Size Selection of Short-necked Clam (*Paphia undulata*) Dredge in Thai Waters: An Application of Selectivity Model to Improve the Fishery Management

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ABSTRACT

The short-necked clam (*Paphia undulata*) has been a commercially important marine species throughout the Indo-Pacific region for centuries. Recently, the sieve sizes of the short-necked clam dredge still need to be reconsidered by fishery managers and stakeholders to ensure the sustainability of this resource. This study aimed to (i) review the short-necked clam fisheries in Thailand, (ii) apply a parametric selectivity model to the short-necked clam dredge, and (iii) assess the catches to determine the suitable sieve size based on size selectivity, maturity size, and marketable size. This study reviewed and analyzed secondary data, including fishery statistics, fishing gears and operations, short-necked clam dredge experiments, and information on maturity and marketable sizes. Our findings indicated that short-necked clam fishery in Thailand dates back to the 19th century, evolving from hand-collecting to dredging by fishing vessels both in the Gulf of Thailand and the Andaman Sea. The parametric model was applied to three different sieve sizes (8 mm, 10 mm, and 12 mm) to enhance the precision of size selectivity estimation. The results revealed that the shell length selectivity of the short-necked clam dredge was 26.0 mm, 30.0 mm, and 36.5 mm for the 8 mm, 10 mm, and 12 mm sieve sizes, respectively, with an estimated selection factor of 3.20. The catch assessment demonstrated that a 10 mm or larger sieve size is optimal for reducing the capture of immature and unmarketable short-necked clams and supporting effective fishery management and sustainable resource utilization.

Keywords: Clam dredge, Marketable size, Maturity size, Short-necked clam, Size selectivity, Thai waters

INTRODUCTION

The short-necked clam (*Paphia undulata*) is a bivalve species in the Family Veneridae. Jindalikit (2000) reported that the ultimate size (L_∞) of this species was 59 mm in shell length (SL), and the maturity size was greater than 31 mm in SL for both females and males at 10–13 months. This species is distributed in the coastal areas of the Indian Ocean and the western Pacific Ocean (AquaMaps, 2019). As a fisheries resource, the short-necked clam is commercially important in Thailand (Supongpan and Jindalikit, 2005; Morillo-Manalo and del Norte-Campos, 2010) and other countries in the Indo-Pacific Region, including Malaysia, Philippines (Morillo-Manalo and del Norte-Campos, 2010), Egypt (Mahmoud and Yassien, 2023), Japan, and Australia (Nateewathana, 1995).

The short-necked clam fishery in Thai waters was first recorded in the early 19th century through hand collecting and diving (Chanrachkij, 2013); then, the short-necked clam dredge operated by fishing vessels in Thailand was introduced (DOF, 1969a) to the fishing grounds in the upper and eastern Gulf of Thailand (DOF, 1969b). Later, the

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fishing grounds expanded nationwide in the Gulf of Thailand and the Andaman Sea (Chanrachkij, 2013). The structure of the short-necked clam dredge operating in Thailand is mainly composed of the mouth opening or entrance, rakes or teeth, and a body with slits, grids, or sieves (DOF, 1969b; SEAFDEC, 2004; Chanrachkij, 2013). The averaged (mean±SD) annual short-necked clam production in Thai waters between 2017 and 2021 was 11,068± 6,845 t with a value of USD 20.49±12.17 million; wherein, the production was mainly from short-necked clam dredges operated in the Gulf of Thailand (DOF, 2021).

For short-necked clam dredge management, Thailand has considered the over-exploitation of fisheries resources, including bivalve species; consequently, the country first enforced the regulations on clam dredge fishery in 1974 by establishing prohibited fishing areas for all bivalve dredges operated by fishing vessels in Thai waters (MOAC, 1974; 1975). The prohibited fishing areas limited the commercial utilization of marine bivalve resources by dredge fishing in some areas for sustainable fisheries as well as for preventing negative impacts on other species in coastal areas. Later on, the management measures were occasionally modified from time to time based on available scientific data (e.g., fishing efforts, catchability, gear selectivity, biological parameters) and resource status. The sieve size or grid size (gap between two bars or bar spacing) of the short-necked clam dredge, hereafter denoted as sieve size, has been regulated since 1985 for capturing short-necked clams by dredge with a sieve size equal to or greater than 12 mm for the purpose of allowing small-sized short-necked clams to escape (Charuchinda, 1990). This regulation has been supported by the study of Charuchinda (1990) on suitable sieve size for short-necked clam dredges using the available biological and socio-economic information at that time.

The management measures have been revised and implemented in 1990 to enhance the sustainable utilization of fisheries resources concerning the fishing area, fishing vessel, and fishing gear for short-necked clam dredge fishery (MOAC, 1990). For the current regulations of short-necked clam dredge fishery using fishing vessel, the fishing area should be offshore (more than 3 nm from the shoreline); the fishing vessel should not exceed 18 m in length overall (LOA); and the dredge should have an entrance width equal to or less than 3.5 m and a sieve size equal to or greater than 12 mm (MOAC, 2017). Although fisheries stakeholders (i.e., dredge fishers) comply with the sieve size regulation, the fishers have requested that the sieve size regulation should be reconsidered to 7 mm or 9 mm to utilize short-necked clam resource before the natural mortality caused by run-off from rivers to the sea, particularly from the Bang Pakong, Chao Phraya, Tha Chin, and Mae Klong Rivers (Supongpan and Jindalikit, 2005). Consequently, specific spatial and temporal management measures in the Upper Gulf of Thailand have been provided for fishing trials during 2018–2021 (MOAC, 2018; 2019), and some studies have been carried out to reconsider the optimum sieve size of the short-necked clam dredge. However, the results of previous trials or studies have not directly addressed the fishing gear selectivity of short-necked clam dredge (DOF, unpubl. data), and the sieve size regulation has been considered and maintained at equal to or greater than 12 mm (MOAC, 2025). Given environmental changes and fishing capacity improvement as well as the present utilizaition of resources that may impact the fisheries biology and abundance of the short-necked clam, it is necessary to review and update the size selectivity of the short-necked clam dredge. This study is crucial to support effective fishery management and ensure the sustainable utilization of the short-necked clam resource.

The objectives of this study were to (i) review the short-necked clam fishery in Thailand, (ii) apply a parametric selectivity model for improving the size selection method of the short-necked clam dredge fishery in Thai waters, and (iii) assess the catches of three different sieve sizes of short-necked clam dredge to determine the suitable sieve size based on size selectivity, maturity size, and marketable size for supporting fishery management. The outcome of this study is intended to support dredge selectivity for effective fishery management and contribute to responsible fisheries using the appropriate fishing gear for sustainable resource utilization, considering stakeholder benefits and socio-economic implications. Moreover, this study

was conducted to correspond to the Action Plan on Marine Fisheries Research for 5-Year Period (2023–2027) of the Marine Fisheries Research and Development Division (2021) as well as to the Sustainable Development Goals (SDGs) of the United Nations (2024), specifically in research and development on technology and innovation for enhancing aquatic resources and fishery management for sustainability and diversity.

MATERIALS AND METHODS

Short-necked clam fishery data

Secondary data on fishery statistics between 1974 and 2021 were obtained from Supongpan and Jindalikit (2005) and DOF (2023) to describe the production of short-necked clam in Thai waters, i.e., the Gulf of Thailand and the Andaman Sea. The information on fishing gears and operations carried out by Thai fishers for catching short-necked clam was obtained from DOF (1969a; 1969b), SEAFDEC (2004), Chanrachkij (2013), and Khawsejan *et al*. (2020).

