Completion Report (MEEF 2019-002, Phase I)

Value of peri-urban and Small-scale Mangrove Forests in the Pearl River Estuary as Fish Habitats

Executive Summary

This project aims to investigate the importance of peri-urban, small-scale mangrove patches in the Pearl River estuary (PRE) in supporting fishery production through the provision of nursery environments. The capacity for coastal wetlands such as mangrove forests to act as nursery sites is thought to depend on (a) the habitat structural complexity; and /or (b) the provision of food; these dependencies are respectively termed the "protection" and "food" hypotheses. Despite that these hypotheses having been proposed for decades, little direct evidence is available for assessing their application to mangrove ecosystems, especially small patches in peri-urban settings. This study tests the protection hypothesis using small mangrove patches in Hong Kong and the PRE.

The specific work packages (WP) of the project are:

1. To assess the value of peri-urban small-scale mangrove forests in the Pearl River estuary as habitat for juvenile fish. We survey the types and species of fish that utilize mangrove patches using underwater video cameras and nets.
2. To understand the importance of mangrove forest structural complexity for supporting juvenile fish use of the habitat. We conduct *ex situ* predation experiments using 3D printed real-size mangrove structure and observe how juvenile prey fish utilize complex mangrove structures as protection from predation by larger fish.
3. To forecast juvenile fish behaviour in realistic mangrove structures under different environmental constraints using Individual Based Models (IBM). We are constructing the IBMs in a collaboration with the University of Giessen in Germany. The results of the models will be validated by the results of WP2.

Phase I (WP1 and WP2, Year 1) of the project focuses on the field and laboratory components whereas Phase II (Year 2) of the project focuses on the modelling component of the project. Based on the above findings, recommend ecologically sound options for the management and restoration of mangrove habitats in the PRE.

Despite the challenges we are facing due to COVID-19 pandemic (e.g. extended periods that the research assistants were required to work from home), we have successfully completed most of the project objectives we set for Phase I, from conducting surveys using video cameras to understand the fish abundance and diversity in various mangrove patches in Hong Kong and PRE, to scanning and printing multiple real-size mangrove tree models. We are currently conducting more predation experiments using the models we have printed and the fish we have collected from the surveys.

Brief description of the Project

This project aims to investigate the importance of peri-urban, small-scale mangrove patches in the Pearl River estuary in supporting fishery production through the provision of nursery environments. The ability of mangrove forests to act as nursery sites is thought to depend on the habitat's structural complexity to provide protection for juvenile fishes, and/or the provision of food. To test this hypothesis, we are utilizing 3D printing technology on small patches of mangrove forests, allowing us to observe *ex situ* their role as a shelter for juvenile fishes. We assess the behaviour and survivorship of juvenile fish associated with these realistic tree models using underwater video cameras in the presence of a predator.

Completed activities against the proposed Work Schedule

Our research project had suffered an unexpected delay due to the severity of COVID-19 pandemic. Field work and face-to-face communication were not able to be executed for several months in 2020 because of work-from-home arrangements. Despite this obstacle, the project team has made progress to achieve the project goals, which is summarized below:

Activities	Proposed timeline	Actual date of execution
Selection of field locations and sites; recruitment of project personnel; procurement of equipment; first team meeting	7-8/2019	Delayed due to project approval process and the opening of internal account by CUHK. Completed on 11/2019. The purchase of video cameras was completed on 3/2020.
Field sampling of fish; scanning of mangrove structure; building of digital 3D model for printing; second plenary team meeting; preparation of first report	9/2019 – 6/2020	Delayed due to COVID-19. Fish sampling started on 6/20 and completed on 12/20. Scanning started on 4/20 and completed on 10/20. First model was printed on 9/20, while the second and third model were printed on 11/20.
Mesocosm experiments using 3D printed structures; third plenary team meeting	7/2020 – 3/2021	Delayed due to COVID-19. First experiment was conducted on 12/2020 and is still ongoing to date.

