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Increasing sustainability of fisheries for resilience of Cambodian communities

Fish Innovation Lab

Final Technical Report [March 1, 2020 – June 30, 2023]

Cooperative Agreement 7200AA18CA0030

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Prepared by:

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Partners/Institutions

Cambodian Fisheries Administration

Community Fisheries (of the Sre Ambel River)

Mississippi State University

Royal University of Agriculture

Royal University of Phnom Penh

U.S. Forest Service

Wildlife Conservation Society-Cambodia

Abbreviations and Acronyms

CFi: Community Fisheries

CI: Conservation International

FiA: Fisheries Administration

M.S.: Master of Science

MSU: Mississippi State University

RUA: Royal University of Agriculture

RUPP: Royal University of Phnom Penh

USFS: U.S. Forest Service

WCS: The Wildlife Conservation Society-Cambodia

Glossary

Community Fisheries Councils: small associations of fishers engaged in co-management.

Co-management: agreements to share responsibility in the management of shared resources, in this case riverine fisheries.

Community-based aquaculture: small-scale aquaculture operations managed by households or entire villages.

Citizen Science: involvement of the general public in scientific research, in this case fishers collecting data on their harvest.

Proximate analysis: chemical laboratory analysis of the contents of moisture, crude protein, total fat, total carbohydrate, and dietary fiber of food.

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Abstract

Fish are a vital resource for nutrition and commerce in Cambodia. In rural communities, access to fish has been a way of life for generations, but in many communities, access is changing. The Sre Ambel River system in southern Cambodia is an example of the challenges caused by changes in many communities in Southeast Asia. The combination of increased population, habitat modification, increased pressure on natural fisheries stocks and decreased access to natural water bodies result in food insecurity and decreased access to traditional nutritive fish resources. Thus, **improving resilience in wild-capture fisheries is a global challenge,** especially in species-rich tropical rivers such as those in Southeast Asia.

Leveraging on ongoing efforts to improve fisheries governance in the Sre Ambel River, our multidisciplinary team worked together to **bridge management of natural fisheries with food processing, to create an innovative model for community-based sustainable management of tropical riverine fisheries** that can be scaled to other species-rich tropical rivers in Asia, Africa, and South America, where food security is a concern. To complement current efforts by the USFS and WCS to establish Community Fisheries Councils and subsistence aquaculture in the Sre Ambel River, our research focused on two objectives: **1) Improve sustainable fisheries management** by assessing changes in the existing fishery through the development of a citizen science harvest assessment program. And **2) Educate and train villagers in standardized food processing and preservation techniques to reduce fish waste**.

Over the past two years, the Citizen Science Fisheries Harvest Assessment program has collected accurate data on the status of the Sre-Ambel fisheries, creating baseline information on harvested species, yield per effort, size distribution, fishing gear selectivity, fishing zones, and distance traveled. During the assessment, 162 species were recorded, represented by 118,528 fish with 48,048 individual-level data entries and photos for species and length verification. Based on program results, many fish species are potentially being harvested at sizes that do not allow reproduction.

We designed and conducted a survey to obtain information on fish preservation, processing, and nutritional knowledge of fishermen. Based on the survey results, we developed filleting, salting, smoking, and using vinegar as inexpensive processing, preservation, and value-added methods that have been tested on both feasibility and effects on fish sensory attributes. Due to COVID-19, we were limited to the number of workshops and direct contact with fishermen; however, we developed a collection of video clips that can be used for research and training purposes beyond the project period. We were able to provide training in the US for a Cambodian graduate student in fish processing and muscle food value-addition practices. Through a clear understanding of species, sensory preference, preservation, and processing methods, fishermen can now target high-value harvests and add values to low-value (low sensory acceptability) catches.

Access to fisheries harvest data, food preservation processing training, and access to nutrient profile data of wild-caught fish and composition and sensory quality of fish products, will enable future adaptive management of natural fisheries. Recommended strategies include eliminating the harvest of small fish that have not yet reproduced, reducing the use of fishing gear that targets juvenile fishes, and evaluating shifts in target species to enhance human nutrition while at the same time allowing for the recovery of overharvested populations. Additional data on life history characteristics of species and habitat changes will be necessary to refine management.

Introduction

Background and Context: Fish are extremely important to the culture and economy of Cambodia (Ratner 2006). Many communities are located along the river systems and wild capture fisheries have shaped lifestyles for generations. In recent years, increasing human populations, habitat modification, and unsustainable fishing pressure have reduced access to fish in many areas (Marschke and Berkes 2006). Both men and women have traditionally been involved in the capture, processing, and marketing of fish, but their roles are changing due to the decreasing reliability of fish stocks (Neal et al. 2019). Given that fish are the major source of animal protein for riverine communities in tropical rivers (McIntyre et al. 2016), declines in capture fisheries directly affect livelihoods, nutrition and food security of local people (Marschke and Berkes 2006; Bènè 2006). Governments are limited in their ability to adapt, largely because they are understaffed and under-budgeted to deal with rapidly changing rural regions. Population dynamics of freshwater fish species are often poorly understood, and as a result, changes in fisheries over time go undocumented, in turn meaning that the success of corrective actions to reduce fishing pressure cannot be determined. Further, this makes it difficult for rural communities to voice concern at the government level.

The Sre Ambel River system, a coastal river in southern Cambodia (Koh Kong Province), is a prime example of these changes and their negative impacts on local people. In response, the government of Cambodia and several international agencies are developing a co-management arrangement with local villages and assisting the implementation of community-based aquaculture in the region to reduce reliance on wild fish (Neal et al. 2019). This includes establishing a Community Fisheries Council as the regulatory authority and implementing demonstration aquaculture of native fish species to reduce pressure on wild stocks.

However, the proposed development project has two major limitations. First, these plans do not include an assessment strategy for wild fisheries, thus evaluation of the program's efficacy in improving river fisheries will not be possible. A proper evaluation strategy is essential if community fisheries governance is to adapt and refine their management over time. Second, both wild capture fisheries and harvest from aquaculture are episodic, and the current fish market in the region primarily commercializes live fish. Preservation and storage of fish when surpluses are available can help overcome periods of food scarcity when live fish are not available. However, technical expertise for fish preservation is limited, and markets and culture for preserved fish need to be developed.

We conducted a research project designed to complement and overcome the limitations of the current government-led international cooperation development project. Our comprehensive research plan involved training two Cambodian graduate students, male and female villagers in technical fisheries management, and men and women villagers in different aspects of post-harvest production, marketing, and fish value chains. We collaborated with the

on, the Wildlife Conservation Society, and the U.S. Forest Service to improve and expand their ongoing efforts in this region.

Project goal, objectives, and approaches: The overall goal of the project was to improve resilience in wild-capture tropical riverine fisheries by **developing a research-based integrative approach that combines sustainable fisheries management, community-based subsistence aquaculture, and post-harvest processing and preservation**. We focused on communities along the Sre Ambel River as a model system. To accomplish this goal, we completed the following two (2) objectives.

Objective 1. Improve sustainable fisheries management by monitoring harvest and implementing a citizen science digital platform for documentation and analysis of harvest to assess change. Representative, knowledgeable and sustainable management is imperative to the success of community fisheries (Jentoft et al. 2003). Further, these co-management arrangements are only successful if improvements in fish communities and populations are demonstrated. To document success, data from before and after program implementation are required. This necessitates an ongoing assessment program. A major challenge worldwide, however, is to develop and implement rigorous and reliable unified methodologies for the data collection on small-scale fishery statistics (Basurto, 2017). We addressed this challenge through the implementation of a: 1) citizen science harvest assessment program to identify the existing fishery prior to the implementation of community co-managed fishery and subsistence aquaculture allowing for future documentation of change, and 2) digital platform to document and analyze fisheries harvest.

Objective 2. Educate and train villagers in standardized food processing and preservation techniques to reduce fish waste. Natural fisheries and aquaculture are seasonal or cyclical, with periods of abundance and scarcity. Live fish is the most accepted form for trade at local markets due to a lack of refrigeration. When harvests occur, many fish die through the capture and handling processes and may go to waste. Useful preservation techniques that are specific to the fish species encountered were taught to villagers in the Sre Amble River. Market linkages and value assessment of fish products were also evaluated. We are aware of the cultural differences in fish consumption among regions in the world. Therefore, our approach followed three stages: 1) we surveyed and assessed local fish processing and fish products, 2) we designed and trained villagers on minimal processing methods, and 3) we produced and further tested processed shelf-stable products.

Research Methods

Study Area

The Sre Ambel River System is located in Koh Kong and Preah Sihanouk Provinces, Cambodia. The river system consists of several rivers that converge into the main channel of the Sre Ambel River just above the city of Sre Ambel. The Kaong River flows from the Dâmrei Mountains in the Preah Monivong Bokos National Park in the east, and the Kampong Som River originates in the Southern Cardamon Mountains National Park near Kâmlôt in the north, with smaller tributaries between the two primary tributaries. This basin includes the four provinces in southern Cambodia – Kampot, Sihanoukville, Kampong Speu, and Koh Kong provinces (Platt et al., 2006). The basin contains a range of terrestrial habitats, including deciduous forests and open savanna in the upland, and wetlands, evergreen riparian forests, and agriculture within the floodplain. The mainstem of the river is lined by mangrove forest just before it exits into the Gulf of Thailand (Platt et al., 2006; Neal et al., 2019). The upper tributaries range from about 25 – 50 meters in width (Platt et al., 2006), while the lower river exceeds 100 m. Disperse communities are located along the river system. At least 10 rural villages depend on the river for sustenance, livelihoods, and cultural continuity (Neal et al., 2019). The river system is mainly located within the Ministry of Agriculture, Forestry and Fisheries Proclamation: *The Sre Ambel Fisheries Management Area for Royal Turtle and Siamese Crocodile*.

Objective 1

1.1. Data Collection and Species Identification

The target villages for this research are located upstream of the Sre Ambel Bridge. The furthest upstream village (Bak Angrut) is in Koh Kong Province, approximately 22 kilometers upstream of the Sre Ambel Bridge. To the eas,t about 20 kilometers, is the most downstream village (Boeng Trach), located in Preah Sihanoukville Province (Fig. 1, Table 1). The population of the participating villages is more than 7,200 people, with more than 1,600 families (Neal et al., 2019).

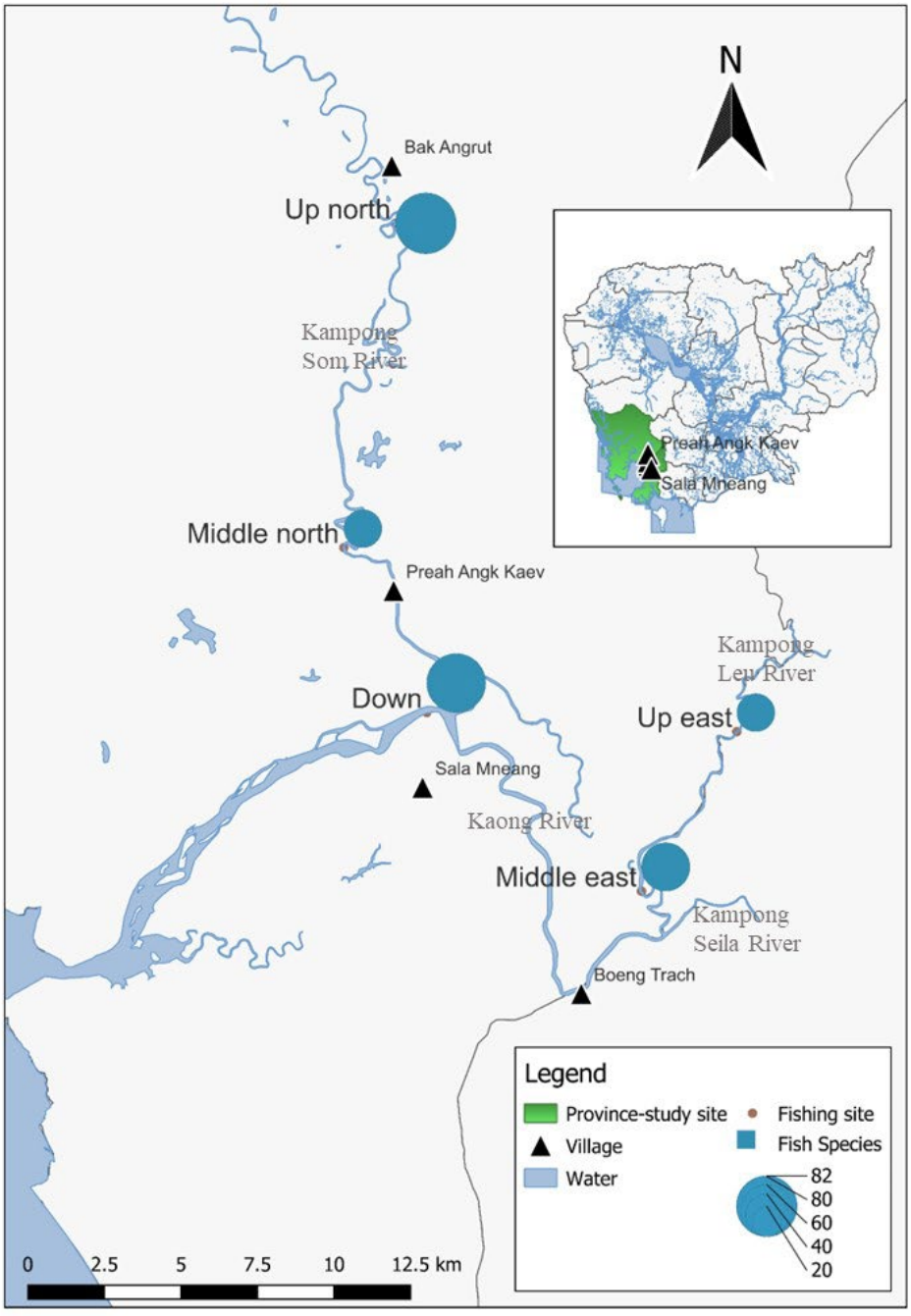


Figure 1. The map of Sre Ambel River in the southern provinces of Cambodia. Circles represent river reaches and species richness

Table 1 Village location for fish sample collection along Sre Ambel River in Koh Kong and Preah Sihanouk Vill (Neal et al., 2019)

Villages	Districts	Provinces	Latitude	Longitude
Bak Angrut	Sre Ambel	Koh Kong	11°16'50.80"N	103°46'16.36"E
Preah Ang Keo	Sre Ambel	Koh Kong	11°11'5.15"N	103°45'18.61"E
Sala Mneang	Sre Ambel	Koh Kong	11°08'07.3"N	103°46'12.6"E
Beoung Trach	Kampong Seila	Preah Sihanouk	11°4'18.95"N	103°50'32.87"E

The study utilized a citizen science approach for collecting fisheries data (Kruger & Shannon, 2000). In early February 2021, an announcement was sent to villages that the study was seeking participants. Interest meetings were organized in each village to introduce the study and interview those interested in participating in this study. To be considered for the program, participants were required to have basic literacy skills, have their own gear, and fish a minimum of 10 times per year, and collect fish within the Sre Ambel River, estuary, and floodplain habitat. Fishing effort in marine environments was excluded. Fifteen (15) experienced fishers were selected for the program, and a one-day training session was conducted on February 19, 2021 to teach data collection protocols. This training course introduced fishers to the study program and the reporting gear provided, provided hands-on exercises on proper fish identification, measurement, photography, and data recording and storage. A training video demonstrating the process throughout a complete fishing trip was produced by MSU, and this video was presented with translation to Khmer. Fishers were provided with a set of data collection tools and field accessories, including: Dry bag to store all tools and accessories, data logbook with waterproof datasheets and laminated instructions and fish catalogue, waterproof camera with GPS (Olympus Corporation TG-6) attached to floating lanyard, fish measuring board (36 cm), flexible measuring tape (100 cm) for longer fish, and pencils, sharpener, and other accessories.

