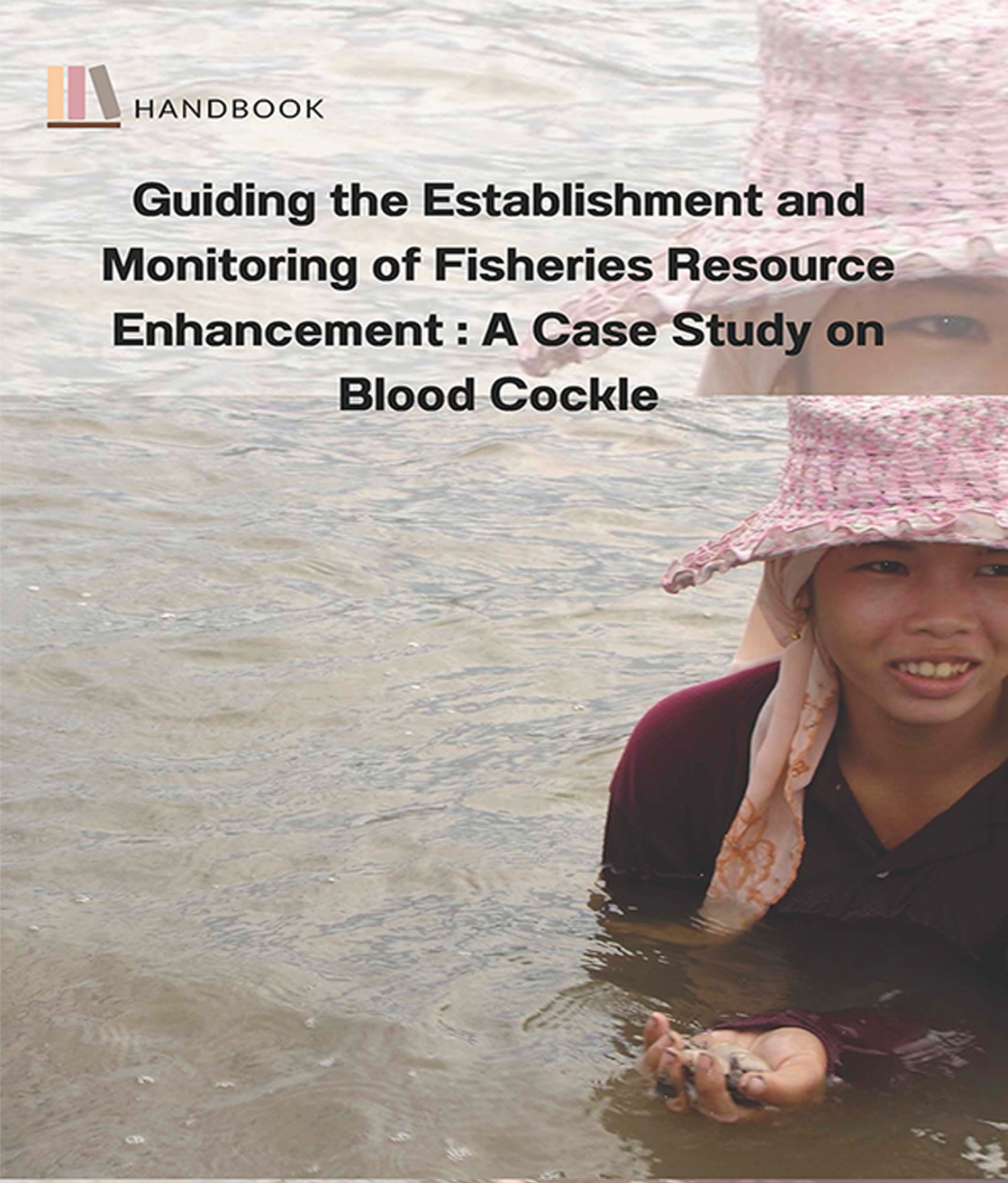
HANDBOOK

Guiding the Establishment and Monitoring of Fisheries Resource Enhancement : A Case Study on Blood Cockle



Southeast Asian Fisheries Development Center
Training Department
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Handbook for Guiding the Establishment and Monitoring of Fisheries Resource Enhancement: A Case Study on Blood Cockle

Southeast Asian Fisheries Development Center

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Fisheries resource enhancement is critical for sustaining fish stocks, securing the livelihoods of fishing communities, and ensuring food security. In Southeast Asia, where coastal communities heavily rely on marine resources, activities like mangrove reforestation, artificial reef installation, and establishing marine protected areas have proven effective in preserving ecosystems and supporting fisheries. Since 2001, the Southeast Asian Fisheries Development Center (SEAFDEC), with support from the Government of Japan's Trust Fund Program, has championed community-based fishery resource management through its Integrated Coastal Resources Management (ICRM) Project, empowering local communities in sustainable marine resource stewardship.

This handbook highlights SEAFDEC's efforts to address the decline of blood cockle populations, a vital marine resource threatened by habitat destruction, illegal fishing, and over-exploitation. By sharing lessons from fish refugia projects in Sihanoukville, Cambodia, it offers practical guidance for adapting management strategies based on scientific research and local needs. With significant declines in blood cockle populations across the region, this resource aims to support sustainable fisheries management, ensuring marine biodiversity and the livelihoods of fisherfolk are preserved for future generations.

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INTRODUCTION

Rational

Blood cockles (*Tegillarca granosa*), are vital to the ecology and economy of Southeast Asia. These bivalves provide an essential source of protein and income for coastal communities while supporting marine ecosystem health. In countries like Indonesia, Thailand, the Philippines, and Malaysia, blood cockles are a dietary staple and feature prominently in traditional cuisine due to their high nutritional value. They are also integral to the livelihoods of small-scale fisherfolk, especially women, who rely on cockle harvesting as a primary or supplementary source of income. Moreover, their cultivation through aquaculture aligns with sustainable development goals, reducing pressure on wild populations and fostering economic opportunities.

Enhancing blood cockle populations is critical to sustaining their benefits amid challenges such as over-exploitation and habitat destruction. Key strategies include habitat restoration, seeding, and establishing protected areas or refugia. Habitat restoration focuses on improving sediment quality and reducing pollution, while seeding involves transplanting juvenile cockles to replenish stocks. Refugia, designated zones where harvesting is restricted, provide safe havens for cockles to grow and reproduce, maintaining biodiversity and supporting fishery stability.