Results/ descriptions on the completed activities with appropriate analysis

Ethics application: We applied for permits to conduct experiments with live vertebrates to Hong Kong's Department of Health in May 2020. The applications were approved on June 2020 (Ref. Nos.: (20-373), (20-374) and (20-375) in DH/HT&A/8/2/1 Pt. 7). Subsequently, we also applied for a permit to CUHK's Animal Experimentation Ethics Committee on the same month and we received the permit on October 2020 (Ref. No.: 20-139-MEF). The approval process by CUHK's ethics committee suffered a significant delay due to the special work arrangements made to combat the spread of the third wave of COVID-19. The non-conventional nature of our experiment (compared to biomedical experiments or clinical trials) may have resulted in the lengthy approval process.

As the predation experiments could not proceed before both approvals were obtained, the four-month delay had impacted the progress of this component of the project. Our original plan was to source juvenile mullets from local hatcheries as the prey species in the experiments. After consulting with the Agriculture, Fisheries and Conservation Department, we contacted a couple of hatcheries that were able to provide us the fingerlings. However, the seasonality and the long waiting time of fish production process (about two months) created an uncertainty to our ability to start the experiments. Eventually, after considering the availability of the prey fish, we decided to instead use the glassy perchlet *Ambassis gymnocephalus* common in the local mangroves as the experimental species (see section on video survey of use by juvenile/small fish of local mangroves).

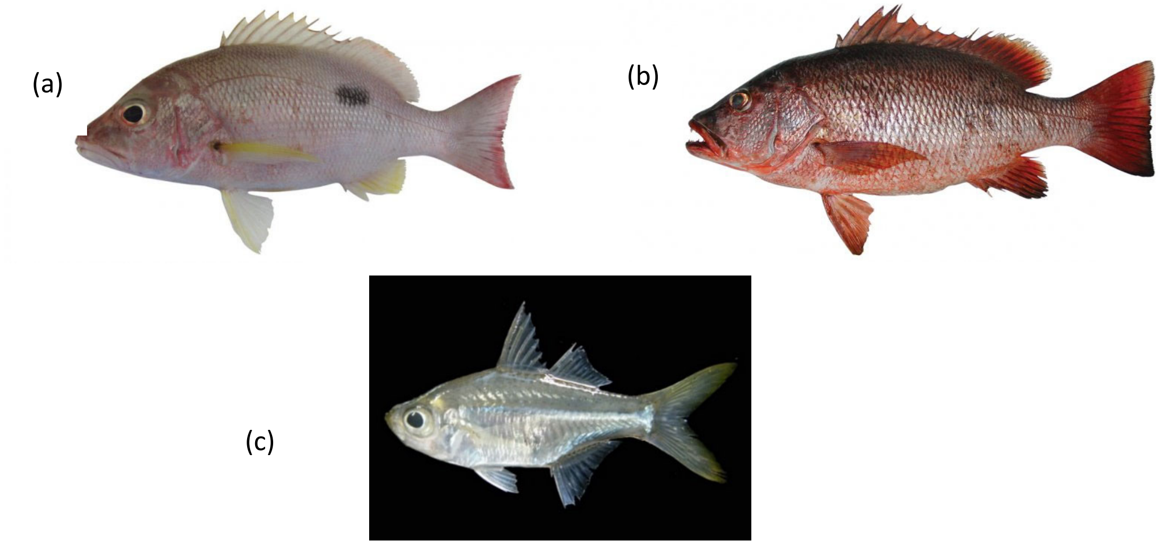

Figure 1. Species used in the predation experiment: (a) Russell's snapper *Lutjanus russelli;* (b) the mangrove red snapper *Lutjanus argentimaculatus*; and (c) the prey species glassy perchlet *Ambassis gymnocephalus*. (Photographs not to scale; (a) and (b) from fishider.org; (c) from Fishbase.se).

