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RESEARCH ON SCIENTIFIC BASIS AND MOVING PERFORMANCE OF GIANT FRESHWATER PRAWN *(Macrobrachium rosenbergii)* APPLIED TO PHUOC HOA FISH-PASSAGE

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LIST OF PUBLISHED WORKS OF THE AUTHOR RELATING TO THE DISSERTATION

1. **Vu Van Hieu**, Nguyen Nghia Hung, Vu Cam Luong (2017). *An overview study of the impacts of dams on the migration of aquatic species and solutions to restore migration routes*. Journal of Water Resources and Environmental Engineering, Thuyloi University. 58(9):149-156.
2. **Vu Van Hieu**, Vu Cam Luong, Nguyen Nghia Hung, Tran Hong Thuy, Di Tien Hoc, Nguyen Tuyet Kieu Diem (2018). *Current state of fish-passage in Phuoc Hoa reservoir and adaption possibility for giant freshwater prawn (Macrobrachium rosenbergii)*. Annually scientific and technological magazines 2017 - 2018, The Southern Institute of Water Resources Research. 182-192.
3. **Vu Van Hieu**, Vu Cam Luong, Nguyen Nghia Hung (2020). *Monitoring of moving performance of giant freshwater prawn in hydraulic laboratory, with practical link to Phuoc hoa fish-passage*. Journal of Fisheries Science and Technology, Nha Trang University. 3:31-39.

CHAPTER I. INTRODUCTION

1.1. The rationale

The fish-passage has had a long historical development since the 17th century in Europe, the main purpose of supporting migratory aquatic species is to overcome obstacles (dams, barricades...) on rivers [95]. To date, there were more than 2,000 studies on upstream moving performance (hereinafter referred to as the moving performance) have been carried out. Almost these studies were focused mainly on a number of fish species that have high economic value, migrate between saltwater (brackish) and freshwater such as salmon species in Europe and America [58] instead of migratory crustaceans.

In Vietnam, there are about 7,000 hydroelectric and irrigated reservoirs covering 44 provinces and cities with different areas [22] However, only the fish-passage was built for Phuoc Hoa reservoir (in 2012) in Binh Duong province. The effectiveness of the fish-passage still has much long debate among number of native migratory aquatic species, which one have a high economic value and are directly and severely affected by Phuoc Hoa dam such as giant freshwater prawn... have not migrated through the fish-passage [2].

Moreover, the giant freshwater prawn, *Macrobrachium rosenbergii*, is an economically important species in many countries and is currently very focused on hatchery production and farming because of their high economic value, domestic consumption and export. Although the farming and hatchery production of the commercial prawn has been developed for a long time, the source of breeding prawn (parents) still relies mainly on wild catching [6], [8], in which the source of the breeding prawn in Be river (in the Dong Nai river basin) has the best quality among the sources in other river basins of Vietnam [11] as well

as some other regions in the world. For Phuoc Hoa dam area, *M. rosenbergii* and eel *(Auguilla marmorata)* are two species that have high economic value, reproductively migrate from freshwater to brackish (salt) water, and are most affected by dams [3], [4], of which the prawn is species with outstanding production should be an economic species prioritized as a target species of the fish-passage. According to Vu Vi An et al. (2011), the giant freshwater prawn appeared a lot in both upstream and downstream of the dam when there was no dam [4], but after building the dam, although the prawns have been obtained, much less than before. For highly affected species such as *M. rosenbergii*, how are the prawn's moving performance in response to the water velocity operation mode, the distance between the resting pools, and the operating time of Phuoc Hoa fish-passage have not been studied and fully understood to make recommendations for appropriate adjustments.

In order to solve the existing above problem, "Research on scientific basis and moving performance of giant freshwater prawn, *Macrobrachium rosenbergii*, applied to Phuoc Hoa fish-passage" was conducted to figure out appropriate solutions to improve the operational efficiency of the fish-passage, supporting the migration of the priority target species, *M. rosenbergii*, thereby contributing to the protection and sustainable development of aquatic resources.

1.2. Research objectives

1.2.1. Overall objectives

Research on the scientific basis and moving performance of the giant freshwater prawn in order to improve the operational efficiency of Phuoc Hoa fish-passage, support the migratory activities of the target species, *M. rosenbergii*, thereby contributing to protection and sustainable development of aquatic resources.

1.2.2. Specific objectives

- Evaluate scientific basis for studying the moving performance of the target species, *M. rosenbergii*, in the area of the aquatic multi-species ecosystem of the tropics, applied to fish-passage.

- Research for providing scientific parameters on water velocity operation management, distance length of fish-passage for the target species of the giant freshwater prawn.

- Research and summarize experimental and practical parameters for proposing solutions to improve the operation management efficiency of Phuoc Hoa fish-passage.

1.3. Research activities

Table 1. Summary of the main tasks of the dissertation

1	- Survey the prawn-fishing status above and below the fish-passage. - Survey on changes in the prawn resources between before and after building Phuoc Hoa dam.
2	- Survey the infrastructure situation of Phuoc Hoa fish-passage. - Survey the operation management status of Phuoc Hoa fish-passage. - Survey experts and fishermen on the efficiency of the fish-passage.
3	- Survey the actual technical parameters of Phuoc Hoa fish-passage and the size of the giant freshwater prawn as a basis for experimental layout. - Evaluate hydraulic conditions of open water channel and equipment. - Monitor the successfully moving ratio and speed of the giant freshwater prawn through the channel at water velocities. - Monitor the position-maintained prawn ratio upstream of the channel. - Monitor the moving performance of *M. rosenbergii* at water velocities. - Estimate the maximum position-holding prawn performance at water velocities in hydraulic equipment. - Summarize the moving performance of the giant freshwater prawn in experimental conditions applied to fish-passage.
4	- Propose the water velocity operational mode of fish-passage in accordance with the moving performance of *M. rosenbergii*. - Proposing solutions to improve the operation management efficiency of Phuoc Hoa fish-passage.