In Cambodia's Prey Nop 2, Sihanoukville, fish refugia were established under the Integrated Coastal Resources Management project to address threats to blood cockle populations from illegal fishing and habitat degradation. These conservation efforts, aligned with regional policies by the Southeast Asian Fisheries Development Center (SEAFDEC), underscore the need for regular monitoring and resource enhancement to secure the ecological and socioeconomic benefits of blood cockles for future generations.

Objectives of the handbook

The handbook serves as a guide for the monitoring process and suggests indicators for monitoring and evaluating fisheries resource enhancement to support the livelihoods of fisherwomen and fishermen, using the Blood Cockle refugia in Prey Nop 2, Preah Sihanouk Province, Cambodia as a case study. The specific objectives of the handbook are;

- To provide a comprehensive guide for establishing and managing fish refugia.
- To outline effective monitoring methodologies for assessing ecological and socioeconomic impacts.
- To support the sustainable utilization of blood cockle resources and dissemination of best practices.

Audience

This handbook is intended for:

- Policymakers and government agencies are involved in marine resource management.
- Researchers and academics studying fisheries resource enhancement.
- Community leaders and fisherfolk engaged in local conservation efforts.
- Development organizations focused on sustainable aquaculture and livelihoods.

PART 1. ESTABLISHMENT OF FISH REFUGIA

Blood cockle is an important resource for food security and livelihoods in Southeast Asia. In Prey Nop 2, Cambodia, blood cockle populations face risks of overexploitation and habitat degradation due to illegal dredging and overharvesting. To address these challenges, fish refugia were established to enhance resources and promote sustainable livelihoods.

1. Site Selection

- Identify areas with significant resources (e.g., blood cockle populations or critical habitats like mangroves and seagrass beds).
- Assess environmental conditions and existing threats (e.g., illegal fishing).

2. Community Involvement

- Engage local stakeholders, including fisherfolk and community leaders, in planning and decision-making.
- Promote awareness about the benefits of refugia for long-term sustainability.

3. Regulatory Framework

- Define clear rules for access and harvesting within the refugia.
- Collaborate with authorities to enforce regulations effectively.

4. Infrastructure and Management

- Install demarcation blocks or markers to define the refugia boundaries.
- Incorporate habitat restoration techniques, such as mangrove reforestation or artificial reef installation, where needed.

5. Capacity Building

- Train local communities in sustainable fishing practices and co-management approaches.
- Provide resources and tools for monitoring and enforcement.

An Example: Case Study on The Establishment of Fish Refugia for Blood Cockle in in Prey Nop 2, Sihanoukville, Cambodia

•Blood cockle resources in Prey Nop 2 face risks from habitat destruction, illegal fishing, and over-exploitation.

•The need for management measures to protect these resources has been recognized since 2007, leading to the establishment of fish refugia.

•2009: The self-regulation of Blood cockle fishing was promoted

•2014: A study found that blood cockle refugia in Prey Nub 2 are still operational with modified management, benefiting both blood cockle harvests and habitat protection.

• 2024: The Survey on Fish Refugia for Enhancing Blood Cockle Resources in Prey Nop 2, Preah Sihanouk Province, Cambodia was conducted to identify the impact of blood cockle resource enhancement on ecological and socioeconomic factors needed for dissemination to another project to apply.

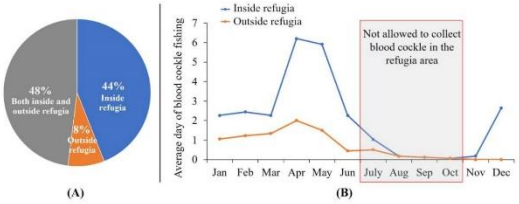

Figure 1. Percentage of blood cockle fishing in the area (A) and duration of blood cockle fishing Prey Sangken village (B)

Box 1: Self-regulatory Measure for Fish Refugia for Blood Cockle	
Location	Khos Angkok
The area covers	1,400 x 1,400 meters, equating to 1.96 km² or approximately 200 hectares
Collecting methodology	Hand collection
Fishing is allowed	Year-round without any limitation on fishing hours
Size restriction	- Juvenile blood cockles, measuring over 100 pieces per kilogram (or less than 10 grams per piece) or smaller than 32 x 22 mm in size, are prohibited from being collected throughout the year. - Broodstock cockles, fewer than 50 pieces per kilogram (or over 20 grams per piece) or larger than 40 x 28 mm, should not be collected during August, the spawning season.
Suggestion to ensure size selection	- Harvested cockles must be filtered using a sieve with a mesh size of 19 x 19 mm, and during August, - An additional sieve with a mesh size of 26 x 26 mm is used to filter gravid Blood Cockles not passing through these sieves are not to be harvested

The suggestion is management strategies should be updated based on the monitoring and evaluation result of local socio-economic conditions, and research on blood cockle biology is recommended to update the spawning ground, season, and population

PART 2. MONITOR AND EVALUATION

1. Resources Enhancement

The resource enhancement for fishery resources can be observed from various perspectives. However, this handbook will be focu on two major topics observed from the field, namely 1) fishery survey, and 2) population survey

2.1 Fishery Survey

A fishery survey is a critical component of evaluating fisheries resource enhancement initiatives, which aims to understand the fishing situations within the focused area to determine the fishing pressure on the fishery resource species. It would provide information for fisheries management policy specific to areas in the future. The characteristics of each area and its resources vary, resulting in unique and distinct fishing activities in different regions. Therefore, defining appropriate indicators and research methods is crucial to ensure they align with the objectives and specific characteristics of the area. This approach helps ensure the study's effectiveness and its applicability to achieve the intended goals. An example of a small-scale fisheries survey can be observed by Boutson *et. Ai,* (2016).

Figure 2. interviewing fisher who collects cockles

1.1.1 Indicators for fishery survey

Choosing appropriate indicators requires consideration of factors as follows.

- Clarity of objectives - Clearly define the specific goals for the survey
- Relevance to target resources and study area - Selecting indicators that are related to the species and ecosystem involved in the study area.
- Feasibility of data collection - Indicators should be straightforward to measure using accessible tools and techniques. Overly complex indicators that require advanced technology or lengthy processes should be considered the suitability before selecting.

