Freshwater prawn farming: global status, recent research and a glance at the future

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Abstract

A review of the current status of freshwater prawn farming globally, with comments on the statistical information available is provided in this symposium keynote paper. A brief overview of the research on freshwater prawn farming that has been published in international journals since 2000 is also provided. Finally, some research needs are listed and some scenarios for future expansion are explored.

Keywords: freshwater prawns, *Macrobrachium*, global, status, future

Introduction

I am honoured to have been invited to make the keynote address at this most important symposium. My interest in freshwater prawns has been a kind of obsession. I have been working with freshwater prawns since 1969 here in Asia, and in North and South America, the Caribbean and Europe. I have written many reviews and articles about this topic. Perhaps my best-known publication has been the FAO manual on freshwater prawn farming that my Thai co-manager, Somsak Singholka and I wrote in the 1980s (New & Singholka 1985). This was translated into French, Spanish, Farsi, Vietnamese and Hindi. However, over the past 20 years it naturally became somewhat out of date. In 2000, Wagner Valenti and I edited what is probably the most up-to-date reference text on the topic (New & Valenti 2000). More recently, FAO asked me to write a new manual on freshwater prawn culture (New 2002a). I hope that this too will eventually be issued by FAO in other languages and translated by others into additional languages, including Indian languages. Dr C. Mohanakumaran Nair has kindly agreed to help in this latter task.

My paper reviews the current global status of freshwater prawn farming, summarizes some of the news and research papers on this topic that have been published since my book was issued (New & Valenti 2000), and makes a tentative glance into the future.

Current global status

First of all this morning, I would like to talk about the global production data. There has been a very rapid global expansion of freshwater prawn farming since 1995 (Fig. 1). This is mainly because of the huge production of China but also, in the last few years, because of a rapid take-off of farming in India and Bangladesh.

The top 15 producers in 2001 are shown in Table 1. China was by far the leader with over 128 300 mt. Viet Nam was second in this league table (28 000 mt) but the actual production level is a little uncertain because it is included in the general FAO category freshwater crustaceans not elsewhere included (nei). However, I believe that most of this consists of *Macrobrachium rosenbergii* production so I have included it in Fig. 1 and Table 1. India came third, with over 24 200 mt in 2001, according to FAO. Last month it was reported (Anonymous 2003c) that 35 000 mt were exported from India in 2002.

The next three places are taken by Thailand, Bangladesh (which is a major exporter of wild-caught freshwater prawns) and Taiwan. Thailand and Taiwan were both pioneers in freshwater prawn farming. The FAO figure for Brazil is a times 10 error in the statistics. Recently I was in Brazil and I confirmed that current production is in the order of 500 mt year^{-1}, not 5000 mt year^{-1}. The figure for Ecuador is also suspect; it has remained exactly the same for the last 7 years. Malaysia, where the life

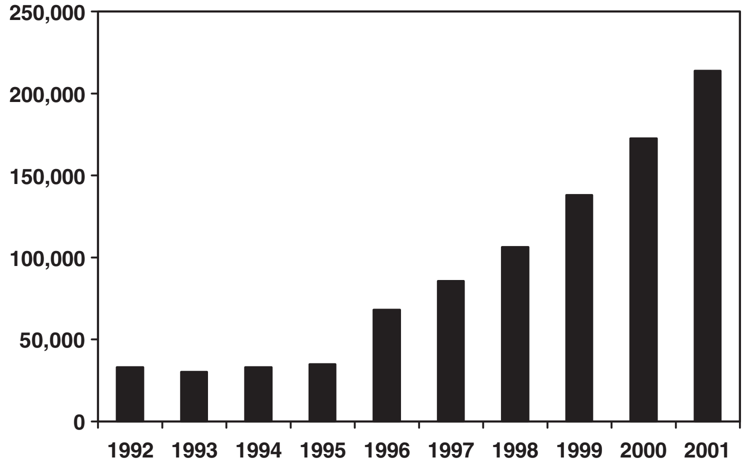

Figure 1 Expansion of freshwater prawn (the FAO data include the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei) farming 1992–2001 (mt) (FAO 2003).

Table 1 Top 15 countries farming freshwater *Macrobrachium rosenbergii** in 2001 (FAO 2003)

#	Country	Farmed production in 2001 (mt)	Notes
1	China	128 338	
2	Viet Nam	28 000	Freshwater crustaceans nei (thought to be mainly *M. rosenbergii*)
3	India	24 230	
4	Thailand	12 067	
5	Bangladesh	7000	
6	Taiwan	6859	
7	Brazil	5380	× 10 error in FAO's 2001 statistics (Brazil was really #9, after Malaysia)
8	Ecuador	800	Possibly incorrect?
9	Malaysia	752	
10	Dominican Rep	62	
11	Guatemala	53	Includes 3 mt of other freshwater prawn species
12	Senegal	50	
13	Mexico	48	
14	USA	44	
15	French Guiana	25	
	Others	153	

*The FAO data includes the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei.
nei, not elsewhere included.

cycle of *M. rosenbergii* was first closed, is now a major producer. The other countries are quite modest producers so far.

Figure 2 shows the production of *M. rosenbergii* in Asia; output in China dwarfs the scale of other producing countries. After China, India, Viet Nam, Thailand, Taiwan and Bangladesh are the main producers. Production in Thailand is starting to rise again. Production in Malaysia, although relatively small compared with other Asian countries expanded rapidly between 1997 and 2000 but fell back somewhat in 2001. Expansion has been much more rapid in India and Viet Nam than elsewhere. In the Indian State of Andhra Pradesh alone, production is now 27 000 mt (Anonymous 2003a), up from 400 mt only 5 years ago. Further substantial expansion is expected, as I am sure we shall hear in this symposium.

Most freshwater prawns are produced in Asia but, as shown in Fig. 3, Chinese production is much more than all the other Asian countries put together. Three species are currently grown in inland waters in China; two are *Macrobrachium* spp. but the other is the marine shrimp *Penaeus vannamei*. *Macrobrachium nipponense* is common in Chinese inland capture fisheries. Its maximum size is 86 mm for males and 75 mm for females. It can naturally reproduce in freshwater and it is one of the few *Macrobrachium* species that has a temperate distribution. These facts, and its popularity with Chinese consumers make it attractive to farm. However, *M. rosenbergii* is regarded as the major species for the export market for freshwater prawns that China hopes to develop. Although some work on its culture was reported in the 1970s, real commercial production of *M. nipponense* did not begin until the 1990s at about the same time as the culture of *M. rosenbergii* began to take off in China (W. Miao, pers. comm. 2003). By now, the quantity of *M. nipponense* produced in farms is about the same as that obtained from the capture fishery. Estimated production of the indigenous *M. nipponense* is rapidly catching up with the

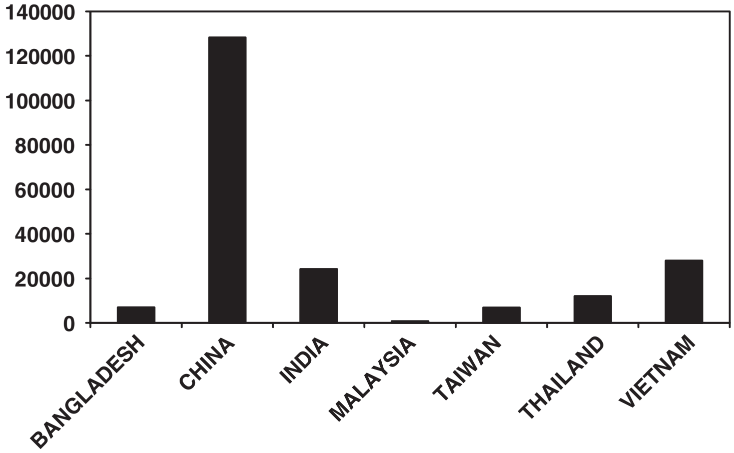

Figure 2 Farmed production of *Macrobrachium rosenbergii* (the FAO data include the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei) in major producing countries in Asia in 2001 (mt) (FAO 2003).

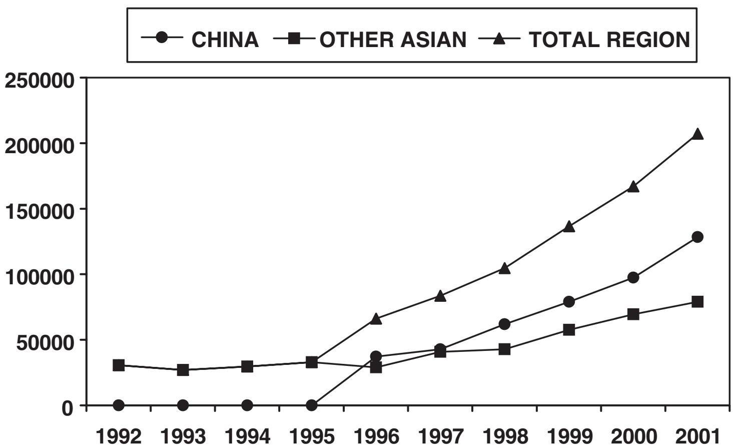

Figure 3 Trends in farmed *Macrobrachium rosenbergii* (the FAO data include the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei) production in Asia (mt) (FAO 2003).

production of the introduced *M. rosenbergii* (Fig. 4). So far, China has not reported its production of *M. nipponense* in its official statistical returns to FAO. An estimated production of 15 000 mt of this species was reared in China in 1999 (Wang & Qianhong 1999) and 120 000 mt in 2001 (W. Miao, pers. comm. 2003). In addition to these two species, experimental culture of one of your own indigenous prawns in India, *M. malcolmsonii*, has started in China.

