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REVIEW ARTICLE

Current status and prospects of farming the giant river prawn (*Macrobrachium rosenbergii De Man 1879*) in the United States

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Abstract

Production of freshwater prawns has expanded in the US with some production in >20 states. Two different approaches to reducing production costs have evolved, one based on minimizing input costs and maximizing harvest sizes, the other on maximizing production (kg/ha). Profitability in both is largely dependent on optimizing selling prices by offering product forms which do not face direct import competition (i.e. live, fresh, whole) Prawns have been recognized as one of the most environmentally sustainable aquaculture crops, and attribute which is very appealing in many markets, especially those emphasizing local foods.

Keywords: prawns, temperate, genetics, sustainable

Introduction

The freshwater prawn, *Macrobrachium* sp., is an important aquaculture crop in many areas of the world. Production totals and values have increased steadily over the past 10 years until the total production of all groups of farmed freshwater prawns is nearing US$ 2 billion annually (New 2010). Prawns can be produced inland without the need for access to saltwater or expensive coastal lands and do not require high levels of fish meal in the diet. These factors make freshwater prawn production a good choice for long-term sustainable aquaculture production (Tidwell & D'Abramo 2010). Prawn production is also well suited for small-scale farmers and markets. Although the vast majority of freshwater prawn production occurs in Asia and in tropical climates, there is significant and increasing interest in the production of prawns in temperate regions.

Production in different climates

In tropical regions, all phases of culture can be performed year round, and prawns can be stocked or harvested at any time. This allows hatchery, nursery and grow-out facilities in tropical areas to be used almost continuously. Tropical hatcheries do not maintain broodstock since berried females can be captured from grow-out ponds when the hatchery needs them. Also, in tropical climates, postlarvae (PLs) can be stocked directly into grow-out ponds, eliminating the nursery phase. Other production scenarios include stocking PLs into nursery tanks for 15 days followed by small nursery ponds for 60 days. Alternatively, one 60-day nursery phase is used. Normally, there are two or three grow-out cycles per year. Rearing systems and farming strategies used in tropical regions are detailed in Valenti and New (2000).

In tropical regions, farms are relatively small and most range from 0.5 to 5 ha of ponds. However, there are a few farms of about 10–50 ha. Semi-intensive monoculture is most common. Prawns may be stocked and completely harvested in a batch system or market size animals can be selectively harvested with replacement stocking in a continuous production system. Farms may also use some combination of the two systems (New 2002). Yields range from 1.5 to 4.5 t ha^{-1} $year^{-1}$ (20–50 g whole prawns).

In temperate zones, there are four distinct phases of production spread over the 12-month period. These include hatchery, nursery, grow-out and broodstock holding. In the northern hemisphere, an example of a typical production schedule would be a female would spawn on March 1. The larvae would be cultured in the brackish water hatchery until April 1 when the PLs would be transferred to the freshwater nursery. In this indoor nursery, the PLs grow from about 0.01 g to about 0.5 g in 60 days. The juvenile prawns are then transferred to the outdoor grow-out ponds on June 1. There they are fed and grown to a mean harvest size of 30–40 g. The prawns are harvested in mid-September and either processed or sold live. A percentage of the mature prawns are kept live in tanks over the winter as broodstock to produce the seedstock needed for the following summer's production. In the southern hemisphere, these dates would be seasonably 'reversed'.

In temperate zones, broodstock holding actually represents a larger portion of the year than any other phase of production. It is a period which is essential to successful hatchery production, but also a period which tends to be ignored or underestimated in terms of importance or expense. Prawns must be maintained indoors in tanks at >20°C, during a period when outside temperatures are often <0°C. Energy expenses can be significant.