- Consistency in analysis - Use standardized methods to ensure that data collected over time are comparable.
- Responsiveness to changes - Indicators should reflect changes in the resource and environment effectively.
- Stakeholder Relevance - consider the relevance of stakeholders. There are many indicators used in fishery surveys, depending on the specific area's character. The example of indicators normally used to assess fishery surveys can be described as follows.

1.1.1.1 Fishing Activity

Fishing activities surveillance in the area can be conducted to understand the dynamics of fishing activities which can be focused on both fishing activities to be promoted or prohibited or understand the dynamics of fishing activities through time dimensions. such as seasonal for snapshot and long-term surveillance. In this process, the market survey can be conducted for more understanding.

- **Types and number of fishing gear:** Type(s) of fishing gear installed onboard, and number of the same fishing gears used
- **Types of focused fishing gear:** active or passive, equipped or by hand.
- **Fishing Ground:** location for fishing
- **Operation methodology:** the information can be.
    - Soaking time
    - Depth of operation
    - fishing gear operation: such as gear setting and hauling step.
    - Seasonal and best seasonal fishing operation
    - Time of operation (daytime/nighttime, full moon/dark moon, or High tide/low tide)
    - Average number of fishing operations
    - Vessel speed
    - Number of fishing vessels operated in the same.
- **Catch:** catch from fishing activities
    - Target species
    - Bycatch species.
    - Catch per unit effort (CPUE) - the single most useful indicator for long-term monitoring of fishery.
    - Species composition and length-weight of fish
    - Selling price

- **Fishing gear surveillance:** which fishing gear was allowed to be operated in the area and which was not. How many cases of illegal or prohibited gear were found to be operating within the area?
- **Other related aspects:** are there other purposes of fishing operations besides collecting the fishery resource for consumption? For example, the collection of juvenile stages of target species for mariculture or for tourism purposes.

1.1.1.2 Fishing Gears Modification

The way to observe the fishing activities within the area includes the observation of traditional fishing gear as well as modified ones. This will help researchers to understand the dynamics of fishing gear through time as well as the fishing gear that should be promoted or prohibited. More information to understand the fishing gear survey can be reached at Chanrachkij *et. al* (2016).

- **Fishing gear characteristics:** fishing gear collection depends on the type of fishing gear. More detail can be explained in the Guide of Fishing Gear Survey (Chanrachkij *et. al,* 2016). Some essential characters are shown below.
    - Fishing gear composition
    - Materials: including information such as type of material, weight, number and thickness
    - Net information: material, mesh size (mm), number of meshes, knot type, and hanging ratio.
    - Rope/twine: material, diameter or thickness, length, weight, color, and position of rope constructed in the gear, number, and tightening pattern.
    - Float and Buoy: material, shape, size, weight, arrangement of the float line (number of floast, interval length)
    - Sinker: shape, design, dimension, weight, arrangement on lead line (number of sinkers, interval length, and pattern of joint)
    - Main line and branch line information: material, diameter, thickness or weight per unit of length, number, twist characteristics, length, color, tightening/knot pattern, the pattern of line rope spicing, and joining pattern.
    - Hook: material, shape, diameter, the height of hook and throat, the width of the gap, the diameter of shrank, type and shape of barb, type of hook eye, and color
- **Fishing vessel:**
    - Type of vessel: a vessel with or without an engine, the engine inside the vessel or outside the vessel, which materials made of the vessel, wooden, iron, fibreglass, etc.

- Size of vessel: length, gross tonnage, and width
- Engine power (Kilowatt or horsepower)

- **Auxiliary gear or fishery support device:** any equipment to support fishing activity should be recorded such as a flashlight, net bag, and board.

1.1.1.3 Size Selectivity

The selectivity range of target species by fishing gear or any size selection tool operated in the area is a necessary indicator to understand the status of each resource. Moreover, fishing gear size selectivity can be an important tool to come up with input control on the selectivity range of fishing gear per area.

More details on the gear selectivity study are provided in the Equation (8) and (9) of the following section.

- **Size of fishing gear/selection tool:** Various sizes of fishing gear can result in different size ranges of target species being collected. The part of fishing gear corresponding to the size selection should be measured such as gill net mesh size.
- **Size of target species:** the cumulative number of target species by each of the size intervals should be collected for further analysis processes.
- **Other aspects:** the side information on fishing activities should be collected as it can have a deep relationship with the size selectivity of the catch such as the operating time, season, or the purpose such as focusing on the market size or juvenile size for mariculture.

1.1.2 Methodology

1.1.2.1 Pre-survey

Pre-survey refers to the preparatory process conducted before a survey to plan and organize all necessary details, ensuring the survey proceeds smoothly, and efficiently, and yields accurate data. This step is included.

- Define the objectives: identify the goal of the survey to determine the indicator for assessment
- Determine the survey area: to scope the study area with mapping
- Designing the survey methodology and selecting tools for the survey: including survey range and period, and preparing the equipment for the fishery survey such as measuring equipment
- The preparation of background information: such as reviewing the fishing gear references, fishery statistics or status in the area, and policy or regulation related to the fishery in the area.

1.1.2.2 Data collection

Data collection for a fishery survey cannot rely on just one method to obtain complete information. Using a combination of different data collection methods is necessary to ensure accurate and precise information. The common data collection methods are categorized into primary and secondary methods. An example of a data collection method will be provided below.

1. **Primary Data Collection Methods:** Original data collected directly by the researcher
    - Field Surveys and direct observations: Involves collecting data directly from the selected area and requires the investigation of weather and sea conditions before the survey.
        - Fishing gear structure: material used for constructing and other assembling techniques
        - Fishing activities: fishing ground/port/site and operation method
        - Fishing vessel: Type and size of vessel
        - Catch data: species composition, CPUE, length-weight
    - Interviews and questionnaires survey: Using structured or semi-structured forms to gather responses from participants.
        - Detail of fishing gear and practice: fishing operation, fishing season, and fishing ground
        - Catch data: target species, bycatch, and total catch
        - Post-harvest: harvest size, selling market, and selling-buying price
        - Fisherman insight and opinion: other aspects might relate to collected data in the area

2. **Secondary Data Collection Methods:** refers to data that has already been collected and published by others, which can be prepared as background information before the survey.

    - Literature Review: Analyzing data from existing research papers, reports, and publications.