Short-necked clam dredge experiment data

In order to apply the size selectivity model for short-necked clam dredge fishing, we obtained short-necked clam dredge experiment data from Charuchinda (1990). The experiment was carried out using dredge vessels in November–December 1988 in two coastal provinces in Thailand, namely, Trat and Samut Prakan. The fishing grounds encompassed 12°09′N to 12°12′N and 102°21′E to 102°24′E in Trat Province. The fishing ground in Samut Prakan Province covered the area 13°20′N to 13°27′N and 100°45′E to 100°57′E (Figure 1).

In the experiment, three different dredges with sieve sizes of 8 mm, 10 mm, and 12 mm were used. The experimental dredges were made of iron with a width of 1.80 m, a depth of 1.20 m, and a height of 0.18 m, which were considered medium-sized dredges in Thailand (Chanrachkij, 2013). Moreover, a polyethylene (PE) net with a mesh size of 10 mm, covered the dredges to collect the small-sized clams that passed through the sieves. The cover net method (Clark, 1963) was applied for determining the retention ratio (probability) from the

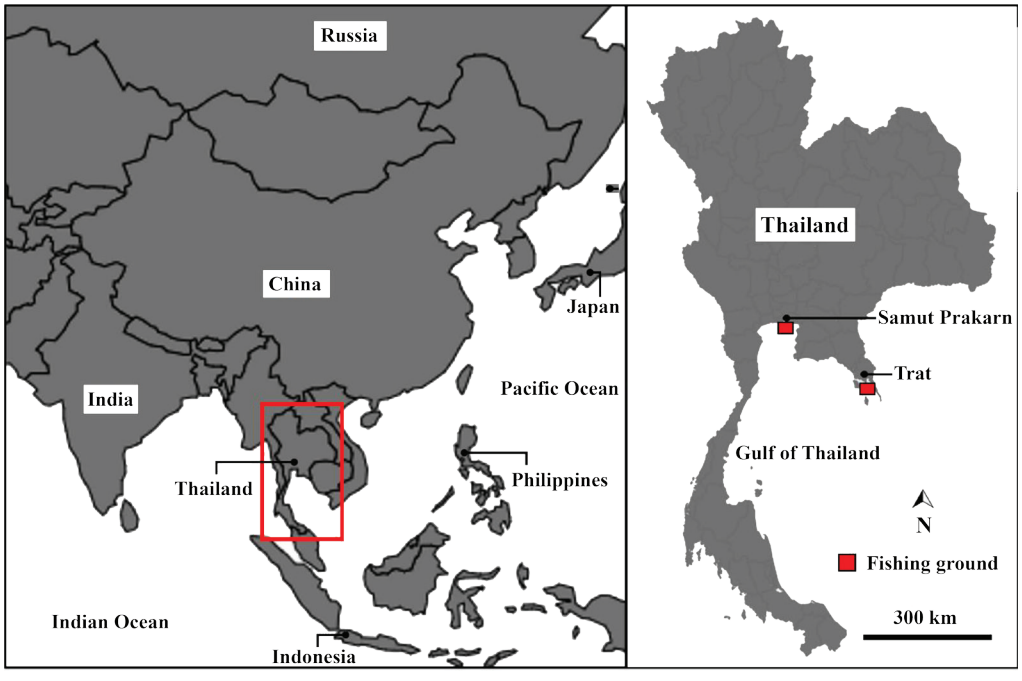


Figure 1. Fishing grounds of the dredge experiment in Trat and Samut Prakan Provinces, Thailand.

encountered short-necked clam population. Each fishing operation was set in areas with abundant short-necked clam, similar to the usual fishing operation of short-necked clam dredge fishers. Each fishing operation was performed for a dredging period of 5 min with a vessel speed of 4 knots (kn) (corresponding to a dredging distance of about 617 m) in fishing grounds with bottom depths of 2–7 m during daytime. For each fishing ground, the three different sieve sizes of clam dredge were used in five fishing operations. There were 30 fishing operations conducted across two areas with three different sieve sizes of clam dredge. For each fishing operation, short-necked clam individuals retained in both the dredge and the cover net were collected, and then they were randomized for measuring SL using Vernier calipers.

Size selectivity model

Generally, size selectivity functions are represented by a selection curve of either a one-tailed curve (e.g., a logistic curve or selection ogive curve) or a two-tailed curve (i.e., modal or normal curve) (Takafumi and Matsuoka, 1997). The one-tailed curve reveals high selection probability on the right side of the curve for larger individuals and low selection probability on the left side for small-sized individuals. On the other hand, the two-tailed curve presents high selection probability at the peak of the curve for individuals of a certain size and low selection probability on both the left and right sides for small- and large-sized individuals, respectively. For the size selectivity model in this study, the short-necked clam dredge was considered as a towed fishing gear, and the logistic curve (*Logit* model) is one of the parametric selection curves described by Wileman *et al*. (1996). Moreover, we also considered the case of dredge clogging or the *CLogit* model, emphasized by Petetta *et al*. (2021); however, we presumed that all clams encountered the experimental dredges and contacted the dredge sieve behind the dredge entrance. As a result, the *CLogit* model simplifies to the *Logit* model (Petetta *et al*., 2021). Therefore, we adopted the *Logit* model (Wileman *et al*., 1996) for this study.

In this study, the traditional selectivity model used by Charuchinda (1990) to support the regulations on sieve size of short-necked clam dredge in Thailand, as mentioned above, was based on a selection ogive curve or non-parametric logistic curve (one-tailed type), which was considered as the reference model. The SL at 50% retention (L_{50}) of the reference model was determined from the cutting point of horizontal and vertical lines on the curve or estimated visually. The products, i.e., L_{50} and selection factor (SF) of the reference model, were also considered as the reference values of each sieve size in each fishing ground. Regarding the concerns or problems caused by the non-parametric selection curve methods (Madsen, 2007), a parametric selection curve method was proposed to improve the size selection method of the short-necked clam dredge, which was also suggested for size-selectivity studies of fishing gears for decades (Wileman *et al*., 1996; Takafumi and Matsuoka, 1997; Jutagate, 2005; Madsen, 2007). The proposed selectivity model was the parametric logistic selection curve (Wileman *et al*., 1996) with a simple calculation method for the obtained data. The L_{50} of the proposed model was not determined from the curve as in the reference model, but it was estimated by the selection parameters from the linear model through Equation 1.

$$S(L) = \frac{e^{(a+b\cdot L)}}{1+e^{(a+b\cdot L)}} \qquad \text{Equation 1}$$

where S(L) is the selection curve function of the L variable, representing SL, or the probability that a short-necked clam of size L is selected or retained when it enters the dredge; a and b are constants of intercept and slope, respectively, of a simple linear equation. Equation 1 can be rewritten as Equation 2 for the simple linear equation.

$$\ln[S(L)/(1 - S(L))] = a + b\cdot L \qquad \text{Equation 2}$$

The variables a and b can be estimated from the simple linear regression between the mid-class values of each SL class (L_i) and the retention probability values of each SL class ($S(L_i)$). The latter can be calculated using Equation 3.

$$S(L_i) = R_i/(R_i + E_i) \qquad \text{Equation 3}$$

where L_i is the mid-class of SL class i^{th}; $S(L_i)$ is the retention probability of SL class i^{th}; R_i is the number of short-necked clams of SL class i^{th} retained in the dredge; and E_i is the number of escapees of SL class ith represented by the number of short-necked clams of SL class i^{th} retained in the cover net. Regarding Equation 2, it is noted that the SL class with 50% retention, L_{50}, is such that $S(L_{50}) = 0.5$, and therefore

$$\ln[0.5/(1 - 0.5)] = a + b \cdot L_{50} \quad \text{Equation 4}$$

$$\ln[1] = a + b \cdot L_{50} \quad \text{Equation 5}$$

$$L_{50} = -a/b \quad \text{Equation 6}$$

For the size selectivity estimation, the probability of a short-necked clam with SL at 50% retention or L_{50} can be estimated as above, and then, the selection range (SR) was estimated using L_{25} and L_{75}. These values were calculated using Equation 7–9.

