Assessing the Effectiveness of Fishery *Refugia* for Blood Cockle (*Tegillarca granosa*) in Sihanouk Province, Cambodia

JTF 6-2 Pillar II.
Promotion of sustainable aquaculture and resources enhancement in Southeast Asia

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Blood cockle (*Tegillarca granosa*) is a crucial bivalve species contributing to the economy of Cambodia. The blood cockle *refugia* site was established in Prey Nop 2, Sihanouk, Cambodia in 2006 to ensure the future stock of the resources. This study aimed to evaluate the effectiveness of the blood cockle *refugia* site considering fishery and population dynamics perspectives. The respondents of this study were all females (n = 25) who collect blood cockle as a supplementary source of income. The collection method inside the *refugia* site is restricted only to hand collection. For the population dynamics, the blood cockle samples inside the *refugia* site exhibited a positive allometric growth pattern and a higher Pauly's condition factor (K) than those from other sampling sites. A greater percentage of the blood cockle larger than the size at first maturity inside the *refugia* site was strong evidence of the effectiveness of the *refugia* site and can be used as a scientific reference for the development of more effective management measures.

The blood cockle (*Tegillarca granosa*) is a bivalve widely distributed in the western and central regions of the Pacific Ocean throughout the Indian Ocean (AquaMaps, 2019; Shao *et al*., 2016). As filter feeder along the coastline, *T. granosa* can accumulate many toxins from a polluted environment such as heavy metals (Yang *et al*., 2023). The populations of blood cockles isolated by water currents suggested that each population is unique (Shao *et al*., 2016). Consequently, they are sensitive to the dropping of salinity, lower dissolved oxygen, toxic pollution accumulation, and other anthropogenic effects and should be assessed and managed by area by population (Moon & Shin, 2010; Srisunont *et al*., 2020; Yang *et al*., 2023).

Blood cockle is an essential resource for many Southeast Asian coastal communities and plays a significant role in the local stakeholders, especially, women and children, who collect them during the low tide and sell the catch for secondary income (Nair, 2000; Ruangsivakul, 2011). However, the population of blood cockle is declining due to the increasing global demand, causing the heavier fishing pressure in various areas as well as habitat degradation and pollution (Chanthana, 2016; Srisunont *et al*., 2020). To ensure the continued production value of blood cockle, sea ranching was one of the aquaculture methods conducted by various scales of traders in Southeast Asian countries such as Cambodia, Malaysia, and Thailand (Nair, 2001; Suanrattanachai *et al*., 2011). By gathering the juvenile blood cockle from their natural habitat, the farmer can control the feed and harvest time to ensure maximum production. However, Chanthata (2016) suggested that sea ranching cannot catch up with the high market demand and also causes the overexploitation of blood cockle seeds from the natural habitat. Thus, area-based management was suggested as an appropriate method to manage the blood cockle resources (Nair, 2000; Pernetta *et al*., 2010; Shao *et al*., 2016).

Hatchery propagation of blood cockle can also be a key for sustainable utilization, particularly in Prey Nop 2 in Sihanouk Province, Cambodia where blood cockle is known to be the major coastal food resource (Nair, 2000; Chanthana, 2016). Furthermore, a specific area with a fishing restriction or prohibition known as a marine protected area (MPA) has been introduced to manage the stock by focusing on the area utilization measure (Edgar *et al*., 2014). Besides, the newly emerged concept of fishery *refugia* as a specific management area that can cover the life cycle of the target species was also recommended (Pernetta *et al*., 2010).

Under the project "Integrated Coastal Resource Management, ICRM-SV," the sub-activity "Encourage and Extend Locally Based Fishery Resource Management" was implemented by SEAFDEC/TD in 2007, with the study "Effectiveness of Blood Cockle *Refugia* in Community Fishery, Prey Nub 2, Sihanoukville, Cambodia" in 2014. Under the project "Sustainable Utilization of Fisheries Resources and Resources Enhancement in Southeast Asia" supported by the Japanese Trust Fund (JTF) 6-2, SEAFDEC/TD conducted a study in 2023 that aimed to evaluate the effectiveness of the fishery *refugia* for blood cockle in Prey Nop 2, Cambodia, taking into account the blood cockle fishery and population dynamics. The fishery aspect covered the survey of fishing activities, gear, and regulations, while the population dynamics included a snapshot assessment of blood cockle samples. This activity also supports the SEAFDEC Strategies, particularly *Strategy No. 1 Securing the sustainability of fisheries to contribute to food security, poverty alleviation and livelihood of people in the region, Strategy No. 3 Ensuring the food safety and quality of fish and fishery products for the Southeast Asian region, and Strategy No. 6 Empowering SEAFDEC to strengthen its roles in the region and to improve its services to Member Countries.*