Recorded production in Central and North American countries is quite small (Fig. 5). Only four nations produced more than 40 mt in 2001 – the Dominican Republic, Guatemala, Mexico and the USA. Figure 6 shows the data for South America. The figures for Brazil have been adjusted but I have not changed the FAO figures for Ecuador, although I remain sceptical about them. The encouraging thing is that production in Brazil, after declining between 1993 and 1999, now seems to be increasing again. The Brazilian government has been concentrating on the promotion of marine shrimp farming but it is hoped that it may now become also interested in a form of aquaculture that may be more sustainable, namely the culture of freshwater prawns. One of the universities there has a large team working not only on the culture of *M. rosenbergii* but also on an indigenous species, *M. amazonicum*, which is thought to have great potential for small-scale farms in the Amazonia region, where it is a feature of the capture fishery. The maximum size of *M. amazonicum* males has been variously reported as 110–150 mm, while the maximum female size recorded is 110 mm.

There is very little production outside Asia and South and Central America (Fig. 7). Senegal and Mauritius, both in Africa, are the leaders but their

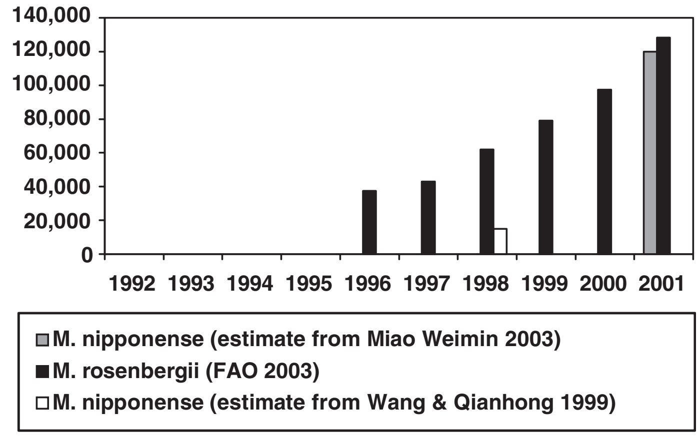

Figure 4 Chinese farmed production of *Macrobrachium nipponense* is catching up with *M. rosenbergi* (the FAO data include the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei) (mt).

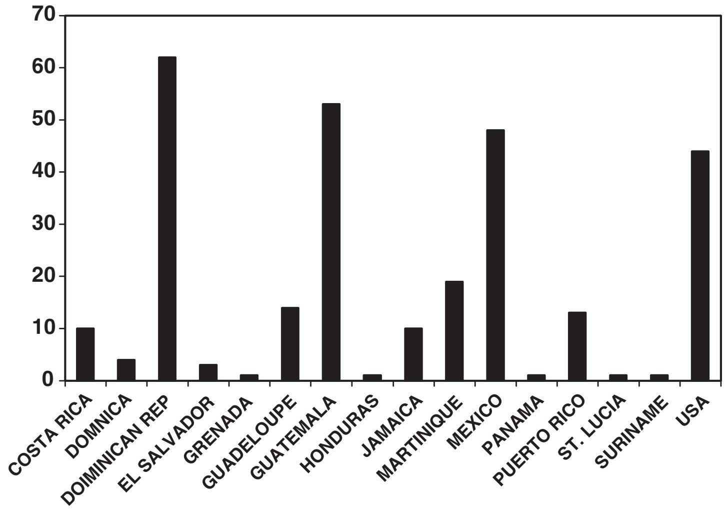

Figure 5 Production of farmed *Macrobrachium rosenbergii* (the FAO data include the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei) in Central and North America in 2001 (mt) (FAO 2003).

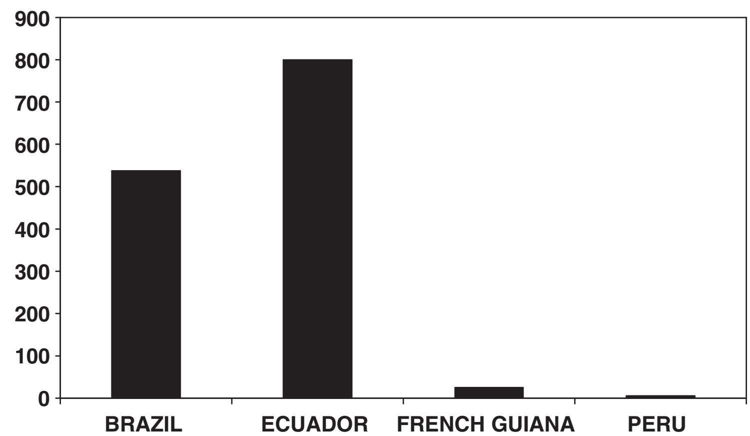

Figure 6 Production of farmed *Macrobrachium rosenbergii* (the FAO data include the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei) in major producing countries in South America in 2001 (mt) (FAO 2003) (*Note*: FAO data for Brazil has been divided by a factor of ten (see text)).

production is still quite small. A newcomer is the Russian Federation, where this species is grown mainly in the heated effluent from electric power generation.

Rate of global expansion

It is difficult to measure the rate of expansion of freshwater prawn farming, because of the lack of statistics

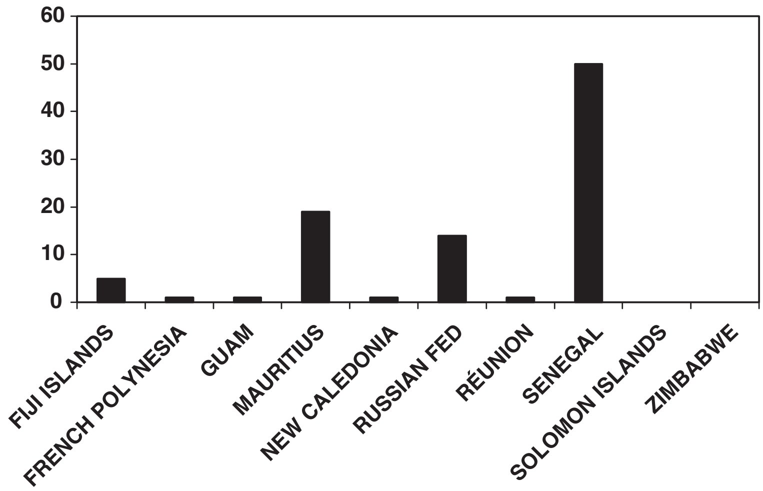

Figure 7 Minor production of farmed *Macrobrachium rosenbergii* (the FAO data include the categories giant river prawn, freshwater shrimps/prawns nei and freshwater crustaceans nei) in other areas in 2001 (mt) (FAO 2003).

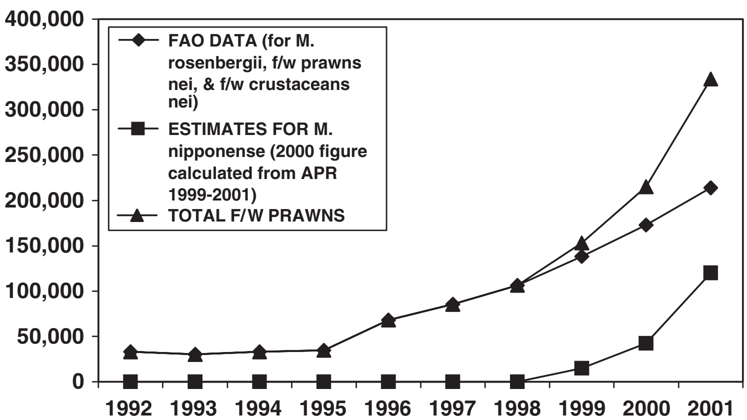

Figure 8 Estimated expansion of freshwater prawn farming 1992–2001 (mt).

about the culture of *M. nipponense* in China. However, if we assume that the estimates for that species that have been cited earlier are reasonably accurate, we can deduce that over 330 000 mt of all species of *Macrobrachium* were raised through aquaculture in the year 2001 (Fig. 8). No doubt there has been further expansion since that time. The average annual expansion rate (APR) of freshwater prawn farming, if all FAO data and the estimates for *M. nipponense* are combined, between 1992 and 2001 was over 29%. Between 1999 and 2001, the global expansion rate was even more rapid (48%). However, nearly 83% of the expansion during that whole decade and over 85% of the expansion between 1999 and 2001 occurred because of the meteoric rise in the reported farmed production of *M. rosenbergii* and the estimated output of *M. nipponense* in China. In particular, the estimated production of *M. nipponense* indicates an APR of nearly 183% year^{-1} between 1999 and 2001; in other words, production appears to be going up by a factor of over 2.8 annually, a very exceptional rate! This shows that, as in the case of many other farmed foodfish species, the inclusion of Chinese data distorts the analysis of trends in the rest of the world. So let us look at the picture after removing the data from China. Without Chinese data, the APR in the rest of the world over the decade 1992–2001 was a more modest 11%. However, the expansion rate seems to be increasing: in the 2 years from 1999 to 2001 it was over 20%.

