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Design of a Viability Test for Freshwater Prawn Aquaculture of Two Different Macrobrachium Species in Aneityum, Vanuatu

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DESIGN OF A VIABILITY TEST FOR FRESHWATER PRAWN AQUACULTURE OF
TWO DIFFERENT *MACROBRACHIUM* SPECIES IN ANEITYUM, VANUATU

By

Cameron Koizumi

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

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In Civil Engineering

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This report has been approved in partial fulfillment of the requirements for the Degree of
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Table of Contents

List of Figures.....	v
Abstract.....	vi
Acknowledgements	vii
Chapter 1 – Introduction.....	1
Chapter 2 – Location	2
2.1 Vanuatu	2
2.1.1 Government	2
2.1.2 Industries.....	3
2.1.3 Aquaculture	3
2.2 Aneityum.....	4
2.2.1 Local Government	4
2.2.2 Aquaculture	5
Chapter 3 – <i>Macrobrachium</i>	7
3.1 <i>Macrobrachium rosenbergeii</i>	7
3.1.1 Biology	7
3.1.2 Lifecycle	8
3.1.3 Aquaculture	9
3.2 <i>Macrobrachium lar</i>	10
3.2.1 Biology	10
3.2.2 Lifecycle	11
3.2.3 Aquaculture	11
Chapter 4 – Imported <i>Macrobrachium rosenbergeii</i>	12
4.1 Hatchery	13
4.1.1 Housing	14
4.1.2 Tanks	14
4.1.3 Water Distribution.....	16
4.1.4 Aeration.....	18
4.1.5 Recommended Layout	18
4.1.6 Operations.....	21
4.2 Grow-Out Ponds.....	23
4.2.1 Culture Types.....	23
4.2.1 Ponds	24
4.2.2 Water Distribution.....	24
4.2.3 Operations.....	26

4.3 Modular Expansion	27
4.4 Advantages and Disadvantages	28
Chapter 5 – Locally Sourced <i>Macrobrachium lar</i>	29
5.1 Hatchery	29
5.2 Grow-Out Ponds	30
5.3 Advantages and Disadvantages	30
Chapter 6 – Conclusion	32
Appendix A – Pipe Size Calculations	36
Appendix B – Copyright Permissions	37
Appendix C – Bill of Materials	38

List of Figures

Figure 2.1 Location Reference for Vanuatu and Aneityum. Used under Creative Commons 3.0. (for permissions see Appendix B)	2
Figure 2.2 Cruise Ship Anchored off of Mystery Island. Used under Creative Commons 3.0. (for permissions see Appendix B).....	4
Figure 2.3 Map of Aneityum. Adapted from Google Earth. (for permissions see Appendix B).....	5
Figure 2.4 Tilapia Aquaculture on Aneityum.....	6
Figure 3.1 Blue Claw Male Macrobrachium rosenbergeii. Used under Creative Commons 3.0. (for permissions see Appendix B)	7
Figure 3.2 Diagram of External Feature of Macrobrachium rosenbergeii. Taken from New 2002 (for permissions see Appendix B)	8
Figure 3.3 Locally caught M. lar on Aneityum.....	10
Figure 4.1 Site Location on Aneityum. Adapted from Google Earth. (for permission see Appendix B).....	12
Figure 4.2 Recommended Layout (not to scale).....	19
Figure 4.3 Cross-section of the Rearing Tank.	20
Figure 4.4 Top View of the Rearing Tank.	20
Figure 4.5 Cross-Section of a Grow-Out Pond.	24
Figure 4.6 Representations of Rippling and Cascading to Induce Aeration. Taken from New 2002 (for permission see Appendix B).	25

Abstract

There is a unique opportunity for freshwater prawn aquaculture on the island of Aneityum in the Republic of Vanuatu. Aneityum has an abundance of fresh water, the streams and rivers on Aneityum are the natural habitat for a freshwater prawn species, *Macrobrachium lar*, and the people on Aneityum regularly work on projects using communal labor for the benefit of the community. Aneityum also hosts 40 – 120 cruise ships a year, bringing hundreds of thousands of tourists to Aneityum and the nearby islet Mystery Island which creates a readily available market in which to sell freshwater prawns.