Mangrove tree model scanning: We initially planned to use the GeoSLAM ZEB-REVO 3D scanner we purchased, but we decided to use another tool and method to scan mangrove trees as the preliminary results we obtained from the scanner did not meet our expectations. The scanner created "point cloud" data that required time-consuming conversion into a print-ready "mesh" data for the scale of our investigation (i.e. at meter level). The meshes created by ZEB-REVO contained a lot of noise, as the tool was very sensitive to small particles and moving objects, which were not avoidable while working in the outdoors. The scanner also was only able to capture point cloud of the external layer of an object, and not the fine details such as wood texture, nooks and crannies from the complex root structures, as well as oyster settlements that are paramount in mangrove trees. The resulting tree textures were relatively smooth, and they contained a lot of background noise that required plenty of digital clean up in the laboratory. The scanner is, however, very useful for digital model construction at the forest level, which will be a natural extension of the present project to investigate the benefits of whole mangrove forest stands to juvenile fish.

Consequently, we acquired Kinect V1 and Kinect V2 to solve the scanning issues we encountered using ZEB-REVO. Although these products had been discontinued from production, the former had been successfully used by the project PI for his research in Australia (Kamal et al., 2014). The Kinects bypassed the need to capture point cloud data and were able to automatically save scanned objects as meshes. However, they required constant connection to a computer and electrical output, which were difficult to supply in the outdoors. The Kinects were highly sensitive to sunlight, thus requiring us to work during dusk and night-time. The results were significant improvements from ZEB-REVO, even though they also required plenty of digital touch-ups in the laboratory (Figures 2 and 3).

We eventually found an alternative method to capture 3-D scans that satisfied our criteria using smart phone cameras, called “photogrammetry”. A software called Meshroom (AliceVision, 2018) allows the reconstruction of a digital mesh from photos of an object taken from different distances and angles. Unlike the scanners we tried, photogrammetry does not require us to carry any equipment but our personal smart phones. It also allows a flexible scanning session as pictures from any time can be stitched together, instead of requiring one continuous scanning period to scan an object (Figure 4).

To date, we have completed the scanning of >15 different trees/small stands of four species (*Kandelia obovata*, *Aegiceras corniculatum*, *Avicennia marina* and *Excoecaria agallocha*). These trees were scanned at four different sites (Shui Hau, Pak Nai, Ting Kok and Lai Chi Wo) between April and October 2020. After processing the photos into a digital mesh, we performed noise cleaning, face reconstructions and cutting of the mesh into desired size with software Meshlab (Cignoni et al., 2018) and Blender (Community BO, 2018) (Figure 5). The completed meshes were then sent to an outsourced vendor for 3D printing.

Figure 2. Research assistant Rinaldi Gotama (right) and student helper Vincent Tran (left) scanning an *Aegiceras corniculatum* patch using a Kinect V1. The Kinect was plugged to a waterproof laptop computer, which showed the scanning process in real time.

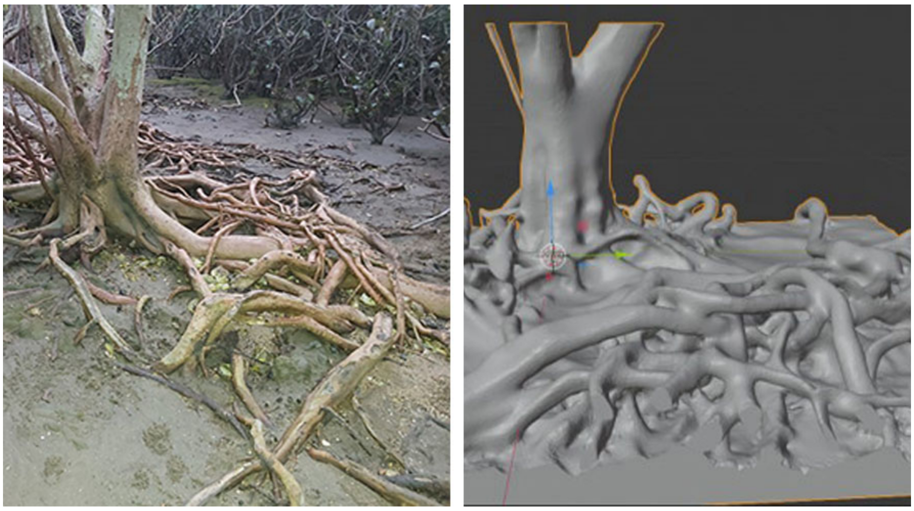

Figure 3. Mangrove tree *Excoecaria agallocha* at Shui Hau (left) and the mesh scanned using Kinect V1 after digital cleaning (right).