So far, in calculating APR, I have included the FAO categories ‘freshwater crustaceans nei’ and ‘freshwater prawns/shrimps nei’ in the ‘all species’ categories. The main effect of this is to add the large estimated production of ‘freshwater crustaceans nei’ in Viet Nam. This category, which is believed to consist principally of *M. rosenbergii*, contributed 12 000 mt in 1992, over 25 000 mt in 1999 and about

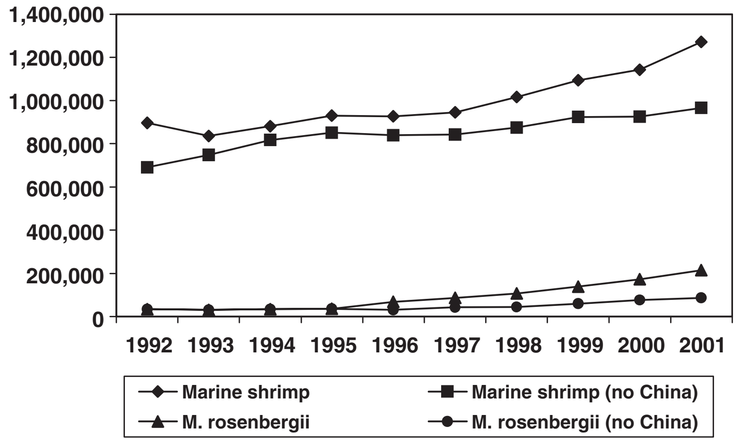

Figure 9 Trend in the farmed production of *Macrobrachium rosenbergii*, compared with the total for all species of marine shrimp (FAO 2003).

28 000 mt from Viet Nam to the global all-species figure for 2001, for example. If we exclude these miscellaneous ('nei') categories and simply look at the FAO data for *M. rosenbergii* alone, the global expansion rate was over 27% year^{-1} over the decade 1992–2001.

If data from China is excluded, the production of *M. rosenbergii* alone still expanded by nearly 12% year^{-1} in the rest of the world in the decade 1992–2001 and increased considerably beyond the decadal average, to over 30% year^{-1} in 1999–2001. The rapid increase in the expansion of *M. rosenbergii* farming outside China is due mainly to massive expansion in India and a resurgence of production in one of the pioneering countries, Thailand. Between 1999 and 2001, the production of *M. rosenbergii* increased at an annual rate of 86% in India and over 19% in Thailand.

The current production of freshwater prawns is still relatively small, compared with the scale of marine shrimp farming. However, marine shrimp farming has not been expanding so rapidly as is shown in Fig. 9, that has been prepared from FAO data (FAO 2003) and includes the two categories 'freshwater prawns, shrimps nei' and 'freshwater crustaceans 'nei', but therefore excludes the unofficial estimates of *M. nipponense* production. The top line of each pair includes Chinese production; the bottom of each pair excludes China. In this figure, the trends for marine shrimp and freshwater prawns look similar. However, if you calculate the annual average growth rates, it becomes clear that freshwater prawn farming has been expanding at a much faster rate than marine shrimp, whether China is included or not. Globally, the APR for the decade was 27.4 per year for freshwater prawns but only 3.9% year^{-1} for marine shrimp. Excluding China, the APRs for the rest of the world were 11.8% year^{-1} for freshwater prawns and 3.8% year^{-1} for marine shrimp.

Recently published news and research results

The literature up to the year 2000 was reviewed by New and Valenti (2000). Since that time I have endeavoured to keep up with the research work that has been published in international journals and the news about research results and farming practices in various magazines. I have tried to summarize this information in the next two sub-sections of this paper.

News of general interest, 2000–2003

Bangladesh

In 2000, Ahmed (2000) reported that 8306 ha were being used for *Macrobrachium* culture in Bangladesh, using wild fry, but ACC (2003) reported that the grow-out area has risen to 40 000 ha. Nandeesha (2001) reported that over 100 000 small farmers earn most of their livelihood from culturing freshwater prawns; however, they still depended on the availability of wild seed. Some farmers were reported to be stocking wild tiger shrimp (*P. monodon*) with wild *Macrobrachium*. *Penaeus monodon* has been grown in low salinities in Thailand and in freshwater in India. However, the dangers of this practice have been identified (Fegan 2002).

Ahmed (2000) reported that freshwater snails were the food of choice by farmers in Bangladesh, although that may now have changed.

Brazil

Moraes-Riodades and Valenti (2001) see a future for the intensive production of *M. rosenbergii* by larger companies for domestic and export markets and small-scale family units (for local use) in the Amazonia region of Brazil. Small-scale family farms could rear this species, as well as the indigenous (and much sought after) *M. amazonicum* using more extensive technologies for local consumption.

China

In China, the province of Hainan is reported to be importing an improved breed of *M. rosenbergii* from the Charoen Pokphand hatcheries in Thailand (Anonymous 2001d). CP claims that whereas a 30-g average size is normally achieved, their 'CPF giant freshwater shrimp' grow to an average of 100 g for males and 60 g for females (Anonymous 2001e) as well as having a 60% meat content (Anonymous 2001f). China is researching *M. malcolmsonii* as a possible replacement for *M. rosenbergii* (Anonymous 2002d). *Macrobrachium malcolmsonii* is said to grow faster than the currently cultured freshwater prawn species in China and is expected to become popular with consumers. The broodstock was introduced from Sri Lanka. An up-to-date review of freshwater prawn farming in China is being presented by Miao Weimin in this symposium, so I will not comment on his earlier published paper (Miao & Ge 2002).

Ghana

The Institute of Aquaculture (Stirling University, Stirling, UK) is working with *M. vollenhovenii* in an attempt to encourage the farming of this species in Ghana, where it is indigenous and the subject of artisanal activity in roadside markets (Brown 2001).

India

In the last 3 years, many articles on *Macrobrachium* farming in India have appeared in international magazines; only a few are sampled in this paper, since I am sure that we will hear much more up-to-date information here during our symposium this week. Simple guidelines for freshwater prawn farming in India have been prepared by Saxena (2003). It has been reported that Andhra Pradesh produces 27 000 mt of *M. rosenbergii*; according to MPEDA, this output could be doubled in 2 or 3 years if farmers take up this type of farming (Anonymous 2003a). The government of Haryana was reported to be wishing to encourage freshwater prawn farming, using inputs and technology from Tamil Nadu (Anonymous 2001c). An earlier phase of the boom in freshwater prawn farming in India, mainly in the coastal provinces of Tamil Nadu and Andhra Pradesh, was described by Fegan and Sriram (2001), who reported that it was more profitable than sugarcane or rice production. However, they warned that better production efficiency and marketing would be essential as the total production increases and farm-gate prices drop. Jain and Diwan (2002) stated that *M. rosenbergii* can be cultured in waters of 15 g L^{-1} and is therefore a suitable species for culture in saline wastelands in India; they also suggested considering *M. malcolmsonii*, *M. idella* and *M. lamarrei*. Commenting that productivity was still quite low in India (an average of 600 kg ha^{-1} in the year to March 2002), Merican and Vasudevan (2003) noted that about 1.2 million ha was available and only about 13% had been used to date. These authors forecast that Indian production of *Macrobrachium* would rise by about 30% per year over the next 2 or 3 years.

Two articles by Reddy and Rao (2001a, b) provided a summary of farming practices in India and concluded that freshwater prawn farming was poised for rapid expansion; however, this potential was being compromised by the high cost of postlarvae (PL) (at that time Rs. 0.75–0.9 each, up to three times greater than PL of *P. monodon*). Another summary of the expansion of freshwater prawn farming in India was provided by Nagarajan and Chandrasekar (2002); a typical cost/income scenario was provided for a farm in Andhra Pradesh, which showed an operating profit of over US$ 1000 ha^{-1} $crop^{-1}$. These authors reported a lack of export demand in 2002 and government restraints on the expansion of the industry because of concerns about the excessive use of groundwater, the potential salinization of agricultural land and the conversion of paddy fields to prawn farms. Nandeesha (2003) reported that the polyculture of freshwater prawns with carps has almost entirely been replaced by prawn monoculture. He reported that about 22 000 ha of ponds were devoted to freshwater prawn culture in the Nellore district of Andhra Pradesh alone. Although hatchery raised seed is now available, their quality is variable.