The objective of this paper is to develop viability tests for two different species of freshwater prawns--the native *Macrobrachium lar* and the exotic *Macrobrachium rosenbergeii*--, and recommend a starting point for freshwater prawn aquaculture on Aneityum. The design of the viability tests includes the layout and operations of both a hatchery and grow-out ponds for the two species of *Macrobrachium*.

The layout and design of hatcheries and grow-out ponds for both species of *Macrobrachium* are very similar. The setup and operations of the viability test for *M. lar* is simpler because the species is native to Aneityum and broodstock for the species is readily available in local streams while *M. rosenbergeii* is exotic and its broodstock would have to be imported. The final recommendation was to start with the viability test for *M. lar*, and then, make the changes to the system to test the viability of *M. rosenbergeii* aquaculture only if it is necessary.

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Thank you to the Peace Corps Vanuatu Staff for their steady support, to Brittany Nelopae, who acted as an example to me of what a successful Peace Corps volunteer on Aneityum looks like, and to Devon Gaffney who shared our time on Aneityum as Peace Corps volunteers.

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Chapter 1 – Introduction

Despite fisheries being a small percentage of the economy in Vanuatu, they play a vital role in rural communities throughout the country, providing nutrition and/or income to nearly 60% of rural households (VFD 2008). Conservation is a traditional part of Ni-Vanuatu (the people of Vanuatu) culture. As coastal regions become overfished, chiefs and the heads of families block portions of reefs from fishing and harvesting of other natural resources so that the populations of various species can recover.

As the population of Vanuatu increases and the demand for fish and shellfish increases, both domestically and for export, developing aquaculture infrastructure can become an important source of nutrition and income to Ni-Vanuatu while protecting populations of local species. In the past 15 years, interest in aquaculture has moved past viability tests to commercial farms for marine shrimp and freshwater red tilapia. Aquaculture has also been used to reseed trochus, green snail, sea cucumber, and giant clam populations. In recent years, interest in rural, small-scale genetically improved farmed tilapia and freshwater prawns has increased (VFD 2008).

Freshwater prawns are regularly caught and consumed by Ni-Vanuatu in rural communities. Local streams and rivers contain a few species of freshwater prawns, but the primary species is *Macrobrachium lar*. Outside of Vanuatu, *Macrobrachium rosenbergeii* is the primary species used for freshwater prawn aquaculture. This paper will propose designs for viability tests for both species of freshwater prawn on the island of Aneityum.

Chapter 2 – Location

2.1 Vanuatu

Vanuatu is an island nation located in the Oceania region, approximately three quarters of the way from Hawaii to Australia (see Figure 2.1). The population is about 288,000, spread across 65 inhabited islands. The official languages of Vanuatu include Bislama, English, and French, but the most commonly used language amongst Ni-Vanuatu is Bislama which is a creole language (CIA Factbook 2019)

Figure 2.1 Location Reference for Vanuatu and Aneityum. Used under Creative Commons 3.0. (for permissions see Appendix B)

2.1.1 Government

In 1906, the French and English agreed to share the colony of New Hebrides under the Anglo-French Condominium. In 1980, the Ni-Vanuatu won independence and control over their own government, renaming New Hebrides as The Republic of Vanuatu. Their government is a parliamentary republic in which regional elections are held to vote for members of parliament (CIA Factbook).

Ni-Vanuatu have a deep respect for their cultural tradition, known as 'kastom', which is enshrined in the Vanuatu Constitution. Section 73 of the constitution says, "All land in the Republic of Vanuatu belongs to the indigenous custom owners and their descendants." Section 83 says, "The legislation shall provide for the division of the Republic of Vanuatu into Local Government Regions and for each region to be administered by a Local Government Council on which shall be representatives of custom chiefs" (CCP 2019). The respect for traditional power structures combined with the logistical challenges of an archipelago nation has resulted in minimal federal involvement in the most rural areas of Vanuatu.

2.1.2 Industries

Three-quarters of Ni-Vanuatu live in rural areas, a majority of which live off of either small-scale or subsistence farming. Despite 65% of the labor force participating in agriculture, agriculture only contributes 27% of the country's GDP. The services sector, which includes tourism and offshore finances, contributes to 61% of the country's GDP, while only 30% of the labor force participates in that sector. Agricultural products include copra, cocoa, coffee, taro, yams, fruits, vegetables, beef, and fish (CIA Factbook 2019).

