A Case Study on Mud Spiny Lobster (*Panulirus polyphagus* Herbst, 1793) Farming in Sea Cages: Insights from Farmers in Southern Thailand

Vutthichai Oniam*, Rungtiwa Konsantad, Wasana Arkronrat and Chonlada Leearam

ABSTRACT

Currently, marine crustacean aquaculture production is high in Asia; however, mud spiny lobster (*Panulirus polyphagus*) production has been slow. Therefore, gaining more knowledge about mud spiny lobster farming and cultivation management is imperative. This study aimed to bridge this knowledge gap by investigating farmers' activities and environmental factors related to farming, focusing on their impact on mud spiny lobster growth and utilization. The study was conducted in 3 locations, namely Ban Chong Lad, Ban Khao Thong, and Ao Nao areas in southern Thailand from April 2022 to February 2023. The study revealed that three spiny lobster species were cultured in these areas. *Panulirus ornatus* had the highest percentage, followed by *P. polyphagus*, with *P. vesicolor* being the least common. The supply chain started with wild seed procurement from collectors, with juveniles cultured in sea cages for 3–5 months for *P. polyphagus* or over a year for *P. ornatus* and *P. vesicolor*. Most lobsters were sold live to Thai and foreign tourists. The growth monitoring of *P. polyphagus* revealed a significant impact of density on growth. Lobsters in Ao Nao, which were stocked at lower density, had higher body weight and growth rate compared to those in Ban Khao Thong and Ban Chong Lad. Notably, regular supplementation with fresh mussels seemed to promote better growth in Ao Nao. Meanwhile, water quality parameters (salinity, pH, dissolved oxygen, and temperature) did not appear to affect the growth of this lobster species across areas. This information provides valuable insights for optimizing mud spiny lobster cultivation practices in sea cages.

Keywords: Lobster farming, Mud spiny lobster, *Panulirus polyphagus*, Sea cage cultivation

INTRODUCTION

Aquaculture is among the fastest-growing economic sectors in the world. Today, Asia contributes about 90% of the total global aquaculture production. Marine crustaceans are one of the world's most valuable sources of seafood, including shrimps, crabs, and lobsters (FAO, 2022). The mud spiny lobster *Panulirus polyphagus* (Herbst, 1793) is an important commercial marine crustacean species. Its distribution spans the coastal waters of tropical regions from the eastern Indian Ocean to the Pacific Ocean. There is high demand for mud spiny lobster for both local consumption and export in many Asian countries (Phillips and Smith, 2006; Radhakrishnan *et al*., 2019). In 2020, fishery trends showed that lobster catches had declined marginally from the recorded peak catches (FAO, 2022). Currently, while the demand for seafood is notably increasing, natural marine resources are decreasing due to overexploitation and habitat destruction. These threats affect all aquatic animal species, including the mud spiny lobster (Radhakrishnan *et al*., 2019). It has been reported that the majority (95.5%) of spiny lobsters *Panulirus* spp.) caught by trawling are either dead or die while being caught (Nitiratsuwan *et al*., 2017). Promising solutions to address this issue include restocking existing fisheries and developing the aquaculture of this species.

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In Thailand, there is a growing interest in mud spiny lobster aquaculture due to increasing demand and a decrease in the native supply. Research and development in this field are focused on two main sectors: utilizing natural resources for cultivation and developing breeding and nursing technologies. The goal is for hatchery technology to provide the required seed equivalent to that from natural supply (Oniam *et al*., 2021; Konsantad *et al*., 2023).

While many countries are interested in mud spiny lobster aquaculture, only a few have successfully farmed them for market due to challenges in securing a seed supply and technical difficulties in sustaining them (Francis *et al*., 2014; Ikhwanuddin *et al*., 2014; Fatihah *et al*., 2016). Currently, cultivation is limited to grow-out activities, especially fattening in floating cages, with seed or juvenile lobsters sourced from natural waters (Solanki *et al*., 2012; Jones *et al*., 2019). This reliance on wild catches is a major obstacle to commercial mud spiny lobster aquaculture development.