Selvaraj and Kumar (2003) predicted that freshwater prawn production in India could increase to 50 000 mt $year^{-1}$ by 2010. Several established freshwater prawn farmers and hatchery operators in Andhra Pradesh and Tamil Nadu have been promoting and assisting similar development in other Indian

States (Nandeesha 2003; J. Susheela, pers. comm. 2004). In a conference held here in Kochi in 2001, a farm-made aquafeed mill in Kuttanad was announced; the freshwater prawn feed produced was said to have reduced feeding costs by 38% and resulted in less non-marketable size animals (Anonymous 2000, 2001a). Merican and Vasudevan (2003) stated that local feed companies in India devoted about 10–15% of their production capacity to feeds for freshwater prawns. Feed production for crustacea is dominated by CP, Waterbase, Avanti and Higashimaru. In addition there is Hanaqua, Grobest, Godrej and 15 smaller companies but it was not clear if all these companies manufacture freshwater prawn feeds.

Jamaica

Macrobrachium farming is proving quite popular in Jamaica where it is grown in polyculture with tilapia (Aiken, Morris, Hanley & Manning 2002).

Malaysia

Macrobrachium rosenbergii is said to be increasingly popular among consumers of all races in Malaysia (Anonymous 2001i).

Philippines

Following 70% survival rates in the (government) hatchery phase, batches of freshwater prawn PL are being distributed to the private sector in the Philippines; polyculture with tilapia is being favoured (Anonymous 2001g). *Macrobrachium rosenbergii* was even being promoted for culture in metal drums in urban areas (Anonymous 2001h).

Pacific

Freshwater prawns were included in the eight species selected as having the most potential for culture in the Pacific region (Anonymous 2002a).

Russia

Freshwater prawns are being produced in one farm in Russia, which produced 6 mt in 2000. Most is sold in Moscow but some in the location of the farm, Astrakhan (Anonymous 2001b); investment was being sought to enlarge capacity.

Thailand

CP was said to be planning a major expansion in freshwater prawn production in Thailand (Anonymous 2001e). The effect of this programme may ultimately filter through to the FAO production statistics.

Viet Nam

Typically, *Macrobrachium* have been reared in conjunction with rice production in Viet Nam, based on wild fry and little or no feed, achieving low productivity (150–300 kg ha^{-1} crop^{-1}). Now hatchery raised PL are more available, many farmers in the Mekong Delta are using both fresh fish and artificial feeds for 6-month culture periods (leaving another 6 months for two crops of rice) to achieve 1000–1500 kg ha^{-1} crop^{-1} (Ridmontri 2002). All major seafood processors in the Mekong Delta and some feed companies have become involved in hatchery and feed supply for freshwater prawn farming, and see processed prawns as an important export item. In this country, Proconco is developing a feed for freshwater prawns and plans to train farmers to run simple hatcheries through its extension work (Buranakanonda 2001).

Miscellaneous news

A number of other items of general news were published during the period. These included the report that freshwater prawns are being considered as a candidate species for an organic label in Asia (INFOFISH 2002). Interest in farming other species has been reported. Nandeesha (2003) reported that there was commercial potential in rearing *M. malcolmsonii* in both India and China. Moraes-Riodades and Valenti (2001) also see a future for the culture of *M. amazonicum* in the Amazonia region of Brazil.

News of scientific and research importance, 2000–2003

Biology

A useful book for the shelves of taxonomists on the biology of palaemonid prawns has been provided by Jayachandaran (2001) and reviewed by New (2002b). One hundred and forty-four pages are devoted to *Macrobrachium* spp. More than 180 valid species are now recognized, far more than the 125 species mentioned by Holthuis (1980). Another useful book is on the biology of decapod larvae (Anger 2001).

Breeding, genetics and sex reversal

Research work on the breeding, genetics and sex reversal of *Macrobrachium* spp. in the past 3 years has been active. In a recent review article on the genetic improvement of freshwater prawns, whose published reference list is unfortunately incomplete, Lutz (2003) states that spermatophore microinjection appears to be a viable means of introducing genetic constructs into *Macrobrachium* species. Gene transfer may therefore complement the promise of 'conventional' selection and hybridization as a means of improving performance in freshwater prawn culture. According to this author, the most important traits that might be improved are, in addition to growth rate, cold tolerance, the duration of larval development and the tolerance of reduced salinity during the larval cycle. An Indo-Norwegian consultation in Mumbai in 2001 identified the need for collaboration between Indian national research institutions and AKVAFORSK on the genetic improvement of freshwater prawns (Anonymous 2002b). It would be interesting to hear if this collaboration has commenced.

Baghel and Saxena (2001) proposed a number of biotechnological tools to enhance freshwater prawn production. These included chromosomal engineering, molecular genetics, genetic engineering and tissue culture engineering. Noting that freshwater prawns were less susceptible to the white spot syndrome virus than marine shrimp, these authors believe that gene transfer should be used to produce strains having a growth hormone gene construct.

Sterile *M. rosenbergii* can be produced when juveniles are irradiated at 1.0 and 1.5 krad using γ radiation from cobalt-60 (Lee & Tiersch 2001). When adult, these irradiated females did not produce eggs, or produced less than 100 eggs that were dropped within 4 days. Irradiated males were shown to produce no, or reduced sperm, and failed to fertilize the eggs of non-irradiated females.

Buranakanonda (2002) reported that there were three major strains (one a cross-bred strain) of freshwater prawns in Thailand and that Kasetsart University had found that the Myanmar prawns from the Yapil River were the meatiest. This university has instituted a breeding programme, using this strain to select for good fecundity and survival, as well as smaller claws and heads. I believe that it is possible that this work has been done in conjunction with CP (see earlier).

Bart and Yen (2001) reported that PL survival (up to 36 days) was much higher (33%) when broodstock *M. rosenbergii* from Thailand were used instead of those from Viet Nam ($<2\%$). Furthermore, cross bred Thai females and Viet Nam males resulted in an even higher PL survival (39%). This work indicates the importance of comparative work on the various strains of freshwater prawns, and the potential improvement that could be gained not only from selection and cross breeding but also, perhaps, from examining whether different strains have different rearing requirements.

Working with *M. australiense*, Dimmock, Williamson and Mather (2002) have found that there is as much trait variation within geographical regions as between different regions. This variation seems to be related to environmental factors (e.g. abdomen size correlates with increased habitat structure). Manipulating temperature reinforces environmental influences on morphology in this species. Breeding work (perhaps with other *Macrobrachium* spp. also) should take local habitat characteristics into consideration.

Chinese scientists have successfully crossed female *M. nipponense* with male *M. hainanense* (Anonymous 2002c; H. Fu, pers. comm. 2002). Isozyme analysis confirmed that the hybrids possessed both maternal and paternal genes. Of the five single pair crosses, four spawned and three hatched hybrids (the other aborted). The hatching rate of the hybrids was over 90% and the survival rate to PL was 20–60%.

In a study providing preliminary information for those seeking to produce hybrids, Graziani, De Donato, Lodeiros, Orta and Salazar (2001) found that, of the four species considered, the closest genetic distances were between *M. carcinus* and *M. rosenbergii* and the most genetically distinct were *M. acanthurus* and *M. amazonicum*. Leucilaminopeptidase (LAP) and Peptidase II (PEPII) can be used to detect the presence of hybrids among these species.

Several institutes in Israel, Thailand and the UK are working with sex-reversed prawns (Anonymous 2000–2001; Brown 2001, 2002; Buranakanonda 2002) but I have not yet seen any peer-reviewed publication on their results.

Cavalli, Lavens and Sorgeloos (2001) showed that under proper rearing conditions, *M. rosenbergii* females are able to spawn up to five times within a 180-day period, compared with three to five times as reported for wild populations. Indicating that the number of viable larvae produced might be increased by *in vitro* incubation, these authors discuss the constraints to this technique; disinfecting the eggs may be necessary to replace the loss of the anti-microbial secretions of the incubating female.