Data collection and fish processing at the end of a fishing trip was time intensive and contributed to the deterioration of fish quality; therefore participants were compensated for their time and loss of fish quality at a rate of US$80 per month. During training and subsequent fishing activities, participants were instructed to fish as they would normally and not modify behavior in any way except to collect required data. There were no restrictions or encouragements from investigators regarding choice of fishing gear, location, or other attributes.

Instructions, datasheets, and the fish catalogue with codes are in Appendix 1-3. These are presented here in English but were translated to Khmer for participants. Briefly, each fisher recorded their identification number, village code, form number, date, and start time when they departed from the shore. Upon reaching their fishing location, they took a photo of the site and recorded the GPS coordinates and gear type fished. Any fish captured and released were recorded onsite, and harvested fish were retained and processed when fishing was complete, and they returned to the shore. Participants recorded the end time when reaching shore. For each fish, the identification code and

length (total length, TL cm) was recorded. If a fish was released, this was indicated by checking a box in the length column. Each fish was photographed on the measuring board to allow verification of species and length. In the event that many fish of the same species and similar size were captured, subsampling was allowed to reduce excessive processing times. A subsample was measured and photographed, and all individuals were counted and reported. Once all fish were processed, participants placed a large 'X' in each column to signify the end of data for that trip. Participants then photographed the datasheet as a backup and moved it to the completed section of the logbook.

A M.S. student, with support from WCS, collected datasheets and photographs and replenished participant supplies at least monthly between March 2021 to February 2022. Periodic verification of data integrity and adherence to protocols were conducted, and additional training was provided as needed (Fig. 2). Data from fishers were entered into Microsoft Excel spreadsheets and each fish entry was synchronized with its corresponding photo; these files were stored on a cloud platform for security and to facilitate convenience of data exchange between collaborators. Each species identification was verified by the student using additional identification resources, including Field Guide to Fishes of the Cambodian Freshwater Bodies and Freshwater Fishes of the Kingdom of Cambodia (Cheb et al., 2016; So et al., 2018), and the online fish database (www.fishbase.de) (Kottelat, 2013). Further fish species verification was provided by Mr. Thach Phanara, an ichthyologist from the Inland Fisheries Research and Development Institute, FiA.

Figure 2 (A) Training on data collection (by Phun Thurn,WCS), (B,C) Follow-up data collection and measuring, fish photograph for identification, entering datasheet in Beoung Trach, and Bak Angrut Villages, (D) Measuring fish, (E,F) Accompanying fishers at Bak Angrut village (Up north site)

Objective 2

2.1. Survey of Fish Preservation Techniques and Processing Methods

A series of questions was designed to solicit information on fish preservation, processing, and nutritional knowledge. The questions were translated to Khmer and back-translated to English to ensure accuracy. The translation was conducted by Cambodian PI and personnel. The survey was conducted in eight locations of Sre Ambel, including Samdach Ta, K'aong, Beong Trach, Sre Ambel, Sala Mneang, Preah Angkeo, Bak Angrut, and Phum Veal. One hundred people from these communities were interviewed. People from Samdach Ta and K'aong were mostly women and did not go fishing, while the rest from the other six communities were fishermen, who went to the river to catch fish. The data were averaged in percentage and summarized.

2.2. Sensory Evaluation of Fish and Cooking Methods

Three fish species were selected for sensory evaluation including strip snakehead (*Channa striata)*, walking catfish (*Clarias batrachus)*, striped catfish (*Pangasius djambal*), and fermented striped catfish. Frying and boiling were the cooking methods for this sensory panel due to their popularity in Cambodia. The fish samples were purchased from Sre Ambel Market and were kept fresh before cooking. The samples with 3-digits code were served to 7 groups of consumers (N = 100) in Sre Ambel communities namely Samdach Ta, Beong Trach, K'aong, Terk P'aong, Sala Mneang, Preah Angkeo, and Bak Angrut. The panelists were given instructions on how to rate each quality of sensory characteristic in terms of appearance, aroma, flavor, texture, and overall acceptability. The consumers evaluated 8 samples and rated the acceptability of the sample on a 9-point hedonic scale with 1 being "dislike extremely" and 9 being "like extremely". Data were analyzed by the GLM procedure of SAS v9.4 with fish species and cooking method as fixed effect and panelist as a random effect.

2.3. Training and Workshops in Fish Processing and Preservation, and Continuity Assessment

Due to COVID-19, we could not conduct in-person training for 2 years. Therefore, we developed a series of video clips of fish processing (eviscerating, skinning, fileting, salting, and smoking). We trained Sitha Som and Chakriya Chum during their trip to the US in March 2023. We conducted two workshops to train fishermen in fresh fish processing and preservation. For smoking, Chakriya experimented various designs similar to what we recorded in a video clip. She trained 50 people in the first workshop. Right after demonstrating the building of the smoker and smoking fish, the participants evaluated the smoked fish and fried fish including, *Cyclocheilichthys apogon* and *Ompok hypophthalamus.* Thirty consumers, who were from Sala Mneang, Beong Trach, Preah Angkeo, and Bak Angrut, evaluated 4 different samples that were directly smoked, indirectly smoked (Brazilian style built during the workshop), fried, and vinegar fried. The *Ompok hypophthalamus* was rated by 18 consumers from Sre Ambel village. The panelists were instructed to rate each sensory attribute for appearance, aroma, flavor, texture, and overall acceptability of sample on a 9-point hedonic scale with 1 being "dislike extremely" and 9 being "like extremely". Data were analyzed by the GLM procedure of SAS v9.4 with fish species and cooking method as fixed effect and panelist as a random effect.

In the second workshop, we recruited 35 participants with 21 participants from the previous workshop. The participants, in addition to being trained in fish processing, were asked to answer questions regarding their intention of how likely they would like to continue participation in the future. The line scale answer of *Definitely Not, Slightly Likely, Likely, Very Likely,* and *Definitely* was used to measure their intention. Fish filleting and the preservation of fish using vinegar were demonstrated to the participants. The fish used for this workshop was walking catfish (*Clarias batrachus).* The 0.1% vinegar solution was prepared and when the fish was dipped in vinegar and allowed to drip for 1 hour before the workshop started to show the effectiveness of the vinegar.

2.4. Nutritional Composition of 11 Fish Species Commonly Consumed

Eleven fish species were collected for proximate and fatty acid analysis for this study including, *Channa striata, Channa lucius, Hemibagrus filamentus, Barbonymus gonionoyus, Larbiobarbus siamensis, Puntioplites bulu, Channa micropites, and Oxyeleotris marmorata* were collected from Sre Ambel river; whereas *Barbonymus gonionoyus* and *Barbonymus altus* were collected from Sre Ambel Market; and *Clarias batrachus*, and *Pangasianodon hypophthalamus* were collected from cultured farm. Samples were randomly collected between September 2021 and May 2022 from fishermen along the river. They were transported in ice-cool box for preparation. Total standard length and weight of fish before and after being beheaded and gutted were measured. Fish head were cut, eviscerated, cleaned with towel paper, vacuum-packaged, and stored at 20°C before being transported to Mississippi State University for analysis.

2.5. A Shelf-Life Study of Natural Antimicrobials and Antioxidants to Preserve Fresh Fish

Forty-five catfish fillets were obtained for 3 replications of 5 antimicrobial treatments (25.5% of buffer dried vinegar, 25.5% rosemary extract, 12.5% combination of buffer dried vinegar and rosemary extract, positive control, and negative control). The fillets were then squared to approximately the same size, weighed, and dipped in the respective treatment solutions for 10 min. For positive control treatment, fish fillets were not dipped and stored at 4°C; whereas for the negative control treatment, fillets were kept at room temperature. The fillets were removed, laid on a wire rack, and allowed to drip for 10 min before the weight was recorded again. At 0h, 12h, and 24h, fillets were withdrawn based on their designated duration. They were blended and 10g of the samples were weighed into a filter bag. Each sample was homogenized in 100mL of buffered peptone water (BPW) for one minute. Serial dilutions were then prepared from the fish rinsate and then were enumerated by directly plating onto 3M Rapid Aerobic Count (RAC) Petrifilm®. The Petrifilm® were incubated at 37°C in aerobic conditions for 24 h. Data were analyzed in SAS V. 9.4 by the GLIMMIX procedure and means were separated at a P value of ≤ 0.05.

Research Results

Objective 1

1.1. Overall Fishery of the Sre Ambel River

For 2 years, 15 fishers from 5 villages collected data on their harvest, with an average of 158 trips per fisher. Trips averaged 12.5 hrs. per fisher (range = 5 – 16.3 hrs.). From March 2021 to February 2023, fishers recorded n = 48,048 individual-level entries for a total of n = 118,528 fish (including the total count of subsampled fish). Those fishes belong to 27 orders, 60 families, 114 genera, and 161 species. The result from all fishing gear types combined found three dominant fish species, *Puntioplites bulu* (17.3%), *Labiobarbus leptocheilus* (11.5%), and *Osteochilus vittatus* (4.1%), which accounted for nearly 39,000 individual fish of the total catch. *Labiobarbus leptocheilus* dominated in both dry (November to April) and rainy (may to October) seasons. Most harvested fish were small (Fig. 3). The three most dominant species were caught as small, likely immature juveniles. *Puntioplites bulu* reaches a maximum length of nearly 50 cm. In comparison, the mean capture size was 17.1 cm (range = 8–49.2 cm), and the species mainly was caught between March-April as small, likely immature individuals (Fig. 4-5). *Labiobarbus leptocheilus* reaches a maximum length of nearly 30 cm, while the mean capture size was 16.7 cm (range = 7–33 cm). Moreover, between March and May, many caught fish were between 10 and 15 (Fig. 6). *Osteochilus vittatus* reaches a

maximum length of nearly 30 cm, while the mean capture size was 15.1 cm (range = 8–25 cm) (Fig. 7).

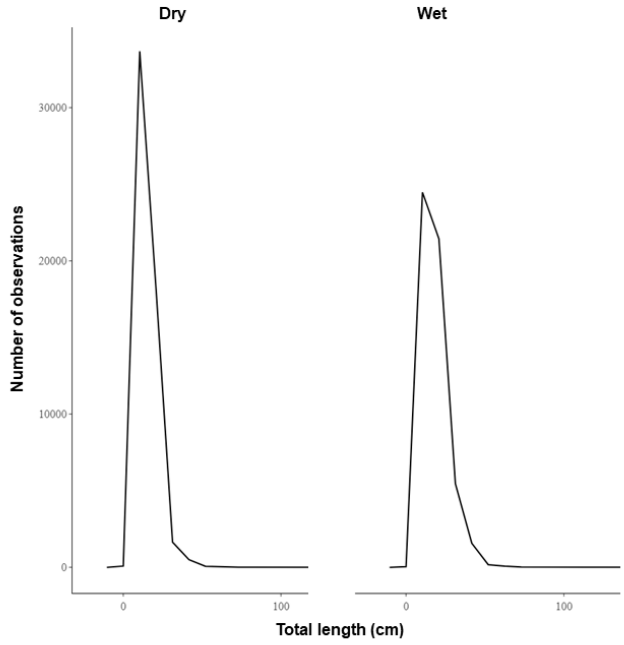


Fig. 3. Length frequency distribution of pooled fish caught in the Sre Ambel River, Cambodia between March 2021 to February 2023 and recorded by fishers in a Citizen Science Fisheries Harvest Assessment program

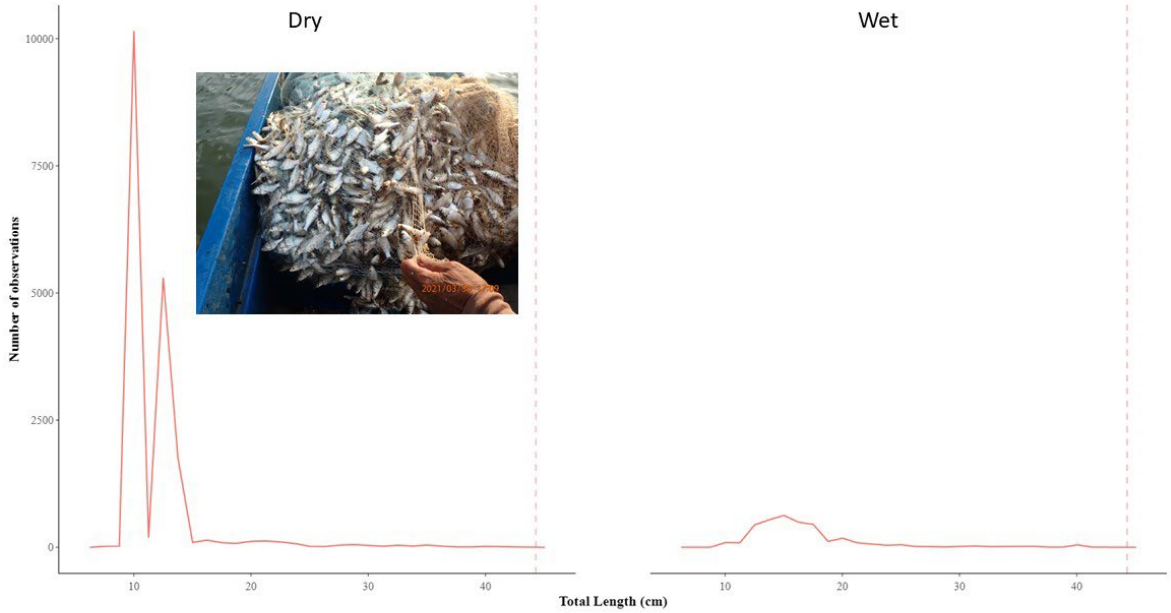


Fig. 4. Length frequency distribution of *Puntioplites bulu* during the dry and wet seasons. Insert shows fish caught between March and April depicting small body size. Maximum size that the species can reach is represented by the dotted line (≈50 cm)