2.1.3 Aquaculture

According to the Food and Agriculture Organization of the United Nations, "The fisheries sector was once important in the country's economy... but today the sector is a minor player. Subsistence fisheries, however, remain extremely important in the local economy for household income and food security" (Amos 2007). In their 2008 – 2013 Aquaculture Development Plan, the Vanuatu Fisheries Department (VFD) said, "... aquaculture development is seen as a potential sub-sector for increasing fisheries production and ensuring that the resources of the wild fisheries are more consciously exploited so that the different fisheries sub-sectors are sustainable" (VFD 2008).

Aquaculture research and development by the VFD and aid organizations includes government-operated giant clam, trochus, and green snail production for the purpose of restocking wild populations, commercial farms for tilapia, coral, and saltwater prawns, and subsistence ponds for tilapia and freshwater prawns. However, in 2015, Cyclone

Pam destroyed much of Vanuatu's aquaculture infrastructure. Aquaculture production dropped from 79 tons of fish, shellfish, and crustaceans in 2014 to just 11 and 15 tons in the following two years (Amos 2007).

2.2 Aneityum

As shown on Figure 2.1, Aneityum is the most southern inhabited island in the archipelago, and it is only 17 km across (Smithsonian Institution 2013). Estimates of the island's population range from 900 to 3,000, and there are three major villages on the island:

Anelcauhat, Umej, and Port Patrick (Spriggs 2007). The villages locations on the island

are shown on Figure 2.3. Industries on Aneityum include small-scale agriculture and lumber, but the main source of revenue is tourism. Just south of Aneityum is an islet locally known as Mystery Island. Every year, 40-120 cruise ships anchor near Mystery Island (shown in Figure 2.2). The cruise ships unload passengers who buy souvenirs or attend tours ranging from fishing and snorkeling to modern village tours which show the current lifestyle of the local people. On the days where a cruise ship anchors, Ni-Vanuatu come from all over Aneityum to Mystery Island to sell goods and provide services for the tourists.

Figure 2.2 Cruise Ship Anchored off of Mystery Island. Used under Creative Commons 3.0. (for permissions see Appendix B)

2.2.1 Local Government

Although they can look very similar, every island in Vanuatu has its own unique, traditional government which involves custom chiefs, laws, and land tenure. On Aneityum, there are 6 regions, and the heads of each family in a region comprise the regional council of chiefs which resolves disputes, decides to block or open up sections

Figure 2.3 Map of Aneityum. Adapted from Google Earth. (for permissions see Appendix B)

of reefs for fishing, and organizes community events. Each regional council of chiefs sends a representative to the island's council of chiefs which does similar work on a larger scale. The Area Secretary is a government position tasked with communicating between the island's council of chiefs and the Vanuatu government.

2.2.2 Aquaculture

The Vanuatu Department of Fisheries and the Pacific Community (SPC) has invested in two aquaculture culture projects on Aneityum: tilapia ponds and *Macrobrachium lar* grow-out ponds. In recent years, workshops were held to teach the local people how to build the ponds and raise the respective cultures. In the case of tilapia aquaculture, the ponds were built by individual families, and their owners were given broodstock to start their culture (see Figure 2.4). The cultures have survived over three years, and are used on a subsistence basis.

Members of the island's council of chiefs and the Area Secretary have approved plans and set aside land to start *M. lar* aquaculture. The final goal of the project is for the aquaculture to be robust enough to sell the prawns to tourists on Mystery Island through restaurants, and eventually, they hope to sell large shipments directly to the cruise ship companies. There have been attempts from individual families to catch wild stock and raise them in grow-out ponds, but they have had little success because of *M. lar*'s ability to travel over dry land for short distances.

Figure 2.4 Tilapia Aquaculture on Aneityum

Chapter 3 – *Macrobrachium*

The genus *Macrobrachium* contains about 230 different species, all of which are prawns that live at least a portion of their lifecycle in freshwater. They live in tropical or subtropical climates and are native to every continent besides Europe and Antarctica. All freshwater prawn used in aquaculture are from the genus *Macrobrachium* (New et al. 2010).

3.1 *Macrobrachium rosenbergii*

Macrobrachium rosenbergii is commonly known as the giant river prawn, and it is the largest species of the genus *Macrobrachium* (see Figure 3.1). The males grow up to 320 mm in length and the females grow to 250 mm. *M. rosenbergii* is naturally found from the east coast of India to Papua New Guinea, and from Thailand down to Australia (New et al. 2010).