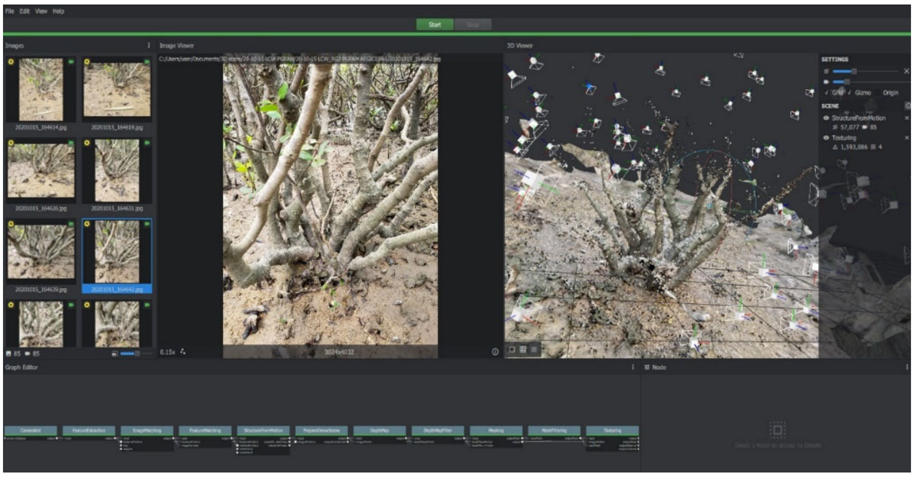

Figure 4. Meshroom interface during mesh reconstruction using pictures of a tree. Left and centre screens show pictures of the actual tree, while the right screen show the reconstructed model. White 'cameras' above the model indicate the location of the smartphone while taking picture.