- Government and Institutional Records: Fishery statistics, regulations and policies relating to the survey area**.**

Indicators	Criteria	Data Collections	Methods
1. The suitability of fishing activities and gear operated in the fish refugia area	• Only specific fishing gear under the agreement can be operated in the refugia area as follows; ◦ Blood cockle shall be collected by hand only. ◦ No mechanically-driven cockle collector such as a Dredger is not allowed to operate within the refugia.	• Blood cockle fishing and other fishing activities around the area (time, duration, and number of daily fishing activities). • Type and character of fishing gear and method for blood cockle fishing. • Catch production of blood cockle.	**Questionnaire and field survey** • Survey the blood cockle fishing, other fishing activities and fishing gear found during the survey. • Interviewing with the fishers the area including the investigation of the illegal fishing gear found in the area
2. The suitability harvest size of blood cockle	• Following the restriction of harvestable size ◦ Blood cockle, over 100 shells/kg.	• The size selectivity and harvest size of blood cockle. • Market price.	**Questionnaire and market survey** • Focus on the size of the catch from blood cockle fishing. *The field survey cannot be conducted due to the lack of tidal data
3. The usage of size selection tools	• The usage or non-usage of size selection tools (filtering of harvested cockles using a sieve with mesh size 19 x 19 mm (blood cockles sifted through this sieve should not be harvested).	• Present or absent of size selection tools. • The details of size section tools found in the area (if have).	**Questionnaire and field survey** • Size selection tools surveying for selecting blood cockle caught around the refugia area.

Figure 3. Framework of indicators, criteria, data collection, and methods from the case study of blood cockle refugia area

1.1.2.3 Data analysis and interpretation

After data collection, the data will be analyzed and interpreted to evaluate the specified indicators. Sometimes 'Criteria' is involved to help guide the process of evaluating and making sense of the data. It also serves as a standard to allow analysts to filter relevant information, facilitate comparisons, and support decision-making. Types of data analysis used in fishery surveys are summarized in **Table 1.**

Table 1 Summary of data analysis

Analysis Type	Focus	Data Type	Examples of Fishery Surveys
Quantitative Analysis	Numerical measurements	Numeric	Species composition, CPUE, and fish length-weight, selling-buying price
Qualitative Analysis	Descriptive observations	Descriptive/ Visual/Drawing	Species identification, fishing activity, and fishing gear construction
Comparative Analysis	Comparison of variables/groups	Numeric/ Descriptive	Seasonal trends, catch in different locations, comparing actual fishing activities with the regulation/policy

1.1.3 Summary

In summary, the fishery survey is useful for understanding the interaction between the community and the fishery resources in the fishing activities perspective which is the primary perspective to be surveyed. The fishing gear survey should be focused into two sub-perspectives known 1) fishing activities as an overall fishing information of the area, 2) fishing gear modifications, to understand the history and dynamics of fishing activities in the area through time, and 3) gear selectivity to understand how communities make use of the particular resources.

Box 2. Results of fishing gear survey from blood cockle refugia in Prey Nop II

- The field survey was conducted to observe the fishery resources and operational practices within and outside the fish refugia for blood cockles in Prey Nop 2, Sihanoukville, Cambodia.
- Including the interview with 25 fishers who are participating in fishing activities within the refugia area.
- Inside the refugia, women collected blood cockles by hand with a simple tools such as plastic containers and flashlights. Collection was carried out daily during low tide, lasting 2-4 hours. Average daily catches were 1.95 kg/person, which followed the criteria of the refugia's self-regulatory. However, dredging was reported 2-3 times per month inside the refugia.
- The local regulations restricted collection sizes to prevent overharvesting was proved to be effective due to the consistency between national law, the area's self-regulatory, and the data collected from the field.
- No mechanical size selection tools were observed; fishermen selected blood cockles by eyes.

1.2 Indicators to monitor the population.

The population survey for fishery refugia can be conducted in two ways known as; 1) snapshot, where the survey can be conducted in a short period, such as a week or less, and 2) time-series, where the more biological information can be delivered such as growth rate, reproductive biology, density per area, etc. In the blood cockle refugia evaluation, the sampling areas were designed to cover the refugia area as much as possible. The designed plan is provided in Figure 4.

The suggested survey methods for the blood cockle refugia can be identified into two types of methods namely.

1.2.1 The Indicator for Snapshot Survey

The snapshot survey can be used as a preliminary observation of the area before planning for further activities. The key indicators for the snapshot survey can be described as follows.

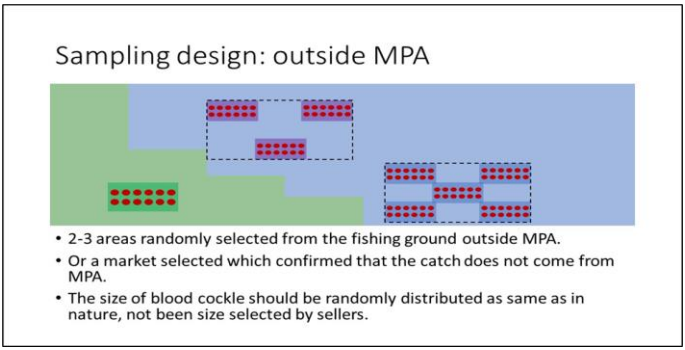

Figure 4. The station designed for blood cockle evaluation. The 5 blue stations were the station design within blood cockle refugia area, the 3 purple stations were the stations for outside of the refugia, and the green station was the market sample.

1.2.1.1 Length-Weight Relationship

The shell length and wet weight of the blood cockles were analyzed using the length-weight relationship (LWR) equation provided by Ricker (1975) as shown in the equation (1);

$$W=aL^b \quad \text{..... (1)}$$

Where W is the individual weight (g), L is the shell length (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.

1.2.1.2 Population Separation using LWR and ANOVA

The significant difference between the LWR of blood cockles from each sample was observed using the ANOVA test for the significant difference in

the regression factor, *b*. In this step, the equation (1) was transformed into a linear relationship using natural logarithmic as shown in equation (2);

$$\ln W = \ln a + b \ln L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Moreover, the size-frequency distribution of blood cockles from each of the samples was compared to observe the majority of size composition. The density of blood cockles in each of the size classes were compared with the size at first maturity of blood cockle which set at 2.00 cm in shell length (Tuaychareorn *et al.*, 1982; Thipyothin *et al.*, 1985; Narasimhan, 1988; Hansopha, 1991).