1.4. Theoretical and practical contributions

1.4.1. Main findings

- The study has solved the problem of selecting target species when building fish-passage in the aquatic multi-species ecosystem of the tropics.

- The study has contributed scientific parameters on management and operation of water velocity, length distance between pools on fish-passage for the target species of the giant freshwater prawn.

- Combine parameters of experimental and practical results to propose solutions for Phuoc Hoa fish-passage operation management.

1.4.2. The practical contributions

- *For the giant freshwater prawn resources:* The results of this study contribute to the protection and sustainable development of the resources.

- *For Phuoc Hoa fish-passage:* The results of the dissertation are scientific basis for state management agencies and the Management Board of Phuoc Hoa dam to refer and apply to Phuoc Hoa fish-passage.

- *For fishermen in Phuoc Hoa area:* The successful dissertation will help the giant freshwater prawn migrate smoothly, creating conditions to increase their production and population as before building the dam, thereby contributing to the improvement of living standards and income for fishermen in the area.

- *For new fish-passage in Viet Nam the next time:* The results of the study are lessons and experiences for new fish-passages in Viet Nam in identifying target species and creating fish-passage operation management mechanisms for target species.

1.5. New scientific contributions of the dissertation

1) On the basis of identifying the target species of fish-passage as the giant freshwater prawn for the aquatic multi-species ecosystem of the tropics, the dissertation has provided a scientific provement and built in-

depth research methodologies suitable to the moving and position-holding performance and behavior of *M. rosenbergii* at water velocities.

2) By experiments with open water channel and hydraulic equipment in experimental conditions, the dissertation studied the mobility of the giant freshwater prawn corresponding to different rate of water velocity.

3) On the basis of target species management, the study assessed the theoretical and practical basis of Phuoc Hoa fish-passage for improving the operation management efficiency of the fish-passage.

CHAPTER II. CONCEPTS AND RESEARCH METHODS

2.1. Secondary data collection methodology

- The collection contents: Information and documents related to fish-passage and the mobility of aquatic species in the world and in Viet Nam...

- Secondary data collection locations: Phuoc Hoa dam Management Board, Research Institute for Aquaculture No. II, An Thai Commune People's Committee...

2.2. Primary data collection methodology

2.2.1. Site survey zoning for Phuoc Hoa fish-passage

The survey zoning for Phuoc Hoa fish-passage is divided into four sections: *(1) Fish-passage section I:* From the upstream inlet/outlet to the first resting pool; *(2) Fish-passage section II:* From the first resting pool to the second resting pool; *(3) Fish-passage section III*: From the second resting pool to the third resting pool; *(4) Fish-passage section IV*: From the third resting pool to the downstream inlet/outlet of the fish-passage.

2.2.2. Site zoning for the area above and below Phuoc Hoa fish-passage

The survey water area of Be river above and below Phuoc Hoa fish-passage is divided into 04 areas: *(1) Area 1:* Be river section flows through Tan Thanh commune, Dong Xoai city, Binh Phuoc province: *(2) Area 2:* Be river section flows through Nha Bich commune, Chon Thanh district, Binh Phuoc province;

(3) Area 3: Be river section flows through An Thai Commune, Phu Giao District, Binh Duong Province; *(4) Area* 4: Be river section flows through An Linh Commune, Phu Giao District, Binh Duong Province.

2.2.3. Experts and fishermen's opinion survey method

- ***Selection criteria:*** *(1) Experts* are state management officials directly or indirectly related to Phuoc Hoa fish-passgae; scientists in irrigation and fisheries who participated directly or indirectly in the project of building the fish-passage *(Appendix 1)*; *(2) Fishermen* are fishing the prawn on the Be river through 04 communes An Linh, An Thai, Nha Bich and Tan Thanh of Binh Duong and Binh Phuoc provinces *(Appendix 2)*.

- ***Survey contents:*** *(1) For experts:* Infrastructure, operation management status and operational efficiency of the fish-passage; *(ii) For fishermen:* The prawn-fishing status above and below the fish-passage; the operational efficiency of Phuoc Hoa fish-passage.

2.3. The method of studying the moving performance of the giant freshwater prawn by physical model

2.3.1. Open channel flume

A rectangular water channel (length L_{kn} = 18 m, width B_{kn} = 0,54 m, height H_{kn} = 1,04 m, slope i_{kn} = 1,45%) was built and installed to create a nearly uniform flow without pressure gradient in the channel (water velocity is independent of time and constant from one section to another). In order to create a nearly uniform flow without pressure gradient, the design, construction and operation of the open water channel must ensure the following conditions: *(1)* Water flow rate is constant over time and along the flow, Q(t,l) = Const; *(2)* Section shape, perimeter and wetted cross-sectional area remain constant along the flow. Therefore, the water depth in the channel remains constant; h(l) = const or dh/dl = 0; *(3)* Bottom slope is constant, i = const; *(4)* The

coefficient of roughness is also constant, n = const; *(5)* The velocity distribution across the cross-sections is constant along the flow [7].

2.3.2. Hydrolic equipment

A rectangular hydraulic equipment (length L_{tb} = 1,5 m, width B_{tb} = 35 cm, height H_{tb} = 35 cm) connected to the PEMS - E40 electromagnetic flow meter system was assembled with transparent plexiglass panels mounted in a sturdy wooden frame with a thin mesh base (grid size about 0.15 mm). One end of the equipment is attached to the water pipe wall with a flow-controlling valve, the another end is left open; both ends of the equipment also have nets to prevent shrimps from escaping; the top of the equipment has two small openings that can be opened and closed.

2.3.3. Giant freshwater prawn and experient-supplying water source

- Experiment-participated giant freshwater prawns: the prawn sources were purchased from a shrimp farm in Thu Duc city, Ho Chi Minh City and transported to the Hydraulic Laboratory for about one month so that the prawns could get used to the new water environment before participating in testing. At the laboratory, the prawns were fed from 3 to 4 times a day, aerated, monitored health and water quality indicators regularly to make adjustments to suit the prawn's habitat conditions.