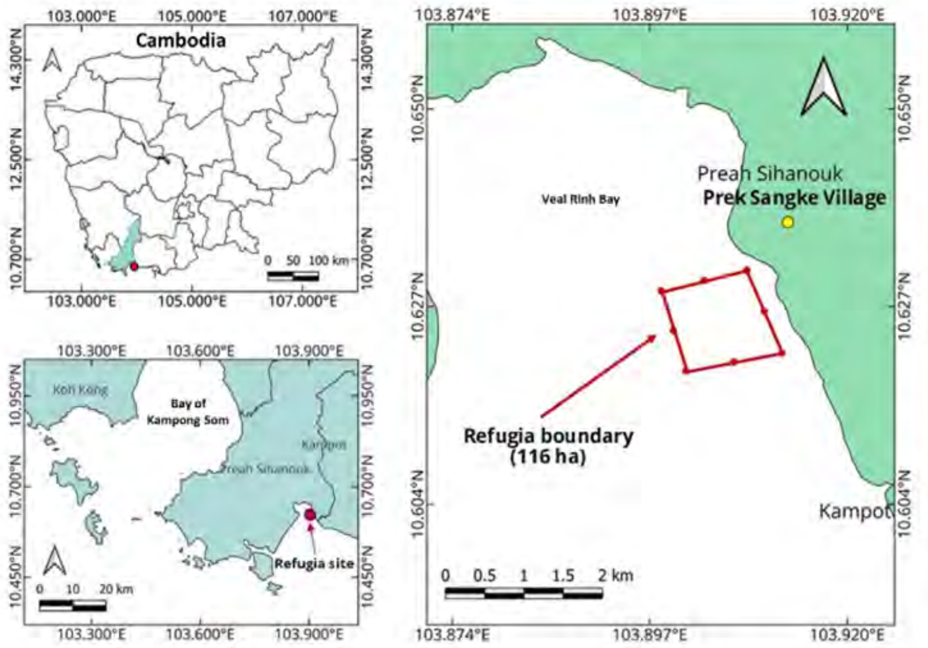

Figure 1. Location of the fishery *refugia* for blood cockle in Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia.

Fishery *refugia* for blood cockle

The fishery *refugia* site for blood cockle was established in 2006 by the members of the Prey Nop 2 Community Fisheries (CFi) as part of the project "Integrated Coastal Resources Management in Sihanoukville, Cambodia (ICRM-SV)" (Try *et al*., 2010). The *refugia* site is located in Prek Sangke Village, Prey Nop 2, covering 116 ha (**Figure 1**). The blood cockle fishing rights in the *refugia* site were awarded to the members of the Blood Cockle Fishers Group (BCFG) as well as to outsiders, where they are allowed to collect the bivalves only by hand. The annual closing season for blood cockle harvest is from 1 June to 31 October, and the collected size should be less than 300 shells/kg or shell length of greater than 2.00 cm.

Blood cockle fishery

A total of 25 female respondents were interviewed about the blood cockle fishery on 18 December 2023 in Prek Sangke Village. The interviews were conducted by the officers from the Fisheries Administration (FiA) of Cambodia using the questionnaire, which includes questions on fishing operation, gear, ground (inside and outside the *refugia* site), season, catch, and price.

Blood cockle populations

The samples of blood cockle were collected on 20–21 December 2023 from five sites, *i.e.* inside *refugia* (IN), outside *refugia* (OT), Prey Nop 2 shallow water (SH), Prey Nop 2 deep water (DP), and Koh Kong (KK). The samples from IN and OT were collected using a modified manual dredge (**Figure 2**), samples from SH were collected by hand, and samples from DP and KK were collected using an engine-powered dredge. Each blood cockle sample was measured for shell length and width (cm) (**Figure 3**) using a vernier caliper and weighed (g) using a weighing scale at the port (IN and OT) and market (SH, DP, and KK).

