawns (total 500 000 per larval cycle) within a maximum of 35 days, is provided in Box 2.

TABLE 2 Characteristics of water suitable for freshwater prawn hatcheries

VARIABLES	FRESHWATER (PPM)	SEAWATER (PPM)	BRACKISHWATER (PPM)
Total hardness (as $CaCO_3$)	<120	-	2 325-2 715
Calcium (Ca)	12-24	390-450	175-195
Sodium (Na)	28-100	5 950-10 500	3 500-4 000
Potassium (K)	2-42	400-525	175-220
Magnesium (Mg)	10-27	1 250-1 345	460-540
Silicon (SiO_2)	41-53	3-14	5-30
Iron (Fe)	<0.02	0.05-0.15	<0.03
Copper (Cu)	<0.02	<0.03	<0.06
Manganese (Mn)	<0.02	<0.4	<0.03
Zinc (Zn)	0.2-4.0	0.03-4.6	<3
Chromium (Cr)	<0.01	<0.005	<0.01
Lead (Pb)	<0.02	<0.03	<0.03
Chloride (Cl)	40-225	19 000-19 600	6 600-7 900
Chlorine (Cl_2)	nil	-	nil
Sulphate (SO_4)	3-8	-	-
Phosphate (PO_4)	<0.2	-	-
Hydrogen sulphide (H_2S)	nil	nil	nil
Total dissolved solids (TDS)	217	-	-
Turbidity (JTU)	nil	nil	nil
Dissolved oxygen (DO_2)	>4	>5	>5
Free carbon dioxide (CO_2)	nil	-	nil
Ammonia (NH_3-N)	-	-	<0.1
Nitrite (NO_2-N)	-	-	<0.1
Nitrate (NO_3-N)	-	-	<20
pH	6.5-8.5 units	7.0-8.5 units	7.0-8.5 units
Temperature	-	-	28-31(ºC)

NOTE: THE SIGN '-' MEANS 'NOT KNOWN' OR 'NO SPECIFIC RECOMMENDATION'.

SOURCE: DERIVED FROM NEW AND SINGHOLKA (1982), CORREIA, SUWANNATOUS AND NEW (2000) AND VALENTI AND DANIELS (2000)

TABLE 3 Artificial brackishwater (12 ppt) for *M. rosenbergii* hatcheries

SALT	QUANTITY (G/M^3)
Sodium chloride (NaCl)	9 200
Magnesium sulphate ($MgSO_4.7H_2O$)	2 300
Magnesium chloride ($MgCl_2.6H_2O$)	1 800
Calcium chloride ($CaCl_2.H_2O$)	467
Potassium chloride (KCl)	200
Sodium bicarbonate ($NaHCO_3$)	67
Potassium bromide (KBr)	9

NOTE: WEIGH AND DILUTE THE SALTS INDIVIDUALLY WITH PREVIOUSLY FILTERED FRESHWATER. ADD THE RESULTING SOLUTIONS TO A TANK IN THE ORDER SHOWN ABOVE, AND MIX THOROUGHLY USING A PVC STIRRER. THEN ADD FRESHWATER UNTIL THE SALINITY IS REDUCED TO 12 PPT. MAINTAIN THE FINAL SOLUTION UNDER STRONG AERATION FOR 24 HOURS AND ADJUST THE SALINITY AGAIN TO 12 PPT, IF NECESSARY, BEFORE TRANSFER TO THE RECIRCULATION SYSTEM.

SOURCE: VALENTI AND DANIELS (2000)

OTHER REQUIREMENTS FOR HATCHERY SITES

In addition to having sufficient supplies of good quality water, a good hatchery site should also:

- have a secure power supply which is not subject to lengthy power failures. An on-site emergency generator is essential for any hatchery - this should be sized so that it has the output necessary to ensure that the most critical components of the hatchery (e.g. aeration, water flow), can continue to function;
- have good all-weather road access for incoming materials and outgoing PL;
- be on a plot of land with an area appropriate to the scale of the hatchery, that has access to the quantity of seawater and freshwater supplies required without excessive pumping. The cost of pumping water to a site elevated high above sea level, for example, may be an important factor in the economics of the project;
- not be close to cities, harbours, mines and industrial centres, or to other activities that may pollute the water supply;
- be situated in a climate which will maintain water in the optimum range of 28-31°C, without costly environmental manipulation;
- have access to food supplies for larvae;
- employ a high level of technical and managerial skills;
- have access to professional biological assistance from government or other sources;
- have its own indoor/outdoor nursery facilities, or be close to other nursery facilities; and
- be as close as possible to the market for its PL. In the extreme case, it should not more than 16 hours total transport time from the furthest farm it will be supplying.

2.2 Outdoor nurseries and grow-out facilities

The success of any nursery facility or grow-out farm depends on its access to good markets for its output. Its products may be sold to other farms (in the case of nurseries), directly to the public, to local markets and catering facilities, or to processors or exporters. The needs and potential of each type of market need to be considered. For example, more income may result if you can sell your market-sized prawns alive. The scale, nature and locality of the

BOX 2

Flow-through requirements for ten 5 m^3 larval rearing tanks

IN A FLOW-THROUGH system, the salinity of the seawater or brine available controls the amount of freshwater necessary to produce the 12 ppt brackishwater needed for larval rearing (Table 4). The daily consumption of 12 ppt water for a single 5 m^3 rearing tank in a flow-through system exchanging approximately 50% of the water per day would be 2.5 m^3 (2 500 L). However, emergencies sometimes occur, when it is necessary to rapidly change all the water in a tank. Pumping capacity must be sufficient to fill any tank with brackishwater within one hour in order to make the daily water exchange as rapid as possible. Thus, in this example, the pumping and pipe work capacity must be sufficient to supply a peak demand of 5 m^3 within an hour (approximately 83 L/min) to each tank. For a complete larval cycle, allowing for some additional exchange to solve rearing water quality problems and assuming that the cycle lasts 35 days, a total of around 90 m^3 of 12 ppt water would be consumed for every 50 000 PL produced. This is equivalent to about 2.6 m^3/day for each larval tank, or 25.7 m^3 for ten tanks. Rounding up, and allowing an additional safety margin, a hatchery with ten tanks of this size would need about 30 m^3 of brackishwater per day.

Assuming a steady intake salinity of 30 ppt (and referring to Table 4), the requirement would be 30 ÷ 10 x 4 = 12 m^3 of seawater per day. The need for the larval tanks would be 30 ÷ 10 x 6 = 18 m^3 of freshwater per day.