The two sizes of the prawn lengths were selected: From 7.5 cm to 9.5 cm (Prawn size I) and from 13.5 cm to 15.5 cm (Prawn size II); 20 prawns of the same size/time were used for tests in the open-water channel; 02 prawns of the same size/time were used for tests in the equipment.

- Experiment-supplying water source: The water supplying for the tests and cultivation of the prawns at the Hydraulic Laboratory was quickly tested to ensure the suitable habitat conditions for *M. rosenbergii* which had been surveyed at the shrimp farm as well as similarity with the water source of Be river in Phuoc Hoa dam area

(collected information from Binh Duong Center of Surveillance - Technology of Natural Resources and Environment, 2018).

2.3.4. The active mobility of the giant freshwater prawn

- Monitor the prawn ratio and speed of moving successfully through the 18 m long channel:

Table 2.2. Steps to monitor the successful movement rate and speed of the prawn

Procedure of test steps	Implementation content of test steps
Step 1. The prawns get used to the new water environment.	Twenty prawns of the same size are placed in a net downstream of the channel and maintaining at the water velocity of 0.2 m/s for 30 minutes to let the prawns get used to the new water environment.
Step 2. Starting the test.	After 30 minutes, the water velocity is raised to the test water velocity (0.3 m/s, 0.6 m/s or 0.9 m/s) and the net is removed to start the test.
Step 3. Monitoring the moving process of the prawns in the channel	The upstream moving process of the prawns in the channel is monitored by a camera system fixed at the beginning, middle and end of the channel or moving according to the prawn's movement.
Step 4. Recording the results.	- *Time recording:* The camera upstream of the channel will record the time for prawns successfully moving through the channel. - *Record the successful movement ratio:* The number of prawns successfully moving through the channel will be recorded at 10 min, 20 min and 30 minutes.
Step 5. Ending the test.	After 30 minutes, 20 prawns are be removed from the channel; the results, survival rate and injury level of the prawns are also be recorded.

- Monitor the upstream position-maintaining prawn ratio of the channel at water velocities:

Table 2.3. Steps to monitor the upstream position-maintaining prawn ratio

Procedure of test steps	Implementation content of the test steps
Step 1. The prawns get used to the new water environment.	Twenty prawns of the same size are placed in a net downstream of the channel and maintaining at the water velocity of 0.2 m/s for 30 minutes to let the prawns get used to the new water environment.
Step 2. Starting the test.	After 30 minutes, the water velocity is raised to the test water velocity (0.3 m/s, 0.6 m/s or 0.9 m/s) and the net is removed to start the test.

Step 3. Monitoring the upstream movement of the prawns.	The upstream moving process of the prawns in the channel is monitored by the camera system fixed at the beginning, middle and end of the channel or moving according to the prawn's movement.
Step 4. Recording the results.	The number of the prawns successfully moving upstream through the channel and still maintaining their position upstream (from the 9th to the 18th meter) will be recorded at 5 hours, 10 hours, and 15 hours.
Step 5. Ending the test.	At the end of 15 hours, all prawns are removed from the channel. The survival rate and injury level of the prawns will be recorded as results.

2.3.5. The maximum position-holding ability of the giant freshwater prawn

Table 2.4. Steps to monitor the maximum position-holding ability of the prawn

Procedure of test steps	Implementation content of the test steps
Step 1. The prawns get used to the new water environment.	Two prawns of the same size are put into the equipment and maintaining at the water velocity of 0.1 m/s for 15 minutes to let the prawns get used to the new water environment.
Step 2. Starting the test (gradually increase the water velocity by 0.1 m/s after 05 minutes).	After 15 minutes, the water velocity is raised to 0.2 m/s for 5 minutes before increasing to 0.3 m/s for 5 minutes... The above procedure is repeated (increasing the water velocity by 0.1 m/s after 05 min) until both prawns are exhausted and pushed to the end of the equipment.
Step 3. Recording the results.	When one or two prawns are exhausted, using strong light or a wooden stick to gently push the prawn up to regain position, if the prawn cannot regain position, recorded: *(i)* How long can the prawn maintain position at the exhausted water velocity; *(ii)* The water velocity is closest to the exhausted water velocity.
Step 4. Ending the test.	The experiment will be ended when all 02 prawns could not hold the position. The survival rate and integrity level of the prawns will be recorded as results.

2.4. Formulas to calculate and process data

- The formula to estimate the maximum position-holding water velocity of the giant freshwater prawn according to the formula of Brett (1964):

$$U_{max} = U_i + [(T_i/T_{ii})*U_{ii}]$$

In which:

+ U_{max} is the prawn's maximum position-holding water velocity (m/s);

+ U_i is the water velocity is closest to the exhausted water velocity (m/s);

+ U_{ii} is the steadily increasing water velocity (0.1 m/s);

+ T_i is the position-holding time at the exhausted water velocity (min);

+ T_{ii} is the steadily increasing time (5 minutes).

- Data processing: The data collected from survey results, testing with the open water channel and hydraulic equipment are processed by Excel software, statistical software SPSS version 25.0 and one-way ANOVA and two-way ANOVA.

CHAPTER III. RESULTS AND DISCUSSION

3.1. The prawn-fishing status above and below the fish-passage

3.1.1. The prawn-fishing activities above and below the fish-passage

- ***Scope, location, and composition of the prawn-fishing fishermen:*** 42.4% of fishermen exploit the prawn within less than 05 km from the dam, 30.3% exploit from 06 to 10 km from the dam, 27.3% exploit more than 10 km from the dam. In addition, 90.9% of fishermen carry out the prawn-fishing activities both above and below the dam; 9.1% of fishermen fish the prawn in one area where they live.