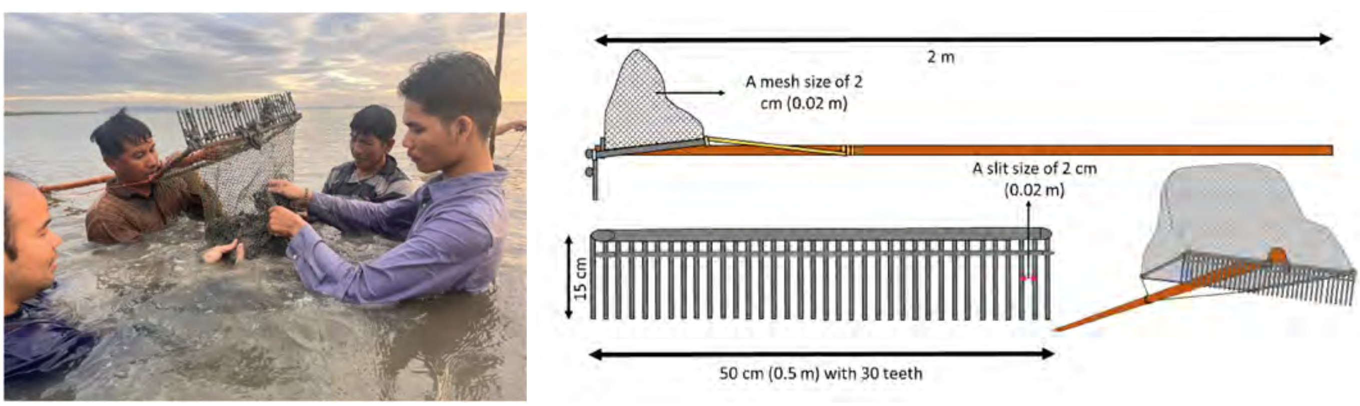

Figure 2. Manual dredge used to collect blood cockle samples from inside and outside the fishery *refugia* for blood cockle

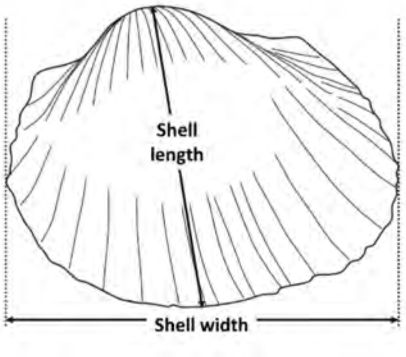

Figure 3. Measurement dimensions for the shell length and width of the blood cockle

The length-weight relationship (LWR) equation ($W=aL^b$) (Ricker, 1975) was used to analyze the blood cockle samples. W is the individual weight (g), L is the shell width (cm), a is a condition factor, and b is the regression factor. The isometric and allometric growth patterns were indicated by observing the significant range of b where $b < 3.00$ or $b > 3.00$ were indicated as negative and positive allometric growth patterns, respectively, and $b = 3.00$ was an isometric growth pattern.

The significant difference between the LWR of blood cockle from each sampling point was analyzed using the ANOVA test for the significant difference in the regression factor b. In this step, the equation $W=aL^b$ was transformed into a linear relationship using natural logarithmic $\ln W = \ln a + b \ln L$. Moreover, the size-frequency distribution of blood cockle in each sampling point was compared using descriptive statistics. The density of blood cockle in each of the size classes was compared with the size at first maturity set at 2.00 cm shell length (Tuaychareorn *et al*., 1982; Thipyothin *et al*., 1985; Narasimhan, 1988).

Another index for describing the characteristics of blood cockle in different sampling points is the use of Pauly's condition factor, K (Pauly, 1983), which is an essential parameter for correlating the different environmental conditions influencing the growth patterns ($3K = 100W/L^3$). Therefore, the effectiveness of the *refugia* site can be evaluated from the larger size and higher Pauly's condition factor of blood cockle compared to the other areas, *i.e.* outside the *refugia* site.

Blood cockle fishery

The respondents (n = 25) in Prek Sangke Village, Prey Nop 2 District, Sihanouk Province in Cambodia were all females, 43 years old on average (20–63 years old), who engaged in blood cockle collection by hand. They belong to Muslim families with an average of four members. Their fishing experience ranges between nine years and 45 years, reflecting early entry into the occupation and long-term involvement in the blood cockle fishery. This underscores the vital role of women in the blood cockle fishery and their significance in the community.

Almost half of the respondents (48 %) indicated that they collect blood cockle from inside and outside the fishery *refugia*, while 44 % collect from inside and 8 % from outside the *refugia* site. In addition to collecting blood cockle, 64 % of the respondents also perform other fishing activities using fish gillnets, crab gillnets, and hand push nets inside and outside of the fishery *refugia* for blood cockle; while 36 % of the respondents engage in other occupations such as mending nets, raising chickens, and grocery shop business.