In addition, sufficient freshwater to maintain holding tanks for PL must be provided. For a hatchery operating ten 5 m^3 larval tanks, facilities for providing an average of 20 m^3/day of additional freshwater (based on a PL stocking density of 5 000 PL/m^2 and an average water exchange rate of 20%/day: 500 000 ÷ 5 000 x 20 ÷ 100) will be needed during the periods when postlarval holding tanks are being operated. [Note: much larger quantities of freshwater will be needed if the PL are held for more than one week, because stocking densities will have to be reduced]

The total water consumption for a hatchery operating ten 5 m^3 tanks producing 500 000 PL in each larval cycle and selling the PL within one week after metamorphosis would therefore be 12 m^3 of seawater and 18 + 20 = 38 m^3 of freshwater per day.

market is the first topic that you should consider and the results of your evaluation will determine whether the site is satisfactory and, if so, the way in which the farm should be designed and operated. Despite the obvious importance of the market, it is surprising how often that this topic is the last criterion to be investigated. It is considered in more detail later in this manual.

It also important to consider other factors to ensure success, including the:

- suitability of the climatic conditions;
- suitability of the topography;
- availability of adequate supplies of good quality water;
- availability of suitable soil for pond construction;
- maximum protection from agricultural and industrial pollution;
- availability of adequate physical access to the site for the provision of supplies and the movement of harvested animals;
- availability of supplies of other necessary inputs, including postlarval and/or juvenile prawns, equipment, aquafeeds or feed ingredients, and power supplies;
- availability of good skilled (managerial) and unskilled labour;

TABLE 4 Diluting seawater and brine to make brackishwater for larval freshwater prawn culture

SALINITY OF SEAWATER OR BRINE (PPT)	AMOUNTS OF WATER REQUIRED TO MAKE 10 M^3 OF 12 PPT BRACKISHWATER	
	FRESHWATER (M^3)	SEAWATER (M^3)
180	9.334	0.666
144	9.167	0.833
108	8.889	1.111
72	8.334	1.666
36	6.667	3.333
35	6.571	3.429
34	6.471	3.529
33	6.364	3.636
32	6.250	3.750
31	6.129	3.871
30	6.000	4.000
29	5.862	4.138
28	5.714	4.286
27	5.556	4.444
26	5.385	4.615
25	5.200	4.800
24	5.000	5.000

NOTE: INCOMING FRESHWATER IS ASSUMED TO BE ZERO SALINITY.

- presence of favourable legislation; and
- availability of adequate investment.

These topics have been discussed in detail in many FAO and other publications, including FAO (1981, 1988, 1989b 1995) and Muir and Lombardi (2000). This section of the manual concentrates on those factors which are particularly important or specific to freshwater prawn farming.

CHOOSING YOUR SITE: TOPOGRAPHY AND ACCESS

Farms must be close to their market so the road access must be good. Large farms will need to have local access for heavy trucks be able to reach the farm easily, for the delivery of supplies and the efficient collection of harvested prawns.

A survey is necessary, to assess the suitability of a site from a topographical point of view. This will include transects, to evaluate slope and to determine the most economic ways of constructing ponds and moving earth. It is important to minimize the quantities of earth to be shifted during pond construction. Flat or slightly sloping lands are the most satisfactory. The ideal site, which slopes close to 2% (2 m in 100 m), allows good savings on earth movement. In addition, ponds constructed on this type of site can be gravity filled (either naturally or by the creation of a dam) and gravity drained. Where potential farm sites are steeper, or if gradients are irregular, care should be taken to ensure that pond sizes and alignments allow efficient construction, and at the same time permit good access and effective water supply and drainage.

The ideal site is rarely available, however. Many successful farms exist where the only feasible method to fill and drain the ponds is by pumping. Some sites, where ponds are excavated in flat, often seasonally flooded areas, may require higher pond banks for flood protection. Prawn farming may be practised in rain-fed ponds but their productivity may be low. The level of productivity in grow-out ponds is governed by complex management factors, which are dealt with later in this manual. The cost of filling and draining ponds, which depend on the characteristics of the site, must be carefully assessed before the site is chosen.

CHOOSING YOUR SITE: CLIMATE

This is another fundamentally important issue. You should study the meteorological records to determine temperature, the amount and seasonality of rainfall, evaporation, sunlight, wind speed and direction, and relative humidity. Avoid highly unstable meteorological regions. Strong storms and winds increase the risks of flood and erosion damage, and may lead to problems with transport access and power supply. As far as possible, do not site the farm in an area which is subjected to severe periodic natural catastrophes, such as floods, typhoons, landslips, etc. If you decide to site your farm in an area subject to floods, you will need to make sure that the banks of individual ponds are higher than the highest known water level at that site, or you will need to protect the whole farm with a peripheral bank.

Temperature is a key factor. Seasonal production is possible in semi-tropical zones where the monthly average air temperature remains above 20°C for at least seven months of the year. This occurs, for example, in China and some southern States of continental USA. For successful year-round farming, sites with large diurnal and seasonal fluctuations should be avoided. The optimum temperature range for year-round production is between 25 and 31°C, with the best results achievable if the water temperature is between 28 and 31°C. The temperature of the rearing water is governed not only by the air and ground temperature but by solar warming and the cooling effects of wind and evaporation. The rate by which pond water is exchanged and the temperature of the incoming water are also important considerations.

Rainfall, evaporation rates, relative air humidity and wind speed and direction also need to be investigated. Ideally, evaporation losses should be equal to or slightly lower than rainfall input, to maintain an approximate water balance. However, in some locations this balance changes seasonally. There may be cooler high-rainfall periods during which water can be stored in deeper ponds, and hotter high-evaporation periods in which water supplies decrease. In these areas, it is still possible for you to produce one or more crops by adjusting production plans. Mild winds are useful to promote gas exchange (oxygenation) between water and the atmosphere. However, strong winds can increase water losses by evaporation and may also generate wave action, causing erosion of the pond banks. Avoid areas where it is constantly cloudy because this makes it hard to maintain a steady water temperature, as it interferes with solar penetration. Periods of cloud cover of several days' duration may also cause algal blooms to crash, which in turn lead to oxygen depletion.

Apart from the dangers of water-supply contamination, you should not site your farm in an area where the ponds themselves are likely to be affected by aerial drift of agricultural sprays; prevailing wind direction should therefore be taken into account. Constructing ponds adjacent to areas where aerial application of herbicides or pesticides is practised is also undesirable. Freshwater prawns, like other crustaceans, are especially susceptible to insecticides.

CHOOSING YOUR SITE: WATER QUALITY AND SUPPLY

Freshwater is normally used for rearing freshwater prawns from postlarvae to market size. Prawns will tolerate partially saline water (reports indicate that they have been experimentally cultured at up to 10 ppt; however, they do not grow so well at this salinity). You could rear *Macrobrachium rosenbergii* in water which may be too saline to be drinkable or useful for irrigation. Water of 3-4 ppt salinity may be acceptable for the culture of *M. rosenbergii*, but do not expect to achieve results as good as those obtainable in freshwater.