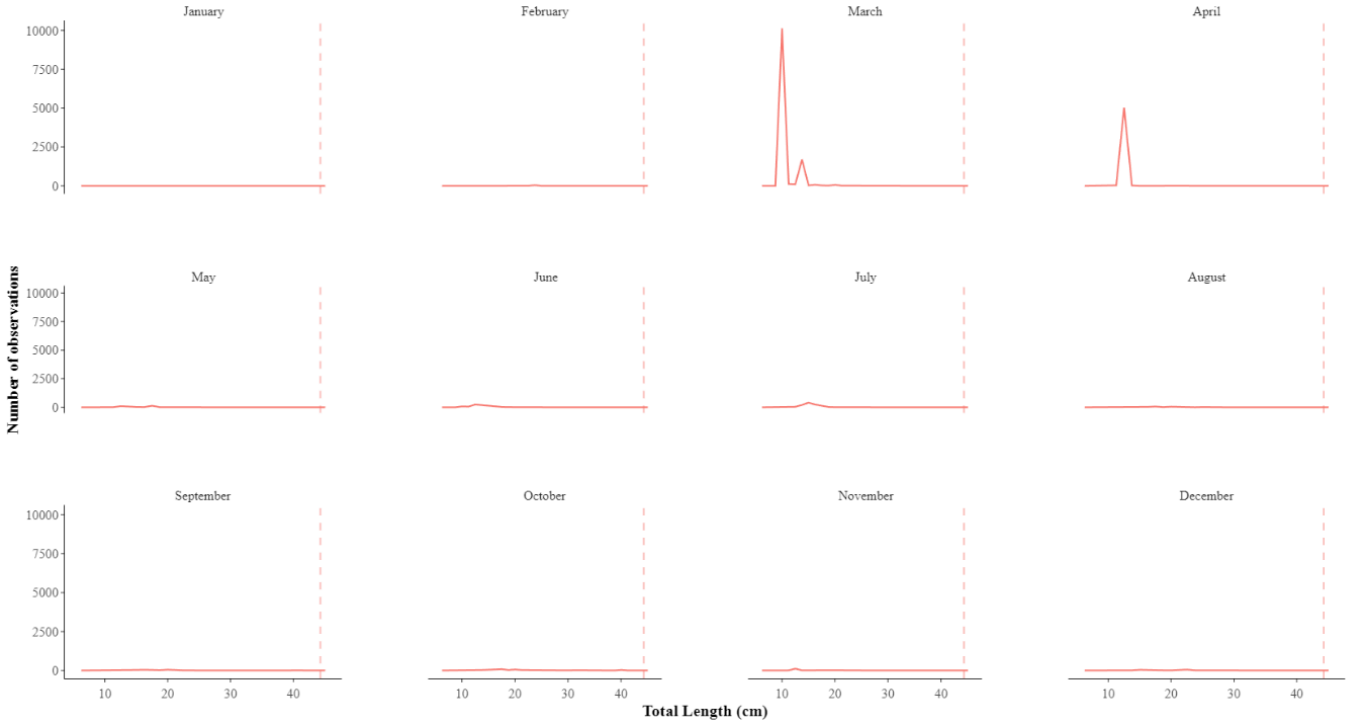
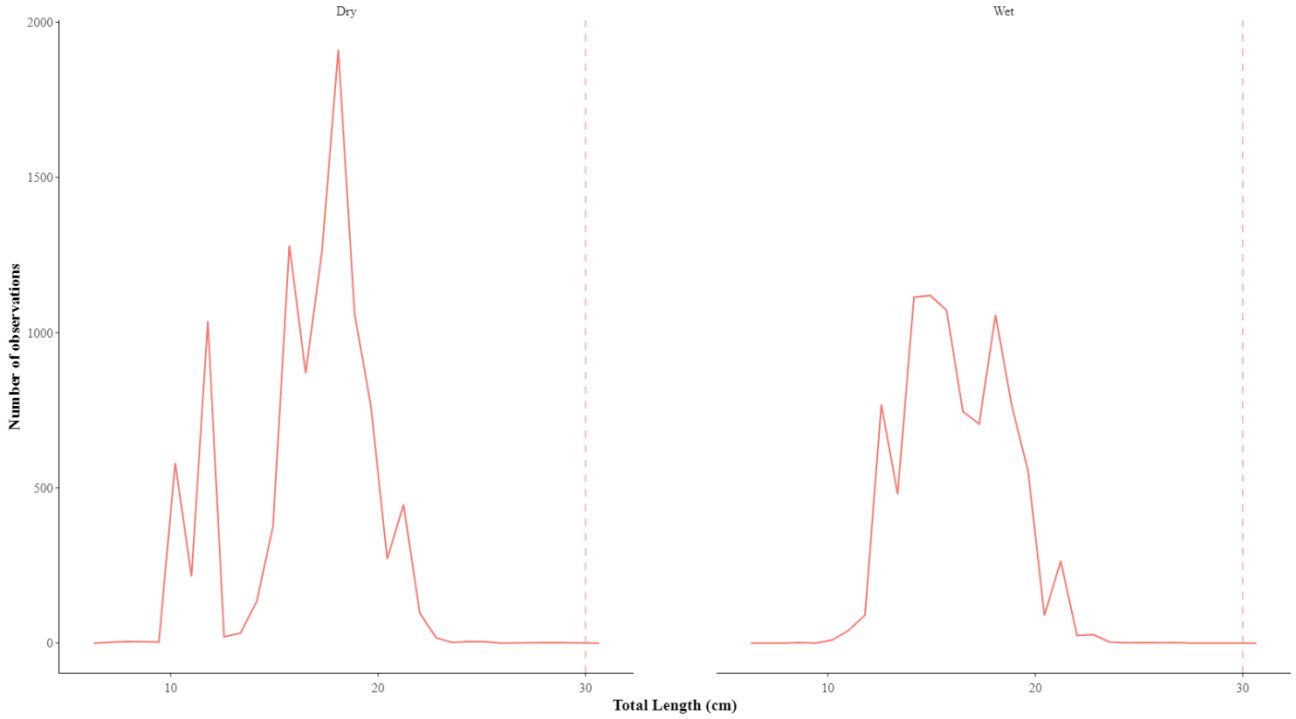


Fig. 5. Length frequency distribution of *Puntioplites bulu*, the most dominant species caught in the Sre Ambel River, Cambodia. Maximum size that the species can reach is represented by the dotted line (≈50 cm).

A.



B.

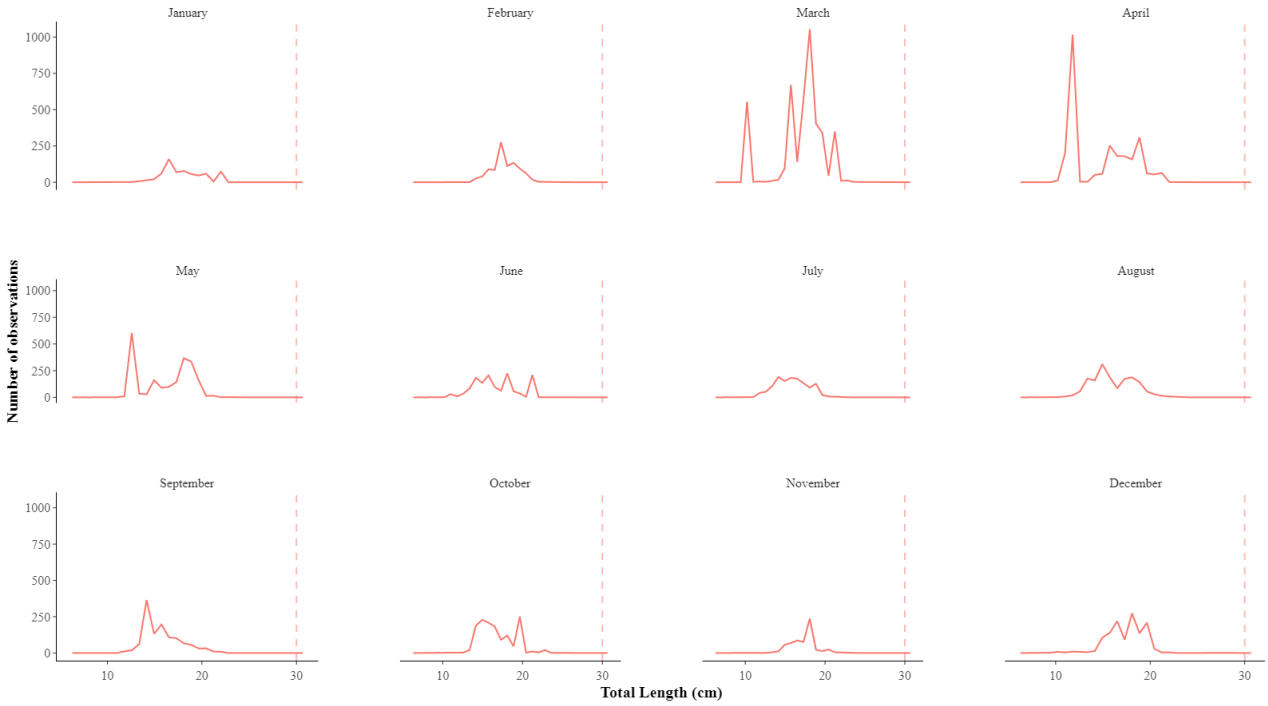
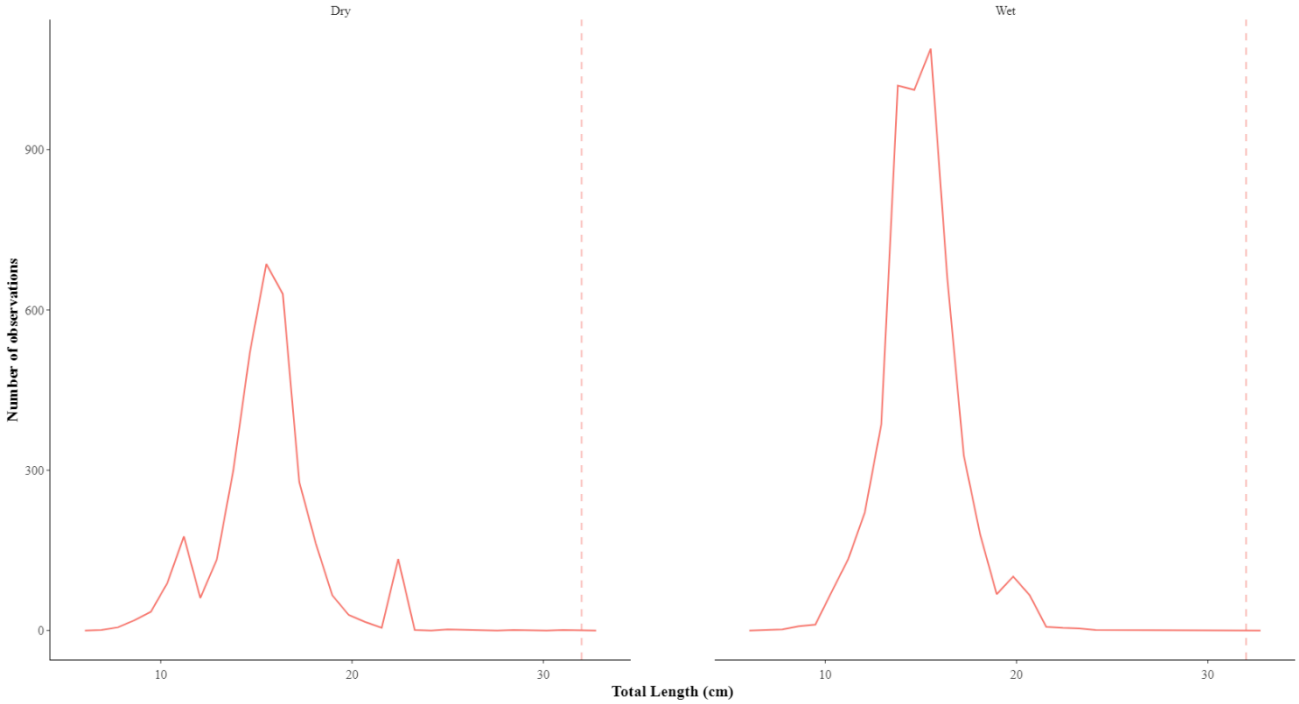


Fig. 6. Seasonal (A) and monthly (B) length frequency distribution of *Labiobarbus leptocheilus*, the second most dominant species caught in the Sre Ambel River, Cambodia. Maximum size that the species can reach is represented by the dotted line (≈30 cm)

A.



B.

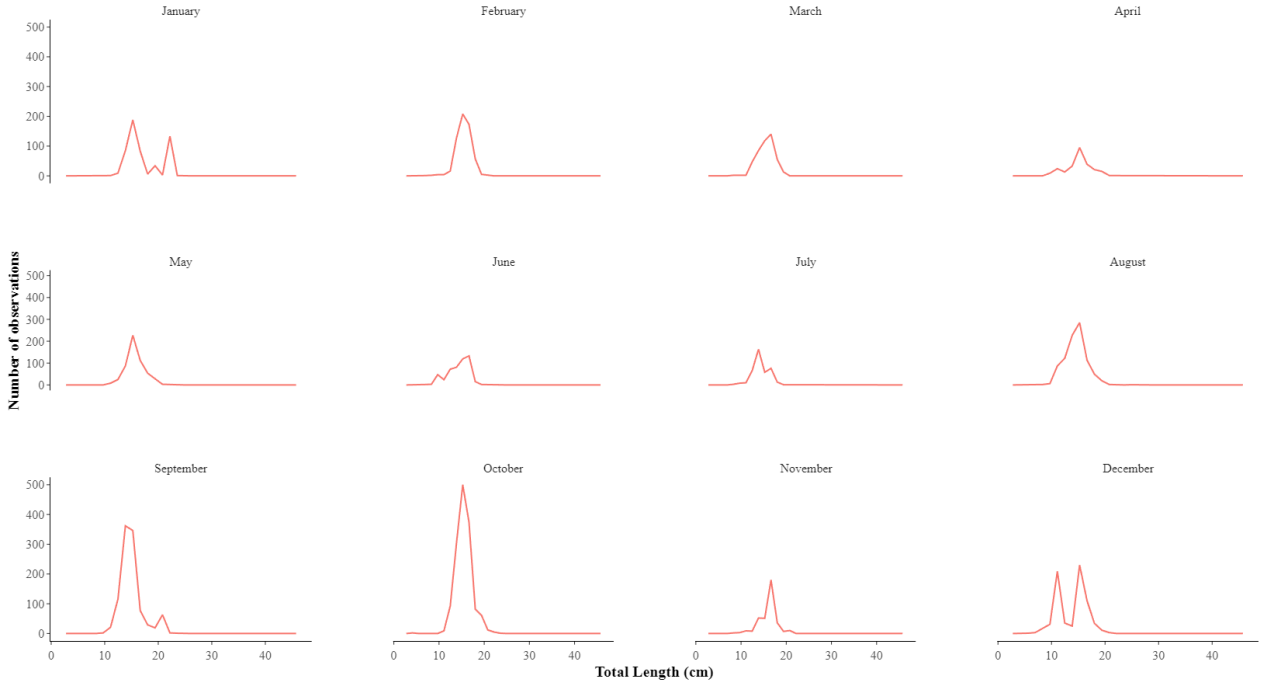


Fig. 7. Seasonal (A) and monthly (B) length frequency distribution of *Osteochilus vittatus*, the third most dominant species caught in the Sre Ambel River, Cambodia. Maximum size that the species can reach is ≈30 cm.