$$L_{25} = (a - \ln 3)/b \quad \text{Equation 7}$$

$$L_{75} = (a + \ln 3)/b \quad \text{Equation 8}$$

$$SR = L_{75} - L_{25} = (2\ln 3)/b \quad \text{Equation 9}$$

Besides, the selection factor (SF) is a constant that describes fishing gear selection, adopted from Reeves *et al*. (1992). SFL is the selection factor based on L_{50}, which can be estimated using the values of L_{50} and sieve size (M) by using Equation 10.

$$SF_L = L_{50}/M \quad \text{Equation 10}$$

In this study, the observed size variable obtained from the experiment data was SL; thus, we estimated the probability of a short-necked clam with SL at 50% retention or L_{50} instead of S_{50}, and calculated SF_L, accordingly. We estimated L_{50} and SF_L of each sieve size of clam dredge for each fishing ground to initially verify the size selectivity model adopted from Wileman *et al*. (1996). Our approach also pooled the experiment data of both fishing grounds to estimate the average size selection or overall L_{50} and SF_L for further data analyses.

Optimum sieve size for short-necked clam dredge

For scientific recommendations for fisheries management for short-necked clam dredge, size selectivity, maturity size, and marketable size of short-necked clam are three necessary criteria for considering the optimum sieve size for short-necked clam dredge. The size selectivity was estimated from the above-mentioned model. The maturity size of the short-necked clam was adopted from Jindalikit (2000), while the marketable size was defined as the industrial marketable size of short-necked clam (Supongpan and Jindalikit, 2005). To assess the catches from the three different sieve sizes of clam dredge, the proportions of short-necked clams based on these three criteria in the catches obtained from the short-necked clam dredge experiment data were estimated for each sieve size of clam dredge.

Data synthesis and analysis

From the secondary data, the annual production of short-necked clam in Thailand during 1974–2021 as well as fishing gears and operations of Thai fishers were synthesized and described. The data obtained from short-necked clam dredge experiments in Trat and Samut Prakan Provinces were pooled and displayed as the number of individuals retained in the dredges (catch) and cover nets (escape) for each sieve size of dredge by SL class. The comparison among catch proportion in number among the three sieve sizes of dredge was tested by Contingency-table analysis and Tukey-type multiple pairwise comparisons for proportions (Zar, 2010).

We estimated the catch per unit effort (CPUE) in terms of swept or dredged area (represented by catch per unit area or CPUA) using catch volume (C, kg) estimation based on the data obtained from short-necked clam dredge experiments.

The catch volume was estimated on the basis of the number of short-necked clams of each SL class retained in the dredge (R) and the SL-BW relationship ($BW = 0.087SL^{3.028}$) reported by Jindalikit (2000) using the following equations:

$$C = \sum V_i \,/\, 1{,}000 \qquad \text{Equation 11}$$

$$V_i = R_i \times [0.087 \times (L_i^{3.028})] \qquad \text{Equation 12}$$

where V_i is the catch volume (g) of short-necked clams of SL class i^{th}; R_i is the number of short-necked clams of SL class i^{th} retained in the dredge; and L_i is the mid-class value (mm) of SL class i^{th}.

The CPUA ($kg \cdot km^{-2}$) for short-necked clam was calculated from catch volume (kg) and dredged area (km^2) using Equations 13–15.

$$CPUA = C/A \qquad \text{Equation 13}$$

$$A = (M / 1{,}000) \times D \qquad \text{Equation 14}$$

$$D = (P \times 1.852) \times T \qquad \text{Equation 15}$$

where A is the dredged area (km^2) for capturing the particular catch volume; M is the width of dredge entrance (m); D is the towed distance (km); P is the vessel speed (kn); and T is the dredging duration (hour, h).

In order to apply the proposed parametric selectivity model, we generated SL selection curves of the three different sieve sizes for short-necked clam dredge using the parametric logistic selection curve (Wileman *et al*., 1996). The histogram of SL frequency distribution of short-necked clam obtained from the short-necked clam dredge experiment data for the three different sieve sizes was also made. We considered a class interval of pooled SL information from the experiment data using the Sturges rule (Sturges, 1926), and the class interval of 2.00 mm was adopted for the SL frequency distribution accordingly. The SL selection curve and histogram of SL frequency distribution were overlaid for the three different sieve sizes to clarify the size selectivity of short-necked clam dredges. For improving the size selection method of short-necked clam dredge fishery in Thai waters, we compared the L_{50} and SF_L of each sieve size of clam dredge in each fishing ground between the reference model and the proposed model using Paired-sample t-test at a significant level of 0.05 (Zar, 2010).

Theoretically, for net fishing gears, the value of size selectivity increases when the mesh size is expanded (and *vice versa*), and SF can be applied to find the value of size selectivity for the particular fishing gear with slightly different mesh size (Wileman *et al*., 1996; Sparre and Venema, 1998). These are assumed to be similar to sieve gears or dredge in this study. Nevertheless, we tested the relationships between sieve size and L_{50} as well as sieve size and SF_L using the two areas and pooled data through Simple linear regression analysis. As a result, an average SF_L ($\overline{SF_L}$) among the three sieve sizes of dredge from pooled data was considered for adoption when the relationship between sieve size and SF_L was not observed. Due to the limitation of extrapolating on SF from the range beyond variable values (Reeves *et al*., 1992), the $\overline{SF_L}$ is presumed to be used to overcome the limitation for interpolating and extrapolating to gain a suitable sieve size for short-necked clam dredge for fisheries conservation and management purposes.

The catches of short-necked clam were assessed according to size selectivity (i.e., L_{50}), maturity size, and marketable size as the three criteria, using the catch data from the short-necked clam dredge experiments. The estimated L_{50} for the three sieve sizes of short-necked clam dredge were used from the parametric logistic curve model. The maturity size of 31.87 mm in SL for the female short-necked clam was obtained from Jindalikit (2000). For the marketable size, the industrially marketable size of short-necked clam was 30 mm in SL (Supongpan and Jindalikit, 2005). It should be noted that the marketable size would gain the market price (regular price), while short-necked clams with a size smaller than 30 mm may still be

accepted but have a low price. For comparison analyses, the size compositions were calculated based on the catch proportion in number of smaller and larger sizes than the L_{50}, maturity size, and marketable size, separately. The size compositions among the three different sieve sizes of short-necked clam dredge were compared for each criterion using Contingency-table analysis and Tukey-type multiple pairwise comparisons for proportions (Zar, 2010).

RESULTS AND DISCUSSION

Short-necked clam production and fisheries in Thailand

The annual production of short-necked clam in Thai waters was mainly from the Gulf of Thailand, though the data were not disaggregated between the two areas (i.e., the Gulf of Thailand and the Andaman Sea) between 1974 and 1984, with the exception that the highest production from the Andaman Sea occurring in 1996 (Figure 2). Before 1980, the annual production was less than 30,000 t when the short-necked clam fishery was still being developed. Then, the annual production increased and was mostly from the Gulf of Thailand, with the peak production of more than 131,000 t in 1987. Later on, the trend fluctuated and declined to below 30,000 t since 2004, with low production from both the Gulf of Thailand and the Andaman Sea. The larger annual production in the Gulf of Thailand in comparison to the Andaman Sea can be considered a result of the area of fishing grounds. Supongpan and Jindalikit (2005) reported that the total area of short-necked clam fishing grounds in Thai waters covered about 2,705 km^2 (1,690,871 Rai), of which 95.4% was in the Gulf of Thailand.