Figure 3.1 Blue Claw Male *Macrobrachium rosenbergii*. Used under Creative Commons 3.0. (for permissions see Appendix B)

3.1.1 Biology

As shown in Figure 3.2, the adult *M. rosenbergii* is segmented into 19 somites, five of which comprise the head or cephalon, with eight forming the thorax and six forming the abdomen. Attached to each somite is a pair of appendages which range in function from antennae to mandibles to legs. While the abdomen is externally segmented, the cephalon and thorax is covered by a single, hard carapace which protects most of the prawn's vital organs. Protruding from the front of its head is a long, slender rostrum (New 2002).

Figure 3.2 Diagram of External Feature of *Macrobrachium rosenbergii*. Taken from New 2002 (for permissions see Appendix B)

M. rosenbergii can be differentiated from the other species in the genus by a combination of the following characteristics:

- It is the largest species of the genus;
- a long rostrum with 11 – 14 dorsal teeth (on top of the rostrum) and 8 – 10 ventral teeth (underneath the rostrum);
- adult males have an elongated second cheliped in which its movable finger is covered in fur;
- the end of its telson reaches beyond the spines of the telson (New 2002).

3.1.2 Lifecycle

M. rosenbergii has a complicated lifecycle which is important to understand to rear them. There is some disagreement on the number of larval stages (the most commonly accepted number is 11), but for the purposes of aquaculture, the 4 important stages of *M. rosenbergii*'s lifecycle are: egg, larvae, post-larvae (PL), and adult. Females who carry eggs, otherwise known as 'berried' females, can lay between 80,000 and 100,000

eggs in a single spawning (although a female's first brood can be as little as 5,000 eggs). Berried females adhere the clutch of eggs underneath their abdomens (New et al. 2010). The eggs are 0.6 - 0.7 mm in length and are bright orange in color up until 2 - 3 days before hatching, when they turn a gray-black color due to the consumption of available nutrients within the egg (New 2002).

Newly hatched larvae are about 2 mm long and initially planktonic, and shortly after hatching, they require brackish water to survive. The initially planktonic larvae are known as zoeae. As the larvae grow, they periodically molt, and after their second molting, the larvae turn omnivorous. Their diet consists of mostly zooplankton, but it also includes small worms and the larval stages of other aquatic invertebrates. Under good growing conditions, the larvae will begin to metamorphose into PL after 19 - 28 days. Physiologically, PL mostly resemble the adult form, and shortly after metamorphosis, the PL travel upstream into freshwater where they grow into full adults. Both the PL and adult natural diet consists of algae, aquatic plants, mollusks, aquatic insects, worms, other crustaceans, and when food is sparse, they are known to turn cannibalistic. The natural lifespan of *M. rosenbergeii* is about three years (New 2002).

Adult females are proportionally smaller than adult males, and *M. rosenbergeii* can be most easily sexed by the elongated second cheliped of adult males. There are three male morphotypes: blue claw males (BC), orange claw males (OC), and small males (SM). BC males have especially long blue claws; OC males have shorter, golden colored claws; and SM have even smaller, almost translucent claws. Males change from SM to OC males to BC males. Although all morphotypes can reproduce, the different male morphotypes have a distinct hierarchy whereby a single BC male is the dominant within a population and OC males show dominance over SM. BC males are the only morphotype that is territorial (New et al. 2010).

3.1.3 Aquaculture

M. rosenbergeii size, survivability, and quick maturation rate has made it by far the most popular choice for freshwater prawn aquaculture. Initial viability studies started in Hawaii in 1965, and over the past 50 years, aquaculture of *M. rosenbergeii* has spread across

the South Pacific to countries like Fiji and Papua New Guinea, to southeast Asia in countries like Malaysia and Thailand, and to mainland Asia in countries like China and India (Gereva 2014).

In their 2008 – 2013 Aquaculture Development Plan, the VFD identified *M. rosenbergii* as a “strong candidate for aquaculture...because its production in hatcheries is well understood and this would allow the production of a regular supply of PL without relying on natural recruitment” (VFD 2008). Since that report, national research has demonstrated successful *M. rosenbergii* aquaculture from the hatchery stage to grow-out and sale at local markets in the capital city of Port Vila. There has been further interest shown by the SPC and VFD to increase the local capacity of established farms and expand operations onto other islands such as Santo (Amos et al. 2014).