The reliability of the quality and quantity of the water available at the site is a critical factor in site choice. However, as in the case of hatchery water supplies, the absolute 'ideal' for rearing sites may be difficult to define; a range of water qualities may be generally suitable. As for hatchery water, the level of calcium in the freshwater seems to be important. Growth rate has been reported to be lower in hard than in soft water. It is recommended that freshwater prawn farming should not be attempted where the water supply has a total hardness of more than 150 mg/L ($CaCO_3$). Table 5 provides some criteria for

TABLE 5 Water quality requirements for freshwater prawn nursery and grow-out facilities

PARAMETER	RECOMMENDED (IDEAL) RANGE FOR FRESHWATER PRAWNS	LEVELS KNOWN TO BE LETHAL (L) OR STRESSFUL (S) TO JUVENILE PRAWNS	LEVELS OBSERVED IN EXISTING PRAWN FARMS IN BRAZIL IN 1998
Temperature (°C)	28-31	<12 (L) <19 (S) >35 (L)	-
pH (units)	7.0-8.5	>9.5 (S)	5.5-8.3
Dissolved oxygen (ppm DO_2)	3-7	2 (S) 1 (L)	-
Salinity (ppt)	<10	-	-
Transparency (cm)	25-40	-	-
Alkalinity (ppm $CaCO_3$)	20-60	-	7-102
Total hardness (ppm $CaCO_3$)	30-150	-	10-75
Non-ionized ammonia (ppm NH_3-N)	<0.3	>0.5 at pH 9.5 (S) >1.0 at pH 9.0 (S) >2.0 at pH 8.5 (S)	0.1-0.5
Nitrite nitrogen (ppm NO_2-N)	<2.0	-	0.1-1.7
Nitrate nitrogen (ppm NO_3-N)	<10	-	-
Calcium (ppm Ca)	-	-	0.01-18.6
Magnesium (ppm Mg)	-	-	0.01-6.8
Total phosphorus (ppm P)	-	-	0.003-4.4
Sodium (ppm Na)	-	-	0.26-30.0
Potassium (ppm K)	-	-	0.01-4.9
Sulphate (ppm SO_4)	-	-	0.1-26.0
Boron (ppm B)	<0.75	-	0.04-0.74
Iron (ppm Fe)	<1.00	-	0.02-6.00
Copper (ppm Cu)	<0.02	-	0.02-0.13
Manganese (ppm Mn)	<0.10	-	0.01-0.31
Zinc (ppm Zn)	<0.20	-	0.01-0.20
Hydrogen sulphide (ppm H_2S)	nil	-	-

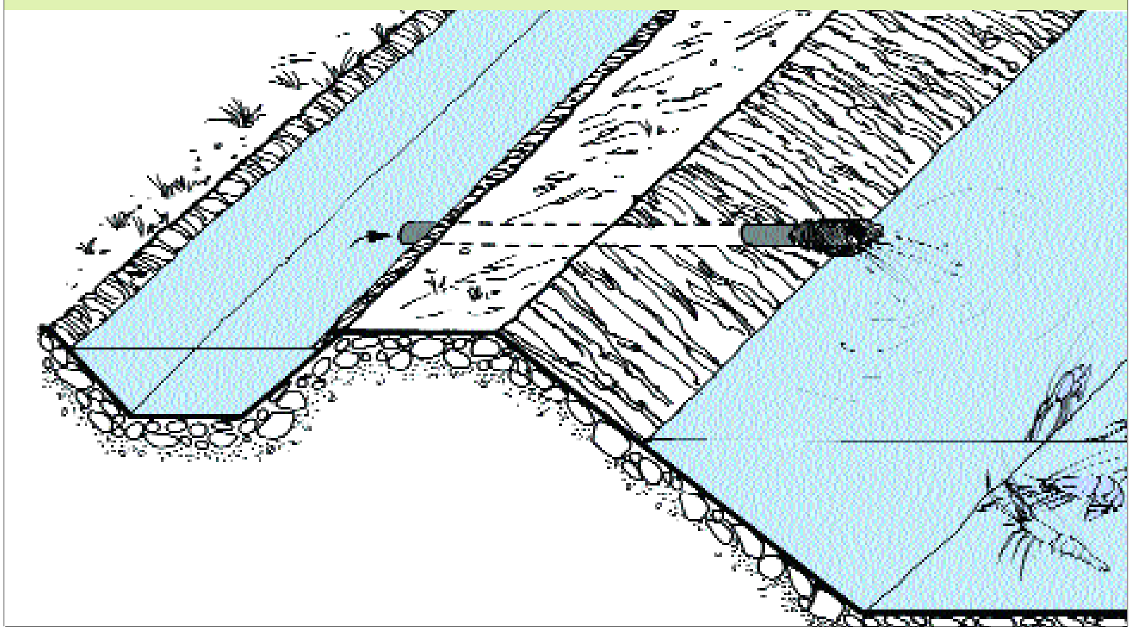
NOTE: THE SIGN '-' MEANS 'NOT KNOWN' OR 'NO SPECIFIC RECOMMENDATION'.
SOURCE: MODIFIED FROM BOYD AND ZIMMERMANN (2000)

water supplies for freshwater prawn nursery and grow-out facilities. The water supply must be free from pollution, particularly agricultural chemicals. Prawn performance is likely to be adversely affected long before lethal levels are reached. However, the exact lethality of various chemicals is still being researched and it is not appropriate to list safe levels in this manual. Those who wish to examine the status of this research may wish to consult Boyd and Zimmermann (2000), Correia, Suwannatous and New (2000) and Daniels, Cavalli and Smullen (2000).

As with hatcheries, the water must also be as predator-free as possible, though standards need not be quite so high. This may be achieved by screening (Figures 8a, 8b and 8c) or by the use of well water. Underground water, because of its chemical and microbiologi-

FIGURE 8a

Grow-out pond inlets need to be screened to exclude predators



SOURCE: EMANUELA D'ANTONI

SOURCE: OSCAR ORBEGOSO MONTALVA

SOURCE: HASSANAI KONGKEO

Figure 8b Screened inlets being used in this freshwater prawn grow-out pond (Peru)

Figure 8c This type of inlet screen is used in Thailand, especially when ponds are filled by long-tail pump cal quality and its lack of predators, is undoubtedly the preferred water source. In practice, sites that only have access to surface water supplies (rivers, lakes, reservoirs, irrigation canals, etc.) are the most commonly used. However, you must be aware of the extra risk that their use brings. Screening the water supply helps to reduce the initial entry of predators but cannot clean up chemically polluted water or water containing disease organisms. You should consider the location of other existing or planned freshwater prawn farms. You can then make an assessment of the risk that the water supplies of the new farm may be contaminated by the effluent from other farms. If you are going to use surface water, constructing your farms close to a waterfall bringing water from a remote and unpolluted watershed or below the dam of a reservoir (though such water, if drawn from the epilimnion, may initially be high in hydrogen sulphide) would be ideal.