During the development of the short-necked clam fishery in Thai waters, regulations or management measures were also enforced to support sustainable resource utilization, such as fishing zonation to prohibit short-necked clam dredge operated by fishing vessels in coastal areas in 1974 (MOAC, 1974), sieve size restriction of less than 1.2 cm in 1985 (Charuchinda, 1990), and fishing capacity limitations to allow a dredge width of equal to or less than 3.5 m in 1990 (MOAC, 1990). In addition, restricted areas for short-necked clam spawning grounds were implemented to limit short-necked clam resource utilization by dredge vessels (MOAC, 1975; 2004).

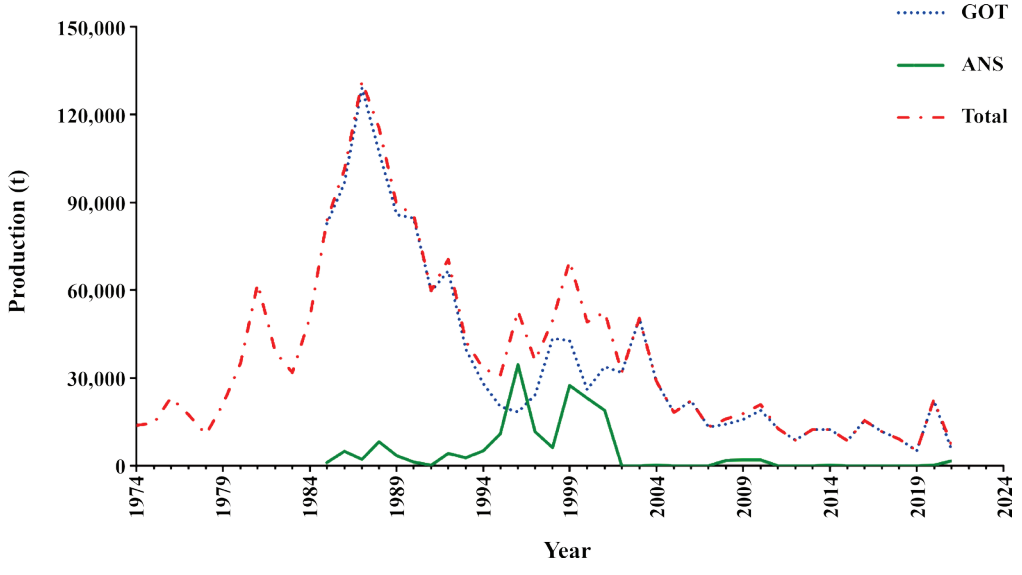


Figure 2. Production of short-necked clam in Thailand from 1974 to 2021 (GOT: Gulf of Thailand; ANS: Andaman Sea; Total: total production from GOT and ANS).

The related regulations for the short-necked clam fishery have been reviewed and revised throughout the production period up to the present (MOAC, 2017; 2019; 2025). These may have had impacts on the production of this species from short-necked clam dredge fishing.

It should be noted that the annual production in the early period of the short-necked clam fishery was increasing due to the development of fishing gears and methods as well as the expansion of new fishing grounds. The low annual production in the late period of the short-necked clam fishery was assumed to be a result of overfishing in the mid-period (during the peak production) and the management measures mentioned above. Other environment factors, e.g., run-off from rivers to the sea, are also considered to contribute to the decline in the short-necked clam population (MOAC, 2019).

For the fishing gears and operations of Thai short-necked clam fisheries, we synthesized information from DOF (1969a; 1969b), SEAFDEC (2004), Chanrachkij (2013), and Khawsejan *et al*. (2020). The literature revealed that fishers began to harvest this resource by hand collecting and diving before 1943 for their livelihood as part of an artisanal or small-scale fishery, and then, hand dredges were introduced and operated in shallow waters as well as dredges equipped with fishing vessels in deep waters (dredgers or dredge vessels) (Chanrachkij, 2013). Short-necked clam dredge vessels in Thailand were recorded in 1967 by the Exploratory Fishing Unit, Department of Fisheries (DOF, 1969a) when the main fishing grounds were in the upper and eastern Gulf of Thailand, i.e., Samut Prakan, Chachoengsao, and Chonburi Provinces (DOF, 1969b). In 1971, the short-necked clam fishery became commercial-scale and nationwide (Khawsejan *et al*., 2020). Chanrachkij (2013) reported that there were nine major fishing grounds in nine coastal provinces in the Gulf of Thailand, namely Trat, Samut Prakan, Samut Sakhon, Samut Songkhram, Prachuap Khiri Khan, Surat Thani, Nakhon Si Thammarat, Songkhla, and Pattani, as well as major fishing grounds in six coastal provinces in the Andaman Sea, namely Ranong, Phang Nga, Phuket, Krabi, Trang, and Satun.

The short-necked clam dredge operated by fishing vessels in Thai waters was generally constructed with an iron frame with an entrance and iron bars with slits for a certain sieve size (Figure 3) (SEAFDEC, 2004). Commercial short-necked clam dredges were designed with sieve size of 8–15 mm; besides, the size of dredge operated in Thai waters was categorized into three groups considering the size of its entrance, i.e., small (about 1.2 m wide), medium (1.8–2.4 m wide), and large (3.0–3.5 m wide) (Chanrachkij, 2013). Later on, the short-necked clam dredge equipped with a motorized fishing vessel was considered commercial-scale fishery due to the regulations (MOAC, 2017; 2019). Recently, short-necked clam dredgers in Thailand were classified into small-scale vessels with a gross tonnage less than 10 GT (DOF, 2024a) and commercial-scale vessels with a gross tonnage equal to or larger than 10 GT (DOF, 2024b). For the fishing operation, fishers shot out one or two dredges onto the sea bottom and towed the dredge (s) by the fishing vessel with a speed of 4–7 kn for around 5 min; moreover, the length of the warp line (towing line) was 3–5 times of the bottom depth (Khawsejan *et al*., 2020).

Catch and CPUA of short-necked clam experimental dredge

The pooled data from the short-necked clam dredge experiments carried out in two fishing grounds for each sieve size of dredge by 2.0 mm class of SL are shown in Table 1. There were 20,732 individuals of short-necked clam retained in both dredges and cover nets from all fishing operations, of which 14,443 individuals were in the catches (retained in the dredges). The remaining 6,289 individuals were considered escapees (retained in the cover nets). The catch proportion (in terms of the number of individuals) among the three sieve sizes of dredges revealed a significant difference ($\chi^2 = 5629$; $p<0.0001$). The sieve size of 8 mm had the highest catch proportion, followed by the sieve size of 10 mm and 12 mm (Figure 4). In other words, the sieve size of 8 mm had the lowest proportion of short-necked clam that escaped, while the sieve size of 12 mm had the highest proportion of short-necked clams that escaped. Moreover, the proportion of small-sized individuals of short-necked

clam in the catch among the three sieve sizes of the dredge was further considered. Figure 5 shows the estimated CPUA of short-necked clam for the three sieve sizes of dredge from the pooled data. The results revealed that the estimated CPUA for 8 mm, 10 mm, and 12 mm were 2,833 kg·km^{-2}, 1,017 kg·km^{-2}, and 382 kg·km^{-2}, respectively. Although CPUA was indirectly estimated for each sieve size of the dredge using the number of short-necked clam of each SL class retained in the dredge and the SL-BW relationship, the results obviously showed that the smaller sieve sizes had a higher CPUA than the larger ones.