Overall, the number of harvested fish species was higher in the dry season (158 species; 98% of the total species harvested) than in the wet season (109 species; 68%). Likewise, the overall catch was higher during the dry season (75,857 fish; 64% of the total fish harvested) than in the wet season

(42,671 fish; 36%). Size of harvested fish averaged 17.9 cm (range 3-124 cm; *Puntigrus partipentazona* and *Pangasianodon hypophthalmus*, respectively) in the dry season and 18.8 cm (range 4-95 cm; *Anabas testudineus* and *Dichotomyctere ocellatus* were harvested as small as 4 cm, *Channa micropeltes* was harvested at a maximum size of 95 cm) in the wet season. In addition to *Labiobarbus leptocheilus*, other dominant species in the dry season include *Osteochilus vittatus, Rasbora paviana, Notopterus notopterus,* and *Cyclocheilichthys apogon*. Other dominant species in the rainy season include *Puntioplites bulu, Mastacembelus armatus, Osteochilus vittatus,* and *Cyclocheilichthys apogon.*

1.2. Spatial and Temporal Distribution of Fish and Fishing

We analyzed spatial and temporal patterns in fish abundance, length, and diversity based on catch from gill nets during the first year (March 2021-February 2022). Total catch varied spatially (Figure 8, Table 1-2). The Up North reach was responsible for 65.6% of the total catch, followed by Middle East (13.7%), Up East (10.8%), Down (8.5%), and Middle North (1.5%). However, these differences were largely due to variability in effort. When standardized to number of trips, fish per trip was highest in the Up East (38.7 fish), followed by Up North (36.2 fish), Middle East (32.9 fish), Down (29.7 fish), and Middle North (12.5 fish). There was an overall difference in fish per trip between river segments ($K=43.76$, $p<0.001$, $df=4$). Pair-wise comparison indicated that Middle North was significantly lower than all other reaches (all $p < 0.001$); the only other difference was that Middle East was significantly lower than Up North ($p = 0.022$).

Table 1 Summary of fish catch in year-1 at all fishing sites at Sre Ambel River

Fishing sites	Number fishing trip	Species richness	Fish abundance	Mean, SD fish length	Min-Max fish length
Down	90	77	2,675	12.54±5.80	3.5 - 46
Middle east	131	52	4,314	17.63±7.61	3.0 - 73
Middle north	37	32	464	16.67±4.53	6.8 - 81
Up east	88	32	3,409	19.97±8.27	10.1 - 99
Up north	571	82	20,672	17.40±6.17	4.0 - 124

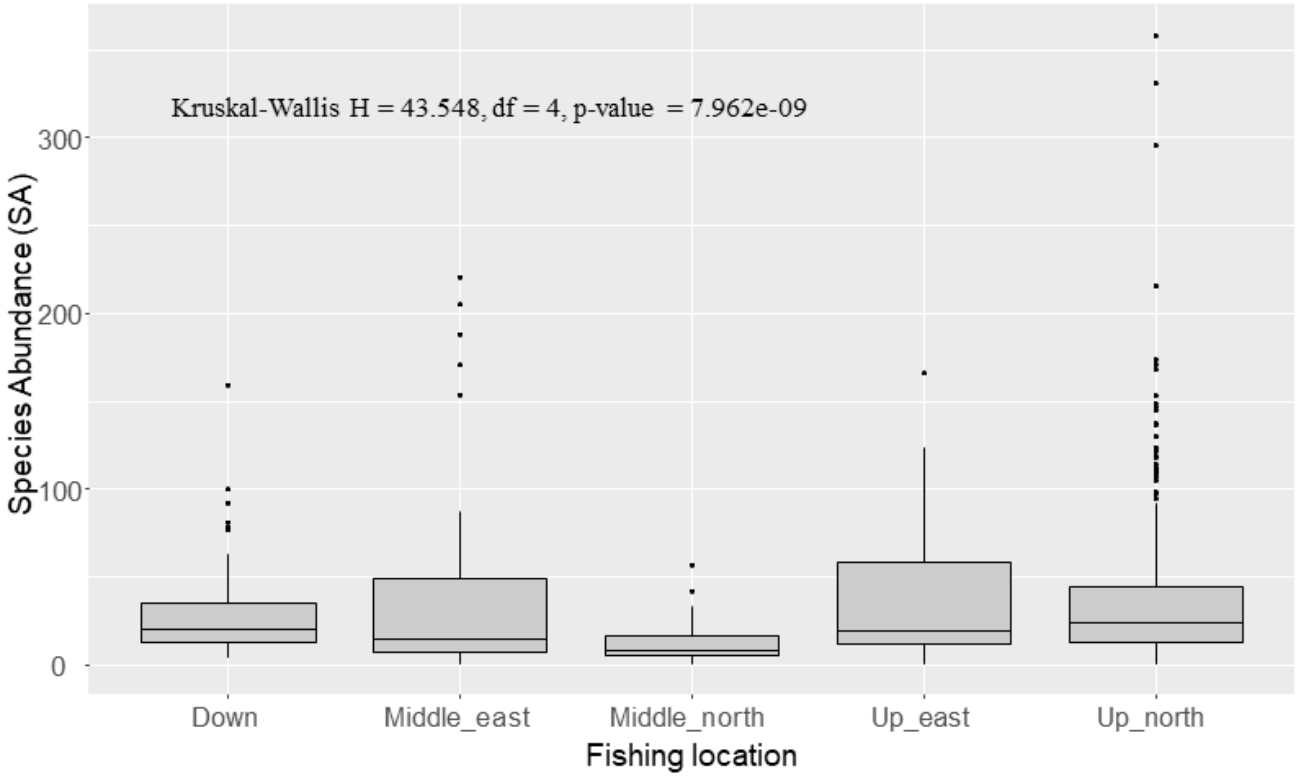


Figure 8. Boxplot showing the difference in species richness (S) fishing sites in Sre Ambel River

Table 2. Results of pair-wise comparison using the Dunn test showing the pair of fish abundance difference between fishing site in Sre Ambel River

	Middle east	Middle north	Up east	Up north
Down	1.00E+00	7.86E-05	1.00E+00	1.00E+00
Middle east		8.81E-04	4.39E-01	2.23E-02
Middle north			2.81E-06	1.30E-08
Up east				1.00E+00

Note: P ≤ 5.00E-02 (0.05) indicates statistically significant differences between fishing locations.

Fish length varied by location (Table 1). Middle East reported the smallest minimum length of fish at 3.0 cm compared to the largest minimum length Up East (10.1 cm). The largest fish maximum fish length was recorded Up North at 124 cm, followed by Up East at 99 cm. In contrast, Down recorded the maximum length was just 46 cm despite having a marine influence. The average fish length ranged between 12.54 cm (Down) to 19.97 cm (Up East).

Species richness (S) varied significantly between river reach ($K=138.45$, $p<0.001$, $df=4$). Pair-wise comparison showed significant ($p \leq 0.05$) differences for six pairs (Figure 9, Table 3). The highest average S was found in the Up North river reach, followed by Down and Middle East. Up East had the lowest average value for S. Up North displayed significantly greater species richness than all sites except the marine-influenced Down river reach. The Up East reach exhibits significantly lesser species richness than all reaches except for Middle North (Figure 9). Diversity ($1/\lambda$; $H=55.64$, $df=4$,

p<0.001) and Evenness (J'; H=58.32, df=4, p<0.001) differed by river reach (Figure 10), and Up North exhibited the highest diversity and Up East the lowest. Median Evenness (J') was at least 0.5 for all river reaches, suggesting the catch was well distributed amongst species (Figure 10).

Table 3 Result of pair-wise comparison using Dunn test to show the probability of having equal species richness between river reaches in the Sre Ambel River

	Middle east	Middle north	Up east	Up north
Down	4.03E-01	3.01E-03	5.46E-08	1.24E-01
Middle east		2.29E-01	1.68E-04	7.20E-08
Middle north			1.00E+00	5.57E-08
Up east				2.13E-22

Note: P ≤ 5.00E-02 (0.05) indicates statistically significant differences between fishing locations.

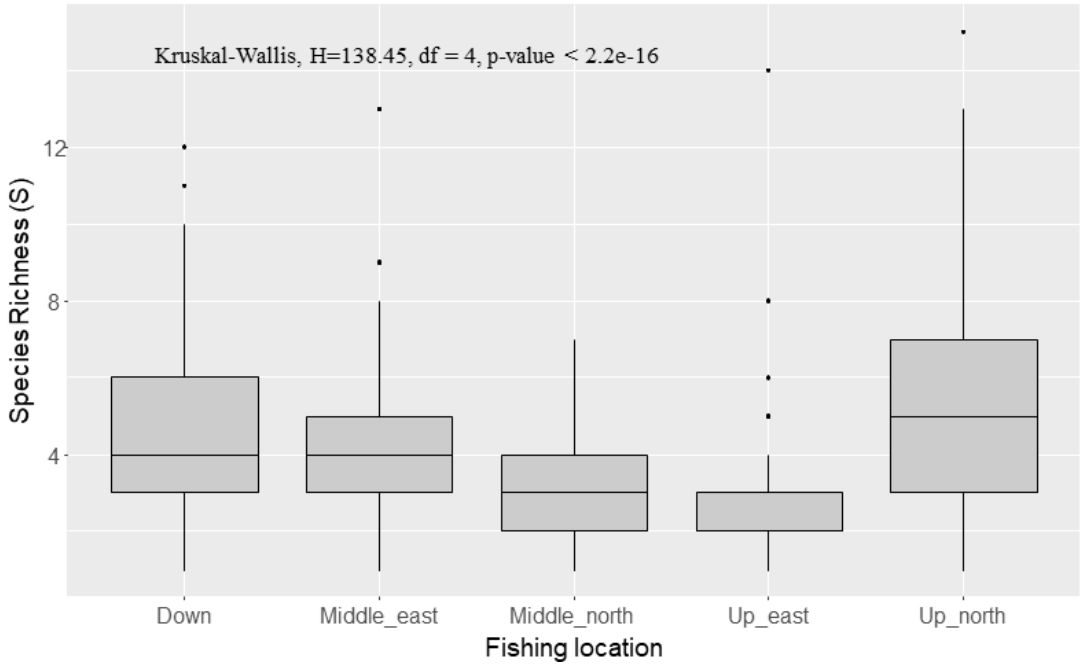
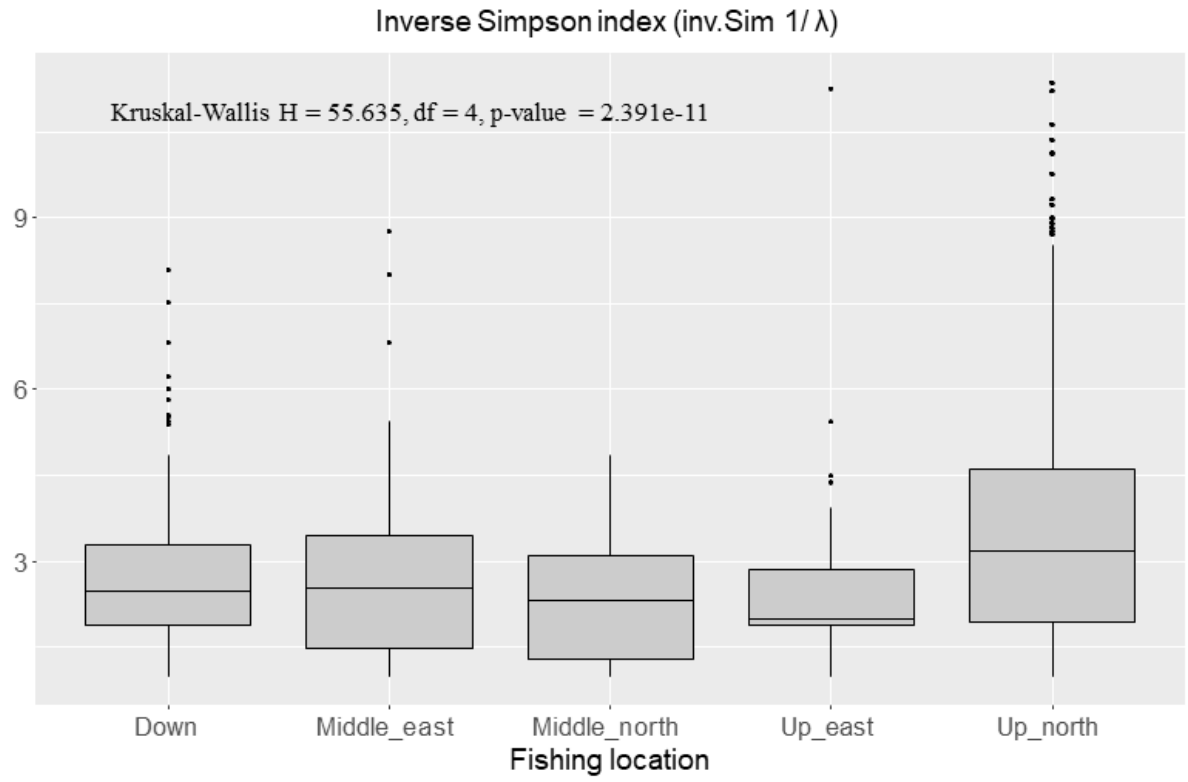


Figure 9. Boxplot showing the difference in species richness (S) fishing sites in Sre Ambel River



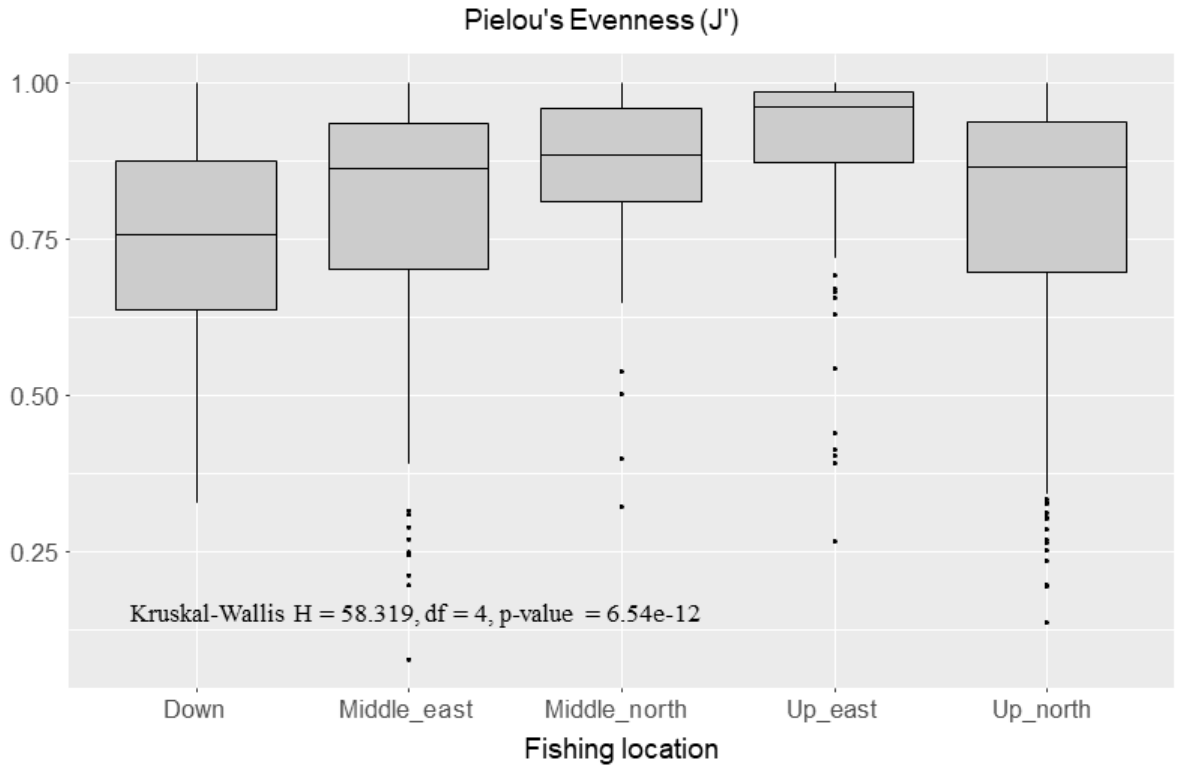


Figure 10. Diversity indices of fish in each fishing site in Sre Ambel River. From top: the Inverse Simpson Index (inv.Simp 1/ λ), and bottom: the Evenness Index (J')

Fish species composition differed significantly between the two seasons (dry and wet) in terms of species richness (S; W=130243, $p < 0.001$), diversity (1/λ; W=130096, $p < 0.001$), and evenness (J'; W=104251, $p = 0.020$) (Figure 11). Average species richness was higher in the dry season (n = 5)

than in the wet season (n = 4), although the highest value per fishing trip was observed in the wet season (15 species).