The collection method for blood cockle inside the *refugia* site is restricted only to hand collection aided with devices such as plastic bowls, gloves, socks, and flashlights during nighttime (**Figure 4**). The respondents usually select large blood cockle by visually estimating their size, without using any size selection tools. The local regulation inside the *refugia* site supports conservation efforts by prohibiting the use of dredge to harvest blood cockle to avoid the capture of juveniles and minimize sediment resuspension. The peak season for blood cockle fishing inside the *refugia* site is from April to May, while the closed season is from 1 June to 31 October (**Figure 5**). The total number of fishing days per year inside and outside the fishery *refugia* are 438 days and 140 days, respectively.

Figure 4. Female fishers collecting blood cockle by hand inside the *refugia* site in Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia

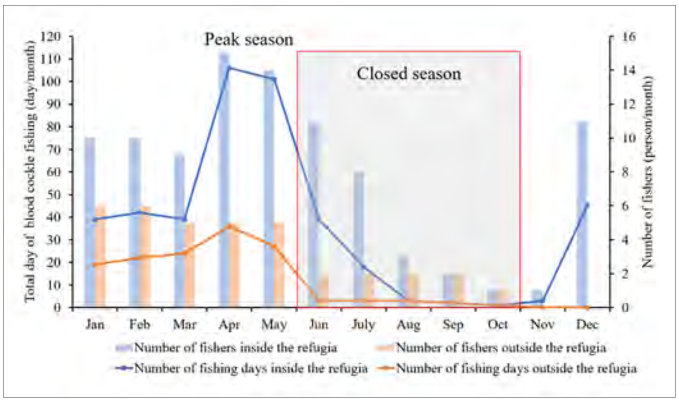

Figure 5. Number of days per month for collection of blood cockle inside and outside the fishery *refugia* of the respondents in Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia (n = 17)

Furthermore, the respondents conveyed that they collect blood cockle for 2–4 hours once a day during the lowest low tide inside and outside the *refugia* site (**Table 3**). The average daily catch of blood cockle inside the *refugia* site was around 1.95 kg/fisher/day (range from 1.0–2.5 kg/fisher/day) with the size range of 60–100 shells/kg. Outside the *refugia* site, the average daily catch was 2.64 kg/fisher/day (range from 1.5–4.5 kg/fisher/day). The size of blood cockle is categorized into small size (70–100 shells/kg) sold at KHR 10,000–12,000/kg (USD 2.5–5.0) and large size (40–60 shells/kg) sold at KHR 20,000–30,000/kg (USD 5.0–7.48They sell the blood cockle to retailers outside of the Prek Sangke Village or at the Trapang Ropov market.

Table 3. Fishing operation of the respondents inside (IN) and outside (OT) the fishery *refugia* for blood cockle Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia (n = 25)

	IN	OT
Peak season	April–May	April–May
Closed season	1 June–31 October	None
Number of fishing operations per day	1	1
Duration of blood cockle collection per day (h)	2-4	2-4
Total number of fishing days per year*	438	140
Average catch quantity per respondent per day (kg)	1.95	2.64
Range of catch quantity per respondent per day (kg)	1.0–4.5	1.5–2.0
Size of blood cockle (no. of shells/kg)	60–100	100–180
Selling price (USD/kg)	Small (66-100 shells/kg): USD 2.5-5.0 Large (40-65 shells/kg): USD 5.0-7.48	

*n = 17 due to the incomplete data from other respondents

The self-regulatory measures for blood cockle fishing include fishing rights, collection methods, closed season, size restrictions, and fishing gear used corresponding to size selection (SEAFDEC, 2010) have evolved since their establishment, this study found that the average size of blood cockle harvested in the *refugia* site is below the minimum requirements of The self-regulatory measures (SEADEC, 2010) with a size limit of 100 shell/kg, and also the Announcement No. 3166 published by Ministry of Agriculture, Forestry and Fisheries (MAFF) in 2009, indicating the prohibition of fishing, buying, selling, or transporting blood cockles in Cambodia, which specifies the size of blood cockle of no more than 300 shells/kg or shell length of greater than 2.00 cm. However, despite that the size restrictions are followed according to the Announcement No.3166, blood cockle is still being collected inside the *refugia* site during the closed season and there have been reports of dredging inside the *refugia* site, contrast with the Announcement No. 320 published by Ministry of Agriculture, Forestry and Fisheries (MAFF) in 2020, referring the regulatory measures of the *refugia*. Therefore, there is a need for continued monitoring and enforcement of regulations for blood cockle.