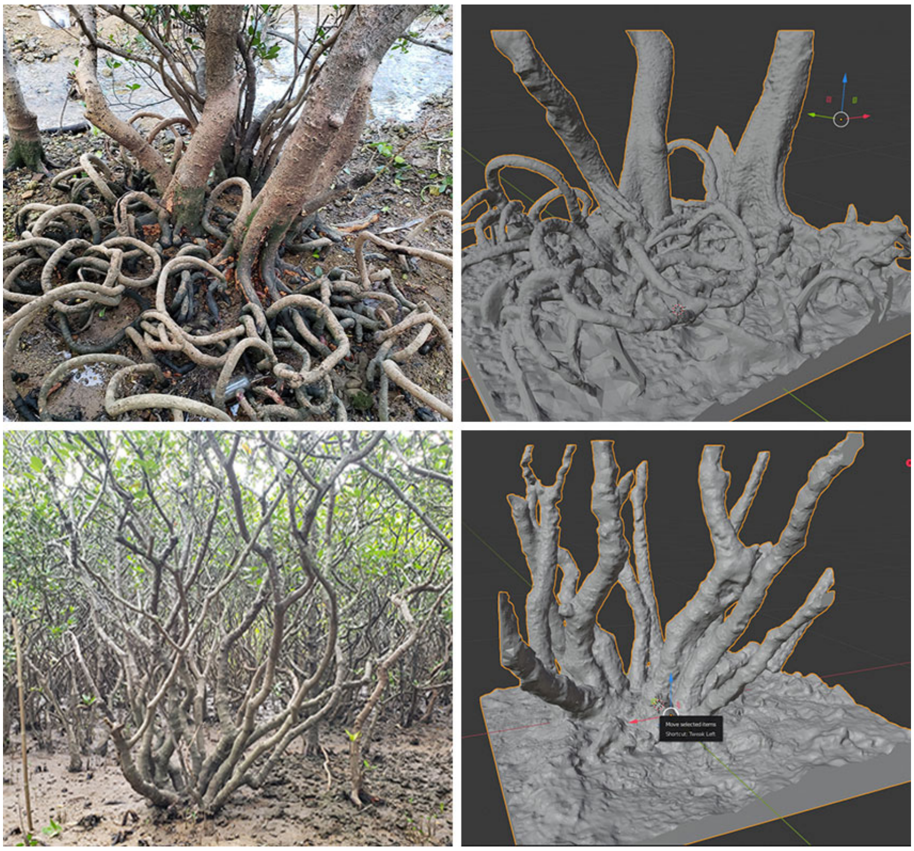

Figure 5. Mangrove trees *Kandelia obovata* (top) and *Aegiceras corniculatum* (bottom) and their 3-D mesh reconstruction using photogrammetry technique.

Mangrove tree model printing: We found seven potential vendors willing to print our mangrove tree models, but finalizing the deal was difficult due to the novelty of our request. We also reached out to the Department of Mechanical and Automation Engineering CUHK, but they did not have the resources to print our models. In the end, we chose MH 3D Print Service Hong Kong, who offered to print our models for the cheapest price (HK$26,000 for our first model and HK$30,000 each for our second and third models). The subsequent models were priced higher than the first due to the vendor's high effort spent on post-printing manual polishing of the model surface (Figure 6).

Out of all the trees we scanned, we have successfully printed one high-complexity *K. obovata* tree (1x0.9x0.7 m), one low-complexity *K. obovata* tree (1x1x0.9 m), and one model of *K. obovata* and *A. corniculatum* trees (1x1x0.7 m). These models were chosen due to the high quality of the scanning results, indicated by the resemblance to the real tree structures, and the successful capture of fine textures. (Figure 7 and Figure 8). The model printing process was a novel attempt even for the commercial vendors. The first model took about one month to complete. Overall, we spent more than 2 months on the fabrication of the three models. As the models were printed in mainland China, there was also some delays due to the reduced freight traffic during the pandemic. We received the last models in late November 2020.

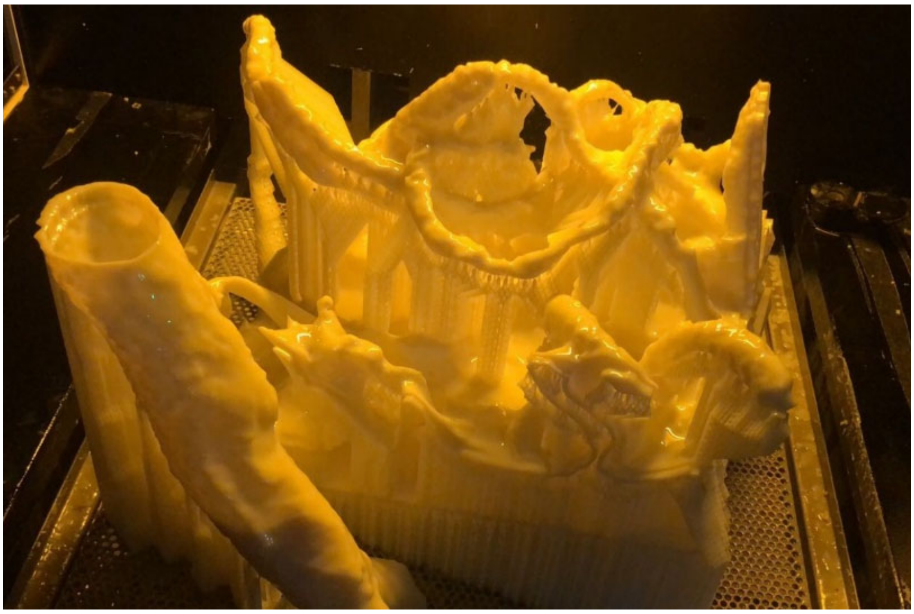

Figure 6. A mangrove tree model being 3D printed.