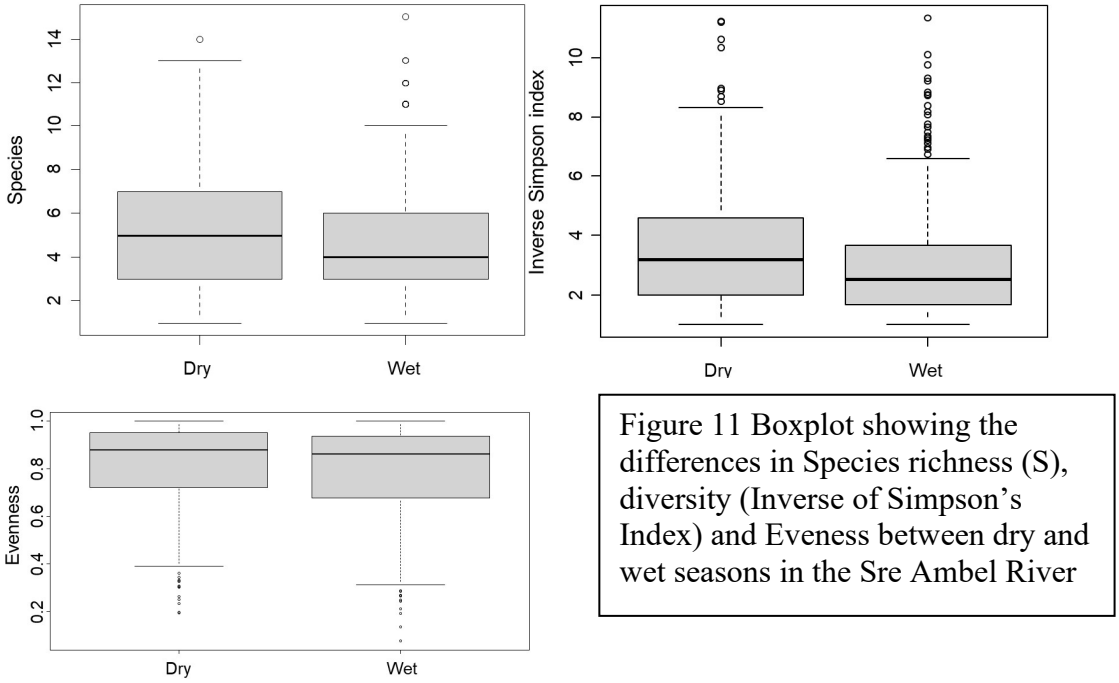


Figure 11 Boxplot showing the differences in Species richness (S), diversity (Inverse of Simpson's Index) and Eveness between dry and wet seasons in the Sre Ambel River

1.3. Trophic Levels of Harvested Fish Species in the Sre Ambel River

Our team collected and processed 531 samples for stable isotope analysis. These include 418 samples of fish tissue and 113 samples of food sources (i.e., terrestrial and aquatic invertebrates, terrestrial vegetation leaves, benthic algae, and plankton). Samples were sent to Louisiana State University for chemical analysis of C and N stable isotope values.

1.4. Field Exchange Visit for CFi Council Members to Pursat Province

Wildlife Conservation Society (WCS) in collaboration with the Department of Community Fisheries Development of Fisheries Administration and Conservation International (CI) and funding support from USAID-Feed the Future and Mississippi State University organized a study exchange to visit Sreychoek and O'Tabrok CFIs in the Tonle Sap Lake located in Krokor District, Pursat Province for 19 members (05 females) from five Community Fisheries (CFi) namely: Bak Angruth, Preah Angkeo, Sala Mneang, Akphiwat Toek Paong O'Chrov CFis from Sre Ambel District, Koh Kong Province and Samaki Preak Kampong Seila, Kampong Seila District, Preah Sihanouk Province. The study exchange was conducted from 22-24 May 2023, aiming at building the capacity of the CFi members in relation to the sustainable management of fisheries resources, the establishment of fish conservation zone, the functioning of CFi council, building relationships with local authorities, fund generation through saving groups, mini-trust fund, government budget, saving groups, and the establishment of fish processing groups. As a result, all participants gain significant experience that inspired them to engage in fisheries management. After the trip, WCS posted news of the trip on the WCS Facebook Page.

https://www.facebook.com/100064574836381/posts/pfbid02hbXWR4T8db19H1xatu6YvB5WdhyNiHyCxfC324qb9tPvKR3jEBoY4GGUBphRHMyRl/?mibextid=jf9HGS

Objective 2

2.1. Survey of Fish Preservation Techniques and Processing Methods

The results from the fish preservation question showed that 58% of fishermen use ice and 25% of them use salt to preserve fish before bringing fish ashore, whereas 41% do not use any preserving methods. Right after catching, fish is stored on the boat for up to 12 hours before bringing fish ashore to sell, cook them for consumption, and further process them. The fish that sold by fishermen are whole, eviscerated, scaled, cut head, and filleted which accounted for 88%, 20%, 16%, 10%, and 3% respectively. Apart from selling fresh fish, the remaining fish are usually further processed by fishermen. 59% of fishermen further processed their catch by salting, 49% by fermenting, 42% by drying, and only 10% by smoking. For fish cooking methods for consumption, 88% of respondents cooked fish by boiling fish in water, 48% by frying with cooking oil, 28% by grilling, 10% by steaming, and 7% by baking. In terms of the nutrition question of the fish cooked in the water, 58% of respondents considered that broth is nutritious and 43% of them considered the cooked fish is nutritious, while 6% did not know whether broth or cooked fish is more nutritious. However, 72% and 56% of respondents feed the cooked fish and broth to their family.

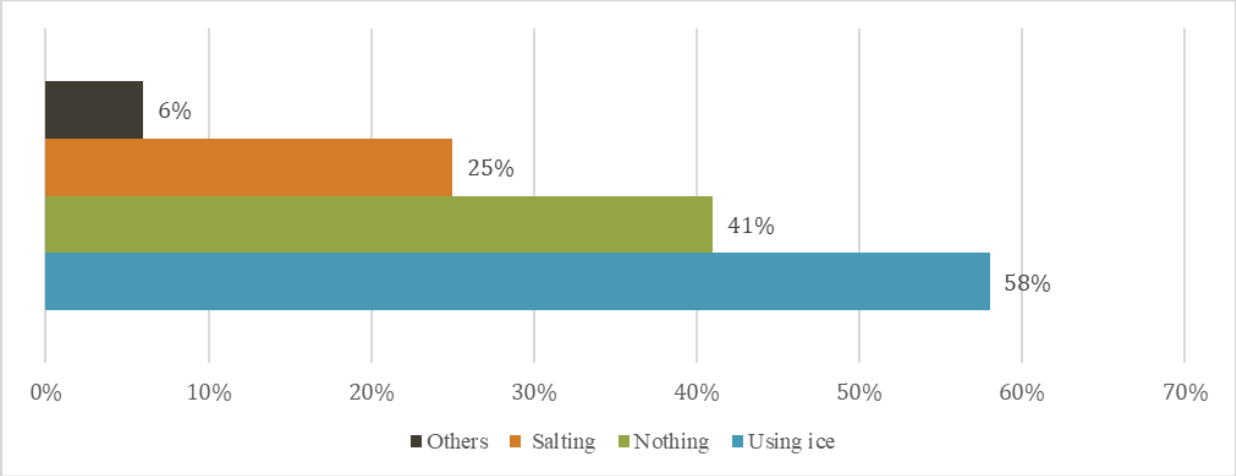


Fig. 1. Preservation methods prior to bringing fish ashore.

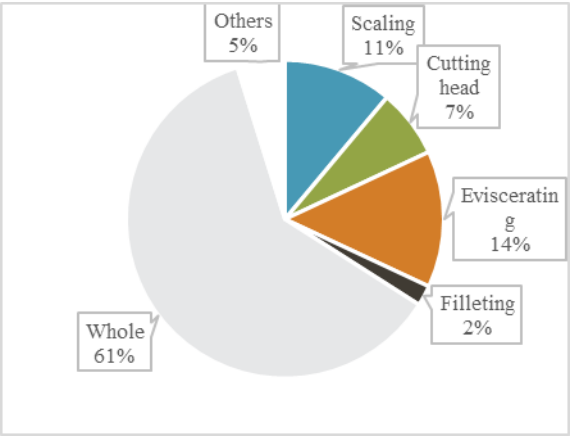


Fig. 2. How fishermen sell their catch.

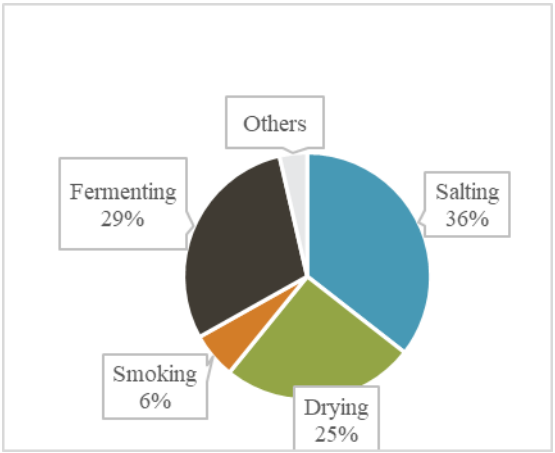


Fig. 3. Fish processing methods

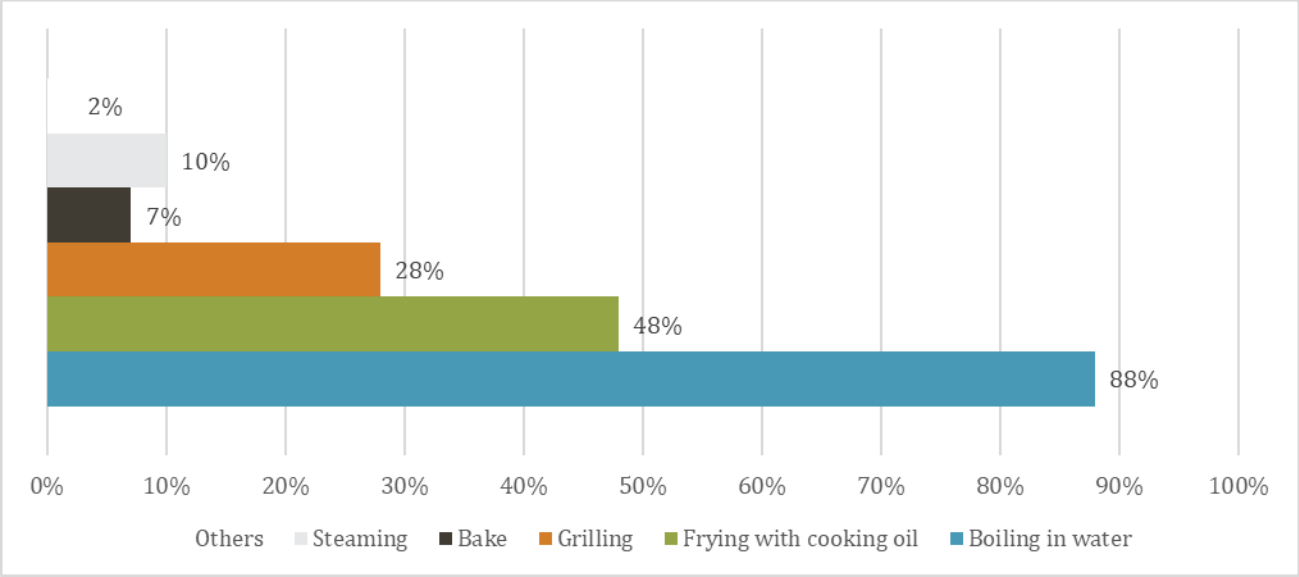


Fig. 4. Fish cooking methods

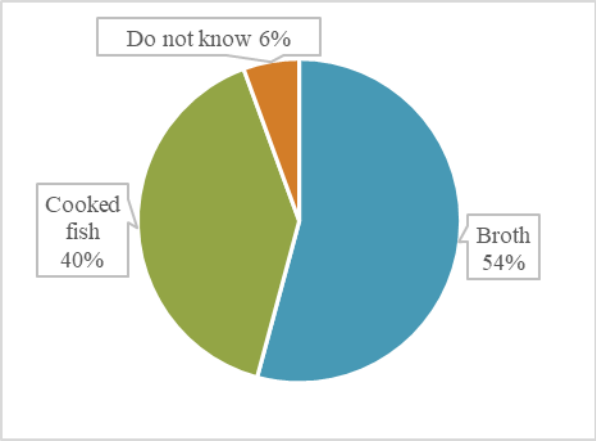


Fig. 5. Nutrients in broth or cooked fish

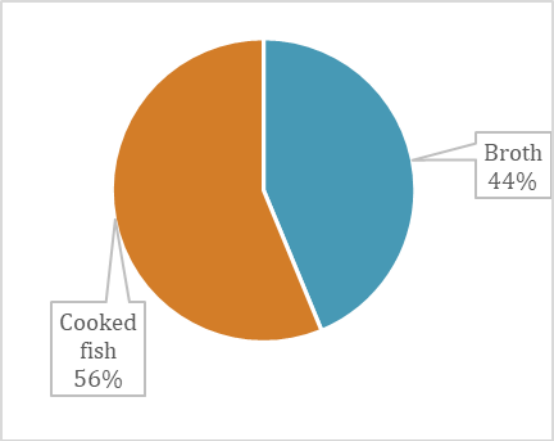


Fig 6. Feeding family's members

In conclusion, most fishermen do not use any preservation methods; therefore, an inexpensive method is needed to help preserve the quality and nutritional values of fish. Most do not further process and add more value to fish. More than 80% cook fish in boiling water and more than half do not know that most nutrients reside in the cooked fish, not broth. These findings create many opportunities for education and training to maximize the value of fish in improving the livelihood and nutritional status of these fishery communities.