The minimum farm size for economic viability depends on several other factors but the quantity and continuity of the available water supply sets an absolute technical limit on the pond area of your farm, and on its potential productivity. Water is required for four major purposes, namely filling ponds, compensating losses from seepage and evaporation, water exchange, and emergency flushing. When determining the amount of water available on a specific site for freshwater prawn farming you should take the rainfall pattern into account. This may be sufficient to replace or exceed evaporative and seepage losses, at least at some time during the year. An example of grow-out water requirements is provided in Box 3.

In addition to having enough water to fill the ponds it is, at the very minimum, necessary to have enough water available throughout the growing period to replace evaporative and seepage losses. Evaporative losses depend on solar radiation and wind and relative humidity and are therefore governed by the climatic features of the site. Seepage losses depend on the soil characteristics of the farm area, mainly its permeability. Seepage losses may be small where the water table is high or where the water level of the pond is the same as in adjoining fields (e.g. in a paddy field area). However, in other cases, particularly where pond construction is poor, seepage losses can be very great. The quantity of water necessary for this purpose must be assessed locally and the cost of providing it is an

BOX 3

Grow-out water requirements

TO FILL A 0.2 ha pond with an average water depth of 0.9 m requires 10 000 x 0.2 x 0.9 = 1 800 m^3 of water. Since it is usually desirable to be able to fill the pond within 12 hours, it follows that it must be possible to extract up to 1 800 ÷ 12 ÷ 60 = 2.5 m^3 (2 500 L) per minute from the water source for this pond. Normally it is only necessary to completely fill a drained pond after a rearing cycle is completed and the pond has been drained and treated, that is, once every 6-11 months.

There will also be times when, because of poor pond water quality, you may find it necessary to flush the pond and replace a substantial proportion of the water while prawns are growing in it. However, it is very unlikely that it will be necessary for you to fill more than one pond at the same time, if you have a small farm. Thus, for example, five 0.2 ha ponds would therefore not require a maximum water supply five times larger than one 0.2 ha pond.

important economic factor. As ponds mature, ponds tend to 'seal' themselves, through the accumulation of detritus and algal growth, thus limiting seepage losses. Seepage losses can also be minimized by a number of techniques, including sealing the ponds with organic matter, puddling, compaction, laying out a 'soil blanket', applying bentonite, or lining them with polyethylene, PVC, or butyl rubber sheeting. Details of these procedures are provided in another FAO publication (FAO 1996).

There is no substitute for the site-specific determination of the water requirements for your farm but an example of water consumption needs for different sized farms, using a number of assumptions is given in Table 6. Techniques for measuring water resources are given in books on hydrology and agricultural water assessment such as ILACO (1981). Methods for estimating seepage and evaporation losses and calculating water requirements are given in FAO (1981). Large-scale farms may wish to consult specialist contractors.

TABLE 6 Example of water requirements for ponds based on various assumptions

TOTAL FARM WATER SURFACE AREA[2] (HA)	QUANTITY OF WATER REQUIRED (m^3/MIN)		
	FILLING PONDS[3]	REPLACING SEEPAGE AND EVAPORATION LOSSES[4]	AVERAGE CONSUMPTION[5]
0.2	2.50	0.041	0.048
0.5	2.50	0.103	0.120
1.0	2.50	0.205	0.239
2.0	2.50	0.410	0.478
3.0	3.75	0.615	0.718
5.0	6.25	1.025	1.196
10.0	12.50	2.050	2.392
20.0	25.00	4.100	4.785
40.0	50.00	8.200	9.570

A supply of drinking water and waste disposal facilities are an added advantage to a freshwater prawn farm site but are not absolutely essential. Provision can be made on-site, for example by obtaining batch supplies of drinking water, sinking a borehole, or collecting and filtering rainwater. However, if ice is going to be made, or prawns are to be processed and packed on site, a supply of high quality water, normally the equivalent of drinking (potable) water, is essential. Aqueous waste disposal from such activities can be routed to a septic tank, a waste lagoon, or a simple soak-away.

2 Assumes an average water depth of 0.9 m
3 For filling ponds at the beginning and on future occasions. Assumes that the unit pond size is 0.2 ha and that the pond can be filled within 12 hours. Also assumes that it will never be necessary to fill more than one pond (or 10% of the pond surface area, whichever is the greater) at the same time. Local experience will tell if this allowance is either not enough or too generous.
4 Assumes average seepage losses of 10 mm/day, which is typical for a clayey loam which has not been puddled (FAO, 1981), 500 mm/yr evaporation (this is extremely site-specific) and 2% water exchange per day. This is equivalent to 100 m^3/ha/day (approximately 0.07 m^3/ha/min) for seepage, approximately 13.7 m^3/ha/day (0.01 m^3/ha/min) for evaporation, and 180 m^3/ha/day (0.125 m^3/ha/min) for water exchange in ponds with an average depth of 0.9 m. Total maintenance requirements are therefore 0.205 m^3/ha/min.
5 This combines the maintenance rate with the quantity necessary to fill all ponds twice per year, averaged out to a volume per minute consumption basis.

CHOOSING YOUR SITE: SOIL CHARACTERISTICS

There must be enough soil available for pond construction, whether the ponds are to be excavated or pond banks are to be erected above ground. Unless good information about the soil characteristics is already available, site assessments should include taking a suitable number of soil cores up to 1 m deeper than the expected pond depth. These must be analysed for their soil classification and chemistry. If rocks, boulders and tree stumps are present, you must consider the cost of their removal (to make the pond bottoms flat and for constructing impervious pond banks) while you are assessing the economic feasibility of the farm. Flooded and saturated areas are difficult to construct ponds in, and the expenses of doing so must be taken into consideration. Construction of concrete pond structures (e.g. pond outlets) is difficult in soils with a high salt content. Preferably, the site should have a shape which allows you to construct regular-shaped ponds. Irregular-shaped ponds are difficult to manage; rectangular ponds are more efficient to operate.

Although supplemental food is given to freshwater prawns reared in earthen ponds, a considerable amount of their food intake is from natural sources. It is therefore preferable to site the farm where the soil is fertile, as this will reduce the need and costs of fertilisation. Since a water pH of 7.0-8.5 is required for successful freshwater prawn culture, it is preferable not to build the farm on potentially acid sulphate soils. These soils have pH values of 4.5 or less, together with high concentrations of soluble iron, manganese and aluminium. Most people associate the occurrence of acid sulphate soils with mangrove areas but they also occur far away from such areas. Aquaculture ponds are frequently constructed on such soils, despite their poor suitability. However, their production levels are often too low, or the costs of liming and fertilisation are too high, for them to be financially viable.