Broodstock

When broodstock are selected at pond harvest, selection is normally based only on body size and sexual morphotype. For females, relatively large individuals (40–60 g) that have already spawned at least once are chosen because they tend to produce large 'clutches' of eggs (about 500–1000 eggs g^{-1} of female body weight). Males include both blue claw males (dominant, breeding) and orange claw males (subdominant, non-breeding). Survival of blue claw tends to be lower than that of the orange claws during broodstock holding and orange claws can attain maturity by spring and the start of reproductive activities. Broodstock are held at a ratio of about 4 females per 1 male. Holding densities are about 10 broodstock m^{-2} of tank substrate and a volume of about 40 L. Broodstock may be held at relatively low temperatures (20°C) to save on energy costs, and then gradually warmed up to about 28–30°C by 3–4 weeks prior to initiating hatchery operations.

Hatchery

In temperate zones most hatcheries are indoor, recirculating, clear water systems. With recirculating systems, it is important to properly colonize or 'break-in' the biofilters prior to the initiation of hatching. This may require 4–6 week and this step is often overlooked or underestimated. The stage of development (ripeness) of eggs can be determined by colour and appearance. Females carrying eggs judged to be within 3–4 days of hatching are transferred either to special larval collection tanks or directly into larval culture tanks. They are allowed to hatch until the desired larviculture density of 50–100 larvae L^{-1} is achieved or until there are larvae ages spanning 2–3 days (a greater range increases cannibalism). Initially, larvae are exclusively fed live *Artemia nauplii*. After about 6 days, a producer made supplemental food is also used. Survival usually averages about 50%. During the hatchery period, primary expenses include *Artemia*, artificial sea salts (US$ 1 10 L^{-1}), and energy (heat and pumps). To be economically feasible, a hatchery likely needs to produce >1 000 000 PLs $year^{-1}$, while 2–3 000 000 $year^{-1}$ is more realistic.

For production of prawns in temperate regions, the nursery phase is needed to produce a juvenile large enough to attain the market size ($\geq$35 g) within the limited growing season in the pond grow-out phase. The nursery period ranges from 30 to 60 days during which the PLs coming out of the hatchery grows from 0.01 to 0.10 g (30 days), to 0.25 g (45 days), or to 0.5 g (60 days). The nursery basically allows the growing season to be extended while the animals are small and more tolerant of crowding. The primary costs during the nursery phase are feed and energy costs, but these tend to be lower than during the hatchery due to warmer spring temperatures and the use of less expensive manufactured feeds. Stocking densities are based largely on the amount of artificial substrate added to the nursery tanks. Typical rates are a combination of about 5 PLs L^{-1} (volume) and 200–400 PLs m^{-2} (surface area) of substrate. Survival rates of 50–90% can be expected, with survival dropping rapidly if carried past 60 days.

Grow-out

Grow-out production is conducted outdoors in earthen ponds and several different management technologies are currently utilized in temperate areas. These include extensive/low input, extensive large scale, semi-intensive and semi-intensive/high input (Tidwell 2011). Extensive/low input is proposed for ponds which are either not purpose built aquaculture ponds or do not have access to electrical power. Ponds are stocked at low densities (20 000–25 000 ha^{-1}) and fed at low rates (12–28 kg $ha^{-1}day^{-1}$). No aeration is available.

Extensive/large-scale production is being proposed for situations where construction of large ponds (>0.5 ha) is feasible and differential pricing based on prawn size is in place. D'Abramo (2004) compared prawn production at 21 000 and 49 400 ha^{-1}. The lower stocking rate scheme had lower production costs (reduced \$0.11 kg^{-1}) and produced higher average weights with higher selling prices (increased \$2.21 kg^{-1}).