2.2. Sensory Evaluation of Fish and Cooking Methods

Consumers preferred fried fish appearance and aroma ($P = 0.001$) over boiled fish but did not differ in their acceptability ratings for flavor, texture, and overall acceptability of boiled and fried fish (Table 2.2.1). In addition, all mean values were between 6.6 and 7.2, indicating that on average, boiled and fried fish were moderately acceptable to consumers. For fish species and preparation method, the appearance and flavor of walking catfish and striped snakehead were preferred ($P < 0.05$) over striped catfish. Aroma followed a similar pattern, with the exception that consumers also preferred the aroma of fermented striped catfish to that of striped catfish ($P < 0.0001$). When cooking

method, fish species, and preparation were evaluated together, the acceptability of appearance and aroma was liked more for fried walking catfish (7.2) than boiled walking catfish (6.7) and boiled striped catfish (6.2) ($P < 0.001$). All other treatments were also preferred ($P < 0.05$) over the boiled striped catfish. In addition, for flavor and overall acceptability, the boiled striped catfish was liked less ($P < 0.001$) than all other treatment combinations with the exception of fried, fermented striped catfish.

Table 1 –Mean scores[1] for consumer acceptability (N =100) of appearance, aroma, flavor, texture, and overall, for three fish species of Cambodian fish, one that was both fresh and fermented, that were either boiled or fried using a 9-point hedonic scale.

Sensory	Cooking methods			Preparation & Species				
Attributes	Fried	Boiled	*P*	Walking Catfish	Stripped Snakehead	Fermented Stripped Catfish	Stripped Catfish	*P*
Appearance	7.0a	6.7b	0.002	7.0a	7.0a	6.9a	6.6b	0.046
Aroma	7.0a	6.6b	<0.001	6.9a	6.9a	6.9a	6.4b	<0.0001
Flavor	7.1a	7.0a	0.230	7.2a	7.2a	7.0ab	6.8b	0.017
Texture	7.1a	7.0a	0.155	7.1a	7.1a	7.0a	6.9a	0.118
Overall acceptability	7.2a	7.2a	0.349	7.3a	7.3a	7.2a	7.0a	0.098

[abc]: Means with the same letter within each row are not significantly different (P < 0.05).

[1]: Scores were based on a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely).

Table 2 –Mean scores[2] for consumer acceptability (N =100) of appearance, aroma, flavor, texture, and overall acceptability for the combined treatments of fish species, preparation method, and cooking method using a 9-point hedonic scale.

Sensory Attributes	Fried walking catfish	Boiled fermented striped catfish	Fried striped catfish	Boiled striped snakehead	Fried striped snakehead	Boiled walking catfish	Fried fermented striped catfish	Boiled striped catfish	*P*
Appearance	7.1a	6.9ab	7.0ab	6.9ab	6.9ab	6.7b	6.8ab	6.2c	0.001
Aroma	7.2a	7.0ab	6.9ab	7.0ab	6.9ab	6.7b	6.9ab	5.9c	<0.0001
Flavor	7.4a	7.3a	7.2a	7.3a	7.1a	7.0ab	6.7bc	6.4c	<0.0001
Texture	7.3a	7.1a	7.2a	7.2a	7.0a	6.9a	6.9a	6.5b	0.0004
Overall acceptability	7.4a	7.4a	7.3ab	7.3ab	7.2ab	7.2ab	6.9bc	6.7c	0.0003

[abc]: Means with the same letter within each row are not significantly different (P < 0.05).

[2]: Scores were based on a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely).

Overall, consumers had a slight preference for the appearance and aroma of fried over boiled fish. Walking catfish was liked moderately for both boiled and fried fish, and striped catfish should be either cooked fried or fermented before it is boiled. In addition, striped snakehead did not differ in acceptability between frying and boiling methods. This indicates that striped catfish is the only fish that should not be boiled, and that striped catfish is better when being fried than when it is boiled.

In conclusion, the type of fish and cooking method impacts sensory attributes greatly. Targeting the right species and promoting them through appropriate cooking methods will promote more consumption of fish. Cooking will also influence the nutritional values of fish. More research is needed in this area.

2.3. Training and Workshops in Fish Processing and Preservation, and Continuity Assessment

Consumers preferred appearance, flavor, texture, and overall acceptability of direct smoked *Cyclocheilichthys apogon* over indirect smoked *Cyclocheilichthys apogon* but do not differ in their aroma acceptability rating for both smoking methods (Table 2.3.1). For fried *Cyclocheilichthys apogon*, all sensory attributes were preferred for both treatments. In addition, all mean scores were

between 6.8 and 7.8, indicating that on average fried *Cyclocheilichthys apogon* that were either fried with or without dipping in vinegar were moderately acceptable to consumers. For the *Ompok hypophthalamus*, all sensory attributes of both direct and indirect smoking were preferred by consumers except that the appearance the direct smoke (8.6) was liked less than that of indirectly smoked (7.6) (Table 2.3.2). The frying methods also followed a similar pattern with the exception that consumers preferred the flavor of *Ompok hypophthalamus* over the one that was not dipped in vinegar. Additionally, consumers liked all the treatments very much with all the mean scores between 7.3 and 8.6.

Table 3 –Mean scores[1] for consumer acceptability (N =30) of appearance, aroma, flavor, texture, and overall acceptability for the direct smoked, indirect smoked, fried, and vinegar fried of *Cyclocheilichthys apogon* using a 9-point hedonic scale.

Sensory Attributes	Direct smoked *Cyclocheilichthys apogon*	Indirect smoked *Cyclocheilichthys apogon*	Fried *Cyclocheilichthys apogon*	Vinegar fried *Cyclocheilichthys apogon*	*P*
Appearance	7.2a	5.7b	6.8ab	7.3a	0.0219
Aroma	7.0ab	5.8b	6.8ab	7.4a	0.0053
Flavor	7.5a	6.0b	7.0ab	7.8a	0.0057
Texture	7.4a	5.9b	7.2a	7.6a	0.0008
Overall acceptability	7.7a	6.5b	7.4a	7.8a	0.0046

[abc]: Means with the same letter within each row are not significantly different (P < 0.05).

[2]: Scores were based on a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely).

Table 4 –Mean scores[2] for consumer acceptability (N =18) of appearance, aroma, flavor, texture, and overall acceptability for the direct smoked, indirect smoked, fried, and vinegar fried of *Ompok hypophthalamus* using a 9-point hedonic scale.

Sensory Attributes	Direct smoked *Ompok hypophthalamus*	Indirect smoked *Ompok hypophthalamus*	Fried *Ompok hypophthalamus*	Vinegar fried *Ompok hypophthalamus*	*P*
Appearance	8.6a	7.6b	8.5a	8.1ab	
Aroma	8.1a	7.7a	8.5a	8.0a	
Flavor	8.5a	7.7ab	8.5a	7.3b	
Texture	8.2a	7.6a	8.5a	8.0a	
Overall acceptability	8.3a	7.5a	8.4a	7.8a	

[abc]: Means with the same letter within each row are not significantly different (P < 0.05).

[2]: Scores were based on a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely).

For the continuity assessment, 21 out of 35 participants joined the previous workshop that involved smoking fish and 20 of them used to smoke fish before. While 15 people were likely to smoke fish for personal use, there were 4 people who definitely smoke fish to sell to others. Accordingly, when asking whether brick or any material could be found to build a smoker, 13 people responded that the materials could definitely be found. In terms of finding the customers to buy their smoked fish, only 8 participants answered that they definitely could find people to buy their products. Meanwhile, half of participants used salted fish for consumption and 13 of them would definitely salt fish to sell to others as well. Regarding filleting fish for personal use, only 3 were likely to do so, while 11 people would definitely fillet fish to sell to others. When being asked about the educational opportunities to better understand the nutritional values of fish and the opportunities to work with WCS in the future, 18 and 14 people would definitely want the opportunities, respectively. Along with the future opportunities in the previous question, 9 would definitely like to form a processor group to further process fish products.

In conclusion, simple and inexpensive techniques can be delivered through various means (video clips, written documents, or in-person training). Due to the nature of processing techniques being empirical, in-person training is preferred, especially when participants can also participate in sensory evaluation of the products they produce. These training sessions changed how the

participants see the values of their products. They understood the concepts of value addition. This emphasizes the fact that Cambodia needs food scientists that focus on adding value to traditional or fresh products according to their understanding of local culture and cuisine. Most participants value the continuing support through program like the FIL; therefore, this needs to be a consideration for the next FIL renewal. Through the training and the research funded by the FIL, the particiants have the tool and knowledge to improve their livelihood.

2.4. Nutritional Composition of 11 Fish Species Commonly Consumed.

The nutritional values of fish are presented in Table 5 and Appendix Table S2.1.

Table 5 Proximate composition of 11 fish species (%)

Species	Common name	Ash	Fat	Moisture	Protein
Channa micropeltes	Giant snakehead	1.35	<0.01	80.3	19.22
Channa lucius	Snakehead murrel	1.48	0.01	79.15	19.68
Channa striata	Striped snakehead	1.11	<0.01	78.35	22.90
Labiobarbus siamensis	Siamese long fin carp	1.5	0.64	78.45	19.60
Oxyeleotris marmorata	Marble goby	1.23	<0.01	79.89	19.44
Puntioplites bulu	Bulu barb	0.98	0.1	78.79	20.59
Barbonymus gonionotus	Java/Silver barb	1.11	5.71	73.68	20.41
Barbonymus altus	Red tailed tinfoil	1.02	5.25	74.5	20.05
Hemibagrus filamentus	Yellow catfish	1.18	0.06	79.47	22.27
Clarias batrachus	Walking catfish	2.1	3.19	75.92	19.04
Pangasianodon hypophthalamus	Striped catfish	1.16	1.77	79.55	18.34

In addition to proximate composition, we analyzed for the first time fatty acid composition (see appendices) of commonly consumed fish species in Cambodia. These data are invaluable for decision-making in targeted catches and conservation efforts. Combining with sensory data, these findings allow us to understand which fish species are more nutritious and also sensory-appealing. However, it was obvious that the participants preferred fried fish; therefore, the impacts of introducing cooking oil and high-heat cooking on nutritional values of fish must be researched. This is also the first effort to our knowledge to analyze the nutritional composition of commonly consumed fish in Cambodia.

2.5. A Shelf-Life Study of Natural Antimicrobials and Antioxidants to Preserve Fresh Fish

A time x antimicrobial treatment interaction was observed in this study ($P < 0.001$). As seen in the figure below, significant differences between the treatments at different time points can be observed ($P < 0.001$). However, a trend can be seen between treatments BDV, BDVRGT, and the positive control (POS), which simulated refrigeration. In all three of these treatments, the number of microbes detected was significantly lower at 24hrs after treatment, as compared to samples at 0hr. A 2.55, 1.15, and 1.61 log CFU/g reduction in aerobic bacterial counts was observed between 0-24hrs for BDV, BDVRGT, and POS, respectively. However, RGT was not significantly different from the negative control, with both treatments resulting in an average of 5.45 and 5.20 log CFU/g of bacteria, respectively, after 24hrs. These results suggest that BDV is a viable candidate as an antimicrobial treatment for catfish in an effort to improve the shelf life.

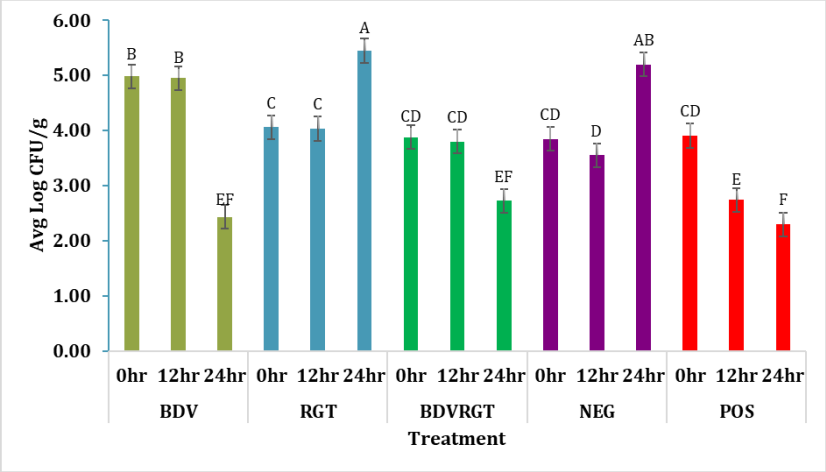


Fig. 8. Aerobic plate count (log cfu/g) of fish fillets treated with buffered dry vinegar (BDV), green tea/rosemary extract (RGT), combination, negative control (NEG), and positive control (POS). A time x treatment interaction was observed to be statistically significant ($P < 0.001$)

Fishermen do not use preservation methods for their catches. This hinders their ability to maximize the value of their products. Buffered vinegar is a very inexpensive antimicrobial that has been used in the meat and poultry industries for a long time. The high pH allows for preservation without damaging fish tissues or causing negative sensory issues. More efforts are needed to research inexpensive preservation and further processing methods (Chakriya Chum came to the U.S. and was trained on further processing for fish) so that fishermen can add more value to their fish and increase profitability for their operation.

Outputs and Conclusions

Objective 1

- Management actions and rules must be based on knowledge of the fish, habitat, and people that are stakeholders in the fishery.
- Over the past two years, the Citizen Science program has collected accurate data on the current status of the fishery including the fish species harvested, number of fish individuals, fish size, gear used, fishing effort, and geographic distribution of the catch.
- The three most commonly harvested species were Bulu Barb (Puntioplites bulu, 17.3%), Bulu (Labiobarbus leptocheilus, 11.5%), and Bony-lip Barb (Osteochilus vittatus, 4.1%), which accounted for 32.9% of the total catch. The commercial potential of these species and their contribution to people's livelihoods in terms of household consumption and income generation remains to be determined. The team recommends conducting an economic analysis of the Sre Ambel fishery.
- The three most dominant species were caught as small, likely immature juveniles. However, data on size at first maturation is not currently available for these species. The team recommends assessing biological traits (size at maturity and reproductive rate) and estimating the sustainable yield of the dominant harvested species in the Sre Ambel River.
- Many species besides the dominant ones are potentially being harvested at sizes that do not allow reproduction. The team recommends assessing biological traits (size at maturity and reproductive rate) of commonly harvested species in the Sre Ambel River.

- Regulations to set minimum sizes allowed to be harvested and/or gear restrictions to reduce non-selecting catch or allow smaller fish to escape should be considered once the minimum size at maturity is established.
- Overall differences in yield per trip between river segments indicate that some areas are more productive than others, such as the Up North, which had greater yield than the Middle East. Conversely, the Middle North was significantly lower than all other reaches.
- Spatial differences in yield can be due to variability in habitats that support fish, such as floodplain forests.
- The team secured further funding from the US Forest Service to characterize floodplain habitat along the Sre Ambel River and link habitat availability to fisheries productivity.
- iFISH will be instrumental in informing the Fisheries Management Program. For example, although information on size at maturity is lacking, fishers can reduce the capture of small fish by restricting fishing in periods of the year when tiny fish are abundant, suggesting they represent the recently born individuals that need to recruit in the population. The team recommends banning the capture of Bulu Barb from March to April; Bulu from March to May, and Bony-lip Barb from January to February.
- Once a Fisheries Management Program is implemented, continuous data collection is necessary to provide before and after information and to determine if management regulations are effective at improving abundance and fish size of harvested species.
- Results from stable isotopes laboratory and statistical analyses are expected by December of 2023 and will be posted on iFISH.