1.2.1.3 Pauly's Condition Factor, *K*

Another index for observing the characteristics of blood cockles from different areas is the use of Pauly's condition factor, *K,* (Pauly, 1983). The equation is shown in equation (3);

$$K = 100 W/L^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The difference in Pauly's condition factor is an essential parameter for observing the different environmental conditions influencing the growth pattern of blood cockles caught in different areas. Therefore, the effectiveness of the fishery refugia can be observed from the larger size and higher Pauly's condition factor of blood cockle compared to the other areas.

1.2.2 The Indicator for Time-Series Survey

Population dynamics is the way to study the fluctuations in the population fluctuations and structures of the target species. The survey should be conducted over a while, such as a year or more, to cover all the possible fluctuation sources, such as migratory patterns, population fluctuations by age groups, fluctuations by time, etc. Moreover, the study on population dynamics can deliver the primary reference points such as utilization rate, the ratio between gear selectivity and maturity, L_C/L_m ratio, the ratio between natural mortality and growth rate, M/K ratio, etc. for further decision making before coming up with the state of stock assessment.

The possible fish population dynamics methods that can be utilized as a monitoring and evaluation method for fishery refugia are listed as follows.

1.2.2.1 Growth Parameters, Asymptotic Length, $L\infty$, and Growth Rate, K

The growth parameter of the target species can be estimated in two (2) ways, the age-based approach using the age determined by individuals plotted along with the changes in size along the study period, and the length-based approach where a certain period is applied such as changing length composition in twelve (12) months. The relationship between length at time t, L_t, and age, t, with the constant parameters, asymptotic length, $L\infty$, and growth rate, K, can be described as follow;

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)\ldots\ldots\ldots \quad (4)$$

Where L_t is length at age t, $L\infty$ is asymptotic or average maximum length, K is growth rate or curvature parameter, t is age and t_0 is the age at length 0.

1.2.2.2 Mortality Estimation and Size at First Capture, Z and L_C

One of the most trigger parameters in fish population dynamics, the mortality parameter usually can be estimated from the declining frequency of the size after being fully recruited to the fishing ground. One method known as

Length-Convert Catch Curve is widely used in Southeast Asia and other tropical regions. From this method, the total mortality, Z, can be estimated as follows;

$$ln\left(\frac{C_{L1,L2}}{\triangle t_{L1,L2}}\right) = c - Zt_{mL}\ldots\ldots\ldots\ldots \quad (5)$$

Where $C_{L1,L2}$ is the catch in number of the fish between size L_1 and L_2, $\Delta t_{L1,L2}$ is the difference of age between size L_1 and L_2, c is the x-axis intercept, Z is the total mortality, and tmL is the age of the midlength or the age of the average length between upper and lower age intervals. The mL and $\Delta t_{L1,L2}$ can be estimated following Equation (6) and (7);

$$mL = (L_1+L_2)/2 \ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$\triangle\, t_{L1,L2} = \frac{1}{K} ln\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

From the relationship of Equation (5), the data can be plotted between $ln\left(\frac{c_{L1,L2}}{\triangle t_{L1,L2}}\right)$ and t_{mL} as shown in Figure 2 where the plot should select the best negative trend for *Z* determination.

The byproduct of the length-convert catch curve is the ability to estimate the size selectivity of the catch to determine which size or age half of the focused population becomes targeted by fishing activity known as selection ogive. The form of the equation is the utilization of the relationship described in Equation (5) and provided in the

comparative form between the actual selection ogive, S_t, and estimated selection ogive, $\hat{S}_t$, as provided below.

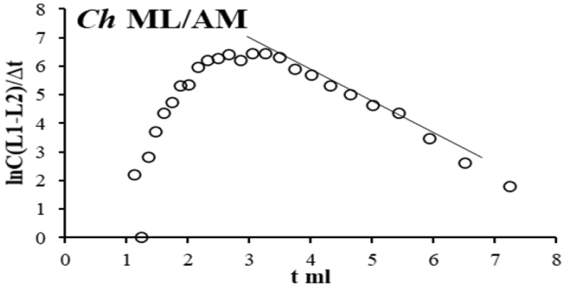

Figure 5. Length-convert catch curve plot between t_{mL} and $ln\left(\frac{c_{L1,L2}}{\triangle t_{L1,L2}}\right)$. The negative slope (black line) is total mortality, Z (Pattarapongpan, 2021).

$$S_t = \frac{c}{\triangle t_{L1,L2} e^{a-Zt_{mL}}} \text{ ……..……..…….. (8)}$$

and estimated selection ogive, $\hat{S}_t$, was estimated using Equation (9)

$$\hat{S}_t = \frac{1}{1+e^{a+bt}} \text{ ……..……..……..…….. (9)}$$

Where *c* is the catch in number from the particular size interval, *a* and *b* are the regression constants for interception and slope, respectively.

1.2.2.3 Natural Mortality, *M*, and Exploitation Ratio, *E*;

According to the definition, natural mortality means the cause of death of the target species that hasn't been reported in the data collection system, which is assumed to be death from natural causes such as predation, disease, longevity,

competition, etc. No exact models account for the M as there are no direct methods to observe mortality from natural courses without interference from researchers. Thus, various techniques are provided by researchers from several regions to cover the possible ways of death by natural courses. One of the most famous methods utilized in tropical regions is Pauly's M equation which incorporates growth parameters, L_∞ and K, and environmental parameters, sea surface temperature, T (Pauly, 1980). The equation is as follows;

$$\log_{f_0} M = -0.0066 - 0.279\log_{f_0} L_\infty + 0.6543\log_{f_0} K + 0.4634\log_{f_0} T \quad \text{... (10)}$$

However, many cases showed that the estimation of this M is very sensitive to the input growth parameters into the model. The M outnumbers the estimation of Z, causing a very unreliable result of the mortality estimation. Thus, the recently suggested model recognized by various researchers and laboratories, such as Then's M estimators (Then et al., 2015) as follows;

$$M = 4.899 t_{max}^{-0.916} \quad \text{..... (11)} \qquad \text{Or}$$

$$M = 4.118 K^{0.73} L_\infty^{-0.33} \quad \text{..... (12)}$$

Where t_{max} is the maximum age for each of the observed stocks, or if this information is unavailable, longevity can also be used.