Blood cockle population

A total of 837 samples of blood cockle were collected with an average shell width of 2.80 cm with a range of 1.90–2.30 cm (**Figure 6**). KK had the largest average shell width (2.30 ± 0.19 cm) while OT had the smallest average shell width (1.90 ± 0.39 cm). Moreover, around 55 % of the blood cockle samples from IN had a shell length larger than 20.00 cm, while more than 70 % of the samples from KK had a shell length larger than 20.00 cm (**Figure 7**).

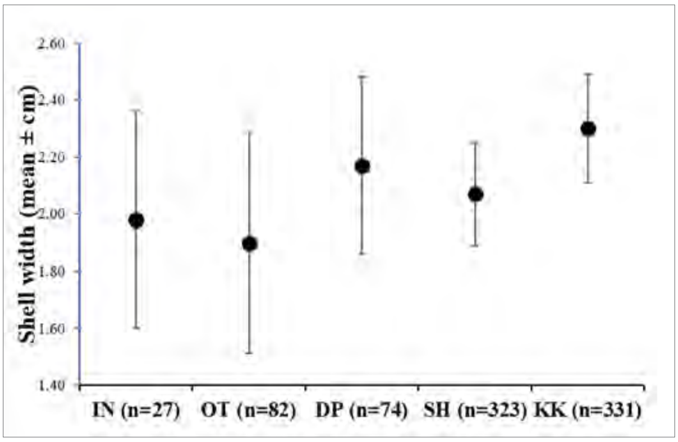

Figure 6. Average shell width (mean ± SD cm) of blood cockle collected from inside *refugia* (IN), outside fishery *refugia* (OT), Prey Nop 2 deep water (DP), Prey Nop 2 shallow water (SH), and Koh Kong (KK) in Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia (n = 837)

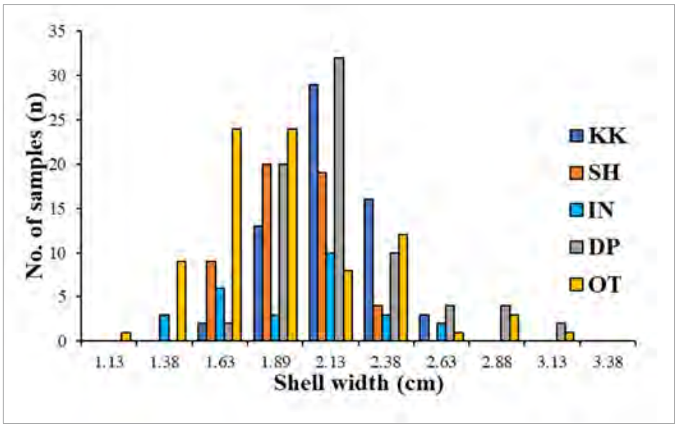

Figure 7. Size (shell width) distribution of blood cockle samples from inside the *refugia* site (IN), outside the *refugia* site (OT), Prey Nop 2 deep water (DP), Prey Nop 2 shallow water (SH), and Koh Kong (KK) in Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia (n = 837)

For the LWR, the regression factor, *b*, indicated that all of the blood cockle samples had a significant isometric growth pattern ($b = 3.00$, $p < 0.05$) except the samples from IN, where a positive allometric pattern was found ($b > 3.00$, $p < 0.001$). A significant difference in the LWR of blood cockle samples among the sampling points indicated that the blood cockle in IN had a substantial difference in this pattern compared to the other sampling points ($p < 0.001$) (**Figure 8**). For the condition factor, *K*, it was found that the *K* from IN was almost the highest ($K = 0.033$), followed by the *K* from SH ($K = 0.034$) and KK ($K = 0.027$) (**Figure 9**).