To improve the income generated from mud spiny lobster cultivation, it is essential to gain a deeper understanding of farmers' activities and cultivation practices. One key aspect is to focus on gathering more knowledge on how farmers utilize mud spiny lobster and manage their cultivation processes. Additionally, a crucial step is gaining this knowledge is to study the environmental conditions in which mud spiny lobsters are typically grown, particularly in sea cages. This study aims to investigate the current status of mud spiny lobster rearing in sea cages, with a specific focus on farmers' activities and the key environmental factors that impact growth, production, and utilization. By understanding these factors, we can enhance the efficiency and sustainability of mud spiny lobster aquaculture. Ultimately, this will contribute to the economic development of the aquaculture industry in the region.

MATERIALS AND METHODS

Study area

Field studies were conducted in three study areas, namely Ban Chong Lad, Phang Nga province (8º04´N 98º34´E), Ban Khao Thong, Krabi province (8º10´N 98º44´E) and Ao Nao, Krabi province (8º61´N 98º37´E), all in southern Thailand (Figure 1).

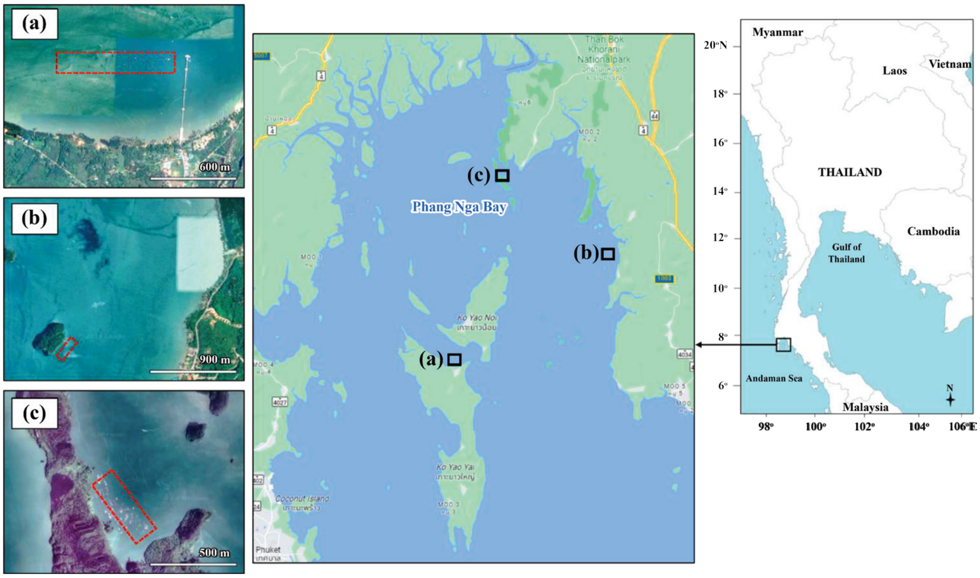

Figure 1. Map of study areas depicting sea cage cultivation sites for mud spiny lobster (*Panulirus polyphagus*): (a) Ban Chong Lad, (b) Ban Khao Thong, and (c) Ao Nao areas.

Data collection

First, quantitative data (e.g., the number of animals, their size, weight, growth, production, and water quality parameter) on mud spiny lobster cultivation in sea cages were collected for the three study areas (three cages per farmer and three farmers per area, n = 9 cages per area). Qualitative data (baseline data and supply chain of mud spiny lobster cultivation) were collected through in-depth interviews, focus group discussions, participant and non-participant observations, and a structured questionnaire given to the owners of lobster farms, lobster fishers, lobster wholesalers (intermediaries), and stakeholders. Both data was collected during April 2022 to February 2023.

As part of the cultivation dataset collected, spiny lobster species in the farmers' cages were identified based on morphological characteristics in existing reference information (Carpenter and Niem, 1998). Each mud spiny lobster was measured for carapace length (CL, in mm), and body weight (BW, in g). The CL was measured using a ruler, recording the distance along the dorsal midline from the transverse ridge between the supra-orbital horns to the posterior end of the cephalothorax. The BW was measured using a set of digital weighing scales to weight the whole animal. The random samples consisted of 10% of the mud spiny lobsters from three cages culture per farmer and three farmers per area. Individuals were collected using a hand net and subsequently were evaluated for their growth at the initial and final stages of culture. At the end of the rearing period or before harvest, each lobster was weighed and measured to assess its final CL and BW. The absolute growth (AG), average daily growth (ADG), and specific growth rate (SGR) were calculated according to the formulas (Amin *et al*., 2020):

$$AG\ (g) = Mf - Mi$$

$$ADG\ (g \cdot day^{-1}) = (Mf - Mi) / t$$

$$SGR\ (\% \cdot day^{-1}) = 100 \times [\ln(Mf) - \ln(Mi)] / t$$

where Mi and Mf are the mean initial and final individual masses, respectively, and t is the growth periods in days.