Figure 7. 3-D printed mangrove tree models. Left: model one, high-complexity *K. obovata* tree; center: model two, low-complexity *K. obovata* tree; and right: model three, *K. obovata* and *A. corniculatum* trees. Models are coated with a non-volatile paint in a colour resembling natural tree surfaces.

Figure 8. The first printed 3-D model. The model measures 1x0.9x0.7 m in size and is coated with a low-volatility paint to match the natural colour of the tree.

Fish surveys and procurement: We abandoned our proposed fish catching method using simulated aquatic microhabitat (SAM) as initial efforts suggested that this device was not very effective in local habitats. SAM relies on fish swimming into an indentation on the sand (from buried plastic food containers) when sea water retreats from the mangrove patches, which was only successful to trap relatively slow-moving and demersal nekton, such as gobies and shrimps. We have been quite successful in catching small juvenile prey fishes suitable for our experiments using different types of nets, such as umbrella nets and centipede nets (Figure 7). We have so far recorded the following species in our nets (in the order of frequency): *Ambassis gymnocephalus*, *Terapon jarbua*, *Mugil cephalus*, Gobiidae (unidentified species), *Gerres* spp., *Scatophagus argus* and *Takifugu alboplumbeus* (Table 1).

Figure 9. Two different types of nets we used to trap fish (left: umbrella net, right: centipede trap).

Besides using nets, we have also deployed multiple underwater video cameras to survey the type of fishes that swim into the mangrove patches when sea water floods mangrove patches. We tied 3 to 6 video cameras to a strong structure (tree trunk, tree branch, or even *A. marina* pneumatophores) facing either the mangrove or the sea, and recorded one-hour long videos right when seawater floods the mangrove patches (when sea level was around 1.4-1.5 meters high above Chart Datum). The supplementary data we collected using the cameras may be important to understand the types of fishes that utilize the mangrove patches but did not get trapped by the nets. We found 4 taxa that we have not encountered in our nets (Table 1, Figure 8 and 9).

Location	**Fish**
Lai Chi Wo	*Ambassis gymnocephalus* *Takifugu alboplumbeus* *Terapon jarbua* Unidentified clupeid schools (likely *Stolephorus* sp.) *
Shui Hau	*Ambassis gymnocephalus* *Takifugu alboplumbeus*
Ting Kok	*Acanthopagrus latus* * *Ambassis gymnocephalus* *Gerres* spp. *Mugil cephalus* *Scatophagus argus* *Sillago* sp. * *Strongylura strongylura* * *Takifugu alboplumbeus* *Terapon jarbua* Unidentified gobies

Table 1. A list of fish recorded on underwater video cameras in three sites. Video cameras were deployed in Pak Nai, but the videos did not capture any fish sighting due to poor water visibility. Each fish was identified to the most specific taxa possible. Asterisks (*) indicate taxa that have not been encountered in nets. *Acanthopagrus latus* (yellowfin seabream) is a predator of most of the other species. Glassy perchlet *Ambassis gymnocephalus* (maximum total length <6 cm), common at all three locations, was selected as the prey species in the predation experiment.

Figure 10. A silver biddy *Gerres* sp. (arrow) recorded on one of our video cameras at Ting Kok in 26 June 2020. The camera was tied facing a patch of *Avicennia marina*.

Figure 11. A school of clupeid fish recorded on one of our video cameras at Lai Chi Wo in 16 October 2020. The camera was tied on the trunk of an *Aegiceras corniculatum* tree facing the sea.

