BIOECONOMIC MODELLING OF AUSTRALIAN BLACK TIGER PRAWN *PENAEUS MONODON* UNDER INTENSIVE POND CULTURE

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SUMMARY

We developed a bio-economic model for the black tiger prawn *Penaeus monodon* for intensive pond culture in Australia. Hatchery, grow-out, and combined hatchery-growout scenarios were evaluated by simulating a varying number of ponds in operation. Annual, six-monthly, quarterly and monthly stockings were included in each business scenario. Net present value (NPV) was the main economic variable used for comparison. Highest profitability in the combined business was obtained in a monthly stocking cycle and largest number of ponds included. Feed cost was the major cost in all scenarios studied. Sensitivity analyses showed feed and survival parameters were critical for profitable business models.

INTRODUCTION

In Australia, consumption of marine prawns is a growing market, and most prawns are sourced from wild-caught stocks (~21,000 tonnes in 2016-17; ABARE 2017), or from imported fisheries and aquaculture product (~31,000 tonnes in 2016-17; ABARE 2017). Seasonal variability in supply of wild-caught prawns, along with potential for domestic replacement of imported product, provide significant market opportunities for locally farmed prawns (Treadwell *et al.* 1991). Despite these opportunities, the Australian prawn farming industry has not grown to dominate the domestic market (~5,000 tonnes in 2016-17; ABARE 2017). Limiting factors are the high-risk nature of the prawn industry, site-specific limitations, capital-intensive investment needed, high reliance on technology and technical expertise (Robertson 2006). The high-risk nature of aquaculture businesses can be reduced by controlling the biological and technological variables, and determining critical thresholds for cost and returns in a profitable business.

P. monodon is the main species of marine prawn farmed in Australia (Government of Queensland, 2018). The advantage and attractiveness for growers of farming this species is its rapid growth rate, large size compared to other species, lower food input costs, and its demand in the market. Prawn production can be divided into post larvae (PL) production hatchery and grow-out animals in ponds. In hatcheries, two critical factors driving productivity are optimum utilization of tank facilities, and larval production from domesticated breeding stock or wild broodstock. Grow-out business operations purchase larvae at day 15 (PL15) from commercial hatcheries to stock their ponds. Some big aquaculture enterprises undertake both hatchery and grow-out operations as a combined business. The commercial viability of grow-out farms has been analyzed in Australia by (Treadwell *et al.* 1991), who demonstrated that small scale farms (30 ha) are profitable under stocking scenarios of either one or two annual production cycles. (Hardman *et al.* 1990) showed that small size farms (6 and 20 ha) had a high uncertainty of returns and risk involved at low and high density stocking rates. Farm sizes over 30 ha have not been modelled yet, and there is an opportunity to increase efficiency of large-scale production systems using multiple stocking events per year and scaling up operational size to capture increased efficiency.

This study presents a bio-economic model of *P. monodon* in Australia under intensive farming systems for three business models (hatchery, grow-out and combined) comparing both scale and variable stocking per year.

MATERIALS AND METHODS

A model of an aquaculture production program of *P. monodon* was developed using the parameters of a typical prawn farming operation in Australia. Information from three different sub models-namely a biological model, and technical model and an economic model were combined into a single model with options to change parameters interactively. The models were initially developed in MS Excel and finally in the form of R scripts. A total of 298 different input parameters based on published studies or experts' opinion were used (data not shown). Breeding and production designs were generated for production over a business period of 10 years. Three different business were simulated for comparing economic performance: 1) Hatchery business: Production size (number of PLs) depended on number of females used for reproduction per spawning event. Small, medium and large production, consisted of 50, 250 and 500 females per spawning cycle, were evaluated. 2) Grow-out business: This included acquisition of PL15 from a commercial hatchery in each production cycle, growing animals in ponds until the harvest size, and sale ex-factory. Each production size depended on the number installed ponds (fixed capacity). A total of 50, 250 and 500 ponds under production were evaluated. 3) Combined business: Both hatchery and grow-out were combined in one business using 50, 250 and 500 fixed ponds, and number of females required for stocking event. Different stocking events per year were added in each business viz. annual, six-monthly, quarterly and monthly. Each stocking type was repeated for 10 years of the business period. All the available ponds were used in annual and six-monthly stocking cycles, whereas in quarterly and monthly cycles, the ponds were used to minimize empty capacity at any given time as shown in Table 1.

In the biological sub-model, a 28-day cycle covered production of eggs, nauplius, protozoea, mysis, PL1 to PL15 in hatcheries. PL15 were transferred to grow-out ponds under intensive culture with a grow out period from 29 to 168 day to obtain an average body weight of 34.45 g at harvest after 140 days. In the technological sub-model, resources required were based on the biological variables for each production phase. In the hatchery, each input was directly linked to the number of larvae generated and tanks used. In the grow-out phase, each input was linked to biomass and number of available ponds. In the economic sub-model, income, investment, depreciation, and cost variables were evaluated on a continuous time scale *i.e.* analyzed on per day basis. Profit of each business was determined by net present value of cash flow (NPV) in USD (Ross *et al.* 2008).

RESULTS AND DISCUSSION

This study presents the first systematic bioeconomic modeling of hatchery and grow-out operations of *P. monodon* for the Australian Industry using a variety of input variables used in Australia and other countries.