In addition, during culture in sea cages, some water quality parameters (e.g., salinity, pH, dissolved oxygen, and temperature) were monitored once a month. Salinity was determined using a refractometer (Master-S10 alpha; Atago, Japan) and the pH of the water was measured using a portable pH meter (pH Testr30; Eutech; Singapore). The dissolved oxygen concentration (DO) and the temperature of the water were measured using an oxygen probe (Pro20i; YSI; USA). Water samples were collected at a depth of about 1 meter below the water surface using a vertical type water sampler (GEM 420-SS; T.Science; Thailand).

Data analysis

The collected data were consolidated and tallied in a spreadsheet and consequently analyzed using a statistical software package. The simple mean and percentage were the main descriptive statistics used to estimate the qualitative data. In addition, the data on growth and environmental factors (salinity, pH, DO, and water temperature) among the three study areas were tested using one-way ANOVA, and differences between means were tested using Duncan's multiple range test at the 95% level of confidence. All data were analyzed using the IBM SPSS Statistics for Windows software (version 21.0; IBM Corp.; Armonk, NY, USA).

RESULTS

Status of mud spiny lobster utilization for cultivation

In the present study, data were collected from key informants, including 8 mud spiny lobster farmers (owners), 3 lobster fishers, and 3 lobster wholesalers. These informants were surveyed through in-depth interviews, focus group discussions, and a questionnaire survey. The questionnaire survey involved 45 stakeholders, including representatives of the spiny lobster farmers, fishers, spiny-lobster seed collectors, and related agencies. However, only 36 respondents were achieved.

The results showed that all spiny lobster being cultivated in sea cages were initially collected from the wild by fishers and then reared until they reached a marketable size. The lobster species reared by the farmers comprised 64.0% ornate spiny lobster (*Panulirus ornatus*), 34.3% mud spiny lobster (*P. polyphagus*) and 1.7% painted spiny lobster (*P. versicolor*). Notably, in the Ao Nao area, mud spiny lobsters accounted for 96.0% of the reared lobsters (Figure 2).

The descriptive statistics for mud spiny lobster cultivation are summarized in Table 1. The data indicate that 95.5% of the spiny lobster farms used integrated aquaculture systems, where cages for spiny lobster (*Panulirus* spp.) were set up within the same floating frames as those for economic marine fish, such as Asian seabass (*Lates calcarifer*), groupers (*Epinephelus* spp.), and cobia (*Rachycentron canadum*). The remaining 4.5% of farms used a monoculture system, exclusively cultivating spiny lobsters (*Panulirus* spp.) in cages. Medium-sized farms, with 16–30 cages, accounted for 63.6% of the total number of farms. Large farms (with 31–45 cages) and small farms (with fewer than 15 cages) each made up 18.2% of the total. Most farmers (72.7%) used a standard cage size of 2.5×2.5×2.5 m (width×length×height) for rearing mud spiny lobsters. Additionally, 45.4% of the farmers raised lobsters at an initial density of 20–30 lobsters·cage^{-1}.

The mud spiny lobster was fed with trash fish and live mussels. The primary feed during the grow-out period was trash fish, with live mussels (specifically the green mussel, *Perna viridis*, and the horse mussel, *Arcuatula senhousia*) used as alternative feed when trash fish supplies were depleted. The trash fish were chopped into small pieces before being fed to the lobsters. Feeding was carried out once a day, with the total feed amounting to approximately 500 g per day for every 20–25 lobsters (only trash fish). Live mussels used for mud spiny lobster feed were obtained from the net cage area of marine fishes around the site; however, the farmers did not record the quantity of mussels utilized. The rearing period lasted 3–4 months, by which time the lobsters typically reached an average weight of 300 g each (but not exceeding 500 g). Rearing a lobster to a size greater than 500 g could take up to 10–12 months. The study found that the main challenges associated with mud spiny lobster farming in the study areas included a scarcity of spiny lobster juveniles, and an inability to produce juveniles locally, necessitating supplementary juvenile supply from outside the area. This led to increased costs, with production expenses being directly proportional to both the seed price and the time required for cultivation.