As discussed earlier, temperate zone production is limited to one crop per year. In certain regions within the temperate zone, physiographic conditions also limit producers to the use of relatively small ponds (<0.5 ha). Under these conditions, a more intensive management approach may be justified to maximize the amount of production which can be achieved within these time and space limitations. For the past 10 years, work at Kentucky State University has been conducted on the development of management technologies directed towards increasing the biomass produced in small ponds without decreasing average harvest weights. Innovations include the inclusion of artificial substrates, use of different feeds and feeding rates, different amounts of aeration, size grading prior to pond stocking and combinations of these factors. Dasgupta and Tidwell (2003) conducted a more intensive investigation into the economics of different technologies developed at KSU from 1991 to 2000. The authors reported that the average yield in 1991 were approximately 1000 kg ha^{-1}. By 2000, this had increased to 2500 kg ha^{-1}. While this technological evolution steadily increased average yields, total production costs (US\$ ha^{-1}) proportionately increased. However, breakeven price of production (US\$ kg^{-1}) was decreased almost 50%.

Recent research

Substrate

Potential mechanisms for the positive impacts of added substrate include reduced negative interactions based on physical separation of prawns, increased availability of natural foods and even improved water quality due to the actions of attached periphyton. The relative effectiveness of different substrate types may be based on how the physical characteristics of the substrate materials contribute to one or more of mechanisms that are assumed to be responsible for the observed growth and survival enhancing responses. To test the impacts of these variables, surface area, mesh size, colour and texture of substrate were evaluated during a 2-year study (Tidwell & Coyle 2008). The different substrate treatments were compared with a control treatment (no substrate) in outdoor tanks during the first year. The most promising substrate materials from that trial were then investigated under pond conditions during the following year. For year 1, juvenile prawns (0.4 ± 0.2 g) were stocked at 123 m^{-2} of tank bottom into twenty-one 18 000 L fibreglass tanks managed as pond microcosms. Substrates were positioned vertically at a rate sufficient to increase the bottom surface area by 100%. Prawns were fed a 32% crude protein sinking prawn diet according to a feed schedule. After 110 days, there was no significant difference ($P > 0.05$) in survival among treatments, averaging 72.6% overall. Prawns in the control treatment had significantly lower ($P \leq 0.05$) average weights (9.5 g), lower production (1342 kg ha^{-1}) and higher FCR (2.5) than those in substrate treatments, which were not significantly different ($P > 0.05$) from one another, with means of 13.4 g, 2404 kg ha^{-1}, and 1.3 respectively.

For Year 2, a lightweight polyethylene bird netting (the lowest cost material from Year 1) was compared with the substrate most commonly used in commercial production (heavy-weight orange polyethylene safety fencing) under practical pond conditions. Juvenile prawns (0.8 ± 0.3 g) were stocked at 61 600 ha^{-1} into six 0.04-ha earthen ponds. Each substrate treatment was randomly assigned to three ponds (replicates). After 101 days, survival (91%), average weight (34 g), total production (2150 kg ha^{-1}) and FCR (3.1) did not differ significantly ($P > 0.05$) between treatments. In these studies, physical characteristics of the substrate materials did not significantly impact prawn production. However, the presence of any of the substrate materials provided significant advantages over no substrate. When compared with the previously recommended and commonly used substrate material, the lightweight netting notably represents a 68% cost savings.

Genetics

The different genetic lines of freshwater prawns cultured in North America were founded with a relatively small number of individuals and little or no introduction of fresh genetic material (resources) over >15 generations creating at least the potential of inbreeding depression. In 2006, researchers at Kentucky State University began a programme to evaluate microsatellite diversity in cultured and wild populations from different geographic regions. Tissues samples were procured from seven cultured and two wild sources and included Hawaii-1, Hawaii-2, India-cultured, Israel, Kentucky, Mississippi, Texas, India-wild and Myanmar-wild. Primer sets for five microsatellite loci were used for amplification of alleles. Genotyping was conducted via capillary electrophoresis. Statistical measures of genetic diversity within populations and between population diversity were calculated for all populations. The average observed heterozygosity ranged from 0.66 (KY) to 0.92 (Myanmar) (Schneider, Tidwell, Gomelsky, Pomper, Waldbieser & Saillant 2012). Average gene diversity ranged from 0.58 (Israel) to 0.94 (Myanmar). The average number of alleles per locus ranged from 4.0 (Israel) to 22.2 (Myanmar) and average allelic richness ranged from 3.96 (Israel) to 20.45 (Myanmar). Based on these results, the Myanmar population appeared to have the greatest diversity among the populations evaluated. Between-population comparisons suggest that these populations exhibit moderately high levels of differentiation. The overall fixation index value suggests that approximately 16% of differentiation results from between population dissimilarity in allelic composition. Genetic distance measurements revealed three distinct groups that have little differentiation within those groups: Group1 (Hawaii populations), Group2 (Myanmar and India cultured), Group3 (TX, KY and MS).