Another indicator extracted from the mortality analysis is the exploitation ratio, E, which can be observed over a ratio between fishing mortality, F, and M. Therefore, before E can be estimated, the F should be explored as we already know Z and M. The relation of three mortality parameters, F, M, and Z, can be described as follows;

$$Z = M + F \quad \text{..... (13)}$$

The F also can be found from the relationship between fishing effort, f, and catchability coefficient, q, the ability of fishing gear to catch the fish. The equation can be observed from Equation (14);

$$F = qf \quad \text{..... (14)}$$

When all of the necessary parameters are ready, the exploitation ratio, E, can be estimated as follows;

$$E = \frac{F}{Z} \quad \text{..... (15)}$$

1.2.2.4 Size at First Maturity, L_m, and Gonadosomatic Index, GSI

The size that the first 50% of the stock of the particular species reaches the maturity stage and is ready to reproduce is known as size at first maturity. This parameter is essential for the species life history study to understand the specific timing or size of the species to be managed properly without the large unnecessary negative impact on the stock. The idea of estimation is similar to the gear selectivity shown in Equations (8) and (9) but using the size, L, and maturity stage as the input. The L_m estimation is shown in Equation (16);

$$L_m = \frac{1}{1+e^{a+bL}} \text{..... (16)}$$

Another method is to estimate the % of gonad development of target species based on the concept that the gonad will gain more in size and weight during the spawning period known as the gonadosomatic index, GSI. The higher % of gonad weight obtained from this study compared to body weight can indicate the spawning period based on the time of capture and the spawning area based on the area of capture as well. The equation is as follows;

$$GSI = \frac{W_G}{W} \times 100 \text{..... (17)}$$

Where WG is the gonad weight and W is the body weight.

With all of this available information, the evaluation can be extended not just only a snapshot assessment but to population dynamics and up to stock assessment level. The workflow and the key indicators that should be used as reference points are provided in the next section.

1.2.3 Methodology to Collect the Indicators and Reference Points

To manage the process properly, the workflow should be available for the users to understand the working process of these analyses. The workflow can be divided into two procedures based on the type of evaluation: snapshot survey and population survey. The workflow chart and table of reference points are shown in Figure 3 and Figure 4.

Based on Figures 4 and 5, the snapshot study of the area requires a comparison between areas to observe the difference between the management methods, which, in this case, is the comparison between inside and outside of the refugia. It can be divided into two parts, one as a biometric comparison and another as a density comparison. Thus, the field data collection should be focused on;

1) Random sampling of the target specimen from the field using the standard fishing gear or adaptive gear based on the purpose of the study.
2) Collect the individual length and weight of the target species using the appropriate equipment (ruler or vernia calipper, different scales of weighting).
3) The specimen should be as fresh as possible without the deformed or damaged body parts, if have, it should be recorded.
4) The time, places, season, environmental condition, etc. should be recorded along.
5) Waterproof paper with pencil are recommended to be utilized in the field as they are easy for clean and maintenance.
6) For the time-series data, the catch amount from local fishers along with the fishing effort should be collected periodically.

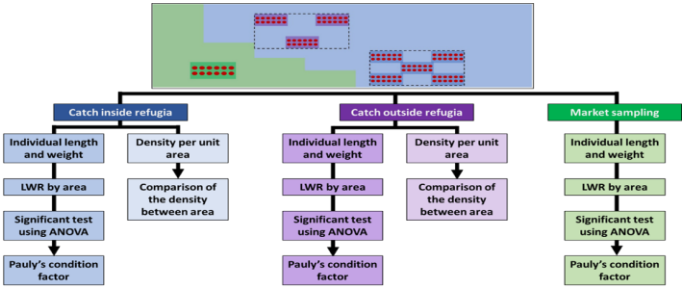

Figure 4. Workflow of data collection and analysis for the snapshot evaluation between the inside refugia, outside refugia, and market.

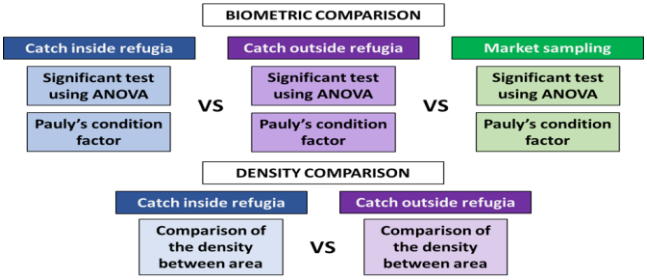

Figure 5. Comparison of the snapshot results which separated into two groups: biometric comparison and density comparison.

For the time-series observation and area evaluation, only one specific area with consistent data collection can provide much information. The growth parameters are an essential set of parameters which can be further useful for the rest of the evaluating process using population dynamics, which workflow can be summarized as follows;

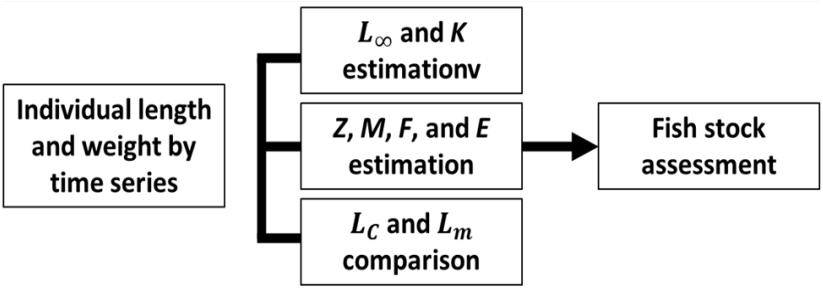

Figure 6. Workflow chart for the time-series area evaluation using fish population dynamics.

In the evaluation process, the reference points should be established as the baseline for the monitoring process, and the proper management measures should be set up. The reference points checklist is provided in Table 1

Table 1. *The list of parameters to be used as reference points with the interpretation guideline*

Types	Param.	Indicators	Remarks
Snap-shot	Pauly's K	$K_{inside} > K_{outside}$	Theoretically, the food abundance inside the refugia should be higher than outside due to the smaller fishing pressure on the ecosystem inside.
	Density (D)	$D_{inside} > D_{outside}$	The density of blood cockles inside the refugia should be higher than outside due to the smaller fishing pressure inside the refugia.