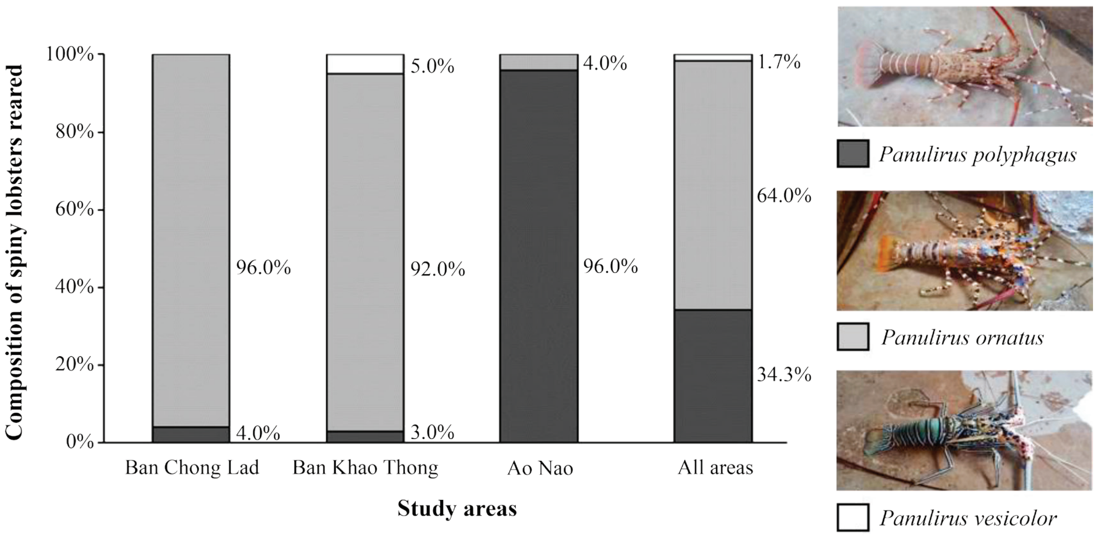

Figure 2. Mean percentage composition of spiny lobsters (*Panulirus* spp.) species reared in sea cages in each study area, and in total for all study areas.

Table 1. Mud spiny lobster (*Panulirus polyphagus*) cultivation in each study area.

Items	Number of lobster farms (% of lobster farms)			Mean (%)
	Ban Chong Lad	Ban Khao Thong	Ao Nao	
Types of cultivation				
Sea cage culture	6 (100%)	4 (100%)	12 (100%)	100
Others	-	-	-	-
Farm cultivation system				
Monoculture	-	1 (25.0%)	-	4.5
Integrated aquaculture	6 (100%)	3 (75.0%)	12 (100%)	95.5
Farm size (No. of cages·farm^{-1})				
Small (≤15)	2 (33.3%)	2 (50.0%)	-	18.2
Medium (16–30)	4 (66.7%)	-	10 (83.3%)	63.6
Large (31–45)	-	2 (50.0%)	2 (16.7%)	18.2
Cage size (width×length×height)				
2.5×2.5×1.5 m	2 (33.3%)	-	-	9.1
2.5×2.5×2.5 m	4 (66.7%)	2 (50.0%)	10 (83.3%)	72.7
3.0×3.0×3.0 m	-	2 (50.0%)	2 (16.7%)	18.2
Initial density (lobsters·cage^{-1})				
20–30	-	-	10 (83.3%)	45.4
31–50	1 (16.7%)	3 (75.0%)	2 (16.7%)	27.3
>50	5 (83.3%)	1 (25.0%)	-	27.3
Culture period of mud spiny lobster				
3–5 months	-	-	10 (83.3%)	45.4
5–7 months	6 (100%)	4 (100%)	2 (16.7%)	54.6

Note: data from field surveys during April 2022 to February 2023.