- ***Working-age:*** The age of the fishermen is mainly from 30 to 50 years old (60.6%), over 50 years old (24.2%), and under 30 years old (15.2%).

- ***Fishing Experience:*** 72.6% of fishermen have been fishing since before building the dam, and 27.4% of fishermen have just started fishing.

- ***Hometown:*** Most of the prawn-fishing fishermen are local people (90.9%); 9.1% of fishermen come from elsewhere.

- ***Fishing gears:*** There are five fishing gears used to fish the prawn, including: bottom net, fishing, hook long line, gillnet, and cast nets.

- ***Fishing Time:*** Fishing time in a day depends on fishing gear and the harvest season of the year, in which fishermen exploit all months of the year but promote fishing in the rainy season.

3.1.2. Changes in the prawn resources before and after building the dam

- ***Changes in the prawn production by fishing gears:*** The prawn production by fishing gear has decreased markedly between before and after building the dam, specifically before building the dam, fishing output according to the bottom net, gillnet, hook long line, fishing, and cast nets are 194.3, 92.9, 60.0, 32.6, and 26.2 kg/household/year, respectively; after building the dam is 44.1, 16.4, 9.3, and 2.5 kg/household/year, respectively.

- ***Changes in the number of fishermen:*** Most of the fishermen assess that the number of fishermen exploiting the prawn in the area has tended to decrease since the Phuoc Hoa dam was built until now.

- ***Changes in dependence on fishing:*** The level of dependence on the prawn fishing has decreased between before and after building the dam.

- ***Changes in the income of the prawn fishing households:*** 69.7% of the fishermen assess that the income from prawn-fishing activities can meet their livelihood needs when there was no dam. However, after building the dam, 84.8% of the fishermen assess that the income can not meet the needs.

3.2. The operation management status of Phuoc Hoa fish-passage

3.2.1. The current state of Phuoc Hoa fish-passage

The infrastructure state of Phuoc Hoa fish-passage was degraded, many locations were eroded, deposited sediment, garbage and aquatic plants floating on the fish-pass, however, the fish-passage still ensure operability.

3.2.2. The operation management status of the fish-passage

The fish-passage is mainly operated in the rainy season; while in the dry season, the fish-passage can be partially openned or closed to prioritize water for irrigation purposes. The operation management coordination

mechanism for the fish-passage is still inadequate and inconsistent between state management agencies and Phuoc Hoa dam Management Board.

3.2.3. Opinions of experts and fishermen on the operational efficiency of Phuoc Hoa fish-passage

Most experts (80.9%) and fishermen (78.8%) underestimated the operational efficiency of Phuoc Hoa fish-passage.

3.3. The moving performance of the giant freshwater prawn at water velocities under experimental conditions

3.3.1. Survey the actual parameters of the fish-passage and the size of the prawn as the basis for the experimental layout

- The actual technical parameters of Phuoc Hoa fish-passage: Combine between the fish-passage parameters and the actual experiment-conducting conditions, the research has selected the following parameters: *(i)* Water velocities are 0.3 m/s, 0.6 m/s and 0.9 m/s; *(ii)* The channel length is 18 m; *(iii)* The water depth is 0.3 m; *(iv)* the fixed slope in the channel is 1.45%; (v) The channel width is 0.54 m; (vi) The duration times are 5 hours, 10 hours, and 15 hours.

- Size groups of the giant freshwater prawn migrating in the Phuoc Hoa area: The prawn is mainly exploited in the rainy season, specifically: *(1)* The size group less than 5 cm in length is rarely exploited or appeared in the area; *(2)* The size group from 6 cm to 10 cm in length is mainly caught from September to December; *(3)* The size group from 11 cm to 15 cm in length is exploited from August to November; *(4)* The size group more than 15 cm in length is exploited from July to December (Table 3.16).

Table 3.16. Ratio of the prawn size groups are exploited in months of the year

Months	Percentage of fishermen choosing to exploit the prawn size groups in months of the year (%)			
	<= 5 cm	6 - 10 cm	11 - 15 cm	> 15 cm
1	-	-	-	-
2	-	-	-	-

3	-	-	-	-
4	-	-	-	-
5	-	-	3,0	-
6	-	-	12,1	-
7	-	-	27,3	12,1
8	-	-	45,4	18,2
9	-	30,3	100	93,9
10	-	36,4	84,8	96,9
11	12,1	51,5	39,4	21,2
12	9,1	54,5	27,3	21,2

There are the prawn size groups that need to be tested, including: from 6 cm to 10 cm, from 11 cm to 15 cm and more than 15 cm. However, the more size group of 10 cm can enter to the reproductive maturity stage so the study selected two groups, including: *(1)* The size group from 7.5 cm to 9.5 cm (Prawn size I), representing the juvenile stage migrating upstream after larval development in the estuary; *(2)* The size group from 13.5 cm to 15.5 cm (Prawn size II), representing the broodstock stage migrating from upstream to the estuary to release larvae and then migrating upstream to grow and develop.

3.3.2. Hydraulic conditions and calibrated equipment

- Evaluation of hydraulic conditions of the open water channel: The actual hydraulic conditions of the channel all satisfy the requirements to create a nearly uniform flow without presure gradient, specifically: *(1)* The flow is maintained fixed over time: $Q_{0.3m/s}$ = 0.053 ± 0.000 m^3/s; $Q_{0.6m/s}$ = 0.102 ± 0.000 m^3/s; $Q_{0.9m/s}$ = 0.147 ± 0.000 m^3/s; *(2)* The cross-sectional shape, perimeter (P_{kn} = 1.15 m) and wet cross-sectional area (A_{kn} = 0.16 m^2) are constant along the flow in the channel so water depth is constant: h_{kn} = 0.3 m; *(3)* The channel bottom slope is kept fixed: i_{kn} = 1.45%; *(4)* The coefficient of roughness is also unchanged (both sides of the mica channel with n_{bk} = 0.008 mm, the concrete bottom of the channel with n_{bk} = 0.2 - 0.8 mm); *(5)* The two channel banks are made of smooth and transparent plexiglass plates mounted in a sturdy iron frame to ensure that the distribution of water velocity across the cross-sections is constant along the flow.