Freshwater prawn ponds should be constructed on soil which has good water retention characteristics or where suitable materials can be economically brought onto the site to improve water retention. The water retention characteristics of soil are highly site-specific and prospective farmers must seek the professional advice of soil engineers and fishery officials from local government departments, such as the Ministry of Agriculture and the Public Works Department. If there are other fish farms or irrigation reservoirs in the area, you should ask the neighbouring farmers for advice, based on their specific local experience. Pervious soils, which are very sandy or consist of a mixture of gravel and sand, are unsuitable unless the water table is high and surrounding areas are always waterlogged. Soils which consist of silt or clay, or a mixture of these with a small proportion of sand, normally have good water retention characteristics. Peaty soils are not suitable. The clay content should not exceed 60%; higher clay content soils swell when moist and crack during the dry season, thus making repairs necessary. Methods for the preliminary assessment of particle sizes, permeability and plasticity (how well soils will compact to their optimum strength and permeability) are given in FAO (1985).

CHOOSING YOUR SITE: POWER SUPPLIES

A source of electricity is desirable but not essential. A variety of power sources may be used for supplying the energy necessary for water movement on the farm including:

- water power itself (gravity and current flow);
- wind;
- electricity;
- petrol and diesel fuel; and
- wood.

Electricity is desirable, although it need not be the sole source of energy, for powering lights, wells and feed-making equipment. The most suitable power source to use is entirely site-specific and depends upon such factors as equipment availability, unit power costs and the characteristics of the site and its water supply. Generating electricity on the farm may be cheaper than running a new supply from the nearest point on the national power grid. Where a power failure would quickly result in severe losses, for example in farms operating highly intensive systems dependent on aeration, a back-up power source (usually a diesel generator) is essential.

The ideal would be for you to be able to move water within your site by gravity but this depends on the nature of the site. In practice, most farms use electric or fuel-driven pumps for supplying water to the ponds (Figure 9) and some also use them for draining the ponds during harvesting (Figure 10). Some small farms prepare cooked feed using wood as a fuel source, while others utilize the time-old methods of wind and water power for transporting water. Windmills and water-wheels can also be used to pump water for filling ponds, or to generate a farm supply of electricity.

Figure 9 Pumps can be powered by old diesel bus engines (Thailand)

SOURCE: HASSANAI KONGKEO

Figure 10 More expensive pumps are used in some countries; this one is being used to harvest freshwater prawns (Hawaii)

SOURCE: SPENCER MALECHA

CHOOSING YOUR SITE: FRY AND CONSUMABLES

There is no fundamental technical difficulty in transporting postlarval freshwater prawns long distances by road, rail or even air. However, you need provide vehicle access close to the pond site. It is not satisfactory to bring PL long distances to your grow-out site if there are going to be further delays due to poor local access. In selecting the site of your farm, it is important to assess the cost of obtaining PL. Transport costs can add enormously to basic stocking costs. Also, PL prices themselves tend to rise as the distance between the farm and the nearest hatchery increases (because there is less competition between hatchery operators).

Also, you need to consider the availability and cost of getting feeds to your potential farm site. A large farm (say 40 ha) which achieves an average output of 2 500 kg/ha/yr, for example, would require an average of about 5 mt of dry feed per week. Supposing that this feed is delivered to the site monthly, it would arrive in 20 mt batches; this means you need good vehicle access to the site. You would also need to provide clean, dry, cool, and secure feed storage facilities on the site. Similar factors apply to the supply of other consumables, such as fertilizers and equipment. Smaller farms, of course, do not have such sophisticated requirements. However, these factors are still important, especially the availability of good storage facilities.

CHOOSING YOUR SITE: LABOUR

Small freshwater prawn farms can be successfully maintained by unskilled labour but outside assistance from community (e.g. cooperative groups of farmers) and commercial sources (hatchery operators, feed suppliers, etc.), is necessary at times of stocking or harvesting. Larger farms require a competent, on-site manager. The amount of labour utilized on freshwater prawn farms varies considerably. For example, it is estimated that a 40 ha farm needs two senior staff and six labourers. At the other extreme, one person should be able to take care of normal maintenance, including feeding but excluding harvesting, of a 1-2 ha freshwater prawn farm. Often this type of farm is family owned and operated.

CHOOSING YOUR SITE: SYMPATHETIC AUTHORITIES AND TECHNICAL ASSISTANCE

You should consider many other factors in selecting your farm site. These include the local and national government regulations concerning water usage and discharge, land use, movement of live animals, import of non-indigenous stocks (where *M. rosenbergii* is not already present), disease monitoring, taxation, etc. In most countries where freshwater prawn farming is technically and economically viable, these regulations are less restrictive than those, for example, applying to the culture of temperate aquatic species in Europe and the USA; the governments concerned are keen to encourage freshwater prawn farming. You should ask the advice of your local inland fisheries department, whose officers should be helpful and anxious to participate in your project. In some countries there may be NGOs that can provide the assistance that you need. The ease of access to assistance and advice when the farm is in operation is an important factor in site selection. No matter how competent you are, there will come a time when you need help, such as water analysis, disease diagnosis, and technical advice. These types of assistance can be obtained from government, university and private sources. Do not site your farm too far from someone who can heed your cries of "help!". Speedy access to qualified personnel and to well-equipped laboratories is invaluable. You should always keep in touch with local fisheries officers but do not expect them to know all the answers. No one does!

CHAPTER 3

Broodstock

3.1 Obtaining and selecting egg-carrying females

OBTAINING BERRIED FEMALES

When freshwater prawn farms are in tropical areas where adult prawns are available year-round, the word broodstock usually refers only to the females that are kept in hatcheries until their eggs hatch, after which they are discarded or sold. The individual value of egg-carrying females is low, especially because they are usually sent to the market after the eggs have hatched, so there is no need to economize in the number used. An indication of the number of berried females required is given in Box 4.

Different considerations apply when freshwater prawns are being grown in temperate regions, as discussed later in this section. Some hatcheries also hold a supply of adult males. Few tropical farms maintain freshwater prawn broodstock in dedicated ponds (a practice which is commonplace in many fish farms), despite the potential advantages (e.g. the ability for selection).

Freshwater prawn eggs are carried under the tail of the adult female prawn (known as 'berried' or ovigerous females) and are easily visible (Figure 4). In the tropics, berried females can be obtained year round from farm ponds containing adult animals but the quantity of berried females available may vary according to the time of year. They can be obtained by cast netting but are frequently selected at times of partial or total harvest. Berried females can also be obtained from rivers, canals and lakes in areas where they are indigenous (native). Some hatcheries prefer to use berried females from natural waters based on the belief that wild females produce better quality larvae than pond-reared ones. However, collecting ovigerous females from the wild often results in considerable egg loss during transport, so many hatcheries prefer to use adjacent rearing ponds for their supplies. The dangers of doing this are discussed later in this section of the manual.