3.2 *Macrobrachium lar*

Macrobrachium lar (shown in Figure 3.3) is commonly known as either the monkey river prawn or Tahitian prawn. Its natural extent ranges from Indonesia to French Polynesia and from northern Australia to southern Japan. They are also native to portions of eastern Africa (Gereva 2014).

3.2.1 Biology

Morphologically, *M. lar* are very similar to *M. rosenbergii* with a few exceptions:

- *M. lar* is smaller than *M. rosenbergii*, only growing up to 180 mm; (Historie 1980)
- *M. lar*'s rostrum has 7 – 9 dorsal teeth compared to *M. rosenbergii*'s 11 – 14 dorsal teeth;

Figure 3.3 Locally caught *M. lar* on Aneityum.

- *M. lar* has three male morphotypes, sharing SM and OC males with *M. rosenbergeii*, but instead of blue claw males, *M. lar* has a morphotype known as black claw males;
- *M. lar* black claw males have elongated second chelipeds like *M. rosenbergeii* BC males (Gereva 2014).

3.2.2 Lifecycle

Again, the lifecycle of *M. lar* is very similar to that of *M. rosenbergeii*. They both have the same four stages of life: berried females carry eggs, which hatch into planktonic larvae that travel to brackish water and turn omnivorous, before metamorphosing into PL that travel upstream into freshwater and finally grow into full adults. The biggest difference is while *M. rosenbergeii* larvae metamorphize after 19 – 28 days, *M. lar* requires 77 – 110 days before metamorphosing, which has generally made them a less favorable choice for aquaculture (Lal et al. 2014).

3.2.3 Aquaculture

While the grow-out phase of *M. lar* aquaculture has been shown to be successful, the hatchery phase has not. Therefore, the only successful examples of *M. lar* aquaculture require catching wild specimens to use in grow-out ponds. Prior to a 2014 study by Lal et al, there had been no hatchery trial for *M. lar* in which larvae survived to become PL, and in that study, only 0.08% of the larvae (5 specimens) survived to become PL (Lal et al. 2014).

In parts of Vanuatu, including Maewo, North Pentecost, and Santo, *M. lar* had been raised traditionally in dual aquaculture with water taro. In 2005, the VFD pilot tested *M. lar* aquaculture by using nets to catch PL from local rivers and streams, and then the PL were successfully reared in two 10 m by 4 m ponds and later sold in local markets (VFD 2008).

Chapter 4 – Imported *Macrobrachium rosenbergii*

Aquaculture of *M. rosenbergii* on Aneityum would require importing broodstock to initially fill the hatchery with larvae since the species is not native to Vanuatu. The Ni-Vanuatu on Aneityum also have little to no experience with freshwater prawn aquaculture, so this chapter describes a small-scale startup of *M. rosenbergii* aquaculture to test its viability without consideration for the efficiency of the system. As shown in Figure 4.1, the land set aside by the Council of Chiefs on Aneityum for prawn aquaculture is on the northern side of the island. It lies between two streams which will act as the water source for both the hatchery and the initial grow-out ponds. In the case that aquaculture proves to be viable, there is an additional discussion on modular expansion of the facilities.

Figure 4.1 Site Location on Aneityum. Adapted from Google Earth. (for permission see Appendix B)

There is almost 50 years of literature on *M. rosenbergei* aquaculture, describing designs and methods for a wide range of settings. For this paper, the focus will be on designs and methods that are appropriate for Aneityum. The designs and methods described will utilize the readily available community labor while minimizing the purchase of outside materials due to erratic shipments. Attention will be paid to simplifying operations due to the lack of skilled labor.

4.1 Hatchery

The two main categories of hatchery systems are flow-through systems and recirculation systems. Flow-through systems have a continuous flow through the rearing tanks from the water source, while recirculation systems circulate water through mechanical and biological filters to remove waste. When operated correctly, recirculation systems have shown to have higher productivity, but they require much more skilled labor to operate (New et al. 2010). The major downside of flow-through systems is it requires an abundance of high-quality water, but Aneityum has an abundance of streams and rivers. An assumption is being made that the streams and rivers on Aneityum have sufficient water quality for rearing *M. rosenbergei* larvae since *M. lar* naturally live in the same water. Part of the viability assessment is to test that assumption. Therefore, it is recommended to use a flow-through system for the context of Aneityum.