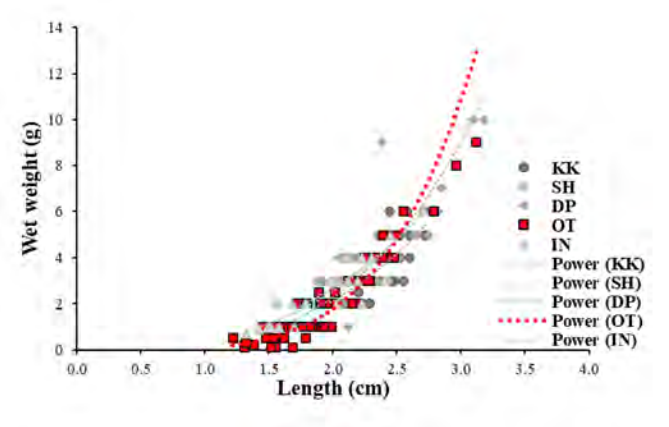

Figure 8. Length-weight relationship with the estimation curve of blood cockle samples from inside the *refugia* site (IN), outside the *refugia* (OT), Prey Nop 2 shallow water (SH), Prey Nop 2 deep water (DP), and Koh Kong (KK) in Prek Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia (n = 837)

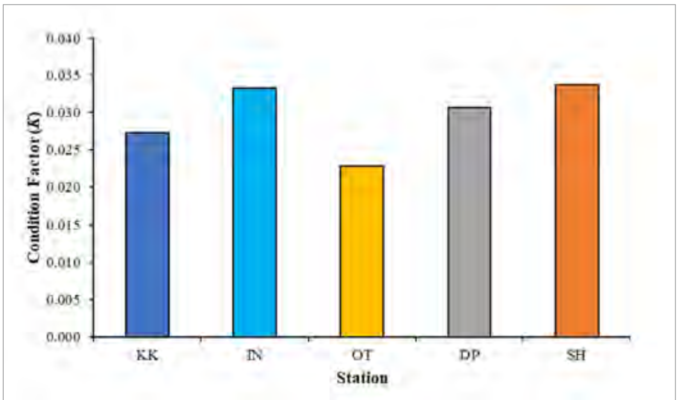

Figure 9. The condition factor (*K*) of blood cockle samples from the *refugia* site (IN), outside the *refugia* (OT), Prey Nop 2 deep water (DP), Prey Nop 2 shallow water (SH), and Koh Kong (KK) in Prek Sangke Village, Prey Nop 2, Sihanouk Province in Cambodia (n = 837)

Effectiveness of the *refugia* site for blood cockle

This study analyzed the biometric parameters to compare the blood cockle samples from IN with those from the OT, DP, SH, and KK. However, the size composition of samples from DP, SH, and KK, which were measured at the markets, can be considered biased since the marketable size was already selected. The significant difference in LWR of the samples from OT was likely to be influenced by several factors including nutrient availability and density where high nutrient with optimum density leads to the positive allometry of blood cockle (Alunno-Bruscia *et al*., 2001). Thus, the distinct positive allometric growth pattern including the high Pauly's condition factor (*K*) in IN compared to OT, DP, SH, and KK can be good evidence of better environmental condition.

In terms of the size-frequency, the data on the size at first maturity of blood cockle samples is limited. Nevertheless, this study followed the threshold size at first maturity at 2.00 cm shell width of Tuaychareorn *et al*. (1982) who reported that the size at first maturity was between 1.80 cm and 2.00 cm from the Gulf of Thailand. Other studies also reported similar size at first maturity from 1.70 cm to 3.80 cm and between 2.00 cm and 2.40 cm for male and female blood cockles, respectively (Thipyothin *et al*., 1985; Narasimham, 1988). Thus, for the precautionary threshold, the length-frequency data in this study was designed to be at 2.00 cm.

Conclusion and Way Forward

The blood cockle fishery in Cambodia has the potential to be developed on a larger scale through appropriate management. One of the management measures that can be developed should be supported by a study of the optimum size of the bivalves that can be exploited without a negative effect on the entire population. Therefore, appropriate biological studies and stock assessment methods should be verified and implemented to strengthen the knowledge and understanding of proper resource use practices among stakeholders, particularly local fishers who still collect blood cockle from the fishery *refugia* during the close season. Nevertheless, the major threat is illegal fishing using dredges in the blood cockle *refugia* site; thus, it is recommended to strengthen law enforcement, surveillance, and cooperation between the local fishers and the government.

The snapshot population assessment of blood cockle found that the *refugia* site was successful in conserving blood cockle resources by enforcing low fishing pressure. Furthermore, the community-based fisheries management in the blood cockle *refugia* site also thrived where the fishing activities are self-regulatory specifically on gear restrictions and resource monitoring conducted by female fishers. The key finding of this study is the significant role of women in the blood cockle fishery, as all blood cockle fishing by hand in the area involved females, contributing to sustaining household incomes through small-scale fisheries.

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