Predation experiment: A predation experiment consists of three steps conducted on three separate days. On step one, we place our model on the centre of our circular mesocosm (d= 2.5m, h=1.1m) and transfer prey fish into the mesocosm to adjust into a new environment. On step two, we transfer our predator fish into a section of the mesocosm separated by black plastic cloth that allows for the diffusion of scent and chemical cues but not visual cues. On step three, we remove the barrier separating the predator and prey and allow predation events to occur. Each step is recorded for one hour by eight video cameras, with four placed on each bottom corner and four placed on top of the model (Figure 12).

We have conducted one predation experiment using one of the printed mangrove structures, one Russell's snapper and fifteen glassy perchlets. The experiment did not result in any predation event. We suspect that the holding area for our predator was too small and did not allow the fish to recuperate from the stress from transfer from one tank to another.

We are currently working on improving our experimental design and conduct more experiments in the near future. These improvements include increasing the size of the predator holding area and increasing the predator and prey numbers to two and twenty, respectively.

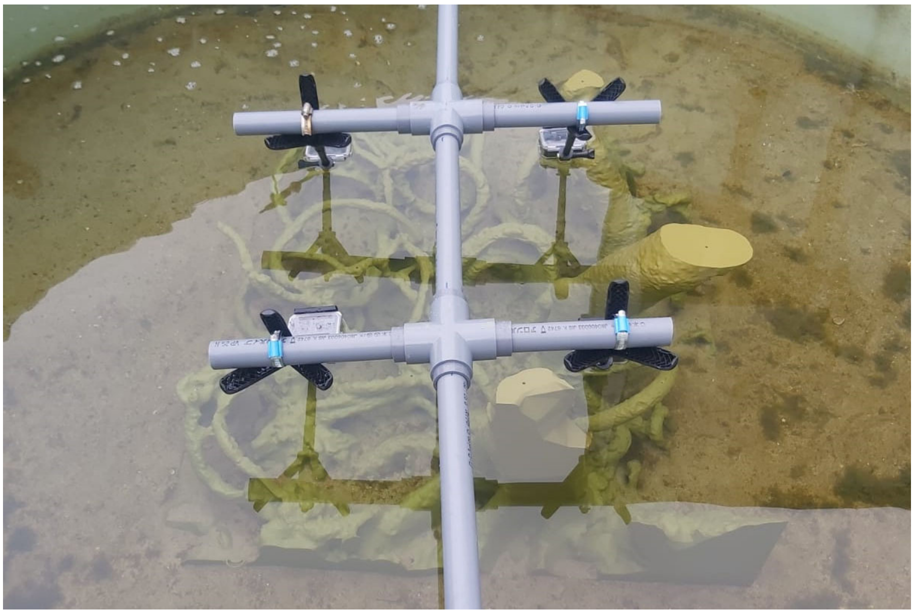

Figure 12. The position of video cameras that allows for continuous recording of the top side of our mangrove tree model during predation experiments. Model one (high complexity *Kandelia obovata*) is pictured in this figure. The cameras are hung just with their lens below water surface to allow Wi-Fi transmission of image to an observer nearby, who can intervene and remove any injured but not ingested prey fish, if necessary. The water level is kept just above the top of the mangrove model to simulate high-tide condition.

Agreement with University of Giessen for Phase II: The PI, in conjunction with the CUHK Office for Research and Knowledge Transfer Services (ORKTS) and Dr Uwe Grueters, have been negotiating an agreement with University of Giessen (Germany) since September 2020, to facilitate the transfer of funds that would allow appointment of the Senior Research Assistant at UoG. The agreement was requested by UoG. This has proved to be a drawn-out process as UoG requires a formal agreement between the two universities before the appointment (and thus the project work) can proceed. The pandemic situation in Europe, particularly Germany, has also contributed to the delay, as university offices had been shut down for multiple periods. We have made significant progress on this front and the agreement is expected to be signed shortly.