Our results revealed that the different sieve size affected the proportion of short-necked clam that was retained or escaped through the dredge. This was considered a result of fishing gear selectivity, where the larger sieve size have a higher escapement proability than the smaller one. Also, the selectivity of the three sieve size would lead to differences in the size composition and CPUA of the catches, as shown in our results. Due to the high variation of dredges-clam encounters among the three different sieve sizes of short-necked clam dredge, we focused on the proportion of retention rather than catch or CPUA to avoid bias caused by dredges-clam encounters as well as environmental factors at both fishing grounds. However, the CPUAs in our results are within the range reported in previous studies. For example, Jindalikit and Thaochalee (2008) reported that the CPUA of short-necked clam dredge in the Upper Gulf of Thailand was 89–205 kg·km^{-2}. Besides,

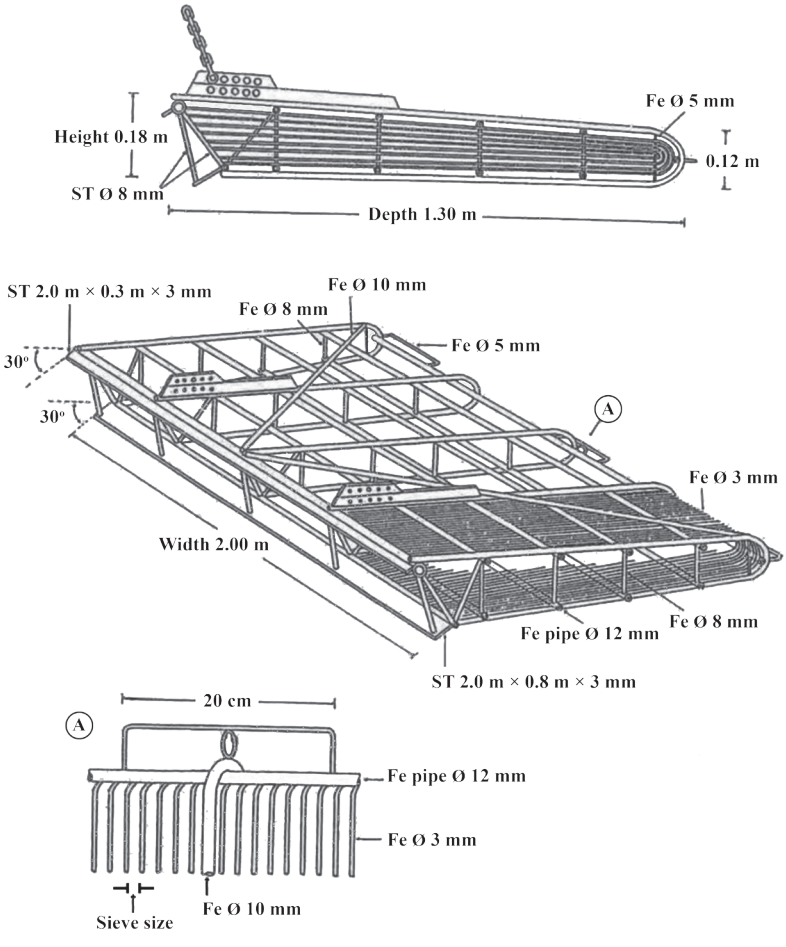


Figure 3. A typical medium-sized short-necked clam dredge operated in Thailand (modified from SEAFDEC, 2004).
Note: ST = steel; Fe = iron

Table 1. Numbers of short-necked clams retained in the dredges (R) and cover nets (E) for each sieve size of dredge by shell length (SL) class (mm), based on pooled data from Trat and Samut Prakan Provinces, Thailand.

SL class	Mid-class (mm)	Nominal sieve size of short-necked clam dredge							
		8 mm		10 mm		12 mm		All	
		R	E	R	E	R	E	R	E
9.6–11.5	10.55	0	5	0	0	0	3	0	8
11.6–13.5	12.55	0	17	0	0	0	2	0	19
13.6–15.5	14.55	0	31	0	2	0	5	0	38
15.6–17.5	16.55	1	64	0	10	0	13	1	87
17.6–19.5	18.55	0	122	0	8	0	13	0	143
19.6–21.5	20.55	14	234	3	6	1	16	18	256
21.6–23.5	22.55	4	246	0	6	0	25	4	277
23.6–25.5	24.55	90	167	3	16	0	33	93	216
25.6–27.5	26.55	327	99	15	116	8	120	350	335
27.6–29.5	28.55	1,305	89	118	364	13	277	1,436	730
29.6–31.5	30.55	2,172	96	412	608	67	531	2,651	1,235
31.6–33.5	32.55	3,117	62	956	663	228	760	4,301	1,485
33.6–35.5	34.55	2,227	47	950	264	278	656	3,455	967
35.6–37.5	36.55	682	17	485	80	224	299	1,391	396
37.6–39.5	38.55	248	0	165	15	124	72	537	87
39.6–41.5	40.55	38	0	44	1	33	7	115	8
41.6–43.5	42.55	5	0	19	0	21	2	45	2
43.6–45.5	44.55	1	0	5	0	8	0	14	0
45.6–47.5	46.55	2	0	3	0	14	0	19	0
47.6–49.5	48.55	0	0	2	0	6	0	8	0
49.6–51.5	50.55	0	0	0	0	4	0	4	0
51.6–53.5	52.55	0	0	0	0	1	0	1	0
Total (individuals)		10,233	1,296	3,180	2,159	1,030	2,834	14,443	6,289

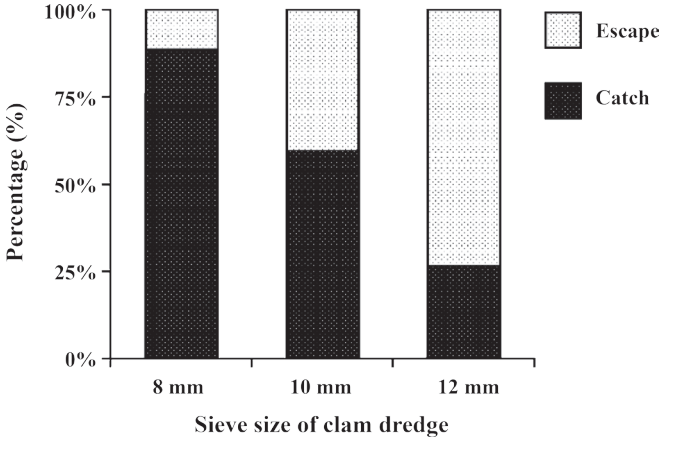


Figure 4. Proportions of short-necked clams retained in the dredge (catch) and cover net (escape) for three sieve sizes of dredge, based on pooled data.

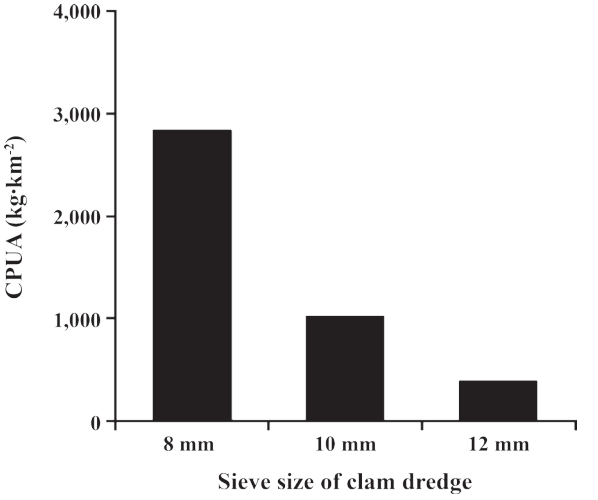


Figure 5. Estimated catch per unit area (CPUA) for three sieve sizes of dredge, based on pooled data.

the study of Chanrachkij (2012) in Paknam Pranburi Estuary in the Gulf of Thailand revealed that the highest CPUA of short-necked clam dredge was estimated to be 2,574 kg·km^{-2}. These previous studies indicated that the CPUA would be influenced by fishing time and/or fishing area which could change the environmental factors of fishing grounds. Therefore, short-necked clam resource monitoring program should be implemented to support effective fishery management for this clam species.