There are two types of flow-through hatchery systems: greenwater and clearwater. Greenwater systems purposefully cultivate phytoplankton in the hatchery tanks as a food source for the larvae. Clearwater systems treat the water before it is introduced into the system, and therefore it eliminates both potential predators and incidental food sources that might naturally exist in the water source (New et al. 2010). Treating the water source adds to the complexity of operations and eliminates food sources for the larvae that naturally exist in the rivers and streams on Aneityum. Larval feed would have to be grown or bought separately in a clearwater system, and both would be difficult in the context of Aneityum, where shipping materials to the island is not reliable. Despite the potential for introducing predators into the system, it is recommended to use a greenwater system.

4.1.1 Housing

According to New, “In tropical areas, tanks in flow-through hatcheries can be situated in the open but you should provide, at the minimum, simple shading (palm fronds or a bamboo framework, for example) where there is a possibility of the water temperature rising too high.” The optimal water temperature in the rearing tank is 28° to 31° and the temperature should not go below 24° or above 33° (New 2002). Local materials such as palm fronds or bamboo are readily available on Aneityum, and the Ni-Vanuatu have extensive experience building structures out of those materials. Available space for the hatchery is not a limiting factor, and using simple structures made of local materials for covering the hatchery tanks facilitates future expansion.

4.1.2 Tanks

The primary criteria for choosing tanks will be material and size. Copper, zinc, bare concrete, and oil are all toxic to larval freshwater prawns and must be avoided. Typical tank material includes: reinforced concrete tanks lined with layers of pure epoxy-resin, fiberglass interior with layers of concrete ‘shot-creted’ on the outside for reinforcement, or prefabricated plastic tanks (New 2002). If tanks with the correct dimensions are available for purchase within the country, it is recommended to use prefabricated plastic tanks. Reinforced concrete and constructed fiberglass tanks both require skilled labor to build, and they are less mobile in the case that the layout of the hatchery needs to be rearranged or moved in preparation for, or response to, a natural disaster such as a cyclone.

Rearing tanks in the hatchery will be sized to provide enough PL to fill three 20 m by 30 m grow-out pond (the recommended size of grow-out ponds by the VFD 2008). Initially, the stocking density of both the hatchery tank and grow-out pond will be kept low for two reasons:

1. An advantage of a clearwater system is that the facilities can produce or purchase as much larval feed as needed. This allows for a higher stocking density because larval feed can be introduced at a variable rate as needed. As a greenwater system, the naturally occurring feed in the water source will provide

sustenance for the larvae which is limited by the net growth rate of the phytoplankton.

2. Operators will need to be trained on Aneityum. Initially they will be prone to making mistakes, and decreasing the stocking density increases the margin for error because available dissolved oxygen, waste removal, and larval feed is not maximized for PL production. Therefore, more than the bare minimum larval feed and water quality considerations will be provided for each individual larva.

Based on the approach that will be described in section 4.3, the grow-out pond will initially be stocked at 1 PL/m². With each grow-out pond having an area of 600 m² and assuming that the rearing tank will provide enough PL to fill three grow-out ponds at that stocking density, the rearing tank will need to provide 1,800 PL.

A normal, clearwater hatchery system has a stocking density of 40 – 100 larvae/L (New et al. 2010). However, with the previously described limitations, an initial stocking density of around 6 larvae/L is recommended. Documented survival rate of larvae in hatcheries, from egg to metamorphosis is 40% to 80% (New 2002). A survival rate of 40% will be chosen for the conditions of the hatchery facilities upon startup.

$$\text{Initial Larvae in Hatchery} = \frac{\text{Desired PL in Ponds}}{\text{Survival Rate}}$$

Therefore, the hatchery must initially be stocked with at least 4,500 larvae. Smaller hatcheries have typically used 1 – 3 m³ tanks. The depth of a water column is recommended to be 0.8 – 1.0 m with at least a 0.15 m freeboard (New et al. 2010). The following formula describes how the number of larvae in the rearing tank was calculated.

$$\# \text{ of Larvae} = \text{Tank Volume} * \text{Larvae Stocking Density}$$

Therefore, a 1 m³ tank with a height of 1 m, a water level of 0.85 m, and a stocking density of 6 larvae/L would be able to hold ~5,000 larvae.