It is well known that increasing the salinity that adult females are kept in enhances hatchability; commonly they are kept at $5\ g\ L^{-1}$. Recently Cheng, Liu, Cheng and Chen (2003) have shown that both male and female adult prawns (*M. rosenbergii*) can adapt to a salinity of 14 g L^{-1} within 2 days. Since this is the commonly used salinity for rearing larvae of this species, this finding could simplify hatchery operation. Law, Wong and Abol-Munafi (2002) found that *M. rosenbergii* egg hatchability is extremely sensitive to hydrogen ion concentration in brackish water. At 12 g L^{-1}, the highest hatching rate (92.22%) was detected at pH 7.0. However, at pH 6.5 and 7.5, hatching rates markedly fell to 5.00% and 13.33% respectively. Hatching rates at pH 5.0, 8.0, 9.0 and 10.0 were zero. This important study indicates that careful control of the pH of the brackish water used to hatch *M. rosenbergii* would increase hatching success, reduce the number of broodstock needed and (perhaps most importantly) reduce hatchery production costs. It is not yet known whether other species of *Macrobrachium* are so sensitive to pH at the time of hatching.

The availability of cryopreserved larvae could greatly assist in facilitating stock distribution where lack of hatchery-reared animals hampers the expansion of freshwater prawn farming. Pillai, Rao and Mohanty (2001) measured the toxicity of various cryoprotectants – dimethyl sulphoxide (DMSO), methanol, glycerol and ethylene glycol – on the first zoeal stages of *M. rosenbergii*. Methanol was found to be the most toxic, followed by DMSO. Larvae could be safely exposed to these cryoprotectants for 20 min at 20 °C at up to 10% v/v. Multiple cryoprotectants (a mixture of these substances) were found to be less toxic than single substances.

Diseases, prophylaxis and the use of immunostimulants

Several papers on the diseases of freshwater prawns, on prophylaxis, and the use of immunostimulants have been published. In a study over a larval rearing cycle of *M. rosenbergii* by Phatarpekar, Kenkre, Sreepada, Desai and Achuthankutty (2002), the bacterial flora was predominantly Gram-negative (75% of the total isolated strains). *Aeromonas*, *Alcaligenes* and *Pseudomonas* were the most frequently observed genera in the water but *Alcaligenes*, *Enterobacteriacae*, *Pseudomonas* and *Streptococcus* were the most abundant on the larvae themselves. *Vibrio* spp. were found in eggs and water but were completely absent in larvae. The bacterial flora of eggs resembled the water but a distinctly different population was associated with the larvae.

Nagarajan and Chandrasekar (2002) reported some of the common problems encountered in the rearing of freshwater prawns in India and the treatment used to counter them. The problems included white muscle or idiopathic muscle necrosis, ciliate infestations, antenna and tail rot, soft shell, hard shell and low dissolved oxygen.

Cheng and Chen (2002) found that *M. rosenbergii* (size not stated) reared at high temperatures (33–34 °C), high pH (9.0–9.5), low pH (4.6–5.0), low DO_2 (1.75–2.75 mg L^{-1}) and exposed to ammonia-N (0.55 mg L^{-1}) and copper sulphate (0.2 mg L^{-1}) experienced a decrease in phenoloxidase activity, leading to a reduction in their immune response and susceptibility to *Lactococcus garvieae* infection. This pathogen, together with the yeast-like *Debaryomyces hansenii* and *Metschnikowia bicuspidata*, has caused many disease outbreaks in Taiwan.

Cheng and colleagues (2003) noted that experimental challenge of freshwater prawns by the injection of bacteria and subsquent exposure to different salinity levels has shown that 5 and 10 g L^{-1} appears to have a favourable effect on survival; Taiwanese farmers are therefore likely to add brine to grow-out ponds.

Goswami and Prasad (2000) have found that benzalkonium chloride (BKC) can be used as an effective anti-bacterial and immunostimulant for *M. rosenbergii*. These authors reported that the minimum lethal concentration for the several bacteria tested ranged from 1.0 to 1.5 ppm. Despite the fact that Liao and Guo (1990) had reported that the tolerance to BKC of this species was 2 ppm in 24 h, Goswami and Prasad (2000) found the 24-h LD_{50} for 2-month old *M. rosenbergii* (weight not indicated) to be 10 ppm. Some caution in its use seems to be indicated until further studies are reported.

The Taura Syndrome (TSV-like) virus that is common in *P. vannamei* has not been found in freshwater prawns (Anonymous 2003b).

Experimental techniques

A development in experimental technique has been noted. The Institute of Aquaculture (Stirling University, Stirling, UK) has shown that it is possible not only to tag the very smallest PL *M. rosenbergii* but also pre-metamorphic larvae (Anonymous 2000–2001). Describing this technique in detail, Brown, McCauley, Ross, Taylor and Huntingford (2003) concluded that VI elastomer tags (a coloured liquid that cures to a flexible solid after injection under the epidermis and fluoresces under UV light) could be used to mark small numbers of individual larval and immediately PL prawns and that VI alphanumeric tags (small biocompatible plastic labels with unique codes that are inserted beneath transparent regions of skin) could be used to mark an unlimited number of individuals with a size of approximately 0.5 g.

Management, including the use of substrates

Several papers on nursery and grow-out management have been published. Marques, Lombardi and Boock (2000) found that high-density nursery culture (either 10 PL L^{-1} for a primary phase using 0.011 g early metamorphosed animals, or 800 PL m^{-2} in a secondary phase stocking the results of the primary phase as 0.053 g PL) of *M. rosenbergii* in cages within an earthen pond seems feasible as a means of reducing nursery phase costs. Van Arnum, Tidwell, Coyle, Vitatoe and McCathy (2001) reported that, under indoor nursery conditions, 0.04 g PL *M. rosenbergii* stocked at 430 PL m^{-2} had a significantly better survival rate (76% over 60 days) with continuous light (L24:D0) than with either L12:D12 (59%) or L0:D24 (58%). No comment on the light intensity or its spectral quality was mentioned in this abstract.

Ranjeet and Kurup (2002a), in a paper on heterogenous individual growth (HIG) mentioned the possibility that differential growth could have a genetic basis. The work of Sun, Weatherby, Dunlap, Arakaki, Zacarias and Malecha (2000) indicates that there are substantial differences in the androgenic gland (AG) protein content, SDS-PAGE polypeptide profile and cellular morphology between the OC, OBC and BC male morphotypes of *M. rosenbergii*; this finding may be a further indication that HIG has genetic as well as social associations. For the moment, however, Ranjeet and Kurup (2002a) have stressed the importance of careful grow-out management in commercial farms to maximize the yield of marketable prawns and synchronize their availability with market requirements. An excellent review on the management of size review has been provided by Karplus, Malecha and Sagi (2000). Ranjeet and Kurup (2002b) found that the trend for *M. rosenbergii* larvae that hatch first to be weaker and take longer to reach metamorphosis appeared to continue into the grow-out phase. However, these findings are in contrast to the results of Zacarias (1986) as reviewed by Karplus and colleagues (2000). Using genetically marked populations, Zacarias (1986) showed that early-hatching larvae are likely to become early-settling PL, which, in turn are likely to become larger juveniles. Further research on this topic is necessary before pre-stocking batch-grading can be truly effective in maximizing production and revenue from freshwater prawn farming.

According to D'Abramo, Daniels, Gerard, Jun and Summerlin (2000), strategies that avoid achieving the critical standing crop that induces what is apparently a chemical-mediated growth reduction are necessary. These could include selective harvesting or stock manipulation and movement. These authors were also able to demonstrate an important feature of immediate benefit to commercial culture in special marketing conditions such as the temperate-zone culture of freshwater prawns – a density threshold that could be used to reduce growth rates and therefore adjust production to suit the best time for marketing. Reductions in weight gain began to occur when a critical biomass density of approximately 500 mg L^{-1} was attained.

Alston and García-Pérez (2001), studying the polyculture of tilapia stocked at 1 m^{-2} and freshwater prawns at 5 m^{-2}, found that removing all female prawns during each monthly partial harvest over a 19-month period increased the numbers of marketable prawns but did not affect mean weight (40 g).

Research on the use of substrates to increase production in freshwater prawn grow-out systems has continued in the USA and is beginning to be applied in small-scale commercial practice. Tidwell and his co-workers in Kentucky have published a series of papers (Tidwell, Coyle, Van Arnum & Weibel 2000a; Tidwell, Coyle, Van Arnum, Weibel & D'Abramo 2001; Tidwell, Coyle, Van Arnum & Weibel 2002) on the use of substrates consisting of 120-cm-wide panels of polyethylene 'construction safety fencing' material, placed in rearing ponds either horizontally or vertically to increase the surface area available to prawns. This material is illustrated in Tidwell and D'Abramo (2000) and New (2002a). In one of their most recent papers, Tidwell and colleagures (2002) reported that they had obtained a significantly increased production rate of freshwater prawns (2653 kg ha^{-1}) when the surface area was increased by 100% compared with a control with no substrate (2140 kg ha^{-1}) in an experiment lasting 106 days where 0.2-g juveniles were stocked at 65 000 ha^{-1}. Higher average final weights were obtained when substrates were used. An intermediate production level between these extremes was achieved with half the quantity of additional substrate but, at this level, it made no difference whether the substrate was hung vertically or horizontally. Vertically hung substrates are easier to install and maintain and offer the possibility of increasing surface area even more than 100%, and therefore the potential of greater production.