Evaluation of the project effectiveness in achieving the proposed objectives as well as the impact (benefits) of the Project

Despite the challenges imposed by the pandemic on our work schedule, the project has made significant progress towards achieving the proposed objectives. Specifically, we have:

- Conducted surveys to assess the use of local small mangrove patches as habitats by juvenile fish;
- Collected footage that will contribute to the production of a video introducing the study and the main findings;
- Successfully scanned and constructed high resolution 3-dimensional digital models of small mangrove patches;
- Using state-of-the-art 3-D printing technology, produced 3 life-size mangrove models for the predation experiment;
- Procured suitable predator and prey species and obtained the necessary approvals for the predation experiment;
- Drafted and finalized an agreement with our collaborator University of Giessen for the modelling work in Phase II of the project.

The above work will collectively provide much needed information for assessing the significance of small local mangrove patches to juvenile, including commercially important, fish. The use of life-sized, realistic, models replicating the natural habitat complexity in assessing the supportive service of mangrove ecosystems is a first in science. This context-sensitive assessment will contribute to the future management of the globally threatened mangrove ecosystems, especially the relatively small patches typical of peri-urban coasts.

Summary and Way Forward

Despite the many challenges encountered in 2020/21, the project has made significant progress towards completing all the objectives of Phase I of the study. We have produced the world first life-size 3-dimensional models of mangrove tree/root structures that can be deployed in experiments on the protective role of small mangrove patches for small/juvenile fish with a high level of realism. While we are still slightly behind schedule, the team is confident that the project objectives will be achieved by the end of Phase II of the project.

References

AliceVision (2018) Meshroom: A 3D reconstruction software. Available at: https://github.com/alicevision/meshroom.

Cignoni P, Callieri M, Corsini M, Dellepiane M, Ganovelli F, Ranzuglia G (2008) MeshLab: an Open-Source Mesh Processing Tool. Eurographics Italian Chapter Conference.

Community BO (2018) Blender - a 3D modelling and rendering package, Stichting Blender Foundation, Amsterdam. Available at: http://www.blender.org.

Kamal S, Lee SY, Warnken J (2014) Investigating three-dimensional meso-scale habitat complexity and its ecological implications using low-cost RGB-D sensor technology. Methods in Ecology and Evolution 5:845-853

Acknowledgments

The project team would like to thank the following persons for assistance with various components of this project: staff of the Chinese University of Hong Kong – Mr. Barry Tai, Ms Phyllis Yau, Ms Yvonne Chan, Ms Belin Chow, Ms Alice Poon, and Ms Kenus Wu; ERM-MEEF – Ms Tiffany Tsang.

Declaration

“I hereby irrevocably declare to the MEEF Management Committee and the Steering Committee of the relevant Funds including the Top-up Fund, that all the dataset and information included in the completion report has been properly referenced, and necessary authorisation has been obtained in respect of information owned by third parties.”

Any opinions, findings, conclusions or recommendations expressed in this report do not necessarily reflect the views of the Marine Ecology Enhancement Fund or the Trustee.

____

Prof. Joe S.Y. Lee, Principal Investigator

28 January 2021

(revised 10 March 2021)

"I hereby irrevocably declare, warrant and undertake to the MEEF Management Committee and the Steering Committee of the relevant Funds including the Top-up Fund, that I myself, and the Organisation:-

1. do not deal with, and are not in any way associated with, any country or organisation or activity which is or may potentially be relevant to, or targeted by, sanctions administered by the United Nations Security Council, the European Union, Her Majesty's Treasury-United Kingdom, the United States Department of the Treasury's Office of Foreign Assets Control, or the Hong Kong Monetary Authority, or any sanctions law applicable;

2. have not used any money obtained from the Marine Ecology Enhancement Fund or the related Top-up Fund (and any derived surplus), in any unlawful manner, whether involving bribery, money laundering, terrorism or infringement of any international or local law; and

3. have used the funds received (and any derived surplus) solely for the studies or projects which further the MEEF Objectives and have not distributed any portion of such funds (including any derived surplus) to members of the Recipient Organisation or the public."

Prof. Joe S.Y. Lee, Principal Investigator

28 January 2021

(updated 25 February 2021)