4.1.3 Water Distribution

As previously stated, an assumption is being made that the water source will provide the nutrients and water quality necessary for *M. rosenbergii* because *M. lar* spends its entire lifecycle in the same water. That being said, larvae for both species require changing levels of salinity throughout its lifecycle. Table 1 describes the salinity in parts per thousand necessary for the different stages of *M. rosenbergii*'s lifecycle (New et al. 2010):

Table 1 Salinity Needed for Different Stages of *M. rosenbergii*'s Lifecycle

Lifecycle Stage	Salinity (ppt)
<i>Broodstock</i>	~ 5
<i>Larvae</i>	12
<i>PL</i>	0

Since the proposed site for the hatchery is near freshwater, seawater, and estuary water, all along the same stream, the intake for the water source will need to be adjustable in order to capture the amount of salinity needed for the specific stage of the prawns. The proposed design will have three separate intakes: one upstream that takes in freshwater with a salinity of ~0 ppt, one that takes in estuary water at a salinity of about 12 ppt, and one downstream that takes in ocean water with a salinity between 30 – 34 ppt. The goal is to give operators flexibility in changing the salinity of the rearing tank based on the prawns' needs. In order to utilize this flexibility, salinity meters will be needed to periodically test the salinity of the inflow from the estuary location. Pipes for the entire system will be made of flexible high-density polyethylene (HDPE) which is commonly used throughout Vanuatu, and they will have a diameter of 50 mm. In key locations along the pipe system (shown in Figure 4.2), gate valves will be placed so operators can control the amount of flow.

A pump will be needed to transport the water from sea level or near sea level to the hatchery. It is recommended to completely replace the water in the rearing tanks twice a day in order to wash out waste and bring in nutrients. Therefore, a single, 1 m³ tank

holding 850 L of water will need a volume of 1,700 L each day or 1.2 LPM (New et al. 2010). To determine the liters of water per minute needed to be pumped during daylight hours (because the pump will be powered by solar power), use the following formula:

$$Pump\ Flow\ \left(\frac{liters}{minutes}\right) = \frac{liters\ of\ water}{Minute} * \frac{24\ hours}{6\ hours\ of\ sunlight}$$

The pump will need to provide 4.7 LPM to an elevated storage tank which will then provide flow to the rearing tank. Operating hours for the pump can be adjusted to only two hours, in which case the pump will need to provide 14.2 LPM over that two hours.

A land survey of the proposed site showed that the elevation difference between the hatchery location and sea level is about 3 meters. The proposed site is about 150 meters away from the water source. Therefore, at minimum, the pump should be sized for a flowrate 14.2 LPM and overcome a change in elevation of 3 meters with a headloss over 150 meters of piping. A 10% safety factor will be applied to assure the pump can handle the load as inefficiencies such as leaks or blockage in the pipe system occur. To choose a pump, the Total Dynamic Head (TDH) must be determined.

$$TDH = Safety\ Factor * (Tank\ Height + Static\ Height + Pressure\ Head + Headloss)$$

The static height is 3.0 meters, the tank height can be estimated to be 3.0 meters, there is no pressure head because the pipe outlets into an open storage tank, and at a flowrate of 14.2 LPM, the headloss is 0.1 meters. Therefore, the TDH is 6.7 meters. A TDH curve can be created by finding the TDH across different flow rates. The specific pump will then be chosen using the TDH curve, and pump curves provided by the pump distributor. An example of a usable pump is a submersible marine pump made by Grainger that uses 12 V, and pumps 233.6 LPM at 0 meters of head. At a TDH of 6.7 meters, the pump would be able to pump ~25 LPM of water which is more than sufficient to meet the needs of the rearing tank.

All electricity on Aneityum is generated either by solar power or gas generators, so solar power will most likely be the electricity source for the pump. In addition, a gas generator (with barrels of gasoline) should be kept in reserve in case solar power fails. The pump will transport water from the source to the elevated 2,000 L storage tank. Water will flow

from the tank to the rearing tank. The storage tank is large enough to hold enough water to completely replace the water in the rearing tank 2.4 times, which could provide flow during night time hours if needed. In addition, the storage tank could provide flow in case of a pump failure over a 26-hour period. The exact solar panels needed for the pump will be determined by the specific pump purchased.

4.1.4 Aeration

New et al. states that a dissolved oxygen (DO) concentration of 5 mg/L or greater needs to be maintained in the rearing tanks. As an approximation, New recommends providing 0.55 m³/hr of air for each cubic meter of water (New 2002). Therefore, every rearing tank, which has 0.85 m³ of water, should be provided 0.47 m³/hr of air to maintain ideal DO concentrations in the tank.