On the other hand, Posadas, Walters and Long (2003), reporting a 120-day experiment where surface area was increased over no-substrate controls by 100%, using similar vertical substrates and juveniles stocked at 50 630 ha^{-1}, found no significant effect on survival rate, harvest size or count, yield or feed conversion. However, the average yield (1497 kg ha^{-1}) obtained by Posadas and colleagues (2003) was markedly lower than those achieved by Tidwell and colleagues (2002). More detailed comparison between these two experiments is necessary, to see what experimental parameters differed, before further research confirms the obvious advantages that Tidwell and colleagues (2002) have found in adding substrates to freshwater rearing ponds.

D'Abramo and colleagues (2000), studying the effects of combinations of water volume, bottom surface area and water replacement rate on weight gain of juvenile *M. rosenbergii*, have highlighted the importance of allowing for maximum density-independent growth of animals for all treatments in experimental work with crustaceans that uses growth as a response variable to compare performance on different diets. Greater weight gain was achieved under both greater water volume and bottom surface area. Increased water replacement did not compensate for lower water volume. Increasing available surface area makes it possible to reduce the water replacement rate. This work is therefore important for moving towards zero-exchange grow-out systems.

Vitatoe, Tidwell, Coyle and Van Arnum (2000) reported that menhaden fish oil could be used as a successful alternative to petroleum products such as oil and diesel fuel for eliminating the air-breathing insects that predate on small, newly stocked freshwater prawn juveniles. Not only does this promote environmental safety and comply with organic certification but it eliminates the possibility that juvenile prawns may consume toxic petroleum droplets after stocking. These workers stated that menhaden fish oil applied at 1.6 gallons (US) per surface acre ($\sim$15 L ha^{-1}) was not only effective in controlling air-breathing insects but also cost-effective in comparison with petroleum-based products.

Nutrition and feeding

Besides genetics, the major area of research publication on *Macrobrachium* in the past 3 years has been on nutrition and feeding. Coyle and Tidwell (2002) suggested that more research should be carried out on management practices that maximize the availability of natural food. 'Phase feeding', where diets with increasing protein levels are applied during the production cycles were suggested; the use of a low protein 'fertilizer' diet for the first month, followed by a 28% protein steam pelleted diet for the next 6 weeks and a 40% protein diet for the final 4 weeks of rearing were used in one trial. This is contrary to normal practice (lowering protein levels as animals become older) but was suggested as a means of providing more and better nutrition when natural foods become grazed down. Further trials described by Coyle and Tidwell (2003) compared phase feeding with the use of a 32% diet (similar to a catfish feed formulation) throughout the rearing cycle. No differences in total production or average prawn weight were observed; however, phase feeding resulted in a 20% increase in the number of animals weighing over 30 g. In each trial feeding rates were 20% higher than normal and stocking densities were relatively high (6.5 and 7.9 m^{-2}). Phase feeding using a marine shrimp diet also increased feeding costs, so careful economic and marketing considerations need to be made in applying such research findings.

Correia, Pereira, Silva, Horowitz and Horowitz (2003) found that increasing the natural productivity of ponds significantly improves feed conversion ratio, with concomitant savings in farm operating costs. Fertilization made it possible to reduce feeding rates by up to 50% with no reduction in yield. In this case, the authors used an average of 2.5 kg of lime, 110 g of simple superphosphate and 340 g of ammonium sulphate per 50 m^2 pond every 2 weeks (in practice, application rates were adjusted on the basis of water-quality analysis) during an 84-day trial. Full feeding was compared with a reduction of 50% throughout the trial and a treatment that consisted of feeding 0%, 25% and 50% of the control feed for the three subsequent periods of 28 days. The latter treatment resulted in prawns that were smaller than market size and a much reduced total net yield. However, a reduction of 50% in feeding rate gave similar final weights and yield.

A successful semi-synthetic broodstock diet (44% protein, 9% lipid) for *M. rosenbergii* was used in reproductive performance trials by Cavalli and colleagues (2001). The formulation included, *inter alia*, casein, lobster meal, soy protein isolate, squid meal, shrimp meal, crab meal, synthetic amino acids, soybean oil, fish oil, a protein extract attractant, astaxanthin, soy lecithin, vitamins and minerals, together with a carrageenan binder and anti-oxidants.

Roustaian, Kamaruddin, Omar, Saad and Ahmad (2001) have demonstrated the importance of lipid as the major metabolic energy source for growing larvae of *M. rosenbergii* and postulated that research on the effects of the lipid composition of broodstock diets would be beneficial. Roustaian, Kamaruddin, Omar, Saad and Ahmad (2000) found that the amino acid composition of *M. rosenbergii* larvae appeared to be relatively unchanged during larval stages I–IX, suggesting that their dietary amino acid requirements could be satisfied by a feed having a similar amino acid profile to the larvae themselves. D'Abramo (2002) reported the successful development of a formulated microbound feed to replace the use of *Artemia* for larval stages V–XI and for PL *M. rosenbergii*. The formulated diet was moist (60% moisture) and could not be reduced to particles below 0.25 mm unless previously dried. The diet was energy dense (46% protein and 37% lipid). Although experimentally successful, as far as I know its use under commercial hatchery conditions has not yet been reported; its unit cost was also not stated in this paper.

Niu, Lee, Goshima and Nakao (2003) found that the food consumption of *M. rosenbergii* PL distinctly increases with temperature (23–33 °C) and is positively related to initial body weight (7–38 mg). Models were constructed to relate maximum food consumption and specific growth rate with water temperature and initial size; these could be used to predict the food requirements and growth of PL in aquaculture.

In an experiment where a series of diets containing varying amounts of trash fish meal and groundnut oil cake with level amounts of shrimp head meal and coconut oil cake were fed to 0.27 g initial weight *M. rosenbergii* and reared for 30 days, Hari and Kurup (2003) found that highest growth rate and maximum protein utilization was obtained with a 30% protein level. In a subsequent experiment using four diets with this protein level, these authors showed that it was possible to achieve similar results as trash fish meal was gradually replaced by groundnut oil cake, thus indicating the potential for dietary cost savings.

Posadas, Walters and Long (2001) and Posadas, Walters and Long (2002) compared different feeds and feeding regimes for the grow-out of *M. rosenbergii* in Mississippi. A daily ration of cottonseed (approximately 3.7 kg ha^{-1}) was applied to all four treatments for the first 30 days of rearing. In the control ponds, a sinking pelletized 32% protein catfish feed was fed from day 31 for the next 90 days to harvest. In the second series of ponds, the pelletized catfish feed was applied for the second 30 days of rearing, followed by an extruded 35% protein catfish feed for the final 60 days. The third series of ponds was treated similarly during the second 30-day period but an extruded 40% protein sinking marine shrimp feed was used for the final 60 days. Finally, in the fourth series of ponds, a 35% protein marine shrimp feed was applied from day 31 for the next 90 days. Although yields were not significantly different, the highest (1183 kg ha^{-1}) was achieved by the control (sinking 32% catfish feed from day 31 to harvest). The authors concluded that dietary protein level had no appreciable effect on yield, survival, feed conversion or final average prawn count (about 22 kg^{-1}). However, FCR in all treatments was rather poor (3.0–4.1:1). No information on the analysis of the various feeds was presented; thus, no comparison of the protein/energy ratios was feasible. It is possible that the dietary protein levels of all treatments in this trial were unnecessarily high. D'Abramo and New (2000) reported the use of commercial freshwater prawns feeds with protein levels ranging from 22% to 38.5% and that, where natural food was also available, several trials have reported success with diets having protein levels as low as 13% or 14%.

Ali and Sahu (2002) found that the use of fermented fish silage as a feed ingredient showed better (but not statistically significant) weight gain, FCR and PER than freshwater prawns fed 35% protein/8% lipid diets containing fish meal or acid fish silage.

González-Peña, Gomes and Moreira (2002) showed that the specific growth rates, feed efficiency conversion and protein efficiency ratios of small and large adult *M. rosenbergii* improved as levels of dietary fibre were increased (substituting cellulose for starch in semi-purified diets) from 0.4% to 8%; they concluded that the inclusion of up to 10% of dietary fibre increases growth rates in adult prawns by increasing nutrient residence time, thus increasing absorption.

Mendoza, Montemayor, Aguilera, Verde and Rodríguez (2001) found significant attractive properties when arginine, cadaverine, freeze-dried red crab extract and coconut extracts were added to a commercial diet for *M. rosenbergii*. Research has shown that anti-nutritional tannins affect *M. rosenbergii* far less than fish (Anonymous 1999–2000).

Using ascorbyl 2 polyphosphate, Hari and Kurup (2002) found that dietary vitamin C levels have a perceptible influence on the survival of *M. rosenbergii* juveniles and recommended an inclusion rate of 135 mg kg^{-1} of ascorbic acid equivalent.