Growth of mud spiny lobster reared in sea cages

One notable disparity in farming practices among the studied areas was the stocking densities. Specifically, the stocking density was 4.7±1.4 individuals·m^{-2} for Ban Chong Lad, 2.6±0.7 individuals·m^{-2} for Ban Khao Thong, and 1.7±0.2 individuals·m^{-2} for Ao Nao. In terms of growth performances, due to the varying initial sizes of the animals among the areas (Table 2), only ADG and SGR could be used for growth comparison. It is interesting to note that despite the slightly smaller initial size of the animals in Ao Nao compared to Ban Chong Lad, the mean ADG and SGR of the spiny lobster reared at Ao Nao were significantly higher. Furthermore, the spiny lobster in Ban Khao Thong which had the smallest initial size, showed a better growth rate, specifically in terms of SGR, compared with Ban Chong Lad. This suggests that factors other than initial size (e.g., stocking density) may be influencing the growth performance of the spiny lobsters in these different farming areas.

Environmental factors

The water quality parameters measured during mud spiny lobster culture in sea cages in Ban Chong Lad, Ban Khao Thong and Ao Nao indicated that the mean water salinity levels for Ban Chong Lad and Ao Nao were not significantly different; however, these two areas had significantly lower mean water salinity levels than for Ban Khao Thong. The mean DO and pH levels for Ban Chong Lad which were significantly higher than for Ban Khao Thong and Ao Nao. The mean water temperatures were not significantly different among the three areas (Table 3).

Mud spiny lobster production and supply chain

At the study sites, crab gill nets and fish traps were common fishing gear used to catch the lobsters. The fishers preferred to use gill nets to catch the lobsters in fishing grounds of the Andaman Sea. About more than 50% of the lobster catch consisted of juveniles of about 150–200 g in size, for which, the selling price to the lobster farmers was THB 100–150 individual^{-1} (approximately 35 THB = 1 USD in 2022) or about THB 400–600 kg^{-1}. Specimens grown in a sea cage to a marketable size of about 400 g have a sale price to the consumer of THB 500–600·individual^{-1} or about THB 1,100–1,200 kg^{-1}.

The marketing mechanism of mud spiny lobster farmers included both wholesaler and direct sales to consumers, with 80% of consumers being Thai tourists and 20% being foreign tourists. The main markets of mud spiny lobster farmers were located in various tourist provinces of Thailand, such as Phuket, Krabi, Phang Nga, Surat Thani (Koh Samui) and Prachuap Khiri Khan (Hua Hin), as well as in Bangkok. The supply chain of the case study, related stakeholders and their roles are illustrated in Figure 3.

Notably, farmers faced significant challenges during the COVID-19 pandemic. The reduction in Thai and foreign tourists, along with a slowdown in exports, compounded by decreased domestic market buying power due to lockdown measures, severely impacted the supply chain.

Table 2. Growth (mean±SD) of mud spiny lobster (*Panulirus polyphagus*) reared in sea cages after 6 months of culture period.

Parameter	Study area		
	Ban Chong Lad, Phang Nga province	**Ban Khao Thong, Krabi provinces**	**Ao Nao, Krabi provinces**
Initial CL (mm)	61.2±5.2^{b}	61.2±5.2^{b}	61.2±5.2^{b}
Initial BW (g)	180.2±40.5^{b}	180.2±40.5^{b}	180.2±40.5^{b}
Final CL (mm)	81.4±4.5^{a}	81.4±4.5^{a}	81.4±4.5^{a}
Final BW (g)	430.2±52.3^{ab}	430.2±52.3^{ab}	430.2±52.3^{ab}
ADG (g·day^{-1})	1.39±0.08^{a}	1.39±0.08^{a}	1.39±0.08^{a}
SGR (%·day^{-1})	0.48±0.02^{a}	0.48±0.02^{a}	0.48±0.02^{a}

Note: Means within row with different lowercase superscripts are significantly ($p<0.05$) different.

Table 3. Water quality (mean±SD) during 6 months of mud spiny lobster (*Panulirus polyphagus*) cultivation in sea cage farms.

Parameter	Study area		
	Ban Chong Lad, Phang Nga province	**Ban Khao Thong, Krabi provinces**	**Ao Nao, Krabi provinces**
Salinity (psu)	28.5±0.9^{a}	30.2±1.5^{b}	28.0±1.5^{a}
DO (mg·L^{-1})	6.5±0.1^{a}	5.8±0.6^{b}	5.4±0.6^{c}
Water temperature (ºC)	29.3±0.2^{a}	29.3±0.3^{a}	29.2±0.3^{a}
pH	8.0±0.6^{b}	7.6±0.1^{a}	7.7±0.3^{a}

Note: Means±SD within each row superscripted with different lowercase letters are significantly ($p<0.05$) different.