In the wild, berried females are most abundant around the beginning of the rainy season. When *M. rosenbergii* is reared in areas where the climate is sub-tropical or temperate (usually originating from stock introduced from another area), broodstock are typically obtained from ponds during the harvest at the end of the growing season and maintained indoors in environmentally-controlled conditions during winter. When freshwater prawns are introduced into an area where they are not found in the wild, great care must be taken to follow national and international guidelines for introductions, including quarantine. A basic code of practice for introductions is given in Annex 10. The topic of quarantine is fully discussed by Bartley, Subasinghe and Coates (1996). From a hygienic point of view it is better to import PL from sources where no diseases have been reported, rather than berried females. The permission and assistance of the local Department of Fisheries should be sought on this topic.

If your hatchery is close to the ponds containing berried females, you can transport them in buckets of water. If you need to transport them longer distances they can be held in tanks or double plastic bags, using techniques similar to those for moving PL, as described later in this manual, except that the rostrum of each animal should be blunted with scissors or inserted into a plastic tube to prevent the bags being punctured. In addition, it is recommended that you shade the animals from light during transport; UV light may harm the eggs. Tying the chelipeds with rubber bands or covering them with plastic tubing also reduces the danger of the plastic bags being punctured. Some people wrap the animals in cloth or plastic or nylon screens or enclose them inside perforated PVC pipes, which are then placed into double polyethylene bags. This is not recommended, because immobilisation results in increased mortality rates during transport. The use of small bags containing only one animal and transported in darkness reduces egg losses. You need to take great care in catching, handling and transporting berried females to minimize egg loss and damage.

BOX 4

Numbers of berried females required

IN TROPICAL conditions, assuming that each berried female available is capable of producing enough eggs to provide 20 000 viable stage I larvae, you would need about 50 berried females for each larval cycle of a hatchery using a total larval tank volume of 50 m^3 (e.g. ten 5 m^3 tanks) producing a total of 500 000 PL per cycle (this also assumes a larval survival rate of 50% to metamorphosis).

Berried females should be carefully selected. Choose animals that are obviously healthy and active, well pigmented, with no missing appendages or other damage, and carrying large egg masses. The ripeness of the eggs is also important. As the eggs ripen, their colour changes from bright orange to brown and finally to greyish-brown a few days before hatching (Figure 11). Those carrying brown to grey eggs are the best ones to bring into the hatchery, as their eggs will hatch within 2 or 3 days. It is best to ensure that you do this so that the whole larval batch is of a similar age. This will increase the efficiency of your feeding operations and reduce cannibalism. The number of females required depends on the volume of the hatchery tank(s) to be stocked with larvae, and on the number of eggs carried by each female.

GENETIC IMPROVEMENT

The topic of broodstock selection and the advantages of maintaining specific broodstock facilities have been discussed by Daniels, Cavalli and Smullen (2000). Genetic selection has been reviewed in Karplus, Malecha and Sagi (2000). Until recently, very little progress had been made in the genetic improvement of *Macrobrachium* although this topic has long been recognized as an area of research that could be expected to yield significant improvements.

Figure 11
The eggs of *Macrobrachium rosenbergii* are carried by the ('berried') females until they are ready to hatch; as they ripen, they change from orange to grey/black (Hawaii)

SOURCE: TAKUJI FUJIMURA, REPRODUCED FROM NEW AND VALENTI (2000), WITH PERMISSION FROM BLACKWELL SCIENCE

Freshwater prawns that originate from eggs that hatch early appear to have an advantage in grow-out because they are the first ones to establish themselves as dominant blue claw males (BC). However, there is no evidence that these 'early hatchers' have any genetic advantage over the 'late hatchers'. Therefore it would be pointless to select larvae from only one part of the spawning period to stock larval tanks. Moreover, selecting eggs from only one part of the spawning period could lead to a reduction in genetic variation and an increase in inbreeding. Proper genetic resource management combines selection and conservation of genetic diversity (Tave 1996, 1999).

Most farmers select larger females, which usually carry more eggs, but this may not be good practice. Selecting fast-growing, berried females from ponds three months after they were stocked, rather than choosing large females six months after stocking, has a positive genetic effect on weight at harvest. Collecting the faster growing females and rearing them in dedicated broodstock ponds would enable you to use selection to improve grow-out performance and also give you the ability to hold the animals until their clutch size becomes larger (after later mating moults).

Experiments have shown that cutting off one of the eyestalks (ablation) of female broodstock increases the number of mature females in a captive broodstock and diminishes the time between each spawn. Young females (about 4 months old after stocking at PL size) spawn about 20 days after eyestalk ablation and spawn again after about 30 days.

There is tendency for the performance (growth rate, survival, FCR) of farmed *Macrobrachium rosenbergii* during grow-out to decline after several production cycles where the berried females used in the hatcheries have been drawn from grow-out ponds. This phenomenon, caused by inbreeding and sometimes known as genetic degradation, has been noticed in a number of countries including Martinique, Taiwan Province of China, and Thailand. In countries where *M. rosenbergii* is indigenous the problem has occurred because of the 'recycling' of animals (broodstock for hatcheries being obtained from grow-out ponds and the process being repeated for many generations). In countries where this species is not indigenous the problem may be worse because the farmed stock has normally originated from a very small number of females (or PL), which were introduced to the country many years ago. When the problem of declining yields (and therefore incomes) occurs, it naturally results in the initial enthusiasm of farmers fading. The solution to the problem must be two-fold: using more wild broodstock, and genetic improvement.

Work on genetic improvement began in Thailand in 1998 and one company has recently introduced a new strain of *M. rosenbergii* that it claims has markedly improved performance (Anonymous, 2001b). This manual does not endorse any specific commercial product or source of PL but welcomes this potential solution to the problem of genetic degradation, in principle.

3.2 Holding your broodstock in temperate zones

In the tropics, where berried females are readily available, special broodstock holding facilities within hatcheries are not necessary, although the advantages of maintaining special broodstock ponds have already been mentioned. However, in temperate zones where freshwater prawns are reared in the summer, indoor broodstock facilities are essential.

In temperate zones it is necessary to provide holding facilities for over-wintering. Broodstock need to be maintained for up to six months and the temperature needs to be above 25°C to prevent loss of eggs. To conserve water and maintain good water quality, a recirculation system is suggested, similar to that used in recirculation hatcheries, as described later in this manual. Nylon mesh netting should be hung vertically or horizontally in the water column (buoyed with PVC piping and floats) and placed on the bottom of the tanks. This minimizes the total tank volume needed, reduces cannibalism, and increases fecundity. The use of large mesh sizes reduces the amount of fouling.