Selectivity of short-necked clam dredge

Figure 6 shows the SL selection curve of three different sieve sizes for the short-necked clam dredge generated by the parametric logistic curve model. The short-necked clam dredge with three different sieve sizes had different SL selection curves and L_{50} values, which confirmed that the short-necked clam dredge has size-selectivity. To clarify the size selectivity of short-necked clam dredges, the histogram of SL frequency distribution of short-necked clam from the short-necked clam dredge experiment data for the three different sieve sizes revealed correspondence to the selection curves (Figure 7). The modes of the SL frequency distributions shifted from the SL class of 27.6–29.5 mm for the 8 mm sieve size to the SL class of 29.6–31.5 mm for the 12 mm sieve size, which was consistent with the change in the selectivity curves for the three different sieve sizes of the short-necked clam dredge. Our results indicated that the larger SL of the short-necked clam was proportional to the number of catch when the sieve size of the short-necked clam dredge was expanded. Hence, the proposed parametric logistic curve model can be applied to estimate size-selectivity. Improving the size selection method of the short-necked clam dredge fishery in Thai waters was carried out by using the proposed model, i.e., the parametric logistic curve model, in comparison to the reference model, i.e., the non-parametric logistic curve. Madsen (2007) emphasized that the use of non-parametric selection curves can cause problematic and more difficult to compare the estimated parameters to other results from standard parametric methods; besides, the L_{50} value obtained from non-parametric selection methods, e.g., fit by eyes or fit directly to retention rates, must be considered with some cautions. Moreover, the parametric model has been widely accepted for size-selectivity studies of fishing gears (Wileman *et al*., 1996; Takafumi and Matsuoka, 1997; Jutagate, 2005; Madsen, 2007; Thorarinsdóttir *et al*., 2010; Petetta *et al*., 2021).

Table 2 shows the sieve size of the dredge and the size selectivity parameters (i.e., L_{50} and SF_L) from the reference model acquired from Charuchinda (1990) as well as the estimated L_{50} and SF_L using the proposed model. The L_{50} and SF_L of each sieve size of the dredge between the

reference model and the proposed model were similar. The comparison of the L_{50} and SF_L between the reference model and proposed model using data from different sieve sizes of clam dredge and fishing grounds revealed that there was no significant difference for both L_{50} ($t = 1.085$; $p = 0.327$) and SF_L ($t = 1.069$; $p = 0.334$). Our results indicated that the parametric logistic curve model can be applied without objection to the traditional selectivity model (non-parametric logistic curve); moreover, the L_{50} and SF_L were also estimated from pooled data for further application to support fishing gear and technology development as well as fisheries conservation and management.

Table 2. Reference and estimated values of size selectivity (L_{50}, mm) and selection factor (SF_L) based on the shell length of short-necked clam for three different sieve sizes of clam dredge (mm) in Trat and Samut Prakan, Thailand.

Fishing ground	Sieve size of dredge		Reference model (Charuchinda, 1990)		Proposed model (This study)		t-value (p-value)	
	Nominal	Actual	L_{50}	SF_L	L_{50}	SF_L	L_{50}	SF_L
Trat	8	7.9	26.10	3.30	26.13	3.31	1.085	1.069
	10	9.7	30.90	3.19	31.01	3.20	(0.327)	(0.334)
	12	11.3	37.90	3.35	37.92	3.36		
Samut Prakan	8	7.9	24.70	3.13	27.31	3.46		
	10	9.7	30.00	3.09	29.99	3.09		
	12	11.3	33.90	3.00	33.93	3.00		
Pooled data	8	7.9	ND	ND	25.96	3.29	NA	NA
	10	9.7	ND	ND	29.96	3.09		
	12	11.3	ND	ND	36.45	3.23		

Note: ND: no data; NA: not available; ns: no significant difference between reference and proposed models using Paired-sample t-test.

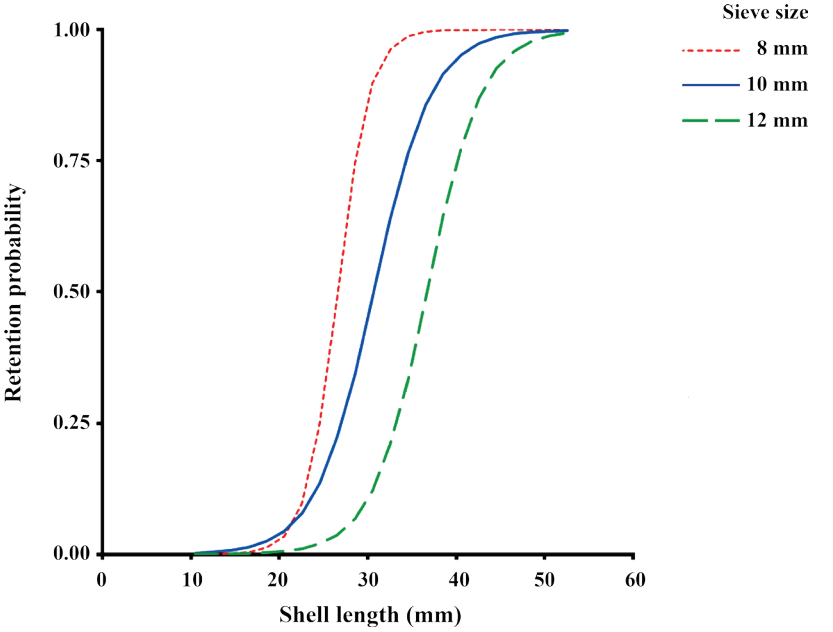


Figure 6. Shell length (SL, mm) selection curves for three different sieve sizes of short-necked clam dredge generated by the logistic curve model.

