Recent Changes in the Bioeconomics of Lobster and Mud Crab Mariculture in Vietnam

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ABSTRACT

The purpose of this paper is to compare trends in the bioeconomics of tropical spiny lobster and mud crab mariculture in Vietnam between 2010 and 2013 using survey processes and bioeconomic analysis. Results show that tropical spiny lobster and mud crab grow-out mariculture remained strongly economically viable in Vietnam despite significant changes in the bioeconomic environment over a three-year period. The most notable changes to the grow-out of tropical spiny lobster were a significant decrease in harvest biomass due to decreased stocking densities and poor feeding techniques. Findings highlight the potential for improvement in stocking and feeding regimes in Vietnam's lobster and crab mariculture industry, which is likely to have positive environmental and economic benefits. There remains significant scope for increasing the size and quality of the seed used and, in the case of crabs, improvements in availability and affordability of hatchery-produced seed. Similarly, there remains significant scope for optimization of feeding rates and improvement of feeding quality.

Keywords*:* bioeconomics, Vietnam, spiny lobster, mud crab, mariculture
JEL Classification*:* Q12

INTRODUCTION

Crustaceans are among the world's most valuable seafood with strong and increasing demand in Asia, Europe, and America. One of the most highly priced crustaceans is tropical spiny lobster (*Panulirus ornatus*), with live specimens from Vietnam currently selling in China for USD 55–75/kilograms (kg). Almost all production of tropical spiny lobster is from capture fisheries, where stocks are either at their maximum sustainable yield or overexploited and in decline (Phillips 2000, 2005). Total global production in 2012 was 30,500 tons (t), with average growth of 20 percent per year over the last five years. Approximately seven percent of this production is from aquaculture sources (FAO 2013). Vietnam produces approximately 74 percent of all aquaculture lobster (Table 1), with Indonesia and, to a smaller extent, the Philippines is also involved in lobster aquaculture (FAO 2013).

Another crustacean farmed in Vietnam is mud crab, which includes several species of the genus *Scylla*. In 2012, total global production was 212,000 t with a growth rate of seven percent per year over the last five years. Unlike tropical spiny lobster, mud crab production is dominated by the aquaculture sector (82%). Most mud crab aquaculture production occurs in China (75%), with smaller quantities produced by the Philippines (9%), Indonesia (8%), and Vietnam (8%). Live mud crabs from Vietnam are currently selling in China for approximately USD 13/kg.

With increasing pressure on fishery resources, alongside the degradation of environmental and aquatic habitats, the world is looking to aquaculture to increase lobster and mud crab production. However, the extent to which aquaculture takes pressure off wild fisheries depends on a number of factors, including the extent by which aquaculture produces pollution, degrades local habitats, produces parasites and diseases, and uses wild-caught fish for seed and feed (Sadovy and Lau 2002). Two management elements of aquaculture that significantly reduce these impacts are the use of hatchery-bred seed and the use of commercially produced diets in the form of pellets that are not dependent on wild-caught fish for protein (which, compared with low-value finfish diets, cause significantly less problems with pollution, parasites, and diseases).

Currently, in Vietnam, mariculture production of tropical spiny lobster is reliant on wild-caught Puerulus, which are reared in small cages in shallow embayments until they are approximately 10–50 grams (g), after which they are sold to farmers for grow-out to market size (approximately 1 kg) (FAO 2014). Commercially viable hatchery technology has been developed in Australia, although it is yet

Table 1. Global aquaculture production of tropical spiny lobster (t/yr unless otherwise specified)

	2008	2009	2010	2011	2012
Vietnam	720	1,003	1,200	1,500	1,500
All countries	1,084	1,406	1,600	1,793	2,026
Indonesia (%)	27	24	19	13	24
Philippines (%)	7	5	6	4	2
Vietnam (%)	66	71	75	84	74

Source: FAO 2013

to be fully commercialized (Jones 2010). Grow-out feeding strategies currently do not include pellets. Rather, they include shrimp, crabs, and low-value finfish (by-catch or by-products) (Petersen and Phuong 2011).