- About the limit state of flow in the channel: The flow in the channel at the water velocities of 0.3 m/s, 0.6 m/s and 0.9 m/s are all stable and nearly uniform flow without pressure gradient *(R < 1)*, however the flow at the water velocity of 0.3 m/s belongs to laminar

flow *(Re < 580)* and the flow at 0.6 m/s and 0.9 m/s has turbulent and heterogeneous flow *(Re > 580)*.

Table 3.18. Water velocity and water depth in the channel

The water velocities are set up for the channel (m/s)		The measured water velocities (m/s)			The measured water depths (m/s)		
		Head	Middle	End	Head	Middle	End
0,3	Surface water velocity	0,31 ± 0,01[a]	0,30 ± 0,01[ab]	0,29 ± 0,01[b]	0,32 ± 0,02[a]	0,32 ± 0,02[a]	0,33 ± 0,02[a]
	Bottom water velocity	0,27 ± 0,01[a]	0,26 ± 0,01[ab]	0,25 ± 0,01[b]			
0,6	Surface water velocity	0,62 ± 0,01[a]	0,60 ± 0,01[b]	0,63 ± 0,01[c]	0,29 ± 0,02[b]	0,30 ± 0,02[b]	0,29 ± 0,02[b]
	Bottom water velocity	0,55 ± 0,01[a]	0,52 ± 0,01[b]	0,55 ± 0,01[a]			
0,9	Surface water velocity	0,87 ± 0,02[a]	0,90 ± 0,02[b]	0,92 ± 0,02[c]	0,33 ± 0,02[a]	0,29 ± 0,02[b]	0,27 ± 0,03[c]
	Bottom water velocity	0,79 ± 0,02[a]	0,82 ± 0,02[b]	0,83 ± 0,02[b]			

(Note: The same row followed by different letters is statistically significant (p<0.05))

- For water velocity: The results of checking the error limits for the water velocities of 0.3 m/s, 0.6 m/s and 0.9 m/s in the tests are generally within the allowable error range (TCVN 8214: 2009) (Table 3.18).

- For water depth: In the tests with the water velocities of 0.3 m/s, 0.6 m/s and 0.9 m/s all maintained within 0.3 m. Hower, there is a difference between the beginning, middle, and end of the channel, which tends to be at locations with high water velocity, the water depth decreases. (Table 3.18).

- The conditions of the hydraulic equipment: In a total of 16 times of testing with each prawn length size (Prawn size I or size II), the water velocity error limit is within the allowable error range (TCVN 8214): 2009).

- Evaluation of supplied water index for prawn farming and for experiments: *(i)* The water environment index in the Phuoc Hoa dam area is similar to the water quality index of the water source supplying for experiments; *(ii)* The water source supplying for prawn culture in the laboratory is suitable and similar to the water source of the prawn farm.

3.3.3. The prawn rate and speed of moving through the channel

- The prawn percentage of successfully moving through the 18 m long channel: Results of monitoring the prawn ratio of successfully moving through the channel in 10 min, 20 min, and 30 minutes at the water velocity of 0.3 m/s is 13.3%, 68.3%, and 94.2% for Prawn size I; 21.7%, 76.0%, and 98.3% for Prawn size II, respectively; at the water velocity of 0.6 m/s is 2.5%, 50.8%, and 79.2% for Prawn size I; 9.2, 61.7, 90.8% for Prawn size II, respectively; at the water velocity of 0.9 m/s, which is 0.0% for Prawn size I and size II, respectively (Table 3.20). Notably for the water velocity of 0.9 m/s, anaphylaxis may have occurred for the prawns participating in the test. Therefore, the experimental studies with hydraulic equipment followed the method of steadily increasing the water velocity after a certain time according to Brett (1964) to reduce the factor of anaphylaxis at high water velocity and make some better recommendations for Phuoc Hoa fish-passage.

Table 3.21. The prawn ratio of successfully moving through the channel

Prawn size	Water velocities (m/s)	No. of tests (times)	No. of prawns (prawn)	The prawn ratio of successfully moving through the channel at 10 min, 20 min and 30 minutes at water velocities (%)		
				10 min	20 min	30 min
Prawn size I	0,3	6	120	13,3 ± 8,8	68,3 ± 6,8	94,2 ± 4,9
	0,6	6	120	2,5 ± 2,7	50,8 ± 7,4	79,2 ± 7,4
	0,9	6	120	0,0	0,0	0,0
Prawn size II	0,3	6	120	21,7 ± 6,8	76,0 ± 5,8	98,3 ± 2,6
	0,6	6	120	9,2 ± 4,9	61,7 ± 9,3	90,8 ± 2,0
	0,9	6	120	0,0	0,0	0,0

Additionally, the results of one-factor and two-factor analysis of variance to assess the impact of water velocity, prawn size, and experimental time on the prawn ratio of successfully moving through the 18 m long channel are presented in Table 3.23.

Table 3.23. The interaction of the factors of prawn size, water velocity and experimental time on the prawn ratio of successfully moving through the channel

Test object	Sig.	Conclusion
Prawn size	0.00	Influence
Water velocity	0.00	Influence
Experiment time	0.00	Influence
Prawn size x Water velocity	0.002	Influence
Prawn size x Experiment time	0.897	No influence
Water velocity x Experiment time	0.00	Influence
Water velocity x prawn size x experiment time	0.650	No influence

3.3.3.2. The prawn speed of moving through the channel

The results of monitoring the prawn speed of successfully moving through the 18 m long channel at the water velocities of 0.3 m/s and 0.6 m/s are 1.15 m/min and 0.92 m/min for Prawn size I; 1.18 m/min and 0.96 m/min for Prawn size II, respectively; the study did not calculate the moving speed at the water velocity of 0.9 m/s because both Prawn size I and size II failed to move successfully through the channel.