Available surface area can be increased by introducing artificial substrates, as shown by the continuing work of Tidwell and colleagues (2000a, 2001, 2002). The latter authors have demonstrated that increasing substrate increases production and improves feed efficiency.

Polyculture

The polyculture of freshwater prawns with other species continues to attract research interest. In Brazil, Dos Santos and Valenti (2002) have shown that stocking densities of up to 6 m^{-2} *M. rosenbergii* PL did not affect the production of tilapia (*Oreochromis niloticus*) stocked at 1 m^{-2} over a 175-day experimental period, and required neither additional feeding nor significant changes in management. At the highest prawn stocking rate, 3721 kg ha^{-1} of tilapia (final average weight 519.6 g) and 818 kg ha^{-1} of prawns (final average weight 14.7 g) were obtained. Lower prawn stocking rates achieved larger final average prawn weights (34 g at 2 m^{-2} and 23 g at 4 m^{-2}). Achieving additional yield without additional feed improves the sustainability of the system. In Puerto Rico García-Pérez, Alston and Cortés-Maldonado (2000) had stocked one 7–8 g tilapia m^{-2}, with or without juvenile prawns (1.0–1.3 g) at 7 m^{-2}, and compared with prawns alone at 7 m^{-2}, in an experiment lasting about 145 days. The feeding rate was adjusted according to the mean biomass. This work showed that this form of polyculture has the potential of maintaining the yield of tilapia production at non-significantly different levels (2942 kg ha^{-1}, in monoculture and 2769 kg ha^{-1} in polyculture) with similar average final weights. However, while 1367 kg ha^{-1} of prawns was obtained in monoculture, this fell to 951 kg ha^{-1} in polyculture. Furthermore, the mean weights of the prawns were significantly different (55 g in monoculture and 31 g in polyculture). It would have been interesting to compare the results of these two papers further if Dos Santos and Valenti (2002) had included a treatment where prawns were stocked alone.

The work of Tidwell, Coyle, Van Arnum, Weibel and Harkins (2000b) suggests that rearing tilapia (*O. niloticus*) with *M. rosenbergii* may improve overall pond efficiency. In this experiment, tilapias were grown in cages attached to a floating deck at the deep end of the pond.

Kurup and Ranjeet (2002) surveyed 122 farms in 1998–2001 in Kuttanad, India (the 'rice bowl' of Kerala); 75 used polders for *M. rosenbergii* culture, alternating with rice. Twenty farms practised monoculture and 55 grew prawns in polyculture with Indian major carps such as catla (*Catla catla*) and rohu (*Labeo rohita*), and grass carp (*Ctenopharyngodon idella*). Comparing monoculture with polyculture, these authors reported yields of 95–1297 kg ha^{-1} of prawns in monoculture, compared with 70–493 kg ha^{-1} of prawns and 200–1200 kg ha^{-1} of fish in polyculture. Revenue generation indicated that monoculture was generally more advisable than polyculture in this situation. The final conclusion was that freshwater prawn culture was a useful way of increasing income and employment where double cropping of rice was not possible because of monsoon flooding. Kurup, Ranjeet and Hari (2002) provide further information confirming this matter, describing it as an 'eco-friendly' form of aquaculture.

Transport survival

The important topic of the survival of prawns during transport from one location to another has also attracted research attention. Juvenile prawns are usually transported in plastic bags filled with water and air or oxygen, often inside styrofoam coolers. Frequently, losses are experienced because of deteriorating water quality and stress. Coyle, Tidwell, Van Arnum and Weibel (2000) reported the effects of density on survival and associated water quality parameters, transporting animals at 10, 25 and 50 g L^{-1} (since they were using 0.26-g animals, this was equivalent to approximately 38, 96 and 192 individuals L^{-1}). Their findings were that although total and unionized ammonia concentrations (and to a lesser extent nitrite levels) increased with density, they were not considered to reach lethal levels at the temperature (22 °C) and pH (average 8.1) conditions used, up to the highest stocking transport density (50 g L^{-1}). The significantly lower survival levels when prawns were transported at 50 and 25 g L^{-1}, compared with 10 g L^{-1} were attributed to reduced dissolved oxygen levels at higher transport densities. After 8 h, DO_2 was 3.2 ppm at 10 g L^{-1}, but only 1.6 ppm at 25 g L^{-1} and 1.3 ppm at 50 g L^{-1}. Although juveniles can tolerate DO_2 levels as low as 1.0 ppm for short periods, the levels found in this study were likely to cause stress. Recommending that juveniles should not be transported at densities in excess of 10 g L^{-1} (e.g. about 38 individuals weighing 0.26 g) in sealed containers when the transport time was eight or more hours, these researchers noted that higher transport temperatures would certainly increase oxygen consumption and nitrogen excretion, making further reductions in transport density essential. In terms of numbers these transport density recommendations seem much lower than those reported or suggested by other authors for young PL. For example, densities in closed containers of 250–417 L^{-1} for short transport times in Brazil and 666 L^{-1} for 24–36 h in Thailand were cited by Correia, Suwannatous and New (2000); 100 L^{-1} when plastic straw was included as a transport habitat by Vadhyar, Nair, Singh and Joshi (1992); 125–250 L^{-1} for up to 16 h by Valenti and New (2000); and 250–400 L^{-1} for up to 16 h by New (2002a). However, since young PL only weigh approximately 0.01 g each, these densities all fall well within the maximum transport density by weight recommended by Coyle and colleagues (2000). Thus 10 g L^{-1} could be recommended as a general maximum transport density for PL and juveniles but, for practical purposes, it would be more useful to know the numbers, rather than the weight, per unit volume. Larger animals (including broodstock) are also sometimes transported long distances. This topic therefore needs further elucidation, so that practical tables could be derived, which would state the number of animals recommended for different animal weights, under various levels of temperature and pH, and for varying transport times.

A glance into the future of freshwater prawn farming

Forecasting the future is little more than gazing into a telescope and expecting. However, it is difficult to resist the temptation.

Characteristics of the sector

In looking at global trends over the period from now until 2006, I would expect that:

- Chinese production of *M. nipponense* will continue to increase, for its domestic market and (hopefully) China will commence declaring its production of this species in its statistical returns to FAO;
- Chinese production of *M. rosenbergii* will expand and this species will become an export product;
- China may develop commercial farming of *M. malcolmsonii* and (perhaps) of *M. amazonicum*, which is larger than *M. nipponense*, but is still more likely to appeal to the domestic market than *M. rosenbergii*;
- production in India and Bangladesh will markedly increase, mainly of *M. rosenbergii*, for both domestic and global markets;
- the output of Thailand will expand significantly, as the country realizes that a global market is becoming available and that the culture of freshwater prawns may be more environmentally acceptable than marine shrimp;
- Brazil will become a significant producer of both *M. rosenbergii* and *M. amazonicum*;
- other Latin American and African countries will increase their activity in this field;
- Research on the culture of freshwater prawns in temperate zones, pioneered in the USA, will become utilized in the temperate zones of other countries;
- markets for freshwater prawns will continue to expand in both industrialized and developing countries.

Future scale of production

In considering the effects of these expectations on the global output of farmed freshwater prawns, I have initially ignored the largest producer, China, partly because such a large proportion of its total production in the last 3 years (namely that contributed by the indigenous species *M. nipponense*) is only an estimate. This, in addition to the very rapid expansion in farmed *M. rosenbergii* production reported to FAO between 1996, when it suddenly reported an output of over 37 000 mt, and 2001, when an output of over 128 000 mt was reported, totally skews any global picture. It is extremely difficult to make meaningful global forecasts if China is included. However, I will try!

Let us look at the possible future in the world excluding China first. As noted earlier in this review, the average expansion rates for *M. rosenbergii* in the world outside China were between about 12% and 30% yr^{-1}, depending on whether we consider the whole decade from 1992 to 2001, or consider only the period 1999–2001. It would probably be over-optimistic to imagine that freshwater prawn farming would continue to expand at 30% $year^{-1}$ in the future! However, even if the more modest expansion rate experienced between 1992 and 2001 continues for the rest of the current decade, global production (excluding China) will be significantly greater by 2010. Figure 10 shows that continued average expansion rates at 12% $year^{-1}$ would result in a global

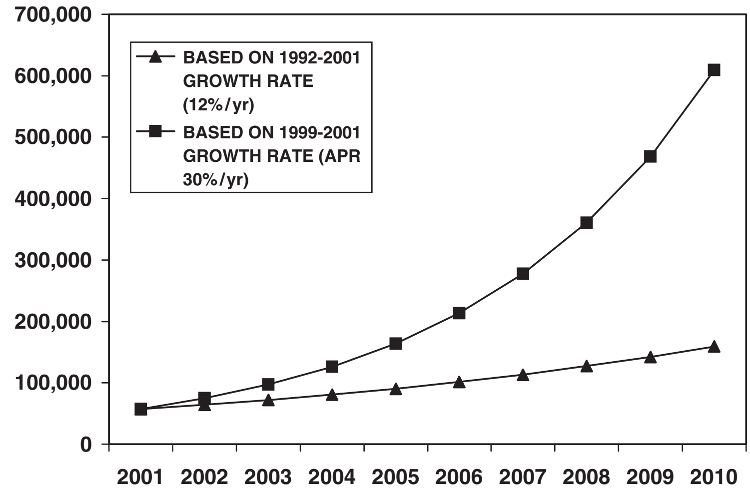

Figure 10 Estimates (mt) of future production of farmed *Macrobrachium rosenbergii* (excluding Chinese and 'nei' production) in the current decade.