Unmet demand for mud crabs in Vietnam has led to overexploitation in many areas, which, in turn, has led to major investment in research into hatchery techniques. Currently, most mud crab seed is now from commercial hatcheries rather than wild stocks. Following the early success of hatchery technology, further research investment was made into the development of cost-effective formulated diets to replace trash fish, as feeds and feeding were perceived to be the next major bottleneck to mud crab aquaculture after commercial hatchery technology was developed and adopted (Allan and Fielder 2004). However, the development and adoption of formulated commercial diets have been slow, with minimal uptake by farmers as yet (Petersen et al. 2013). This is likely to change as mud crab farming intensifies in Vietnam.

Bioeconomic modeling is a widely used tool for analyzing the possible effects of policy intervention and technology change on household welfare and quality of natural resource use. It can closely integrate biophysical processes with economic decision behavior and has been used widely in fishery/aquaculture management applications (Affholder et al. 2010; Anderson and Seijo 2010; Clark 1985; Sinh et al. 2003). In 2010, household surveys of small-scale lobster and mud crab farmers were carried out to generate data on the bioeconomics of marine aquaculture of these species. These surveys and the corresponding bioeconomic analyses were reported in Petersen and Tuan (2011) and Petersen et al. (2013). The surveys and analyses were repeated in 2013 to compare trends in the bioeconomics of these two focus species through time. The purpose of this paper is to present this comparison, with special focus on adoption of stocking and feeding practices over the three years.

METHODOLOGY

This paper reports on the outcomes of six bioeconomic models populated from household surveys across Vietnam. The surveys included developing, pilot-testing, revising, and administering a 47-question questionnaire face-to-face with small-scale farming households in mid-2010 and again in mid-2013. Readers are invited to contact the authors for a copy of the questionnaire. The respondents were randomly selected and surveyed by Vietnamese collaborators from the Research Institute for Aquaculture No. 2 (southern farmers), the Research Institute for Aquaculture No. 3 (central Vietnam mud crab farmers), and Nha Trang University (central Vietnam lobster farmers). Three models were developed and populated with 2010 data; lobster farming for central Vietnam (documented in Petersen and Tuan [2011]), and mud crab farming in central and southern Vietnam (documented in Petersen et al. [2013]). The data in each of these three models were revised with the 2013 data, and results of the two years of data were compared in this paper.

The data presented were grouped and averaged. Survey location and sample size are provided in Table 2. Overall, 120 questionnaires were administered across five provinces in 2010 and a further 90 in four provinces in 2013.

Each of the bioeconomic models follow the same methodology, which is described below in two subsections. The biological component is described, followed by the economics component.

Table 2. Location and sample size for 2010 and 2013 household surveys

	Lobster		Mud crab	
	Province	**Sample size**	**Province**	**Sample size**
		2010		
Central	Khanh Hoa Ninh Thuan Phu Yen	40	Binh Dinh Khanh Hoa Phu Yen	40
South	-	-	Bac Lieu	40
Total		120		
		2013		
Central	Khanh Hoa Ninh Thuan Phu Yen	40	Khanh Hoa Phu Yen	25
South	-	-	Bac Lieu	25
Total		90		

The Biological Component of the Bioeconomic Models

The biological component of the models has the same theoretical framework across regions but differs across species. The main difference across species is that the mud crabs gain some nutrition from provision of supplemental feeds and some from natural productivity in their environment, while the lobsters gain all their nutritional requirements from feeding. Mud crabs would survive in the absence of supplementary feeding (although with lower growth rates than when supplementary feeding is available), whereas the lobsters would not.

It is assumed that mud crab growth conforms to a quadratic growth function as follows (adapted from Jones et al. [2001] to suit local conditions):

$$wMAX = a + bx + cx^2 \quad (1)$$

where *wMAX* is the maximum possible individual mud crab weight (g) given ideal conditions at age x (days), *a* is individual mud crab weight (g) at stocking, and *b* and *c* are parameters that differ across growing conditions in Vietnam. An ideal feeding regime is generally not practical under current socioeconomic conditions in Vietnam[1]. Equation 1 is calibrated for Vietnamese conditions using feed and growth data from the surveys. Actual crab weight at harvest (after 3 to 5 months, depending on the region) and the biomass gain due to feeding conditions is calculated to determine an actual growth function for mud crabs that depends on feed quality and quantity, as shown in Equation 2:

$$W_H = a + bx/d + cx^2/d \quad (2)$$

1 This biological model was chosen as it is the best-fit for mud crab growth as a per-weight measure (for example, compared with logistic, von Bertalanffy and Cobb-Douglas growth models). It is specified as a per-weight measure (rather than length) as the price of mud crab is specified in terms of weight. At the early stages of mud crab growth, it follows a Cobb-Douglas or von Bertalanffy type shape if formulated in terms of time and length. However, it does not contain an asymptote for maximum size or weight. Mud crabs are harvested in Vietnam well before reaching this maximum size or weight. The reader should ensure that the aquaculture cycle fits within the increasing portion of the curve when using this model.

where wH is actual individual mud crab weight (g) at harvest; a, b, and c are as defined for Equation 1; and d is a calibration factor representing crab growth at harvest, depending on feed quantity and quality as follows:

$$d = (wMINh + g_F) / wMAXh \quad (3)$$

where $wMINh$ is individual mud crab weight (g) at harvest in the absence of feeding, $wMAXh$ is individual mud crab weight (g) at harvest given optimal conditions, and g_F is individual mud crab biomass gain due to feeding (g/crab/crop):

$$g_F = q_F / FCR_F \quad (4)$$

where q_F is the quantity of feed provided to the mud crab (g/mud crab/crop) and FCR_F is the feed conversion ratio (wet weight) of the feed. The survey results show that farmers altered q_F three times during the grow-out period as the mud crabs grew. Therefore, three different feeding phases were included in the bioeconomic models.

The total weight of production for mud crab is equal to the total number of surviving crabs (number of stocked juveniles multiplied by the survival rate, both of which are taken from the survey data) at the end of the grow-out period multiplied by crab biomass at harvest.

In the case of lobster, the individual biomass at harvest (W_H) is taken from the survey data. Farmers used four different growth phases (including a nursery phase) to vary the stocking rate (using differently sized cages) and feeding regime (details of which are presented in the results section). The biological model measures biomass gain from each of these phases, w_i, multiplied by the total number of surviving lobsters (number of stocked lobsters multiplied by the survival rate) at the end of each growth phase, N_i. This is summed across each phase to measure total biomass gain at harvest (W_H) as per Equation 5:

$$W_H = \sum_{i=1}^{4} \left(N_i * w_i\right) \quad (5)$$

Biomass gain in phase, wi, is measured by dividing the quantity of feed during growth phase, qFi, with the $FCRi$ (wet weight) of the feed during growth phase, i, as per Equation 6.

$$wi = q_{Fi} / FCR_i \quad (6)$$

As the lobsters grow (between stocking and harvest), stocking rate, feed quantity, and quality were varied. The methodology described above allows for the analysis of different feeding regimes (feeding different quantities of feeds with different *FCRs* and feed prices) on lobster growth, up to a maximum harvest size. The number of lobsters cultured is reduced in each successive phase to account for mortality. The biological component of the bioeconomic model is used to calculate the individual crustacean weight at harvest, given the size of stocked seed, the feeding regime used, and the grow-out period. The size of the lobster and the quantity of feed used are then fed into the economic component of the model.

The Economic Component of the Bioeconomic Model

The economic component of the model was the same across regions and for each species. The annual enterprise gross margin was calculated using a simple net revenue function as shown in Equation 7:

$$NR = TR - TC \quad (7)$$

where:

NR = annualized net revenue (Vietnamese dong, VND);
TR = annualized total revenue (VND); and
TC = annualized total costs (VND)

Total revenue is a function of individual harvest weight and price as shown in Equation 8:

$$TR = W_H * P_H * z \quad (8)$$

where:

W_H = total weight of production (kg);
P_H = farm-gate price, which is dependent on individual weight (VND/kg); and
z = number of crops per year

Total costs are a function of stocking costs and a number of miscellaneous fixed and variable costs as shown in Equation 9:

$$TC = C_{Si} + \sum C_{Fi} + C_L + C_{CP} + C_O + C_I + C_M \quad (9)$$

where:

C_{Si} = seed costs at grow-out phase
i = 1 (VND/yr);
C_{Fi} = feed costs at each grow-out phase
i = 1 to 4 (VND/yr);
C_L = labor costs (VND/yr)
(computed as half the opportunity cost of off-farm labor alternatives);
C_{CP} = cage purchase or pond maintenance costs (VND/yr);
C_O = other costs (VND/yr);
C_I = interest costs (VND/yr); and
C_M = contingency costs for miscellaneous purchases (VND/yr)

Annual seed costs, C_S, are a function of stocking and cage/pond parameters as shown in Equation 10:

$$C_{Si} = SR_i * S_{CP} * N_{CP} * P_S * z \quad (10)$$

where:

SR_i = stocking rate at grow-out phase
i = 1 (individuals/m2/crop);
S_{CP} = average cage or pond area (m2/cage or pond);
N_{CP} = number of cages or ponds;
P_S = price of seed (VND/individual); and
z = number of crops per year

Annual feed costs are a function of the quantity and price of feed for each growth phase as shown in Equation 11:

$$C_F = \sum_{i=1}^{4} Q_{Fi} * P_{Fi} * z \quad (11)$$

where:

Q_{Fi} = quantity of feed at growth phase,
i = 1 to 4;
P_{Fi} = price of feed at growth phase,
i = 1 to 4; and
z = number of crops per year

Capital costs are annualized by dividing the costs by the number of years to replacement.

A benefit-cost ratio (*BCR*) is calculated by dividing total revenue (*TR*) by total costs (*TC*) as shown in Equation 12:

$$BCR = TR / TC \quad (12)$$

This BCR is measured using annual benefits and costs and summarizes the return to investment for the grow-out operation in an average year.

RESULTS

This description of recent changes in the bioeconomics of small-scale lobster and mud crab mariculture farming in Vietnam focuses on the difference in household survey results for tropical spiny lobster and mud crab between 2010 and 2013. It is presented in two parts. A description of the data inputted into the biological models (husbandry, biological, and economic information) is provided in the first part. The results of the bioeconomic model are provided in the second part. Monetary values are provided in nominal United States dollars (USD) which, at the time of data collection, had an exchange rate of USD 1 = VND 19,400 in 2010 and USD 1 = VND 21,200 in 2013.

Description of Recent Changes in the Bioeconomics of Small-scale Lobster and Mud crab Mariculture Farming in Vietnam

Tropical spiny lobster was cultured in floating sea cages in protected bays along the coast of central Vietnam. Very little change was identified over the three-year study period for survival rates of the Puerulus stocked (Table 3). However, the price and size of stocked juveniles had increased, and the stocking density and number of individuals stocked had decreased, all by approximately 20 percent.

In contrast, mud crabs were farmed in inland earthen ponds with substantial differences in stocking practices between central and southern Vietnam. Central mud crab farmers have moved toward significantly larger crablets over the time period, with significantly higher price. They have also intensified their stocking density to stock a larger number of individuals. Southern farmers have moved towards significantly smaller and cheaper crablets over the time period but have increased the stocking density. With a slight decrease in pond size, this has led to a slight decrease in the number of individuals stocked. The survival rates of stocked crablets have increased by approximately five percent for both regions but from a significantly lower

Table 3. Seed, stocking, and survival information

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Cage or pond	Cage		Pond			
Price of seed Puerulus (USD/ individual)	13	16	0.072	0.18	0.035	0.023
Weight of stocked seed (g/individual)	2.5	3.0	13	29	4.0	0.029
Stocking density (individuals/m^3)						
• Nursery phase	94	76	0.40	1.1	0.52	0.55
• Phase 1	15	4.0	0.40	1.1	0.52	0.55
• Phase 2	5	2.3	0.40	1.1	0.52	0.55
• Phase 3	3	1.3	0.40	1.1	0.52	0.55
Number of individuals stocked	2,000	1,600	6,000	10,000	13,000	12,000

base in southern Vietnam (8%) compared with that in central Vietnam (53%).

Lobster farmers had increased the average length of the grow-out cycle by two months, without increasing the number of lobster crops produced each year due to the use of staggered stocking (Table 4). Despite this longer grow-out cycle, the weight of harvested lobsters had decreased. Coupled with a decrease in the number of individuals stocked, this led to a 33 percent decrease in total harvest biomass. The farm-gate price had also decreased by approximately seven percent.