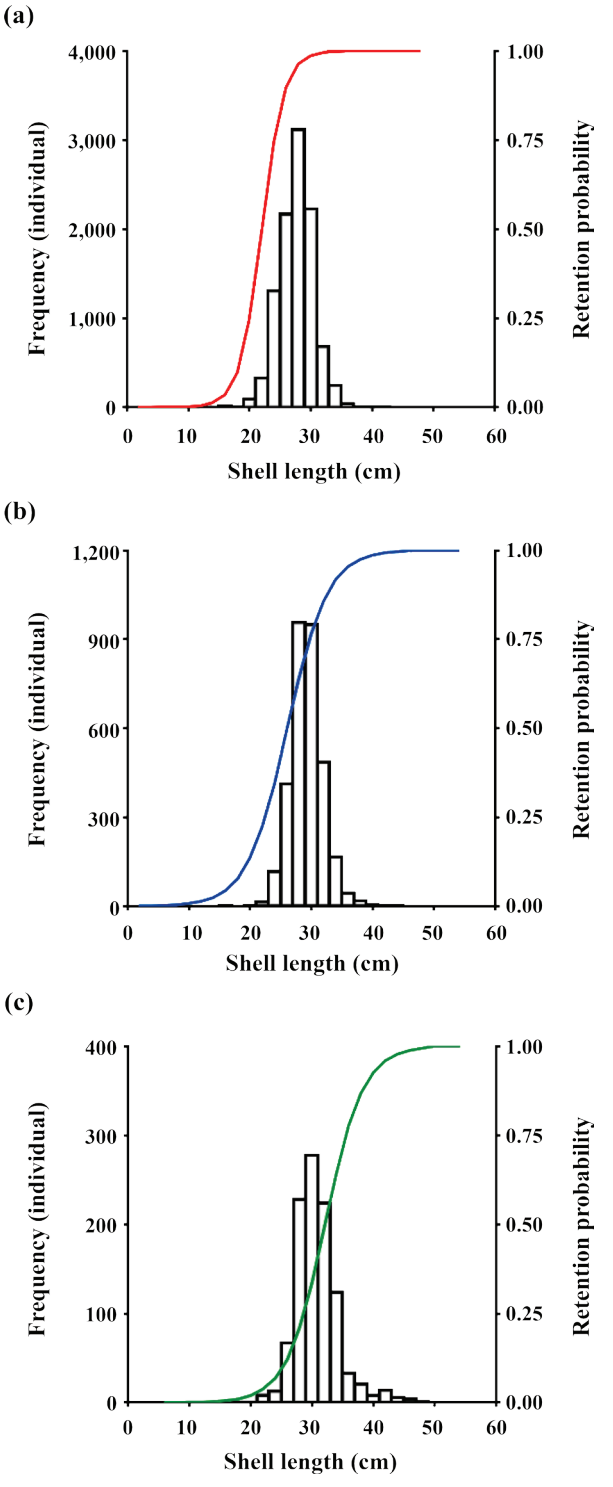


Figure 7. Shell length (SL, mm) frequency distribution of short-necked clams in the catch (bars) and the size selectivity curve (line) for three different sieve sizes of short-necked clam dredge: (a) 8 mm; (b) 10 mm; and (c) 12 mm.

The relationships between sieve size and L_{50} as well as between sieve size and SF_L were tested by Simple linear regression analysis. The relationship between sieve size and L_{50} showed a positive linear correlation ($r^2 = 0.9135$; $p<0.001$). This confirmed that the size selection, represented by L_{50}, of the short-necked clam dredge increased when the sieve size was expanded. Besides, there was no correlation between sieve size and SF_L ($r^2 = 0.2320$; $p = 0.189$), which emphasized that SF_L did not change significantly when the sieve size was adjusted between 8 mm and 12 mm. Hence, the average SF_L or $\overline{SF}_L$ of 3.20±0.10 among the three sieve sizes of dredge from the pooled data was applied in this study, and also suggested for further application to determine the suitable sieve size for short-necked clam dredge for fisheries conservation and management purposes.

As an application of $\overline{SF}_L$ for determining the suitable sieve size for short-necked clam dredge for fisheries conservation and management purposes, we acquired maturity size from previous studies in four provinces in Thailand, including Phang Nga, Samut Sakhon, Surat Thani, and Trat Provinces (Table 3). The value of $\overline{SF}_L$ (3.20) was applied to calculate the suitable sieve size (mm) for short-necked clam dredge regarding the acquired maturity sizes where the sieve size (M) was a quotient of maturity size (mm) divided by $\overline{SF}_L$ or M = matuarity size / $\overline{SF}_L$. This study generated the suitable sieve size for the short-necked clam dredge in the four provinces where the available biological information (i.e., maturity size) of short-necked clam among them was found to be different. Our finding was considered as the related minimum sieve size, which varied among fishing grounds as a result of their specific maturity size. This study focused on the value of SL at 50% maturity, which was highly considered a crucial biological information parameter for fisheries conservation and management purposes. Only Jindalikit (2000) reported on SL at 50% maturity; consequently, the related minimum sieve sizes calculated for males and females were 9.88 mm and 9.96 mm, respectively. Therefore, a 10 mm sieve size or larger can be recommended for short-necked clam dredge fishing in Samut Sakhon Province and adjacent areas. It should be noted that the suitable sieve size for the short-necked clam dredge for other fishing grounds should be reconsidered using SL at 50% maturity of short-necked clam in particular fishing grounds.

Assessment of catch from short-necked clam experimental dredge

Data analyses were also performed to assess the catches captured with three different sieve sizes of short-necked clam dredge based on the size selectivity, maturity size, and marketable size of short-necked clam. Figure 8 reveals the proportions in number between smaller and larger sizes of short-necked clam retained across the three

Table 3. Previous studies on maturity size in terms of shell length (SL, mm) of short-necked clam from different fishing grounds in Thai waters, and the related minimum sieve size (mm) for short-necked clam dredge calculated using the average selection factor ($\overline{SF}_L$).

Province (Reference)	Sex	Observed smallest SL at maturity	SL at 50% maturity (L_{50})	*Related minimum sieve size
Trat (Tuaycharoen *et al*., 1985)	Male	38.6		NA
	Female	42.5		NA
Samut Sakhon (Jindalikit, 2000)	Male	23.0	31.60	9.88
	Female	23.8	31.87	9.96
Surat Thani (Tuaycharoen, 1987)	Male	29.1		NA
	Female	30.6		NA
Phang Nga (Sutthakorn and Tuaycharoen, 1993)	Mixed	14.3		NA

Note: *Based on the $\overline{SF}_L$ value (3.20±0.10) calculated in this study and L_{50}; NA = not available due to the lack of an L_{50} value.

different sieve sizes, (8 mm, 10 mm, and 12 mm), based on their size selectivity value of 26.0 mm, 30.0 mm, and 36.5 mm, respectively. We found that the proportion in number of short-necked clam in the catch with a size smaller than the L_{50} value was less than 5% for 8 mm and 10 mm sieve sizes, while it was more than 50% for the 12 mm sieve size. The proportion in number of short-necked clam with a size smaller than L_{50} in the catches was significantly different among the three sieve sizes (χ^2 = 5,490.2; p<0.001). The proportion in number of short-necked clams with a size smaller than L_{50} captured by the 12 mm sieve size was higher than the proportions of 8 mm (q = 65.7; p<0.001) and 10 mm (q = 51.5; p<0.01). Besides, the proportion of clams with a size smaller than L_{50} captured by the 10 mm sieve size was higher than the proportion of 8 mm (q = 15.0; p<0.01).

This was the result of the size selectivity of the short-necked clam dredge and the size distribution of short-necked clam in the population. Theoretically, the proportion of sizes smaller than L_{50} should be 50% or less as a result of fishing gear selectivity and population structure as mentioned above. The results revealed that the proposed parametric size selectivity model can be applied for improving the size selectivity estimation for the short-necked clam dredge fishery in Thai waters.

In terms of maturity size, the report of Jindalikit (2000) on 31.60 mm in SL for male and 31.87 mm in SL for female maturity was adopted. Our results showed that the proportion of immature short-necked clam in catches was reduced when the sieve sizes of the short-necked clam dredge were larger (Figure 9). We also found that the proportions of the number of immature short-necked clam in the catches among the three sieve sizes were different (χ^2 = 760.5; p<0.001). The proportion in number of immature short-necked clam in the 8 mm sieve size was higher than in the 10 mm (q = 33.1; p<0.01) and 12 mm (q = 31.8; p<0.01). Moreover, the proportion of the number of immature short-necked clam in the 10 mm sieve size was higher than in the 12 mm (q = 10.3; p>0.05). The results showed that the catches of the 8 mm sieve sizes had the highest potential loss for short-necked clam stock due to the highest proportion of immature short-necked clam. On the other hand, it should be noted that immature individuals can still be harvested in a minimum amount, which is accepted by the market and/or fitted for human consumption. Hence, market-driven factor (i.e., marketable size) was included for suitable sieve size consideration for the short-necked clam dredge fisheries.