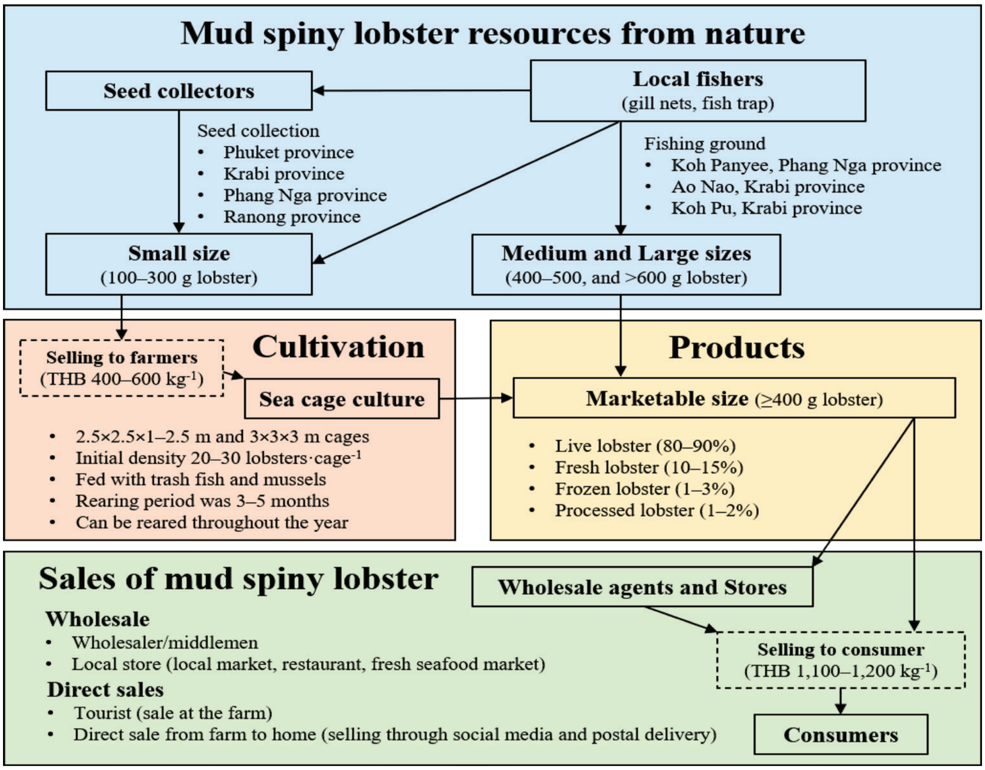

Figure 3. Mud spiny lobster (*Panulirus polyphagus*) production and supply chain for this study.

DISCUSSION

The spiny lobster species cultured in the study areas are similar to those widely cultured in tropical Asian countries such as Vietnam, the Philippines, India, and Indonesia (Mojjada *et al*., 2012; Ikhwanuddin *et al*., 2014; Fatihah *et al*., 2016; Jones *et al*., 2019). These species were selected mainly due to the availability of juveniles, which are procured from natural habitats. *Panulirus ornatus* outnumbers the other species in the study area and, along with *P. versicolor*, receives high consumer preference due to its attractive color and thus they demand high retail price (2–3 times that of *P. polyphagus*). However, *P. ornatus* and *P. versicolor* require a longer culture period (about 1–1.5 years) due to its larger marketable size (>1 kg), whereas *P. polyphagus*, with a smaller market size (around 400–450 g), reaches market size in only 4–6 months. This makes *P. polyphagus* the second most popular species cultured after *P. ornatus*. *P. versicolor* is the least cultured species despite its popularity among consumers, primarily due to the limited natural seed supply.