Mud crab farmers had not changed the length of their grow-out cycle significantly, but they had increased the number of crops per year, with some farmers introducing staggered stocking. The weight at harvest of mud crabs in central Vietnam had increased by 77 percent, largely due to improved feeding regimes (discussed further below). Combined with an increase in the number of individuals stocked, this has led to an increase in total harvest biomass in the central Vietnam farms, on which they were able to capitalize with a further 22 percent increase in farm-gate price. Apart from an increase in the average number of crops per year, southern mud crab farmers had not experienced significant changes in either harvest biomass or price parameters.

In general, over the three-year study period, tropical lobster farmers had reduced the number of cages during the earlier grow-out phases and increased the number of cages in the later grow-out phases (Table 5). They had significantly increased the average size of all cages, which they had been able to acquire at relatively lower cost per cage.

The number of ponds used to farm mud crabs was largely unchanged, at two farms in central and one farm in southern Vietnam (Table 6). However, the average individual pond size had halved in central Vietnam. Pond size had slightly increased in southern Vietnam, with a significantly larger increase in cost to prepare and maintain the pond for each harvest.

Table 4. Harvest information

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Average number of crops per year	1.0	1.0	1.5	2.2	2.0	3.5
Length of grow-out cycle (mon)	18	20	3.5	3.7	4.5	4.3
Survival (%)	65	66	53	56	8.0	8.4
Weight at harvest (kg)	1.0	0.85	0.30	0.53	0.32	0.30
Total harvest biomass (kg)	1,300	870	960	3,000	370	310
Farm-gate price (USD/kg)	67	62	6.8	8.3	6.5	5.7

Table 5. Cage information – lobster

	Average number of cages per household		Average size of cage (m^3)		Average cost of cage purchase (USD/cage)		Average time to replacement (yr)	
	2010	2013	2010	2013	2010	2013	2010	2013
Nursery phase	8.4	5.4	2.7	4.1	77	38	5.2	5.0
Phase 1	9.0	7.9	14	52	190	170	5.0	5.0
Phase 2	14	16	16	52	210	170	5.0	5.0
Phase 3	14	24	23	52	240	170	4.5	5.0

Table 6. Pond information – mud crab

	Central		South	
	2010	2013	2010	2013
Average number of ponds per household	2.0	1.9	1.0	1.2
Average individual pond surface area (m^2)	6,300	3,600	20,400	22,000
Average individual depth (m)	1.2	1.1	1.2	1.2
Average individual pond size (m^3)	7,500	3,800	25,000	26,000
Average total pond culture area (m^3)	15,000	7,200	25,000	26,000
Annual pond preperation and maintenance (USD/crop)	96	98	157	350

There had been some notable features in the change in equipment requirements over time (Table 7). On the average, lobster farmers had moved away from the necessity of owning boats and were more likely to acquire lights and pumps to clean the cages. Conversely, the average mud crab farmer had become more likely to acquire a boat, lights, nets, and pumps.

The change in proportion of farmers using various feeds is shown in Table 8. All lobster farmers were still using a combination of low-value finfish and shellfish as feed in all grow-out phases, with no farmers converting to the use of pellets either in whole or part. Central mud crab farmers had increased their use of pellets and shellfish in all phases instead of feeding low-value finfish, although only in grow-out phase 1 did a majority of farmers use pellets. Perhaps, in response to this, the harvest weight and price experienced by central farmers had increased. Southern mud crab farmers were feeding finfish exclusively, with farmers moving into finfish feeding in the nursery phase in 2013 when no feeding was conducted during this phase in 2010.