Objective 2

- As preservation is not typically used prior to bringing fish ashore to help fish stay fresh, fishermen need an inexpensive preservation method and buffered vinegar is a promising approach because it does not affect sensory attributes and was effective as shown in our study. Additionally, salting and fermentation are techniques that commonly apply to process fish in Sre Ambel besides smoking which should be further investigated in terms of its processing and nutritional contents. This survey result provides the first data on fish processing techniques in the study area.
- Most fishermen are willing to fillet and smoke fish to sell to others. The processed products of fish added value to fish and at the same time reduce fish waste.
- Smoking increases the value of fish and fishermen can easily build one that fits their needs. And from our continuity assessment session with them, it was also revealed that the obstacle of moving forward with processing fish were lack of support, equipment, and the source of fish.
- Crucial information on fish size and nutritional composition is now available for the target approach to harvest and preservation as mentioned in objective 1. Preferred cooking methods are also known, which allows for better fish consumption in Cambodian households. This information will enable further study on the importance of fish nutrition and processing technology in the future.

- A collection of video clips fresh fish processing and further fish processing methods is available for further training beyond the grant period.
- A clear understanding of species, sensory preference, and processing method now allow for target harvest and value addition to low-value (low sensory acceptability) catches.

Overall

Managing fisheries requires data. The Citizen Science program and iFISH should be continued to provide continuous monitoring of the fishery as additional management actions are implemented. Having continuous data will allow for adaptive management of the fishery – that means the ability to adjust management actions as the fishery responds. Additional data on life history characteristics of species and habitat changes will be necessary to refine management. Fishing smart by integrating ecological, nutritional, sensory, and processing knowledge, and targeted harvest will lead to sustainable fisheries, improved livelihoods, and better nutrition.

Technologies/Innovations developed, and what phase was achieved

Objective 1

- A web-based data visualization and analysis application called *i-FISH*: *Community Fisheries Assessment Tool – Sre Ambel River Fishery, Cambodia* (https://ifish.shinyapps.io/ifish/). This is a novel web-based data visualization and analysis platform to make spatial and temporal comparisons, define baselines, and evaluate stocks exploited by artisanal fisheries in tropical rivers.
- The App development phase was completed, user experience optimized, and local- and national-level state holders were trained on how to use it to gain knowledge of the current state of the Sre Ambel fisheries and potential future use after community-based fisheries management implementation.

Objective 2

- Sensory training video clips for future research in Cambodia – applied in the field
- Digital materials, including various video clips of fish processing and preservation techniques for future training in Cambodia – applied in the field
- Smoking fish using Brazilian-style, indirect, brick smoker – applied in the filed
- Buffered vinegar for fish preservation without cold chain – proof of concept in a lab setting and tested in the filed for sensory attributes.

Key Beneficiaries

Objective 1 &2

- Local stakeholders: Community Fisheries (CFi) Councils of five villages in two provinces (Bak Angruth, Preah Angkeo, Sala Mneang, Akphiwat Toek Paong O'Chrov CFis from Sre Ambel District, Koh Kong Province and Samaki Preak Kampong Seila, Kampong Seila District, Preah Sihanouk Province).
- National Government: Fisheries Administration of Cambodia

How the scientific results were disseminated

Objective 1

Fisheries Management Workshop: Exit Strategy for Sustainable Fisheries

Sre Ambel, Koh Kong: In mid-June 2023, WCS in collaboration with the Mississippi State University, conducted three fisheries management workshops focusing on the exit strategy for sustainable fisheries management with five CFi located along the Sre Ambel River System. The workshops aimed at transferring knowledge of citizen science fisheries research where members of CFis lead the fish data collection within their communities. After a two-year data collection, the project uploaded all harvest data onto the iFISH App (https://ifish.shinyapps.io/ifish/). We presented the findings of the citizen science data collection summarized by iFISH, critical conservation messages for CFi councils such as minimal fish size to harvest, fishing location, fish composition, gear types, how to visualize data on iFISH using different tabs and queries, and applications of iFISH for future sustainable fisheries management. The workshops played a vital role in building their capacity to be able to continue the citizen science data collection program and gain knowledge on the use of the iFISH App for long-term sustainable fisheries resources management.

During the workshops, the project staff also handed over a smartphone (built-in with a SMART application) to each of five CFi councils which were funded by the USAID-Feed the Future- Fish Innovation Lab to assist them with monthly SMART patrols to reduce illegal fishing activities that harm to fisheries resources. WCS also posted news on Facebook about the support to encourage local people to engage in freshwater conservation.

https://www.facebook.com/100064574836381/posts/pfbid023ENTmhj76vgjiJSfpvX1aEwy4KSt17AkNdBTYK2vhgSvGCuqWjS9UJmD8TGfw2MXl/?mibextid=jf9HGS

Objective 2

We trained three WCS staff and one graduate student in various research techniques and fish processing. Fish processing skills and knowledge were disseminated in two workshops with an assessment of continuity. Video clips for training purposes are now available for further use beyond the grant period. We publish findings at 2023 Aquaculture America and during the final PI meeting in New Orleans. Data will be transferred to the FIL management entity for further dissemination.

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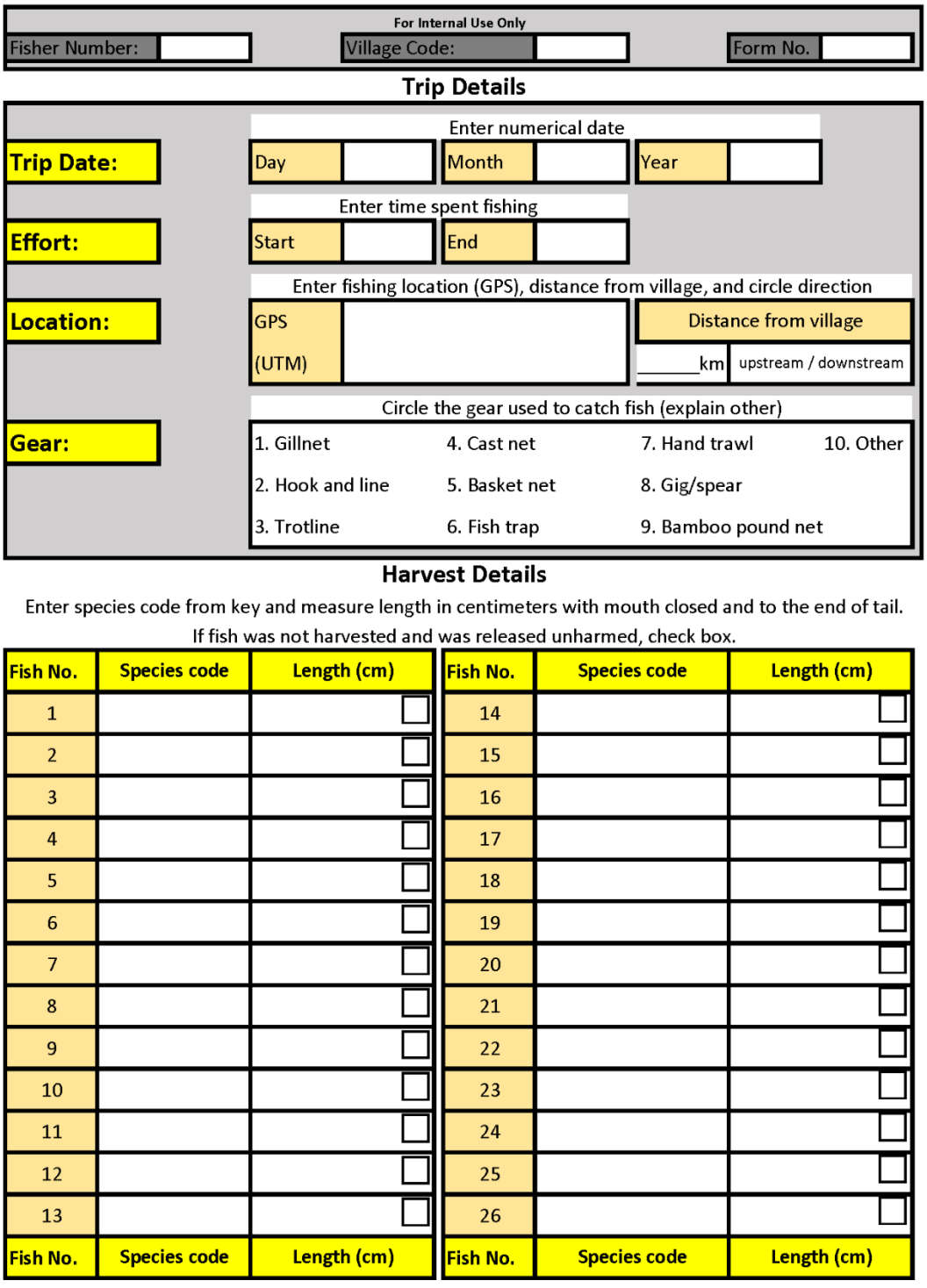
Appendices

Appendix 1. Instructions to complete harvest data collection

Instructions
Thank you for participating in this important study on the Sre Ambel River fishery. Our goal is to detemine how the fishery changes though time. Local villages are establishing a "Community Fishery" and taking pressure off of natural fisheries by raising fish in cages. This research project will monitor changes in the river to see if fish populations are improving.
To be successful, this research must have quality data collection. It is important that you record every fishing trip, regardles of how many fish you caught or even if you did not catch fish. Also, it is important that you report only on your catch. If you fished with another person and they used their own gear, only report what you harvested. Please follow the instructions below. Finally, please do not make up data. If you forget to record a trip, just let us know.
First, tell us about your fishing trip:
1. For each trip, record the date (day, month, year) and how many hours and minutes you were fishing.
2. Using the equipment provided or your cell phone, record the GPS coordinates of your fishing location. Also provide the distance from your village and whether you traveled up or down the river.
3. We want to know how you fished. Please circle the gear type. If you use more than one gear, circle each gear that you used. If your gear is not listed, circle "other" and describe your gear.
Next, tell us about what you caught and harvested:
Record a separate line of data for every fish you harvested.
4. Using the photographic key to fishes, enter the species code where indicated.
5. Next, use the measuring board to measure each fish. Put the mouth of the fish against the board stop, close the mouth, and squeeze the tail. Measure to the tip of the tail at the fishes longest point in centimeters. Write this number in the length column beside the correct species code.
6. Repeat for every fish you caught that day. If you catch more fish than 80 fish in a trip, use the form extension provided.

Appendix 2. Citizen Science Fisheries Harvest Assessment Data Collection Template



For Internal Use Only

Fisher Number: | Village Code: | Form No.

Trip Details

Trip Date: Enter numerical date — Day | Month | Year

Effort: Enter time spent fishing — Start | End

Location: Enter fishing location (GPS), distance from village, and circle direction — GPS (UTM) | Distance from village: _____km | upstream / downstream

Gear: Circle the gear used to catch fish (explain other)

1. Gillnet	4. Cast net	7. Hand trawl	10. Other
2. Hook and line	5. Basket net	8. Gig/spear	
3. Trotline	6. Fish trap	9. Bamboo pound net	

Harvest Details

Enter species code from key and measure length in centimeters with mouth closed and to the end of tail.
If fish was not harvested and was released unharmed, check box.

Fish No.	Species code	Length (cm)	Fish No.	Species code	Length (cm)
1		☐	14		☐
2		☐	15		☐
3		☐	16		☐
4		☐	17		☐
5		☐	18		☐
6		☐	19		☐
7		☐	20		☐
8		☐	21		☐
9		☐	22		☐
10		☐	23		☐
11		☐	24		☐
12		☐	25		☐
13		☐	26		☐
Fish No.	Species code	Length (cm)	Fish No.	Species code	Length (cm)

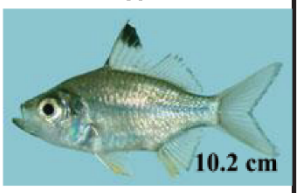
Appendix 3. Sre Ambel Species Identification Key. Page 1 of 20.

Likely Species

001

Ambassis buruensis

002

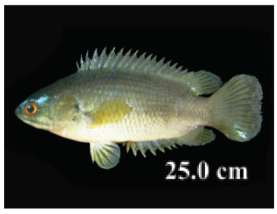


Ambassis kopsii

003

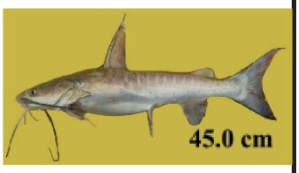
Parambassis siamensis

004



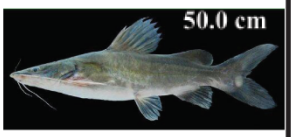
Anabas testudineus

005



Hexanematichthys sagor

006



Hemibagrus filamentus

007

Hemibagrus nemurus

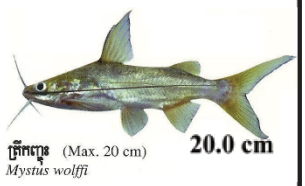
008

Mystus albolineatus

009

Mystus rhegma

010

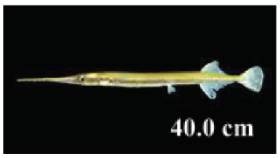


Mystus wolffi

011

Pseudomystus siamensis

012



Xenentodon cancila

Appendix 4.