The egg-carrying capacity of the females is reduced at higher broodstock densities. A maximum stocking rate of one adult prawn per 40 L of water is recommended. For every twenty females, you should hold one or two BC males and two or three OC males (each >35 g), if eggs are required 3-4 months after the adults are stocked. If newly hatched larvae are not required until six months after the adults are stocked into broodstock facilities, the number of OC males should be adjusted to three or four per 20 females (to allow for male mortalities).

The total quantity of broodstock to be maintained in temperate facilities obviously depends on the final demand for PL. Only about 5% of the females will spawn together and an adult mortality of 50% should be anticipated during the holding period. Assuming an average of 45 000 larvae/45 g female, obtaining a single batch of 100 000 larvae at the end of the holding season would therefore require you to over-winter about 90 females, each about 45 g in weight (plus, using the proportions and timing indicated in the previous paragraph, 5-9 BC males and 9-18 OC males). This would provide a batch of 100 000 larvae at least once a week, thus allowing your hatchery to supply enough PL to stock 1 ha of ponds (assuming a stocking rate of 5 PL/L and a 50% hatchery survival rate to the PL stage) per week. These numbers can be adjusted according to your needs. It would be foolish to base the whole cycle of operations on a single tank, however; many accidents and other unforeseen circumstances can arise. It is therefore suggested that you split whatever broodstock animals you hold into a minimum of three holding systems.

3.3 Managing your broodstock

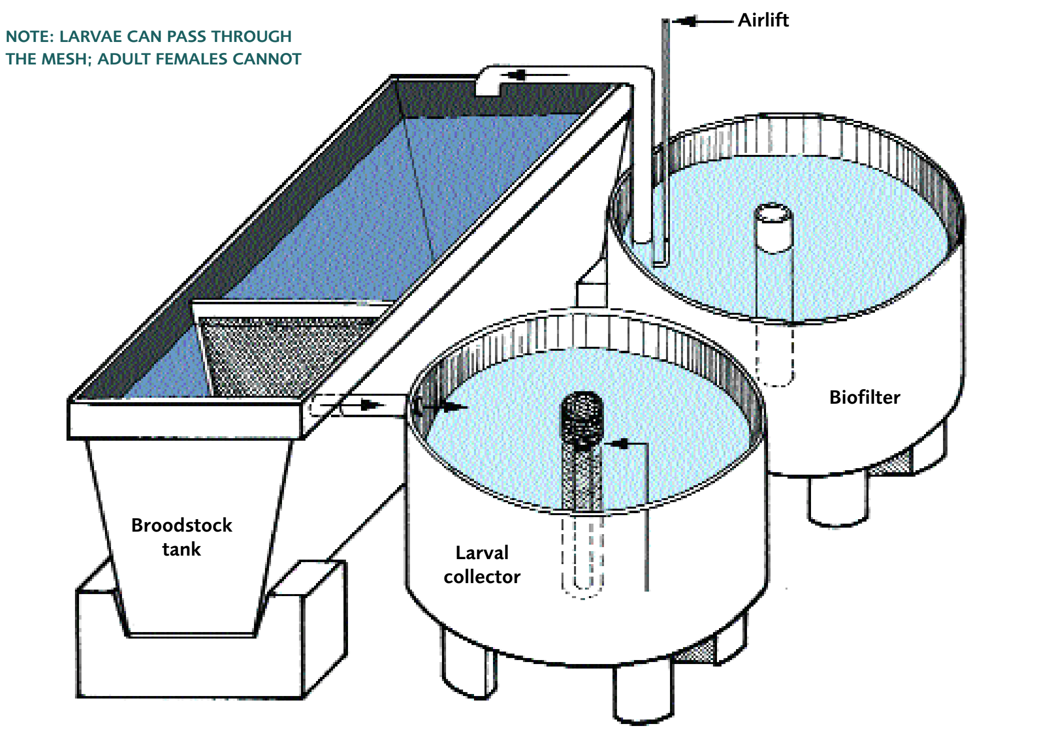
Managing broodstock in outdoor facilities in the tropics is similar to managing grow-out facilities. However, in temperate climates where broodstock are over-wintered, special care is necessary to ensure good health and maintain maximum survival. Broodstock should be disinfected upon arrival at the hatchery by placing them into freshwater containing 0.2 to 0.5 ppm of copper sulphate or 15 to 20 ppm of formalin for 30 minutes. However, it should be remembered that the use of these chemicals in aquaculture is prohibited or controlled in some countries. Aeration should be provided during these treatments. Similar precautions should be taken in handling berried females which are brought into tropical zone hatcheries from ponds or the wild. Adult prawns can then be transferred to holding tanks which contain freshwater at an optimum temperature of 27-31°C.

The water quality for indoor broodstock holding facilities should be similar to that for hatcheries. The selection and sex ratio of males to females has been discussed earlier. A nutritionally complete diet is essential to promote superior egg production and quality. Commercially pelleted grow-out feeds can be used but need supplementation. Broodstock should be fed at a daily rate of 1-3% of total biomass, adjusted to match consumption. Half of the pelleted ration should be substituted with the equivalent amount of pieces of beef liver or squid (or similar fresh feeds, such as mussel flesh), cut to the appropriate size, at least twice per week. 1 kg of a wet feed is roughly equivalent to 200 g of pelleted diet. Thus, (for example) if the normal daily ration you are providing to your broodstock is 30 g of the pelleted diet, on two days per week you would need to replace half of it with 75 g of the fresh feed. The daily food ration should be given in two equal portions, normally in the early morning and late afternoon. Two broodstock diets designed for *Macrobrachium rosenbergii* are described in Annex 3.

Specific separate facilities for hatching freshwater prawn eggs are rarely used in commercial hatcheries. The most common system for hatching utilized in tropical hatcheries is described in the hatchery management section of this manual. However, especially in temperate hatchery facilities, a separate hatching facility is easier to control. In this system, berried females can be collected from the holding system and placed into a tank where the eggs are allowed to hatch, and stage I larvae are obtained either with a collecting device, as mentioned below, or simply netted from the system. Figure 12 shows a hatch-

FIGURE 12

This hatching system consists of a 300 litre rectangular hatching tank and two 120 litre circular tanks, one for collecting larvae and one to house a biofilter