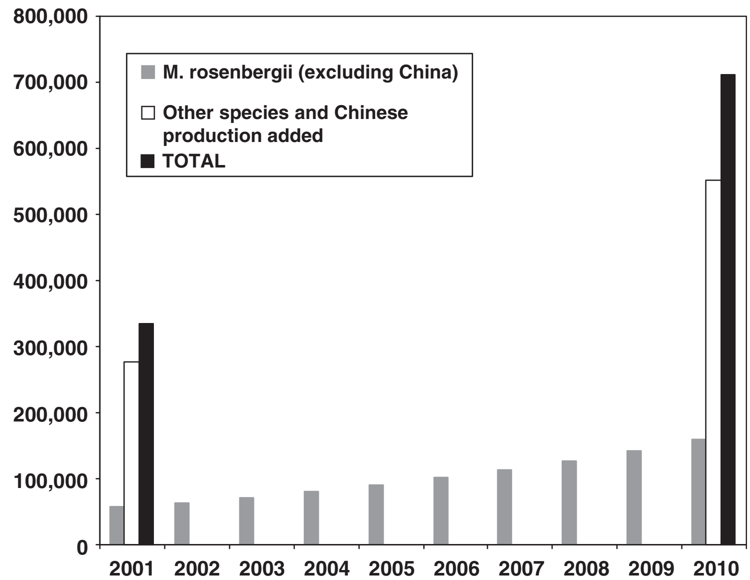

Figure 11 Estimate (mt) of the future production trend based on a doubling of Chinese and 'nei' production between 2001 and 2010 and a 12% annual expansion rate for *Macrobrachium rosenbergii* in the rest of the world.

farmed output of *M. rosenbergii* alone of over 159 000 mt by 2010. The estimate shown in Fig. 10 not only excludes the potential production from China but also the production of other *Macrobrachium* spp. and the production of Viet Nam, which is currently 'lost' within the FAO category 'freshwater crustaceans nei'.

So now let us look at what may happen if we include potential growth of the sector in China and Viet Nam. It is entirely possible that the output of *M. rosenbergii* and *M. nipponense* in China in 2010 will be double that in 2001 (which would result in a production approaching 500 000 mt) and that the assumed production of *M. rosenbergii* in Viet Nam and other minor producing countries not specifically reporting their output as *M. rosenbergii* (the nei categories) may also double between 2001 and 2010. If this happens, and production in the rest of the world expands at 12% year^{-1} (the same as in the decade 1992–2001), the total output of freshwater prawns by the end of this decade would exceed 700 000 mt year^{-1} (Fig. 11). Figure 12 shows what would happen if Chinese and Vietnamese production trebled and the expansion rate in the rest of the world continued at 30% year^{-1}, the rate achieved between 1999 and 2001. If that happened the global production of freshwater prawns would reach over 1.4 million-mt year^{-1} by 2010.

This then is the potential picture. Based on a doubling or trebling of output in China and Viet Nam

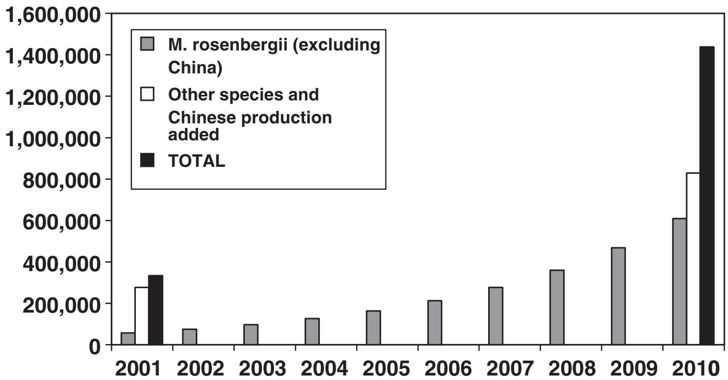

Figure 12 Estimate (mt) of the future production trend based on a trebling of Chinese and 'nei' production between 2001 and 2010 and a 30% annual expansion rate for *Macrobrachium rosenbergii* in the rest of the world.

and continuing expansion rates of between 12% and 30% year $^{-1}$ in the rest of the world, the farmed production of *Macrobrachium* spp. would be between 700 000 and 1.4 million mt by 2010. In these scenarios, the potential production of other *Macrobrachium* spp., such as *M. malcolmsonii*, *M. vollenhovenii* and *M. amazonicum* have not been considered.

Being cautious myself, I would expect that total global freshwater prawn production will be in the region of 750 000–1 000 000 mt year $^{-1}$ by the end of the current decade. This would place its production almost in the same order of magnitude as the marine shrimp farming sector now but, of course, entirely different in its characteristics.

Research needs

Finally, I would just like to present a 'bullet' list of the major topics where I believe further research and development would significantly support the future development of commercially successful and environmentally and socio-economically sustainable small- and large-scale freshwater prawn farming.

In my view, the important topics are:

- Careful consideration of the economic implications of every experiment. Cost considerations should be incorporated into experimental design, so that results can be quantified in financial, as well as purely scientific terms. In this way, the really important research findings can more quickly be adopted in farming practice and benefit both farmers and consumers.
- Freshwater prawns remain undomesticated, although unconscious (and sometimes negative) selection may have taken place in countries where the parent stocks were introduced in very small numbers. Conventional selection and breeding for desirable traits or (if consumers will accept it) by gene manipulation and transfer is essential to improve the viability of freshwater prawn farming. Further work on hybridization to combine the attractive traits of various species is also warranted. For example, it may be possible to combine the delicate flavour of one species, which commands a premium price, with the more rapid growth rate and/or final market size of another.
- Genotype/phenotype effects on HIG need much more elucidation. Knowledge on this topic is probably a prerequisite for successful selection, improved management, and enhanced profitability.
- I have often remarked that there should be less research on the hatchery phase of species of fish and crustacea, where so much is already known and successful hatchery technologies exist and have been so widely put into practice. In my view, research on the nursery and grow-out phases, although such experiments are less easily replicated and need to be lengthier than work with larval stages, should be a major priority. In this aspect of research work, I include all aspects of management, including feeding, health management, nutrition, water management, optimizing and maintaining biomass levels to improve product marketability (in other words adapting management procedures to increase the proportion of marketable prawns; of course, the definition of what is marketable depends on the specific characteristics of the market that the farmers wish to supply) and, perhaps most important of all for this genus, practical and effective size management.
- Despite my apparent bias against work with the larval stages, new information that should improve hatchery viability (such as those mentioned earlier in this review) is still being generated.

Further work on factors affecting the broodstock and larval phases of freshwater prawn farming, particularly on sustainable health management in hatcheries and the effect of broodstock nutrition and management on larval quality merits continued attention. In particular, resolution of the apparently conflicting results of studies on the subsequent performance of early versus late-hatching prawns in grow-out seems important. However, I repeat my opinion that expenditure on these topics should not be at the expense of neglecting work on the nursery and grow-out phases. The ideal solution would be experiments that follow the comparative performance of different populations through both hatchery and grow-out phases. Adequate research funding and long-term commitment of both research managers and research scientists are prerequisites for this type of experimental work.

- It is clear that, in many locations, there may be value in the polyculture of freshwater prawns with other crustacea and/or finfish; further research to quantify benefits is required. Work on the integration of freshwater prawn farming with other forms of activity sharing the same resources, such as crop and livestock production, would also be valuable.
- Socio-economic and environmental research is also essential, to ensure that freshwater prawn farming is responsible and sustainable, and that consumer attitudes towards our products (both in international and domestic markets) remain positive.
- The use of suitable harvesting, handling and processing techniques are also important to ensure that our products are of high quality. In this area, I think that further studies on the effect of various methods of handling prawns on product quality are vitally important. The critical period between removing prawns from the rearing enclosure and commencing their transfer to the sites where fresh or chilled products are marketed, or to processing plants, merits particular attention.
- Finally, I would like to stress again that consideration of cost factors need to be a facet of all experimental protocols. Research results may be biologically interesting but economically impossible to apply. Please think carefully about this when designing and reporting your experimental work. Those of us who are involved in peer review for aquaculture journals should also bear this in mind.

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