Based on the mud spiny lobster supply chain in the present case study, farmers faced significant challenges during the COVID-19 pandemic. The decrease in Thai and foreign tourists and the slowdown in exports, combined with reduced domestic market buying power due to the lock-down measures, mirrored issues seen with other economically important aquatic animals such as blue swimming crab (*Portunus pelagicus*) (Kongsup and Ongkunaruk, 2022), black tiger shrimp (*Penaeus monodon*) and giant freshwater prawn (*Macrobrachium rosenbergii*) (Bashar *et al*., 2022). Price of mud spiny lobsters fluctuate based on demand, supply, quality and quantity. Ensuring the supply chain structure and traceability is crucial for successfully bringing the product to the consumer (Elfiana *et al*., 2022).

In the present study, after approximately 6 months of mud spiny lobster cultivation in sea cages, it was observed that lobster density in the cage influenced the growth of the reared lobsters whereby the growth decreased when the density of lobsters stocked per unit area increased. The results obtained from the present study were similar to those reported by Solanki *et al*. (2012), where the density of *P. polyphagus* culture in cages at 1 lobster·m^{-2} resulted in better weight gain and growth rate than at a density of 2 lobsters·m^{-2}. Subhan *et al*. (2018) reported that *Panulirus* culture in tank at densities of 10 and 18 lobsters·m^{-2} showed better levels for BW, CL, SGR, and FCR than at a density of 26 lobsters·m^{-2}. Sakthivel *et al*. (2014) reported that rearing 70–80 g BW *P. homarus* at a density of 25 lobsters·m^{-2} resulted in a survival rate of 80% and Wahyudin *et al*. (2017) reported that rearing *P. polyphagus* in a cage at a density of 100 lobsters·m^{-2}, produced a survival rate in the range 60–75%.

In addition, the lobsters in the Ao Nao area were regularly supplemented with live mussels (*Perna viridis* and *Arcuatula senhousia*) once a week whereas no supplementation was provided in the other areas (only mussels were fed as alternative food source only when the amount of trash fish was insufficient). Previous reports revealed that live mussels were more suitable as feed for lobster than other feeds (Thomas *et al*., 2000), which may be because of better protein digestibility as compared to fish protein (Williams, 2007). Therefore, the rearing factors, such as the release rate and feed type, should be considered by farmers cultivating lobsters in cages where the aim is to increase productivity. Knowledge and information regarding favorable environmental conditions for sea cage systems are critical to develop mud spiny lobster cultivation in the future.

For the environmental factors, the levels for salinity, DO, and water temperature in each area fall within a suitable range previously reported (e.g., salinity ≥25 psu, Vidya and Joseph, 2012; DO ≥5 mg·L^{-1}, Mojjada *et al*., 2012; water temperature in the range of 22–31 ºC, Jones *et al*., 2019). However, water pH in the study areas (7.6±0.1–8.0±0.6) was slightly lower than a suitable pH and pH range of 7.8–8.2 recommended for spiny lobster culture (Mojjada *et al*., 2012). The low pH may be due to heavy rain fall during monsoon season (October 2022–January 2023) which both directly lowered pH of sea water. Additionally, less direct sunlight during that period decreases photosynthesis of phytoplankton and water plants and thus hampers pH enhancement (Yang *et al*., 2020).

CONCLUSIONS

This study revealed that three species of spiny lobster were cultured in the study area. The highest percentage was *Panulirus ornatus*, followed by *P. polyphagus*, while *P. vesicolor* was the least common. The supply chain of spiny lobster in these areas started with procurement of seed from seed collectors and a minority from fishers. Then, the juveniles were cultured in sea cages for 3–5 months for *P. polyphagus* or >1 year for *P. ornatus* and *P. vesicolor*. Almost all of the products were sold live to Thai and foreign tourists.

The growth monitoring study of mud spiny lobster (*P. polyphagus*) in the three areas revealed a significant impact of density on the growth. Lobsters raised in the Ao Nao area exhibited higher growth rates compared to those in Ban Khao Thong area. Farmers in Ao Nao released fewer lobsters per cage compared to those in Ban Khao Thong and Ban Chong Lad areas. Notably, regular supplementation of fresh mussels seemed to promote better growth rate in Ao Nao area. Meanwhile water quality parameters were not significantly different across areas.

This is the first report on the status of spiny lobster culture in Thailand. Further studies are required since this business is defined as “high risk-high profit” with several risks the farmers would encounter, as reported in other countries such as Vietnam, including availability of seeds, devastating diseases, and risk from live feed, among others (Petersen and Phuong, 2010). Further in-depth studies throughout the supply chain will benefit the sustainability of this business.

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