In addition, the results of one-factor and two-factor analysis of variance to evaluate the correlation between the factors of prawn size and water velocity to the moving speed are presented in Table 3.25.

Table 3.25. Interaction of the factors of prawn size and water velocity to the prawn speed of moving through the 18 m long channel

Test object	Sig.	Conclusion
Prawn size	0.294	No influence
Water velocity	0.000	Influence
Prawn size x Water velocity	0.725	No influence

3.3.4. The prawn ratio of maintaining upstream of the channel at water velocities during extended time periods

The percentage of the prawn maintaining position upstream of the open water channel for extended periods of 5 hours, 10 hours and 15 hours at the water velocities of 0.3 m/s, 0.6 m/s and 0 ,9 m/s is summarized in Table 3.26.

Table 3.26. The prawn ratio of maintaining upstream of the channel

Prawn size	Water velocity (m/s)	No. of tests (times)	No. of prawns (prawn)	The prawn ratio of maintaining upstream of the channel (%)		
				5hrs	10hrs	15hrs
Prawn size I	0,3	6	120	88,3 ± 7,5	69,2 ± 7,4	30,8 ± 7,4
	0,6	6	120	70,8 ± 8,6	36,7 ± 8,8	0
	0,9	6	120	0	0	0
Prawn size II	0,3	6	120	91,7 ± 6,1	83,3 ± 6,8	47,5 ± 6,1
	0,6	6	120	82,5 ± 8,2	48,3 ± 8,2	12,5 ± 7,6
	0,9	6	120	0	0	0

In addition, the results of evaluating the interaction between the factors of prawn size, water velocity and experimental time to the prawn percentage of holding position upstream of the channel are presented in Table 3.29.

Table 3.29. The interaction of the factors of prawn size, water velocity and experimental time to the prawn percentage of maintaining upstream of the channel

Test object	Sig.	Conclusion
Prawn size	0.00	Influence
Water velocity	0.00	Influence
Experiment time	0.00	Influence
Prawn size x Water velocity	0.28	No influence
Prawn size x Experiment time	0.007	Influence
Water velocity x Experiment time	0.00	Influence
Water velocity x Prawn size x Experiment time	0.134	No influence

3.3.5. Monitor the upstream moving performance of the prawn

The moving performance of the prawn can be divided into 5 levels from favorable to difficult: swimming forward, crawling forward, crawling backward, standing, and launching backward against the water stream (Table 3.29).

- At water velocity of 0.3 m/s: The prawns mainly swim and crawl forward with corridors moving along both banks of the channel; little use of the ability to crawl backwards and hold the position; do not use the backward launching ability.

Table 3.29. The moving performance of *M. rosenbergii* at water velocities

Moving performance	Moving corridor	Levels of movement at water velocities					
		0,3 m/s		0,6 m/s		0,9 m/s	
		Size I	Size II	Size I	Size II	Size I	Size II
Swiming forward	Near the middle of the channel	-	+	-	-	-	-
	Along the channel	+++	+++	-	-	-	-
Crawling forward	Near the middle of the channel	-	+	-	-	-	-
	Along the channel	+++	+++	-	-	-	-
Crawling backward	Near the middle of the channel	+	+	-	-	-	-
	Along the channel	+	+	+++	+++	+	++
Standing	Near the middle of the channel	-	-	-	-	-	-
	Along the channel	+	+	++	+	+++	+++
Launching backward	Near the middle of the channel	-	-	+	+	+	++
	Along the channel	-	-	-	-	-	-

(Note: +++: Many; ++: Medium; +: Little; -: Not used)

- At a water velocity of 0.6 m/s: The prawns often use the ability to crawl backwards with the corridor along the two banks of the channel; less standing and launching backward; do not use the ability to swim or crawl upstream.

- At water speed of 0.9 m/s: The prawns use the ability to stand (along the channel) and when moving, they often use their launching performance; little use of the backward crawling ability; do not use the forward swimming and crawling ability.

3.3.6. The maximum position-holding water velocity of the prawn

The results recorded that the maximum position-holding water velocity of Prawn size I and size II is 1.39 m/s and 1.54 m/s, respectively and summarized in Table 3.30.

Table 3.30. The maximum position-holding water velocity of the prawn

U_{iiT}	T_{ii}	Prawn size I			Prawn size II		
		n_{TI}	T_{iTI}	U_{iTI}	n_{TII}	T_{iTII}	U_{iTII}
0,1 - 1,0	5	-	-	-	-	-	-
1,1	5	1	4,50	1,0	-	-	-
1,2	5	1	3,53	1,1	-	-	-

1,3	5	-	-	-	2	3,86 ± 0,47	1,2
1,4	5	15	2.04 ± 0,82	1,3	4	2,24 ± 1,35	1,3
1,5	5	11	2,41 ± 1,33	1,4	9	2,42 ± 1,24	1,4
1,6	5	4	1,13 ± 1,00	1,5	6	2,02 ± 1,49	1,5
1,7	5	-	-	-	6	3,77 ± 0,54	1,6
1,8	5	-	-	-	5	2,03 ± 1,01	1,7
U_{iiT} = 0,1	T_{ii} = 5	n_I = 32	T_{II} = 2,22 ± 1,19	U_{iI} = 1,35 ± 0,10	n_{II} = 32	T_{III} = 2,70 ± 1,31	U_{iII} = 1,48 ± 0,15
Survival ratio (%)			87,5			96,9	
Integrity ratio (%)	+++		78,1			90,6	
	++		18,8			9,4	
	+		3,1			0,0	
- Brett's maximum water velocity formula (1964): $U_{max} = U_i + [T_i/T_{ii}]*U_{ii}$							
- Maximum water velocity for Prawn size I: U_{maxI} = 1,35 + (2,22/5)*0,1 = 1,39 (m/s)							
- Maximum water velocity for Prawn size II: U_{maxII} = 1,48 + (2,70/5)*0,1 = 1,54 (m/s)							