Time-series	Exploit. ratio (E)	$E \leq 0.50$	Fishing mortality and natural mortality are compensated. Therefore, the ratio should be 50:50 to ensure sustainable utilization. However, it is adjustable based on further scientific evidence.
	The ratio between fishing size selection sand maturity size L_c/L_m	$L_c/L_m \geq 1.0$	The size at first capture should be the same or larger than the size at first maturity to ensure that the exploited stock has a chance to reproduce at least once.
	Other SA* reference points	Limit reference points (F_{MSY}, F_{max}, $F_{20\%}$, etc.)	The reference points that should not be exceeded to ensure sustainability utilization such as MSY level.
		Target reference points ($F_{0.1}$, $F_{40\%}$, etc.)	The reference points that are set as the precautionary points that can be exceeded only in a certain amount.

*SA: Stock Assessment

Box 3. Results from bloodcockle refugia in Prey Nop 2, Preah Sihanouk Province, Cambodia

- The field survey was conducted by SEAFDEC between 20-21 December 2023 in Prey Nop II, Phra Sihanouk, Cambodia using the snapshot evaluation.
- The evaluation aimed for Pauly's condition factor (Pauly's *K*) and the density (*D*) comparison.
- The results found that *K* inside is significantly higher than the outside of the refugia.
- However, the density, *D*, was not much different where the density inside the refugia was slightly higher than the outside.
- Results showed that the establishment of fishery refugia seems to be effective.

1.2.4 Summary

In summary, the area evaluation can be divided into groups based on many factors influencing the activity. In the study of blood cockle refugia in Cambodia, time and budget limitations were the major effects influencing the survey plan and design, which aimed to gather as much information as possible. The survey, this time, decided to be a snapshot survey according to the limiting of time based on the budget available. Therefore, a quick information extraction from the length-weight comparison, Pauly's condition factor, and density per area were selected for the area.

However, it is suggested that this method should not be the conventional method used in future events. A more comprehensive way, such as a time-series population dynamics study or stock assessment, should be considered. The possible stock assessment methods suggested as Beverton and Holt's Yield per Recruit Analysis, Thompson and Bell's prediction model, and Spawning per Recruit Analysis as both of them can deliver the biological-based reference points such as F_{max}, $F_{0.1}$, $F_{X\%}$, and *F*-factor. One of the merits of these analyses will be the proper establishment of a data collection system aiming for consistent time-series biological data collection which can be further applied to the fishery data such as catch and fishing effort in the future. Once this mechanism has been settled, the surplus production model (SPM) based on catch and the catch per unit effort (CPUE) can be considered.

2. Livelihood Security

2.1 Indicators to Monitor Human and Social Well-Being in Fisheries Communities

Based on the insights from the provided document, the following indicators can be proposed to monitor human and social well-being in fisheries communities:

1) **Demographic and Household Characteristics**

- **Age distribution**: Average and range of ages among fishers.
- **Family size and composition**: Number of family members by gender.
- **Years of fishing experience**: Duration of engagement in fisheries activities.

2) **Economic Indicators**

- **Primary and secondary occupations**: Types of jobs and their contribution to household income.
- **Monthly and daily income**: Earnings from fisheries and supplementary jobs.
- **Expenditure patterns**: Average daily and monthly household expenses.
- **Savings**: Presence and amount of financial reserves.

3) **Livelihoods and Job Opportunities**

- **Dependence on fisheries**: Percentage of individuals engaged in fishing as their main or supplementary occupation.
- **Diversity of income sources**: Variety of economic activities beyond fishing (e.g., mending nets, grocery sales).
- **Gender-specific roles**: Distribution of tasks between men and women in fishing and household activities.

4) **Resource Utilization and Access**

- **Fishing gear usage**: Types of tools and methods employed.
- **Fishing areas**: Access to and use of designated refugia and surrounding zones.
- **Harvest practices**: Compliance with size and catch restrictions.

5) **Social Perceptions and Well-Being**

- **Community participation**: Involvement in fisheries management and decision-making.
- **Awareness of regulations**: Understanding and adherence to fisheries guidelines.
- **Impact of fish refugia**: Perceived benefits and challenges of conservation measures.

6) **Gender and Social Equity**

- **Women's roles in fisheries**: Contribution to resource collection, processing, and sales.
- **Household responsibilities**: Balance between fishing and domestic tasks.
- **Opportunities for training and support**: Accessibility to capacity-building initiatives.

7) **Education and Awareness**

- **Understanding of conservation efforts**: Knowledge about fish refugia and sustainable practices.
- **Community education programs**: Availability and effectiveness of outreach initiatives.

8) **Challenges and Recommendations**

- **Barriers to livelihood improvement**: Issues like illegal fishing, unclear regulations, or lack of resources.
- **Community feedback**: Suggestions for improving management practices and support systems.

These indicators provide a comprehensive framework for assessing the socio-economic and cultural dimensions of fisheries communities, ensuring their well-being is integrated into resource management strategies.

2.2 Methodology for collecting the indicators.

2.2.1 Baseline Data Collection

- **Secondary Data Review**:
    - Gather information on existing regulations, practices, and socio-economic data from the Fisheries Agency, Academic/Local government office.
    - Review the paper/article to understand historical trends in blood cockle harvesting.
- **Primary Data Collection**:
    - Conduct fieldwork using surveys, interviews, and focus group discussions.
    - Collect data on demographics, income, occupational roles, and perceptions of refugia.

2.2.2 Tools and Techniques

1) Questionnaire **Survey**

- Target: Fisherwomen and men involved in blood cockle collection.
- Method:
    - Structured questionnaires focusing on socio-economic factors (e.g., income, expenses, secondary occupations).
    - Specific questions on fishing practices, tools, and the perceived benefits/impacts of fish refugia.
- Implementation:
    - Conduct interviews with fisherwomen and fishermen who and other stakeholders (middlemen, aquaculture)
    - Record occupational patterns and demographic data.

2) Focus Group Discussions

- Target: Separate groups of men and women (e.g., 7 participants each).
- **Focus:**
    - Women's roles in hand-collecting blood cockles.
    - Men's roles in using fishing gear and supporting collection efforts.

    - Community perceptions about refugia benefits and challenges.
- **Outcomes:**
    - Identify complementary gender roles in fishing and resource management.