These results demonstrate that based on allozymes and microsatellites, genetic diversity in prawn populations is highly variable and that prawn populations possess relatively high levels of genetic diversity, compared with previously published research. An additional significant outcome of the genetic diversity analysis is the knowledge that many cultured populations exhibit reduced diversity.

Based on these results, the Texas, Hawaii and Myanmar strains were chosen as the best candidates for further comparisons. Prawn broodstock from all three strains were procured and transported to KSU. Since seedstock costs constitute greater than 50% of operational cost in temperate climates, strain performance during the hatchery phase can be an important trait. In the spring of 2009, a hatchery comparison of the Texas, Hawaii and Myanmar stains was conducted and completed. Prawn PLs from the three strains were successfully hatched and stocked into 12 tanks in the closed recycle experimental prawn hatchery system. There were four replicate tanks per strain stock at 16 000 PLs tank^{-1}. Data were collected on growth, survival and days to PLs of the three stains. Hatchery evaluations indicated that the cultured strains (Texas and Hawaii) exhibited superior hatchery performance, most importantly, increased survival to PLs. Also, the Texas strain demonstrated faster larval development which resulted in metamorphosis to PL 2 days earlier than the other evaluated strains.

To evaluate pond production characteristics, the three genetic strains [Texas (domesticated), Hawaii (domesticated), and Myanmar (wild)] were characterized and compared under two different pond grow-out management technologies. Juvenile prawns from each strain were stocked into 0.04-ha ponds as 45-day nursed juveniles at stocking weights of 0.3 ± 0.2 g (Hawaii), 0.3 ± 0.2 g (Myanmar) and 0.4 ± 0.3 g (Texas). In Trial 1, prawns from the three strains were stocked at 24 700 ha^{-1} (Low Input management technology) and in Trial 2 at 74 000 ha^{-1} (High Input management technology). The High Input ponds had artificial substrate added in a vertical orientation. Each of the six treatment combinations was replicated in three ponds (total of 18 ponds). Prawns were fed a sinking pellet (32% protein) once daily at a standardized rate. After 112 culture days prawns were harvested, bulk weighed and counted. In Trial 1 (Low Input) survival of Texas prawns (95%) was significantly higher ($P \leq 0.05$) than Myanmar prawns (77%). Survival of Hawaii strain prawns (86%) was intermediate and not significantly different ($P > 0.05$) from other strains. For average weight, total production, FCR, and marketable percentage Texas and Hawaii strain prawns performed significantly better ($P \leq 0.05$) than Myanmar prawns but were not significantly different ($P > 0.05$) from each other. For Trial 2 survival, average weight, total production, FCR, PSI, total marketable production and the per cent of animals achieving marketable sizes were all significantly better ($P \leq 0.05$) in Texas and Hawaii strain prawn than in Myanmar prawns, but not significantly different ($P > 0.05$) from each other. These data appear to indicate that rather than inbreeding depression, these cultured strains demonstrate the positive impacts of domestication. This initial pond grow-out comparison indicated the two cultured stains exhibited superior production when compared with the wild Myanmar strain, based on average weight and survival. These pond trials also demonstrated strain differences in terms of age at maturation, population structure and sex ratios which appear to have a genetic basis and could have positive impacts in regards to selection of desired traits. Prawns from the different strains were also processed and evaluated for traits related to storage stability. Differences in stability against protein denaturation and oxidation were indicated among the stains (Liu, Xiong, Liu, True, Rentfrow & Tidwell 2010). The results indicated that Myanmar prawns had the best quality among the three different strains evaluated during refrigerated storage, suggesting the potential for improvement of product quantity and storage through genetic selection.