Table 7. Equipment requirements

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Boats						
• Number	1.0	-	-	1.0	-	1.0
• Cost (USD/item)	1,400	-	-	220	-	110
• Time to replacement (yr)	8.0	-	-	9.4	-	5.2
Diving suit						
• Number	1.0	1.0	-	-	-	-
• Cost (USD/item)	62	8.8	-	-	-	-
• Time to replacement (yr)	4.0	3.0	-	-	-	-
Lights						
• Number	-	2.6	1.7	2.3	-	1.1
• Cost (USD/item)	-	18	10	4.4	-	9.7
• Time to replacement (yr)	-	1.0	1.3	2.1	-	1.0
Diving suit						
• Number	-	-	1.0	1.0	1.0	8.9
• Cost (USD/item)	-	-	1,500	1,600	62	41
• Time to replacement (yr)	-	-	2.4	2.6	2	1.9
Nets						
• Number	-	-	1.0	1.0	1.0	8.9
• Cost (USD/item)	-	-	1,500	1,600	62	41
• Time to replacement (yr)	-	-	2.4	2.6	2	1.9
Pump						
• Number	-	1.0	-	1.4	1.0	1.1
• Cost (USD/item)	-	240	-	390	260	320
• Time to replacement (yr)	-	5.0	-	7.1	7.0	4.8

Table 8. Percentage of farmers using various feeds

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Nursery phase						
Pellets	0	0	18	40	0	0
Finfish	100	100	83	64	0	100
Shellfish	100	100	8	28	0	0
Grow-out phase 1						
Pellets	0	0	28	56	0	0
Finfish	100	100	100	84	73	100
Shellfish	100	100	10	52	0	0
Grow-out phases 2 and 3						
Pellets	0	0	15	40	0	0
Finfish	100	100	98	72	100	100
Shellfish	100	100	10	48	0	0

On the average, in 2013, lobster farmers were using similar feeding rates compared with 2010 (Table 9), but with a much higher calculated feed conversion ratio of 22 compared with 14 (based on feeding quantity and harvest weight). The poorer conversion rate has led to a decrease in the individual biomass weight of harvested lobster (a decrease from 1,000 g to 850 g), despite a two-month increase in the grow-out period.

Central mud crab farmers increased their feeding rates and southern mud crab farmers decreased theirs, with associated impacts on harvest weights (which increased significantly in central Vietnam and decreased slightly in the south). Because it is not possible to measure the amount of food mud crabs are eating from the natural pond environment through survey processes, an FCR of 30 for combined low-value finfish and shellfish diets and 2.0 for pellets were assumed in this analysis (Petersen et al. 2013). Reduced feeding rates by both the lobster and southern mud crab farmers may be due, at least in part, to the 46 percent increase in the average price of low-value finfish (Table 10). In contrast, the average price of low-value finfish increased by a smaller 10 percent for central mud crab farmers (who increased their feeding rates).

The survey included a number of questions about farmers' perceptions of manufactured diets compared with current diets. Overall, farmers indicated that they perceived lobsters to be adaptable to pelleted diets, but that the use of such diets would lead to slower growth rates. They did not know about the relative prices of pelleted diets and current diets, but they did perceive that pellet diets were rarely available and that they were unsure whether they would try them if they were available.

The perceptions among mud crab farmers differed across regions. Central farmers who indicated that they used pellets did so because they were easily available and had fewer environmental impacts. Shellfish and low-value finfish were used by these farmers due to the perceived faster growth rates and lower cost. Overall, farmers in both regions indicated that they perceived that mud crabs had trouble adapting to pellets and that they were more

Table 9. Approximate quantity of feed used (g/crustacean/day)

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Nursery phase						
Finfish/ shellfish	4.0	6.0	1.4	0.54	0.90	0.17
Pellets	-	-	-	-	-	-
Grow-out phase 1						
Finfish/ shellfish	25	20	2.3	8.6	10.9	2.9
Pellets	-	-	-	-	-	-
Grow-out phase 2						
Finfish/ shellfish	35	41	5.4	10	14.9	4.4
Pellets	-	-	-	-	-	-
Grow-out phase 3						
Finfish/ shellfish	45	41	na*	na	na	na
Pellets	-	-	na	na	na	na

Note: na*=not available

Table 10. Prices of feed

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Average price of finfish (USD/kg)	0.54	0.79	0.41	0.45	0.26	0.38
Average price of pellets (USD/kg)	na*	na	na	1.30	na	na

Note: na*=not available

expensive than current diets, although there was a greater level of uncertainty in the south. Central farmers perceived pellets to be readily available but that they would lead to slower growth rates, whereas southern farmers perceived that they are not readily available and they did not know whether they would lead to faster or slower growth rates.

In 2010, crustacean farming was the domain of male household members, which remained the case for lobster and mud crab farmers in central Vietnam (Table 11). However, southern mud crab farming was dominated by female household workers in 2013. A minority of households employed labor for their operations in 2010 or 2013.