The hatchery business had positive NPV of cash flow when serving at least 50 ponds monthly (with a farm size of 250 ponds) (Table 1). For all the other scenarios the hatchery business was not profitable. Monthly stocking events reduced the effect of fixed costs but proportionally increased the cost of feed and breeders, the later was offset by the proportional increase in the sales of PLs. When customers are stocking annually, six monthly or quarterly, hatchery facilities were underutilized which increased the proportion of fixed cost in the hatchery business. In this study we have used fixed input parameters for production and reproductive performance, however, in practice, there can be a large variation in reproductive performance in hatchery (Uddin and Rahman 2015), any such variation in breeding behavior can change production costs. A decrease in reproductive performance is potentially a high-risk variable which can affect profitability in large-scale hatcheries.

Table 1. NPV of cash flow (in millions of USD) in hatchery, grow-out, combined business, as per the number of ponds installed (50, 250, 500) and multiple stocking per year (annually, six-monthly, quarterly, monthly), analyzed over a business period of 10 years

Ponds available	Ponds harvested annually	Stocking event	Business		
			Hatchery	Grow-out	Combined
50	50	Annually	-1.95	0.83	-0.40
	100	Six-monthly	-1.62	10.8	9.94
	100	Quarterly	-0.88	11.8	11.7
	120	Monthly	-0.45	16.2	16.5
250	250	Annually	-6.64	7.30	1.35
	500	Six-monthly	-4.90	57.4	53.2
	500	Quarterly	-1.09	62.7	62.3
	600	Monthly	1.69	85.1	87.5
500	500	Annually	-12.5	15.6	3.76
	1000	Six-monthly	-8.99	116.1	107.8
	1000	Quarterly	-1.38	126.3	125.6
	1200	Monthly	4.37	171.3	176.3

In the grow-out business, all the scenarios modelled with 50 to 500 ponds stocked annually, six-monthly, quarterly, and monthly production cycles were profitable. The highest profitability was obtained with monthly stocking in farm operations where 500 ponds were used (171.26 million USD), which was over 200 times more profitable than 50 ponds stocked annually (0.83 million USD). When farms with 500 available ponds were stocked on a monthly basis, 100 ponds were used simultaneously such that a total 1200 ponds were harvested over a period of twelve months (Table 1). In monthly production cycles, there was a minimal time gap to prepare and use each pond, this maximized use of facilities and productivity. In all farm sizes, stocking ponds annually significantly underutilized available resources and this is shown in the proportionally heavily reduced profitability compared to stocking at higher frequency (Table 1).

The combined business (incorporating a hatchery with grow-out business) produced higher profit than grow-out business only when the hatchery business was profitable i.e. when at least 250 ponds were used under a monthly stocking cycle. A negative NPV of cash flow was obtained when 50 ponds were stocked and harvested annually, since under the combined business, the negative NPV of cash flow of the hatchery had to be absorbed (Table 1). However, in a combined business the farm is independent from commercial suppliers of PLs but this comes at a significant cost.

Sensitivity analyses of key biological and economical parameters were used to analyze impact on NPV in each business. In the base model survival in the ponds was set at 66%; when survival decreased to 50%, NPV of cash flow decreased in grow-out and combined business. Conversely when survival increased from 66% to 70% NPV of all business models increased due to the increase in income. Labor cost was increased from 100% in base model to 110% to examine the impact on NPV cash flow, which was marginal on each business, as the labor requirements were proportional to the biomass produced and number of animals farmed and harvested. The main cost in each business was feed. Here a fixed biological variable of Feed Conversion Ratio (FCR) was used in the model. FCR can have a high impact on NPV of cash flow in each business. Increment in feed cost of 20% with respect to base model had a high impact on profitability in each business (the results not shown).

In this study the number of broodstock used per stocking event was fixed using an average reproductive performance. However, in practice, reproductive performance can be highly variable (Coman *et al.* 2006) which may require the culture of larger numbers of broodstock, which in turn affects profitability. An industrial scale production of *P. monodon* culture requires a strategic plan for consistent supply of broodstock which can be insured by well domesticated stocks preferably incorporating selective breeding programmes. We have used scenarios without any genetic improvement. The efficiency of prawn farming can be significantly increased by incorporating advanced genetic improvement programmes using genomic information (Khatkar *et al.* 2017; Zenger *et al.* 2018), however, bioeconomic modeling of such breeding operations is critical for evaluating their profitability. The bio-economic modelling developed and presented in the present study can be extended further to evaluate different breeding designs.

In this study, NPV was analyzed in time continuous *i.e.* per day basis and was very responsive to changes in biological parameters of high effect (*i.e.* survival and feed). Analysis of NPV on a continuous time basis produced a much better assessment of economic impact which is impossible to capture under simple models or models comparing profitability on an annual basis (Treadwell *et al.* 1991; Hardman *et al.* 1990).

CONCLUSIONS

Under Australian conditions grow-out business for *P. monodon* appears to be profitable for a range of farm sizes (50 to 500 ponds). Hatchery business are only profitable in large-scale operations supplying customers on monthly basis. Combining hatchery and grow-out is only warranted for large-scale operations under intensive stocking. Overall, survival and feed parameters had greatest impact on NPV for the scenarios modelled here. This is the first and most comprehensive bio-economic model for *P. monodon* under intensive culture conditions using NPV on a continuous time basis.

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