Figure 10 shows the proportions of the number of short-necked clam captured by the three sieve sizes of clam dredge regarding the industrially marketable size, i.e., 30 mm in SL (Supongpan and Jindalikit, 2005). There was a significant difference in the unmarketable short-necked clam in the catches among the three sieve sizes of clam dredge (χ^2 = 457.2; p<0.001). The proportion of the number of unmarketable short-necked clam in the 8 mm sieve size was higher than that in the 10 mm (q = 29.8; p<0.01) and 12 mm (q = 24.0; p<0.01). Whereas the proportions of the unmarketable short-necked clam in the catch caught by 10 mm and 12 mm were not significantly different (q = 4.9; p>0.05). The results revealed that the proportion of the number of unmarketable short-necked clam in catches was reduced when the sieve size of the short-necked clam dredge was expanded.

Since we adopted the value of SL at 50% maturity at 31.60 mm for male and 31.87 mm for female from Jindalikit (2000), the related minimum sieve size for short-necked clam dredge, considering the maturity size (i.e., 9.88 mm for male and 9.96 mm for female), corresponded to the 10 mm sieve size for short-necked clam dredge. Nevertheless, it should also be noted that the related minimum sieve size for short-necked clam dredge depends on the maturity size in the areas of concern or fishing grounds. In our study, the use of a short-necked clam dredge with a 10 mm sieve size was able to reduce more than 50% of the immature short-necked clam in comparison to the 8 mm sieve size; moreover, more than 75% was reduced by using the 12 mm sieve size. The use of 10 mm and 12 mm sieve sizes also avoided the catch of unmarketable size of short-necked clam by more than 70% and 85%, respectively, in comparison to the 8 mm sieve size. Besides, almost all the short-necked clam in the catches (more than 95%)

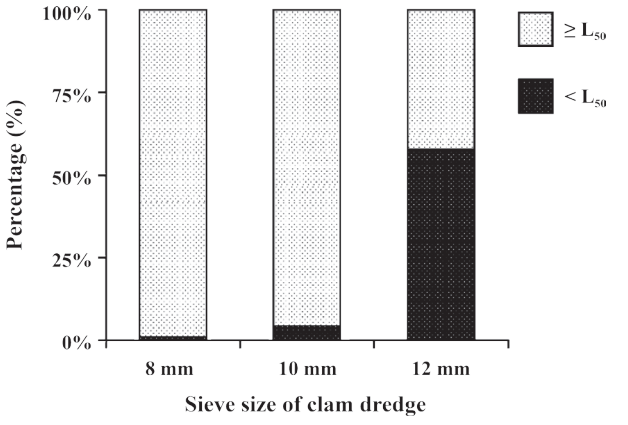


Figure 8. Proportions in number of smaller and larger short-necked clams retained by three different sieve sizes of clam dredge, based on the size selectivity value.

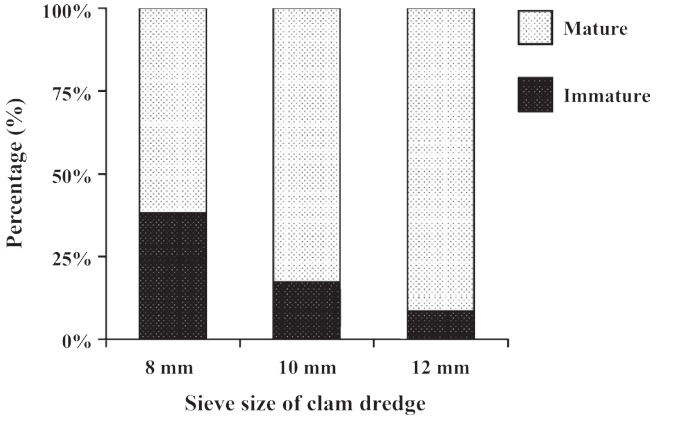


Figure 9. Proportions in number of immature and mature short-necked clams retained by three different sieve sizes of clam dredge, based on maturity size for shell length.

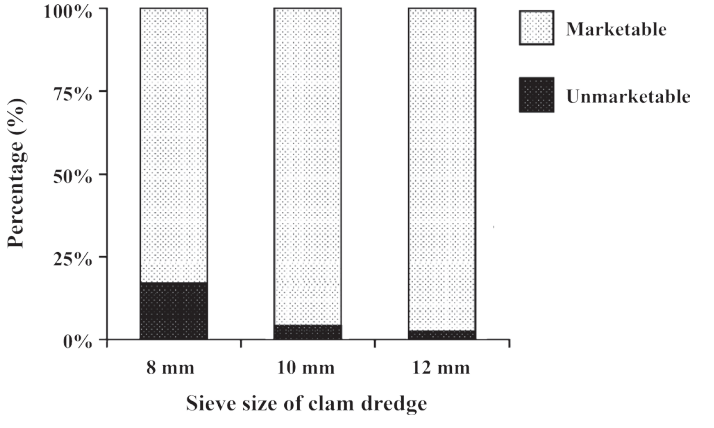


Figure 10. Proportions in number of unmarketable and marketable short-necked clams retained by three different sieve sizes of clam dredge, based on industrially marketable size.

captured by 10 mm and 12 mm sieve sizes were accepted as industrially marketable sizes. In other words, small-sized individuals or bycatch in terms of small size was less than 5% and should be acceptable. The results also showed that the catches of the 8 mm sieve size had the highest biological and economic losses due to the high proportions of immature and unmarketable short-necked clam, respectively, though the 8 mm sieve size had the highest CPUA among the three sieve sizes. Therefore, the optimum sieve size for the short-necked clam dredge in our study should be at least 10 mm. This can be a suitable sieve size for the short-necked clam dredge for fisheries conservation and management purposes in the particular fishing ground, i.e., Samut Sakhon Province and adjacent areas (the Upper Gulf of Thailand), regarding the maturity size reported by Jindalikit (2000) and the industrially marketable size reported by Supongpan and Jindalikit (2005). In this study, the maturity size was similar to the marketable size, and could be different in other cases; however, both variables were considered to have different aspects (i.e., biological and socio-economic, respectively), and should be compromised in fishery management. In addition, other fishing grounds with different biology of this species (i.e., maturity size, L_{50}) should be further considered in determining the suitable sieve size of the short-necked clam dredge for effective fishery management in particular fishing ground. This aligns with the conservation and sustainable use of the oceans, seas, and marine resources for sustainable development supporting SDG14 or "Life below water" (United Nations, 2024).

CONCLUSIONS

The short-necked clam fisheries in Thailand have had a long history since the 19th century. Among fishing methods, short-necked clam dredge equipped with fishing vessels have recently become the main fishing gear for harvesting short-necked clam in both small-scale and commercial-scale fisheries in Thailand. The results confirmed that the parametric size selectivity model of the short-necked clam dredge is applicable for supporting fishery management of short-necked clam, considering the scientific and socioeconomic information (i.e., maturity and marketable sizes). There were differences in the size composition in the catches among the three sieve sizes of clam dredge, according to the size selectivity, maturity size, and marketable size of short-necked clam. In order to reduce the proportion of immature short-necked clam in the catch and to avoid the catch of unmarketable short-necked clam, the optimum sieve size for the short-necked clam dredge should be 10 mm or larger, as a result of the size selectivity model application in our case.

We recommend that the biological information of the short-necked clam (i.e., maturity size, L_{50}) should be further studied for the current situation and more precision in short-necked clam resource management. As a way forward for fisheries management, further application is needed for other fishing grounds where the L_{50} value of the short-necked clam is different from our study. The results of our study can also be applied to other dredge fisheries which have the same capture process as the short-necked clam dredge. For the development of the size-selectivity method, further study on the short-necked clam dredge selectivity model based on the shell width parameter could be considered as an alternative tool for fisheries resource management.

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