In 2010, most lobster farmers borrowed money. However, the high rates of returns that were drawn from these operations then (with a BCR of 2.1) and in the intervening years meant

Table 11. Labor requirements

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Household Labor						
Average number of hhd* members working on the operation	1.6	1.0	1.5	1.7	2.1	1.8
Percentage of hhd members who are male	100	100	83	79	60	38
Total number of days worked per week (for all hhd members)	8.5	7.0	10	8.3	8.0	12
Hired labor						
Percentage of operations that employ hired labor	40	0	1.3	8.0	0	4.0
Average number of hired workers	0.9	na	1.5	1.5	na	2.0
Total number of days worked per week (for all hired workers)	6.3	na	10	11	na	16
Cost of hired personnel (USD/worker/month)	10	na	66	160	na	-

Note: *hhd= household; na= not available

that these farmers could increase their equity and improve their financial position such that they no longer needed to borrow money in 2013 (Table 12). Mud crab farmers had also substantially reduced the amount of money borrowed. However, the proportion of southern mud crab farmers borrowing money had increased to capitalize on significantly reduced interest rates.

Bioeconomic Analysis

The changes in the bioeconomics of tropical spiny lobster and mud crab mariculture from 2010 to 2013 are provided in this section. Total revenue is a function of harvest biomass, farm-gate price, and the number of crops per year. In the case of lobster farming, the average harvest biomass had decreased significantly and, coupled with a decrease in price, had led to a substantial decrease in total revenue (Table 13). In the case of mud crab farming in central Vietnam, harvest biomass had increased significantly and, coupled with a significant increase in price and increase in number of crops harvested each year, had resulted in a significant increase in total revenue. In the case of southern mud crab farming, both harvest biomass and farm-gate price had decreased slightly. However, the number of crops harvested each year had significantly increased, resulting in an increase in gross revenue.

Total costs had increased for both species in all regions, both in terms of total costs and costs per unit production, with the exception of central mud crab farmers who have experienced constant costs per unit of production (not adjusted for CPI). The dominant cost sources for lobster farming were seed and feed. While

Table 12. Credit information

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Households that borrowed money (%)	83	0	25	32	28	56
Amount of credit borrowed (USD/crop)	11,000	na	1,200	46	610	280
Average interest rate (%/month)	1.0	na	1.3	1.0	4.4	1.7

Note: na*= not available

seed costs had decreased as a proportion of total costs, feed costs had increased in proportion due to poorer FCRs and higher feed costs. Feed and seed were also the dominant cost sources for central mud crab farmers due to increases in both price and quantity of feed and seed used. Southern farmers employed low feeding rates, hence the dominant cost sources for these farmers were labor, pond maintenance (which increased as a proportion of total costs due to increased prices), and seed costs (which decreased as a proportion of total costs due to reduced prices and quantities used).

The combined impacts of changes in biomass size and prices had led to a significant decrease in net revenue for lobster farmers and southern mud crab farmers and an increase in net revenue for central mud crab farmers. However, for both species in all regions, these operations remained very profitable with BCRs above 1.2, which indicates a minimum of a 20 percent return of money spent. Removing the cost of household labor had little impact on this return on investment.

DISCUSSIONS AND CONCLUSIONS

Tropical spiny lobster and mud crab grow-out mariculture remains strongly economically viable in Vietnam, despite significant changes in the bioeconomic environment from 2010 to 2013. The most notable changes to the grow-out of tropical spiny lobster were a substantial decrease in harvest biomass due to decreased stocking densities and poor feeding techniques. Our results suggest an increase in the FCR of these farms from 14 to 22, which may be a result of decreased feed management, poorer feed quality, poorer stock quality, or a combination of all. However, the greatest level of uncertainty shown by the farmers surveyed was on the quantity of feed used. Hence, this increase in FCR may be reflecting inaccuracies in the data provided. It certainly shows that farmers did not carefully measure or record the feed quantities used. This is an area for potential improvement of these systems, especially given that feed costs are approximately 30 percent of total costs.