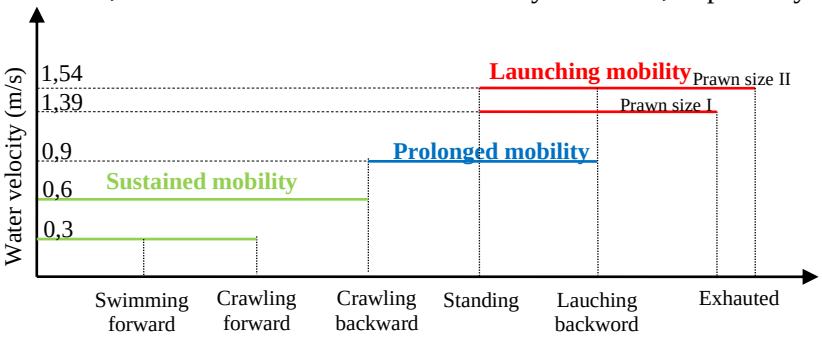
In addition, the monitoring results show that, when the prawns lose their position at a certain water velocity limit, the prawns will launch against the flow to move to another location. This shows that the maximum position-holding water velocity can be considered as the maximum water velocity for the launching ability, specifically: The launching water velocity of Prawn size I and size II can be estimated as 1.39 m/s and 1.54 m/s, respectively, with steadily increasing water velocity by 0.1 m/s after 05 minutes.

3.3.7. Summarize the moving performance of the giant freshwater prawn at water velocities in experimental conditions applied to fish-passage

The monitoring results of the moving performance of Prawn size I and size II at water velocities under laboratory conditions show that: *(1)* The water velocity of 0.3 m/s is the sustained water velocity - swimming and crawling forward; *(2)* The water velocity of 0.6 m/s is the sustained water velocity - crawling backwards; *(3)* The water velocity of 0.9 m/s is the prolonged water velocity - crawling backwards, holding and launching; *(4)* The water velocity of 1.39 m/s and 1.54 m/s is the maximum position-holding water velocity of Prawn size I and size II - the busrt water velocity of Prawn size I and size II, respectively; *(5)* The

theoretical maximum moving distance of Prawn sizes I and size II is 1,035 m and 1,062 m at the water velocity of 0.3 m/s; 552 m and 864 m at the water velocity of 0.6 m/s; 9.0 m and 18.0 m at the water velocity of 0.9 m/s, respectively.

The summary results of the moving performance of *M. rosenbergii* under experimental conditions applied to fish-passage show that: *(i)* The water velocity limit for fish-passage operation in accordance with Prawn sizes I and size II is less than 0.9 m/s; *(ii)* Water velocities from 0.9 m/s to 1.39 m/s and from 0.9 m/s to 1.54 m/s will be limited to a lower length distance of 9.0 m for Prawn size I and 18 m for Prawn size II, respectively; *(iii)* Water velocity greater than 1.39 m/s for Prawn size I and 1.54 m/s for Prawn size II will become a hydraulic barrier to the moving and position-holding performance of the giant freshwater prawn. At the same time, the maximum moving distance between the two resting positions on fish-passage for Prawn size I and size II is 1,035 m and 1,062 m at the water velocity of 0.3 m/s; 552 m and 864 m at the water velocity of 0.6 m/s; 9.0 m and 18.0 m at the water velocity of 0.9 m/s, respectively.



The moving peformance of giant freshwater prawn

Figure 3.15. Diagram showing the mobility of Prawn size I and size II

3.4. Propose fish-passage operation management solutions for the giant freshwater prawn

3.4.1. Propose fish-passage's water velocity operation mode for the prawn

Table 3.33. Operation management solutions for Phuoc Hoa fish-passage for the target species of the giant freshwater prawn

No.	The status of Phuoc Hoa fish-passage and the prawn's mobility	Propose fish-passage management operation solutions for the target species of *M. rosenbergii*
1	- The operation water velocity according to the design of the fish-passage is less than 0.6 m/s. - Prawn sizes I and size II move smoothly at the water velocity of 0.3 m/s and 0.6 m/s; difficultly at the water velocity of 0.9 m/s and maximally at the water velocities of 1.39 and 1.54 m/s, respectively. - Migration season of *M. rosenbergii* in Phuoc Hoa area takes place from May to November or December every year; in which, the size group under 10 cm appears from September to December and the size group over 10 cm appears from May to December every year.	- The water velocity operation mode for Phuoc Hoa fish-passage under 0.9 m/s is suitable for the target species of *M. rosenbergii*; however, priority for flexibly managing and operating the fish-pass according to the season or months of the year, specifically: *(i)* From May to August, the fish-passage are prioritized to operate at water velocity under 0.9 m/s; *(ii)* From September to December, the fish-passage are preferred to operate at water velocity under 0.6 m/s; *(iii)* From January to April, the fish-passage are prioritized to operate at water velocity under 0.3 m/s. - In addition, the highest operation water velocity of the fish-passage should not exceed 1.39 m/s.
2	- The distance length between the resting positions at Fish-passage section I, II, III and IV is 125, 180, 780 and 815 m respectively. - The theoretical maximum distance of Prawn sizes I and II is 1,035 and 1,062 m at the water velocity of 0.3 m/s; 552 m and 864 m at the water velocity of 0.6 m/s; 9.0 m and 18.0 m at the water velocity of 0.9 m/s, respectively.	Research to shorten the maximum distance between two resting positions in Fish-passage section III and IV around 552 m. On the other hand, the maximum length limit in some transition locations such as the position behind the flow control sluice; the position at coordinates (0688202E; 1262224N) is 9.0 m with slope around 1.45%, minimum depth of 0.3 m.