Table S2.1 Fatty acid profile of 11 fish species from the Sre Ambel River

Scientific Name	Channa striata	Channa lucius	Hemibagrus filamentus	Barbonymus gonionotus	Labiobarbus siamensis	Pangasianodon hypophthalamus	Clarias batrachus	Barbonymus altus	Puntioplites bulu	Oxyeleotris marmorata	Channa micropeltes
Common Name	Striped snakehead	Snakehead murrel	Yellow catfish	Java/Silver barb	Archkok/Trey ach kok	Striped catfish	Walking catfish	Kahe/Trey kahe	Kanh chrea/Trey kanchrea	Damrey/Trey Damrey	Giant snakehead
C8_0	0.095	0.092	0.086	0.098	0.109	0.289	0.117	0.108	0.234	0.092	0.196
C10_0	0.000	0.011	0.013	0.035	0.068	0.060	0.000	0.043	0.049	0.000	0.000
C11_0	2.726	2.735	2.728	2.727	2.721	2.719	2.758	2.739	2.782	0.000	2.720
C12_0	2.300	2.366	2.385	2.942	2.373	24.249	28.420	2.878	3.313	2.248	2.272
C14_0	0.767	1.479	1.351	8.277	3.296	66.428	24.852	33.902	13.712	0.882	1.086
C15_0	0.401	1.113	0.698	3.631	2.135	1.913	2.813	3.089	3.486	0.567	0.448
C16_0	16.423	18.525	66.069	414.492	52.968	331.851	208.819	472.438	165.145	18.064	19.765
C17_0	1.456	1.733	1.742	5.358	2.880	1.934	2.280	4.006	5.704	1.427	1.201
C18_0	12.770	14.167	15.246	104.734	18.278	63.677	56.782	100.811	37.459	9.109	11.194
C19_0	1.545	1.520	1.431	1.826	1.559	0.000	1.572	1.741	1.618	1.451	1.522
C20_0	1.420	1.432	1.496	3.047	0.000	1.423	1.394	0.000	0.000	0.000	0.000
SFA	39.902	45.174	93.246	547.165	86.388	494.543	329.806	621.756	233.501	33.841	40.404
C8_1_UN	0.741	0.126	0.826	0.794	0.731	0.695	0.842	0.820	0.693	0.696	0.828
C11_1_UN	0.174	0.171	0.172	0.172	0.000	0.000	0.165	0.173	0.000	0.000	0.179
C14_1_cis9	0.000	0.102	0.094	0.283	0.000	0.504	0.430	0.161	0.914	0.000	0.000
C15_1_cis9	0.383	0.585	0.719	1.932	0.940	1.227	1.718	2.912	1.436	0.481	0.705
C16_1_cis6	0.419	0.422	0.468	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C16_1_cis9	2.380	4.830	2.450	12.281	8.958	9.700	10.745	9.667	10.023	5.640	0.287
C16_1_cis7	7.825	7.914	8.670	8.333	9.020	8.292	8.181	8.005	11.612	0.000	7.800
C17_1_cis10	1.570	1.799	1.620	1.648	1.527	0.000	1.437	2.131	2.387	1.634	1.544
C18_1_cis9	8.834	15.525	47.839	610.236	27.697	289.076	213.985	667.417	103.572	5.180	7.392
C18_1_cis11	0.409	5.037	3.627	11.923	3.279	4.046	11.279	11.962	8.135	1.586	1.948
C18_1_cis12	0.000	0.000	0.155	0.000	0.000	0.000	0.107	0.098	0.729	0.000	0.000
C20_1_cis11	0.000	0.057	0.587	4.912	0.000	1.014	2.729	7.312	0.499	0.000	0.062
C24_1_cis15	0.592	0.337	0.549	0.721	0.425	0.320	0.483	0.317	0.000	0.000	0.503
MUFA	23.326	36.906	67.776	653.234	52.579	314.873	252.102	710.976	140.000	15.218	21.248
C18_2_cis9,12	7.973	9.599	10.645	303.153	9.464	50.949	83.259	157.132	8.034	5.653	6.447
C18_3_cis6,9,12	0.431	0.472	0.431	1.059	0.000	0.000	2.637	1.282	0.000	0.000	0.000
C18_3_cis9,12,15	0.526	0.376	0.997	6.158	1.137	1.324	8.762	9.704	0.484	0.202	0.446
C18_2_cis9trans11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C18_2_trans10cis12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C20_2_cis11,14	0.000	0.189	0.439	3.794	0.000	1.371	1.365	1.896	0.293	0.000	0.147
C20_3_cis11,14,17	1.810	1.606	4.736	12.834	2.529	6.201	15.048	10.198	4.207	0.000	1.759
C20_4_cis5,8,11,14	12.831	9.501	7.751	21.010	10.155	7.099	12.790	12.645	11.956	7.349	8.110
C20_5_cis5,8,11,14,17	3.247	3.483	3.455	4.895	4.055	3.244	3.596	3.679	3.151	0.000	0.000
C22_2_cis13,16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.478	0.000	0.000	0.096
C22_4_cis7,10,13,16	0.295	0.300	0.419	0.191	0.194	0.073	0.151	0.170	0.230	0.000	0.093
C22_5_cis7,10,13,16,19	3.115	3.022	3.549	3.102	2.783	0.388	1.120	0.758	0.370	0.364	0.432

C22_6_cis4,7,10,13,16,19	8.906	4.855	14.586	23.411	3.341	1.846	18.305	34.791	3.297	4.989	5.541
PUFA	39.134	33.404	47.007	379.607	33.657	72.496	147.033	232.733	32.022	18.557	23.071
C20_2_cis11,14	0.000	0.189	0.439	3.794	0.000	1.371	1.365	1.896	0.293	0.000	0.147
C20_3_cis11,14,17	1.810	1.606	4.736	12.834	2.529	6.201	15.048	10.198	4.207	0.000	1.759
C20_4_cis5,8,11,14	12.831	9.501	7.751	21.010	10.155	7.099	12.790	12.645	11.956	7.349	8.110
C20_5_cis5,8,11,14,17	3.247	3.483	3.455	4.895	4.055	3.244	3.596	3.679	3.151	0.000	0.000
C22_2_cis13,16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.478	0.000	0.000	0.096
C22_4_cis7,10,13,16	0.295	0.300	0.419	0.191	0.194	0.073	0.151	0.170	0.230	0.000	0.093
C22_5_cis7,10,13,16,19	3.115	3.022	3.549	3.102	2.783	0.388	1.120	0.758	0.370	0.364	0.432
C22_6_cis4,7,10,13,16,19	8.906	4.855	14.586	23.411	3.341	1.846	18.305	34.791	3.297	4.989	5.541
LCPUFA	30.205	22.957	34.934	69.237	23.056	20.223	52.374	64.615	23.503	12.702	16.178
C13_0_12methyl	0.000	50.834	50.829	50.807	50.893	0.000	50.870	50.823	51.527	0.000	0.000
C14_0_13methyl	0.205	0.392	0.775	0.342	0.797	0.413	0.521	0.309	0.260	0.269	0.209
C14_0_12methyl	0.000	3.511	3.484	3.975	3.652	3.809	3.854	3.564	9.400	0.000	3.471
C15_0_14methyl	0.537	0.608	0.992	0.871	0.876	0.494	0.640	0.580	4.472	0.598	0.537
C16_0_15methyl	0.000	0.000	0.000	0.774	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C16_0_14methyl	63.682	63.625	64.155	63.871	0.000	63.474	63.482	63.767	65.575	63.497	0.000
C16_1_cis9_14methyl	0.738	1.231	0.390	0.313	0.557	0.817	1.756	0.501	0.622	0.442	0.942
C18_0_17methyl	0.000	0.000	0.000	1.042	0.000	0.000	0.812	0.788	0.000	0.000	0.000
BCFA	65.162	120.201	120.626	121.994	56.774	69.007	121.934	120.332	131.856	64.806	5.160
P/S	0.981	0.739	0.504	0.694	0.390	0.147	0.446	0.374	0.137	0.548	0.571
SI	0.639	0.642	0.812	0.530	1.002	1.277	0.826	0.659	1.357	1.002	0.912
ω3 PUFA	17.604	13.343	27.323	50.401	13.845	13.003	46.831	59.130	11.509	5.555	8.178
ω6 PUFA	21.529	20.061	19.684	329.206	19.813	59.492	100.202	173.603	20.513	13.002	14.893
ω6/ω3	1.223	1.503	0.720	6.532	1.431	4.575	2.140	2.936	1.782	2.341	1.821
ω3 LCPUFA	17.079	12.967	26.326	44.243	12.707	11.679	38.069	49.426	11.025	5.353	7.733
ω6 LCPUFA	13.126	9.990	8.608	24.994	10.349	8.544	14.305	15.189	12.479	7.349	8.446
ω6 LCPUFA/ω3 LCPUFA	0.769	0.770	0.327	0.565	0.814	0.732	0.376	0.307	1.132	1.373	1.092

Appendix 5

ឈ្មោះ.....

Continuity Assessment for FIL Cambodia

កម្រងសំណួរវាយតម្លៃបន្តទៅលើគម្រោងការកែច្នៃត្រី

1. Smoking fish produce good flavor, allows fish to be used in many different ways, and makes it last longer. **Knowing that, will you smoke fish for personal use?**
   ការឆ្អើរត្រីជួយបន្ថែមរសជាតិដល់ត្រី ហើយអាចយកទៅធ្វើម្ហូបបានច្រើនមុខ និងជួយអោយត្រីទុកបានយូរ។
   ដោយដឹងថាត្រីឆ្អើរផ្តល់នូវអត្ថប្រយោជន៍ដូចខាងលើ តើអ្នកអាចនឹង**ឆ្អើរត្រីសម្រាប់ហូប**ក្នុងគ្រួសារដែរឬទេ?

   Definitely Not / មិនធ្វើទេ — Slightly likely / ប្រហែលជាអាច — Likely / អាចនឹងធ្វើ — Very likely / អាចនឹងធ្វើច្រើន — Definitely / ប្រាកដជាធ្វើ

2. Smoking fish produces good flavor, allows fish to be used in many different ways, and makes it last longer. **Knowing that, will you smoke fish to sell to others?**
ការឆ្អើរត្រីជួយបន្ថែមរសជាតិដល់ត្រី ហើយអាចយកទៅធ្វើម្ហូបបានច្រើនមុខ និងជួយអោយត្រីទុកបានយូរ។
ដោយដឹងថាត្រីឆ្អើរផ្តល់នូវអត្ថប្រយោជន៍ដូចខាងលើ តើអ្នកអាចនឹង**ឆ្អើរត្រីសម្រាប់លក់**ដែរឬទេ?

Definitely Not — Slightly likely — Likely — Very likely — Definitely

មិនធ្វើទេ — ប្រហែលជាអាច — អាចនឹងធ្វើ — អាចនឹងធ្វើច្រើន — ប្រាកដជាធ្វើ

3. **Have you smoked fish before?**
តើអ្នកធ្លាប់ឆ្អើរត្រីដែរឬទេ?

□Yes □ធ្លាប់

□No □មិនធ្លាប់ទេ

4. **Did you participate in the previous workshop that involves smoking fish?**
តើអ្នកបានមកចូលរួមសកម្មភាពបង្ហាញពីការឆ្អើរត្រី នៅស្ថាប័នអង្គការWCSនៅឃុំបឹងព្រាវ ដែរឬទេ?

□Yes □បានចូលរួម

□No □មិនបានចូលរួមទេ

5. **Do you have access to how-to videos of building indirect smokers?**
តើអ្នកអាចចូលទៅមើលវីដេអូបង្ហាញពីរបៀបធ្វើឡឆ្អើរត្រីដែលមិនប្រើភ្លើងដោយផ្ទាល់ទេ?

□Yes □អាច

□No □មិនអាចទេ

6. Can you find bricks or similar materials to build an indirect smoker?
តើអ្នកគិតថា អ្នកអាចរកឥដ្ឋ ឬសម្ភារៈដែលស្រដៀងនឹងឥដ្ឋ ដើម្បីយកមកធ្វើឡឆ្អើរបានដែរឬទេ?

Definitely Not — Slightly likely — Likely — Very likely — Definitely

មិនអាចរកបានទេ — ប្រហែលជាអាចរកបាន — អាចនឹងរកបាន — អាចនឹងរកបានច្រើន

ប្រាកដជារកបាន

7. Having tasted smoked products, do you think you can find customers who want to buy smoked fish?
ក្រោយពីបានភ្លក់ត្រីឆ្អើរដែលឆ្អើរដោយមិនប្រើភ្លើងដោយផ្ទាល់រួចហើយ
តើអ្នកអាចរកអតិថិជនដែលអាចទិញត្រីឆ្អើរនោះបានដែរទេ?

Definitely Not — Slightly likely — Likely — Very likely — Definitely

មិនអាចរកបានទេ — ប្រហែលជាអាចរកបាន — អាចនឹងរកបាន — អាចនឹងរកបានច្រើន

ប្រាកដជារកបាន

8. Would you attend educational opportunities to better understand the nutritional values of fish and how to retain fish nutrients during cooking fish for your family?

តើអ្នកអាចនឹងមកចូលរួមសកម្មភាពអប់រំ
ដែលទាក់ទងនឹងការស្វែងយល់កាន់តែច្បាស់អំពីសារធាតុចិញ្ចឹមដ៏មានប្រយោជន៍ដែលមាននៅក្នុងត្រី
និងរបៀបចម្អិនដែលអាចរក្សានូវសារធាតុចិញ្ចឹមសំខាន់ៗក្នុងត្រីដែរទេ?

Definitely Not Slightly likely Likely Very likely Definitely

មិនមកទេ ប្រហែលជាមក អាចនឹងមក អាចនឹងមកច្រើន

ប្រាកដជាមក

9. Will you produce more filleted fish for personal use?
តើអ្នកអាចនឹងធ្វើត្រីដោយយកតែសាច់ សម្រាប់ហូបខ្លួនឯងទេ?

Definitely Not Slightly likely Likely Very likely Definitely

មិនធ្វើទេ ប្រហែលជាអាច អាចនឹងធ្វើ អាចនឹងធ្វើច្រើន ប្រាកដជាធ្វើ

10. Will you produce more filleted fish to sell to others?
តើអ្នកអាចនឹងធ្វើត្រីដោយយកតែសាច់ យកទៅលក់ដែរទេ?

Definitely Not Slightly likely Likely Very likely Definitely

មិនធ្វើទេ ប្រហែលជាអាច អាចនឹងធ្វើ អាចនឹងធ្វើច្រើន ប្រាកដជាធ្វើ

11. Will you produce more salted fish for personal use?
តើអ្នកអាចនឹងធ្វើត្រីប្រឡាក់ សម្រាប់ហូបខ្លួនឯងទេ?

Definitely Not Slightly likely Likely Very likely Definitely

មិនធ្វើទេ ប្រហែលជាអាច អាចនឹងធ្វើ អាចនឹងធ្វើច្រើន ប្រាកដជាធ្វើ

12. Will you produce more salted fish to sell to others?
តើអ្នកអាចនឹងធ្វើត្រីប្រឡាក់យកទៅលក់ដែរទេ?

Definitely Not Slightly likely Likely Very likely Definitely

មិនធ្វើទេ ប្រហែលជាអាច អាចនឹងធ្វើ អាចនឹងធ្វើច្រើន ប្រាកដជាធ្វើ

13. Would you work with the WCS to find ways to make fish last longer if opportunities presented themselves?
ប្រសិនបើអង្គការWCS មានគម្រោងផ្សេងទៀតពីរបៀបទុកដាក់ត្រីអោយបានយូរ
តើអ្នកអាចនឹងចូលរួមជាមួយអង្គការWCSទៀតដែរឬទេ?

Definitely Not Slightly likely Likely Very likely Definitely

មិនមកទេ ប្រហែលជាមក អាចនឹងមក អាចនឹងមកច្រើន

ប្រាកដជាមក

14. Would you like to create a fish processor group to provide processed products to your community?

តើអ្នកអាចនឹងចងក្រងក្រុមអ្នកកែច្នៃផលិតផលត្រីដើម្បីលក់ និងផ្គត់ផ្គង់ក្នុងសហគមន៍ស្រែអំបិលដែរឬទេ?

Definitely Not មិនធ្វើទេ | Slightly likely ប្រហែលជាអាច | Likely អាចនឹងធ្វើ | Very likely អាចនឹងធ្វើច្រើន | Definitely ប្រាកដជាធ្វើ