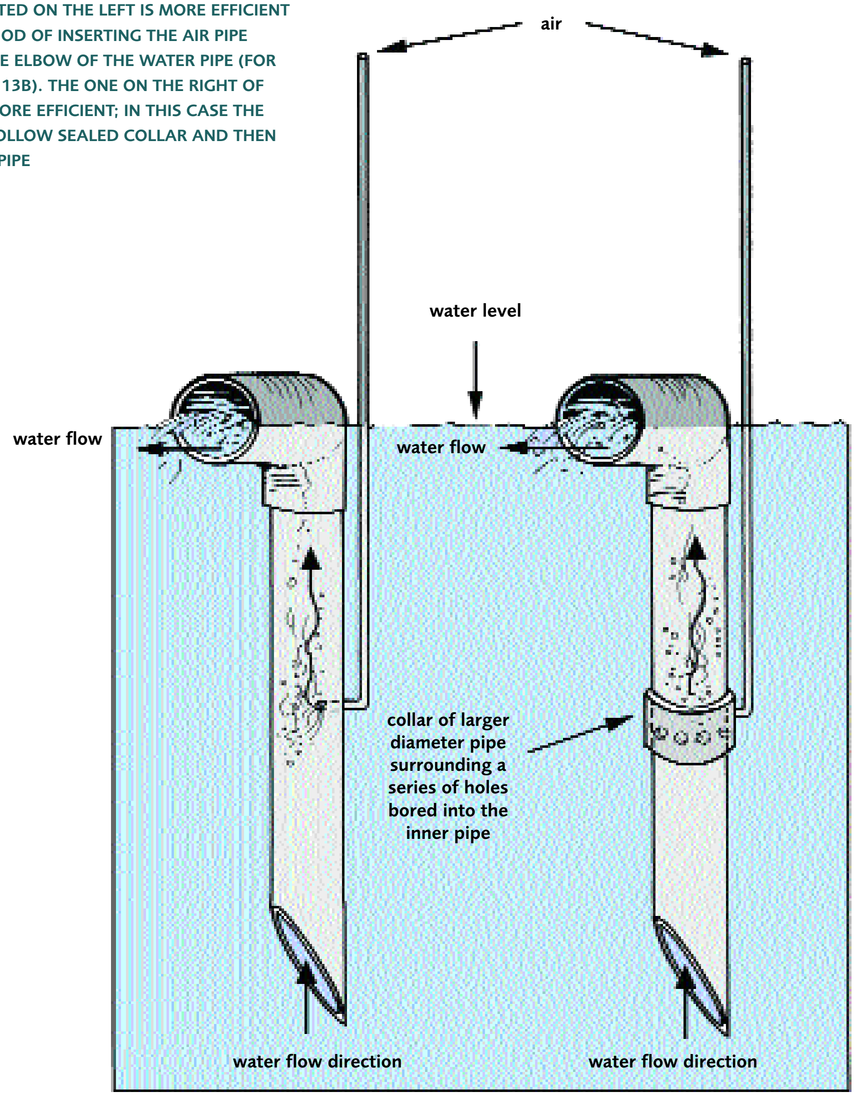
SOURCE: EMANUELA D'ANTONI, DERIVED FROM DANIELS, CAVALLI AND SMULLEN (2000) ing system that consists of a 300 L rectangular hatching tank and two 120 L circular tanks, one for collecting larvae and one to house a biofilter. Up to sixty females with brown to grey eggs can be placed into the hatching tank, which contains adequate habitat structures (e.g. a piece of pipe for each individual). The hatching tanks need to be covered to exclude light and the interior should be painted with black epoxy-resin paint, except around the area where the overflow pipe is located, which should be painted with a lighter colour, such as beige (or, if the tank is translucent, left unpainted). Black painted grating (e.g. egg crating or louvre material) is used to divide the tank into two chambers.

The largest chamber, occupying about 80% of the total tank volume, is used to hold the females and to keep them separate from the larvae as they hatch. Water overflows into

FIGURE 13a

Airlift pumps can be constructed in many different ways

NOTE: THE ONE ILLUSTRATED ON THE LEFT IS MORE EFFICIENT THAN THE NORMAL METHOD OF INSERTING THE AIR PIPE THROUGH THE TOP OF THE ELBOW OF THE WATER PIPE (FOR AN EXAMPLE, SEE FIGURE 13B). THE ONE ON THE RIGHT OF THIS DRAWING IS EVEN MORE EFFICIENT; IN THIS CASE THE AIR GOES FIRST INTO A HOLLOW SEALED COLLAR AND THEN PASSES INTO THE WATER PIPE



SOURCE: EMANUELA D'ANTONI, WITH ACKNOWLEDGEMENTS TO AREA, HOMESTEAD, FLORIDA, USA

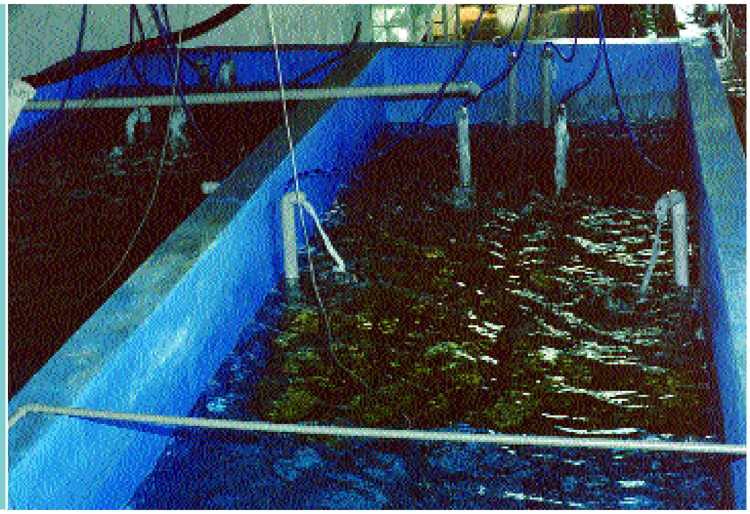


Figure 13b
Airlift pumps keep the water moving and oxygenated (Peru)

SOURCE: OSCAR ORBEGOSO MONTALVA

the collection tank and then passes through a 180 µm mesh screen, located around a central standpipe, into a biofilter. The larvae will flow with the water leaving the hatching tank because they (being positively attracted to light) move towards the lighter area of its wall, which is illuminated. Water is returned to the hatching tank from the filter tank by airlifts (Figures 13a and 13b). Hatching usually occurs at night but as the hatching tanks are covered, larvae can be collected during the daytime. The water in this system should be preferably maintained around 28°C. If you use slightly saline water (~5 ppt) it will result in greater hatchability. Recently, some evidence has been published (Law, Wong and Abol-Munafi, 2001) indicating that the hatching process is extremely pH sensitive. If this is corroborated, the pH may need to be adjusted to 7.0-7.2 for hatching. pH outside this range appears to result in substantially reduced hatching rates. The light regime for the broodstock is not important but direct sunlight should be avoided. To enhance water quality for the hatching larvae, it is recommended that berried females should not be fed at all during the 2-3 day period prior to egg hatching. Larvae are then removed from the collection tank and transferred to the hatchery phase. Further details of this and alternative hatching systems are provided in Daniels, Cavalli and Smullen (2000).