3) Observation

- Directly observe the collection of blood cockles and auxiliary activities.
- Assess the usage of tools and practices like hand-collection versus mechanized methods.
- Note adherence to local size-selection practices and regulations.

4) Data Validation Workshop

- Engage stakeholders, including fishers, FiA representatives, and SEAFDEC officers.
- Present findings for community validation and gather feedback.
- Address ambiguities through bilingual explanations and active discussions.

2.2.3 Data Analysis

- **Quantitative Analysis**:
    - Analyze demographic data, income levels, and occupational patterns.
    - Compare differences in fishing practices inside and outside refugia areas.
- **Qualitative Analysis**:
    - Assess gender-specific roles in fisheries management.
    - Evaluate community perceptions of refugia benefits and challenges.
- **Comparative Analysis**:
    - Examine historical versus current practices and their socio-economic impacts.

2.2.4 Key Focus Areas

1. **Gender Roles**:
    - Understand women's exclusive role in blood cockle collection and men's complementary activities (e.g., net fishing).
    - Highlight responsibilities in household and caregiving alongside fishing activities.
2. **Livelihoods**:
    - Assess the income dependency on blood cockle collection as primary or supplementary employment.
    - Explore secondary occupations and their economic contributions.
3. **Community Perspectives**:
    - Collect feedback on fish refugia's effectiveness, challenges (e.g., navigation blocks, illegal dredging), and improvement suggestions.
4. **Regulatory Awareness**:
    - Evaluate understanding of size and harvest restrictions.
    - Analyze community compliance and enforcement gaps.

2.2.5 Ethical Considerations

- Obtain informed consent from participants.
- Ensure confidentiality and respect for participants' cultural and gender norms.
- Use bilingual approaches to minimize communication barriers.

2.3 Reporting

- Summarize findings with a focus on:
    - Gender-specific contributions to fisheries.
    - Socioeconomic benefits and challenges related to fish refugia.
    - Recommendations for sustainable management and community participation.
- Include visual aids (charts, tables) to highlight key data points.

Box 4. Result of data collecting of blood cockle collector in Prey Nop 2, Preah Sihanouk Province, Cambodia

-There are 28 females who are the Blood Cockle collector by hand
- The average member in the family is about 4 persons with 2 women and men on average, it shows a Nuclear Family in Presy Sangkae
-Fishing experience average is 23 years old, it shows that women here start collecting blood cockle when they were young
-The income from Blood Cockle collecting is an average 308,806 Riel (USD76) per month
-Women primarily engage in blood cockle fishing while men use gill nets, assisting each other with fishing tasks, though household responsibilities remain mainly with women.
- Both women and men benefit from the Blood Cockle refugia to support their family livelihoods and agree on protecting the refugia from dredgers, which threaten the Blood Cockle stock

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ANNEX

Questionnaires for Survey Fisheries and Livelihood

The Respondent: Fisher in/around fish refugia for blood cockle in Prey Nop 2

Part 1: Basic information about the responder who is answering the questions

1. Responding name: .....
   Contact: .....
2. Age: .....year
3. Occupation…….

4. Religion…….

5. You do blood cockle fishing as …. Main occupation …. yes ….no, Income/month……..…

6. Your main occupation if not blood cockle fishing……Income/month…….

6. Secondary occupation ……Income/month……..

7. Number of your family members……Men……. Women……

8. Expenditure in family……..……

9. Saving ……

10.Fishing experience …… year

Part 2: Fishing gear type and catch

2.1 What type of fishing gear do you use?

Fishing gear category for blood cockle	**Fishing ground**		**The number of simultaneous fishing gear during fishing**	**Fishing boat** Length and weight (m.)/ Horsepower (HP)
	Fish refugia	**Outer Fish refugia** (specify)		
Collecting blood cockle by hand				
Dragger				
Others (specify) …….				

Other fishing gear category (except for blood cockle)	**Target species**	**Fishing ground**		**The number of simultaneous fishing gear during fishing**	**Fishing boat** Length and weight (m.) Horsepower (HP)
		Fish refugia	**Outer Fish refugia** (specify)		

2.2 Do you use any auxiliary gear or fishery supporting device for blood cockle fishing?

Select	Auxiliary gear/fishery supporting device	Note
	Do not use any auxiliary gear	
	Board	
	Plastic bowl/net bag	
	Others (specify)…… ……...	

2.3 Is there any size selection of blood cockles after fishing? …. Yes…. No

What kind of method was used for the size selection? …. Hand

…. Size selection sieve (specify mesh size ……mm)

…. Others (specify ……...)

What is the minimum size of blood cockle you collect? ……mm. or ……pc/kg

2.4 Estimate the number of your blood cockle fishing per day ……times/day ……. hours/time

2.5 Estimate the total number of blood cockle fishing days in a typical year……. days/year

Divided in ……days/year for blood cockle fishing inside the fish refugia area ……days/year for blood cockle fishing outside the fish refugia area

Blood cockle fishing duration (add the amount of blood cockle fishing day per month)

Area	1	2	3	4	5	6	7	8	9	10	11	12
Inside the fish refugia area												
Outside the fish refugia area												

2.6 Average total daily catch of blood cockle ……. kg., estimated value of an average day's catches …… KHR.

Note (In case of selling separated by size):
……
……
……..

2.7 The duration of the highest blood cockle catch in the fish refugia area ……, the average daily catch of blood cockle during the duration ……. kg.

2.8 Where do you sell blood cockles that were caught?

……
……
……
……
……
……

Part 3: Catch information on blood cockle

On a scale of 1-5 from totally not agree to totally agree

No.	Question	scale				
		1	2	3	4	5
1	Did you only collect blood cockles in the Fishery Refugia?					
2	Do you understand the rules and regulations of Fishery Refugia in your area?					
3	Do you agree that the blood cockles collected in the refugia are larger and have a higher abundance than outside of the refugia?					
4	Do you agree that the establishment of Fishery Refugia can benefit your livelihood?					

Opinion about Refugia for Blood cockle

1. Please compare the stock of blood cockle in Prey Nop 2 in currently and last five years

……
……
……

2. Do you think how important of fish refugia in Pre Nop 2

……
……
……

3. What benefit/impact that you gain for refugia

……
……
……

4. Are there any suggestion?

……
……
……

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