3.4.3. Proposing solutions to improve the management operation efficiency of Phuoc Hoa fish-passage

Table 3.34. Summarizing solutions to manage and protect the fish-passage

No.	Research results	Proposing solutions for the fish-pass
1	Fish-passage section I, II, III and IV have 1 (10 m), 3 (28 m), 6 (45 m)	Study to overcome the positions of soil erosion, rocks, garbage, and vegetation

	and 9 (52 m) locations with soil and rock erosion, respectively; 2 (35 m), 2 (16 m), 7 (38 m) and 5 (26 m) locations where sediment and garbage are deposited.	growing in the canal; reinforce and plant crops on both sides of the fish-passage as well as plant trees along the fish-pass to limit erosion and protect Phuoc Hoa fish-passage.
2	- The fish-passage is operated mainly in the rainy season, while in the dry season the water outlet is only partially openned. - The management and operation mechanism of the fish-pass still has many overlaps and inconsistencies between the dam management board and local authorities. - The situation of entering and leaving the fish-passage for fishing has not been controlled.	- Study to establish the fish-passage operation management team and launch legal documents banning fishing within the fish-passage. - Considering to set up protective fences around the fish-passage to prevent people from fishing in the fish-passage and reducing external impacts on the migration of fish species through Phuoc Hoa fish-passage.
3	Depth of inlet/outlet downstream of the fish-passage is quite shallow; the gate location is also far (> 500 m) from Phuoc Hoa dam, so it cannot take advantage of the water flow to attract fish; the current status of the gate has deteriorated with two banks of landslides that need to be overcome.	Research to adjust the minimum depth of the entrance/exit downstream of the fish-passage is 0.3 m in compare with the water surface of Be river; move the entrance location of the fish-passage closer to Phuoc Hoa dam; reinforce the entrance with concrete or plant trees on both sides to limit landslides and increase the operational efficiency of the fish-passage.
4	The bottom net gear used in the area below Phuoc Hoa dam is destructive for aquatic species in general and the freshwater prawn in particular.	- Promulgate regulations banning the use of bottom net gear in the area around Phuoc Hoa dam. - Adjusting the banning time on the prawn fishing in Be River area from May to December instead of from April to June as now.

CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

- On the basis of identifying target species of fish-passage as the giant freshwater prawn, *M. rosenbergii*, for the aquatic multi-species ecosystem of the tropics, the study provided scientific and practical data related to the moving performance (sustainable, prolonged and

launching ability) of *M. rosenbergii* as a basis for the development of in-depth research methods (active and forced movement) in accordance with the moving and position-holding performance and behavior of *M. rosenbergii* at water velocities under hydraulic laboratory conditions, with practical relevance for Phuoc Hoa fish-passage.

- By experiments with the open water channel and hydraulic equipment in hydraulic experimental conditions, the dissertation studied two prawn's size groups from 7.5 cm to 9.5 cm (Prawn size I) and from 13.5 cm to 15.5 cm (Prawn size II) move smoothly at the water velocity fluctuating around 0.3 m/s and 0.6 m/s; difficulty in the water velocity fluctuating around 0.9 m/s; maximally at the water velocity fluctuates around 1.39 m/s and 1.54 m/s, respectively, corresponding to six levels of movement from favorable to difficult including: swimming forward, crawling forward, crawling backward, holding the position, launching and exhaustion with a maximum length of 1,035 m and 1,062 m at 0.3 m/s; 552 m and 864 m at 0.6 m/s; 9.0 m and 18.0 m at 0.9 m/s, respectively.

- On the basis of the results on the mobility of *M. rosenbergii* at water velocities under experimental conditions, the study proposed: *(i)* Fish-passage operation water velocity which is suitable for Prawn size I and size II is less than 0.9 m/s; *(ii)* Water velocities from 0.9 m/s to 1.39 m/s and from 0.9 m/s to 1.54 m/s would be limited to a lower length distance of 9.0 m for Prawn size I and 18 m for Prawn size II respectively; *(iii)* Water velocity which is greater than 1.39 m/s for Prawn size I and 1.54 m/s for Prawn size II will become a hydraulic barrier to the prawn's ability to move and hold the position. For Phuoc Hoa fish-passage, the study proposed flexible operation of the fish-passage's water velocity for the target species of the giant freshwater prawn according to the month of the year, specifically: *(1)* From May to August, the fish-passage is prioritized to operate at water velocity below 0.9 m/s; *(2)* From September to

December, the fish-passage is preferred to operate at water velocity below 0.6 m/s; *(3)* From January to April, the fish-passage is prioritize to operate at water velocity below 0.3 m/s. At the same time, the maximum water velocity to operate the fish-passage does not exceed the water velocity limit of 1.39 m/s.

- On the basis of target species management, the study assessed the theoretical and practical basis of Phuoc Hoa fish-passage as a basis for proposing four solutions to improve the operation management efficiency of Phuoc Hoa fish-passage in general and for the target species of *M. rosenbergii* in particular.

4.2. Recommendations

- The operating fish-passage on targeting species of the giant freshwater prawn, it is necessary to control the water discharge corresponding to the water velocity which does not exceed 0.9 m/s to create favorable conditions. For Phuoc Hoa fish-passage, it is necessary to add rough objects (cobblestones...) in the channel bed to create better traction force for the prawn to move in large flood conditions; implement a ban on fishing, restore and clear damaged sections; properly operate the water velocity, the distance between resting pools as well as greatly control the water inlet and outlet of the fish-passage.

- Research and continue testing the mobility of *M. rosenbergii* in the field of Phuoc Hoa fish-passage to better suit the actual operation management status of the fish-passage.

- Conduct studies to evaluate the operational effectiveness of Phuoc Hoa fish-passage in terms of collecting samples of aquatic species migrating through the fish-passage as well as applying for advances in science and technology in evaluating the effectiveness of the fish-passage.