Mud crab farming has exhibited significant changes through time, and these changes were quite different for farmers in central and southern Vietnam. In central Vietnam, almost all key variables had exhibited significant increases. These included seed size and stocking density, which has led to a significant increase in the number stocked and harvest biomass. The number of crops per year had also increased with the growing adoption of staggered stocking. Notably, farmers had increased their adoption of shellfish and pellets in their feeding regimes, as well as increased feed quantity per crab. These increases in management parameters led to substantially improved economic performance parameters.

Table 13. Annual economic statistics (USD/year unless stated otherwise)

	Lobster		Mud crab			
	Central		Central		South	
	2010	2013	2010	2013	2010	2013
Total revenue	86,000	54,000	9,700	54,000	4,400	7,300
Total cost	42,000	46,000	2,700	11,500	2,300	6,100
Total cost/kg production	33	53	1.9	1.8	3.4	4.8
Cost structure (% total cost)						
• Seed	61	54	24	35	40	19
• Feed	24	36	25	44	7	11
• Labor	3	1	10	7	28	39
• Cage/pond cost	3	4	5	2	14	20
• Other costs	1	0	28	7	6	5
• Interest	5	0	0	0	0	1
• Contingency	5	5	5	5	5	5
Net revenue	44,000	7,900	7,000	43,000	2,1000	1,200
BCR*	2.1	1.2	3.6	4.7	1.9	1.2
BCR: no household labor costs	2.1	1.2	4.0	5.1	2.7	2.0

Note: BCR= benefit-cost ratio

The prices of both seed and feed had increased as had the farm-gate price. Significant increases in harvest biomass capitalized on the increase in farm-gate price to provide a significant increase in total revenue. The increase in total revenue was proportionally greater than the increase in total costs, leading to an increase in the BCR.

The bioeconomic environment of mud crab farming in the south had not experienced such dramatic change over time. The most substantial changes included a large decrease in the size of crablets stocked and an increase in the number of crops per year with the adoption of staggered stocking by some farmers. This had led to an overall small decrease in harvest biomass. Southern mud crab farmers significantly reduced their use of pellets and shellfish in favor of low-value finfish, significantly reducing feeding quantities (although, again, this was a matter of significant uncertainty by farmers when providing feed quantity information). Overall, the smaller seed, coupled with reduced feeding rates and poorer feed quality, led to decreased harvest biomass and therefore reduced profits. However, these profits and the BCR were not drastically reduced, thanks to the increase in the number of crops per year.

Overall, these findings highlight the potential for improvement in seed management and feeding regimes in Vietnam's lobster and crab mariculture industry. There remains significant scope for increasing the size and quality of seed used, based on availability and affordability, for lobster and mud crab grow-out mariculture. Similarly, there remains significant scope for optimization of feeding rates and improving feeding quality. The uncertainty regarding feed quantities used by farmers highlights the potential for improving precision techniques of feeding to improve FCRs.

These findings highlight some clear implications for aquaculture policy, management, and research prioritization. The dominant cost sources are feed and seed, so efficiency gains in these areas are likely to be especially effective for improving economic viability. There is also significant room for providing policy and management incentives for encouraging practice change from low-value finfish to pelleted diets. This change is likely to lead to improved growth rates, fewer problems with parasites and diseases, fewer environmental problems, and more stable water quality. With help through extension services and improved feeds, the FCRs can be significantly reduced to allow significant economic benefits.

Survey results show a strong need to improve farmers' perceptions regarding the benefits of pelleted diets. Perceptions regarding the availability of pellets and the adaptability of lobsters and crabs to eating pellets were mixed. Most farmers incorrectly perceived that these diets would lead to slower growth rates but evidence from this study presents the contrary — that use of pellet feeding resulted in improved growth rates. Extension and education about the best practice in the use of pellets and their short- and long-term benefits are likely to have significant positive impacts on the long-term economic viability and environmental quality of mariculture farming in Vietnam, while protecting wild fish stocks.

Policy, research, and extension initiatives that encourage the widespread availability of hatchery-produced seed of good quality is likely to allow farmers to increase the number of seed stocked, increase survival rate, and therefore increase harvest biomass. If this can be achieved at low cost, it will enable economic viability of lobster and crab mariculture in Vietnam to thrive, while again protecting wild fish stocks, in the long-term.

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