The following year's pond trails were designed to evaluate and compare intraspecific hybrids of the Texas (T), Hawaii (H) and Mynamar (M) genetic strains. Four test crosses were produced and compared with pure Texas strain (as the reference strain). Fifteen 0.04-ha ponds were utilized and the five genetic groups were replicated in three ponds each. After 115 days all ponds were harvested. Prawns were counted, weighed and identified according to sexual morphotype. Survival was significantly higher ($P \leq 0.05$) in the HxT (female × male) cross (93%) than in the TxT (85%), TxM (86%) or MxT (86%) groups. Specific growth rate (SGR) was significantly higher ($P \leq 0.05$) in the MxT (4.8% day^{-1}) than in the TxM (4.5% day^{-1}) or TxH (4.3% day^{-1}) crosses. Other production parameters did not differ among the genetic groups. In terms of premium sizes, the MxT cross had significantly greater percentage of animals achieving weights of >50 g and >70 g than the HxT or TxH crosses. The two Myanmar crosses also achieved greater unit production (kg ha^{-1}) of these size categories. Morphotype data indicate that the Myanmar crosses likely had delayed sexual maturation in both sexes. The Myanmar crosses appear to possess positive production traits which might be exploited through further genetic selection. This research in its entirety provides the fundamental groundwork for genetic improvement of cultured strains in the United States and has prompted renewed interest in developing a selective breeding programme for freshwater prawns in the United States.

Marketing

In temperate regions, large-scale production for processed markets may not be economically competitive with the products imported from Asia. However, production of product forms which are not, and will not likely be, imported from Asia may hold potential for production in temperate regions. These include fresh product, whole prawns and live prawns. These are also desirable to consumers who are interested in knowing where and how their food was produced. McDonald, Caporelli, Coyle and Tidwell (2011) evaluated the marketing of fresh whole prawns on ice in farmers' markets. Prawns were sold directly to consumers at US$ 17.60 kg^{-1}. Customers were very supportive of buying locally produced seafood products and were willing to pay the stated price, which would be a profitable selling price for local producers. They found that advanced advertising, cooked samples and printed handling and preparation guidelines were important to many customers. Proper postharvest handling procedures are important for product quality and consumer satisfaction (Tidwell & Coyle 2011). Additional marketing research examined direct marketing of fresh whole prawns on ice to Asian consumers (Rimmele & Dasgupta 2011). The research utilized an experimental auction procedure to determine the true willingness to pay (WTP). Findings included that the average WTP of US$ 13.20–17.60 is in the range of profitability for local producers. Other findings included a preference for medium-sized animals, as opposed to the larger sizes preferred in other markets.

Prawns also appeal to Non-Governmental Organization groups and consumers concerned about the environmental sustainability of different seafood products. The Seafood Watch Seafood Report produced by the Monterey Bay Aquarium Fish-Wise programme evaluated freshwater prawns on five criteria of sustainability including (1) use of marine resources (i.e. fish meal), (2) risk of escaped fish to wild stocks, (3) risk of disease and parasite transfer to wild stocks, (4) risk of pollution and habitat effect and (5) management effectiveness. They rated the freshwater prawn as 'Low Environmental Concern' in all five categories. They also awarded the prawns a 'Best Choice' designation and stated the prawns were 'one of the most sustainable seafood choices available'.

Conclusion

The freshwater prawn may be best suited for small-scale producers and lends itself to local producer/direct sales marketing. Best marketing and profitability opportunities may be in regions with a strong local foods movement. Production of prawns in these regions offers 'localvores' a desirable protein and/or seafood option not previously available in many regions. It also is a very good candidate for sustainable production practices, which is also strongly appealing to this same clientele.

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