An oil-free, radial blower is recommended as they will not introduce toxic oils into the rearing tank, and small, inexpensive radial blowers can be easily found. Air can be distributed throughout the tank by using either circular porous airstones or 20 mm PVC pipes perforated with a 0.8 mm drill bit at intervals of 0.3 to 0.5 m (New et al. 2010). It is recommended to use the perforated PVC pipes because they are easily purchased in Vanuatu, and the pipes can be placed to circulate water at the bottom of the tank which prevents waste and debris from accumulating in the tank.

The radial blower will be solar powered, but DO concentrations need to be maintained through the night. Therefore, the solar photovoltaic system will need a battery that can keep the blower running through night time and cloudy hours. A backup battery and blower are recommended because complete mortality of the larvae can happen within a short period of low DO concentrations. The exact solar power and battery system needed will be determined by the specific blower purchased.

4.1.5 Recommended Layout

The hatchery site lies between two streams. As shown in Figure 4.2, the intakes for the pump will be at three different locations on one of the streams. Water will be pumped from the stream up to the 2,000 L storage tank, and then flow from the storage tank to the rearing tank.

Figure 4.2 Recommended Layout (not to scale).

The storage tank will need to be elevated above the rearing tank. Once the hatchery is stabilized during the larval stage of *M. rosenbergii*'s lifecycle, water will flow through the rearing tank at steady state. The outflow will then be carried into the other stream. Outlet flow can either be transported by pipe or a lined or unlined open channel. There are limited pollutants in the outflow, so there are minimal environmental concerns.

Figure 4.3 Cross-section of the Rearing Tank.

Figure 4.4 Top View of the Rearing Tank.

Although flat-bottomed tanks are useable as a rearing tank, it is recommended to use a tank with a conical bottom to prevent food and waste from accumulating in corners. Since available space is not a limiting factor, the shape of the tank is not important. As shown in Figure 4.3 and Figure 4.4, the rearing tank should have an inlet and two outlets. One of the outlets is located at the bottom of the tank, and the second outlet is a turn-down pipe on the side of the tank, as shown in Figure 4.3 and Figure 4.4. The turn-down pipe has a valve so the operator can regulate the outflow from the rearing tank. Water will flow into the rearing tank through the inlet and out of the turn-down drain which is covered in a filtersock. The other outlet is a cleanout at the very bottom of the tank, and it will be used to remove accumulated waste and debris in the tank.

4.1.6 Operations

Prior to hatchery startup, the water distribution system should be flushed with 3 days of constant flow with freshwater taken from the most upstream pumping site (New et al. 2010). Each individual cycle, from broodstock management to transferring the PL to the grow-out ponds, takes from 30 – 40 days.

The majority of established prawn farming is located throughout Southeast Asia, but according to Gereva, the VFD has shown interest in importing *M. rosenbergii* broodstock from nearby Fiji which has an established and growing prawn industry (Gereva 2014). Once the initial broodstock spawn, future broodstock can be taken straight from grow-out ponds. There has been some concern that the practice of taking broodstock from grow-out ponds within the same facility will cause an ‘inbreeding depression’, but further studies have shown no evidence of deterioration of genetic variability (New et al. 2010). In tropical regions such as Vanuatu, additional facilities for broodstock are not typically used. In addition, not having hatching tanks simplifies operations, so broodstock can be kept in the rearing tanks (New 2002).

Berried females with a length of 10 – 12 cm typically carry 10,000 – 30,000 eggs and it can be assumed that 50% of the clutch will be lost before hatching.

$$\# \text{ of larvae} = \# \text{ of eggs} * 0.5$$

Since the goal for a single rearing tank is to be stocked with ~5,000 larvae, a single berried female with a length of 10 – 12 cm should be more than sufficient to provide enough larvae. When berried females are initially placed directly into the rearing tank, water level in the tank should be lowered to ~30 cm, and the salinity should be ~5 ppt. After the eggs hatch (which normally happens at night), the females are removed from the rearing tank, and the water level is raised to its normal height of 85 cm. The salinity in the tank can then be slowly increased to 12 ppt over a 4-hour period (New et al. 2010).

The larval stage of *M. rosenbergii* can last anywhere between 19 – 40 days (New 2002). After the water level and salinity of the rearing tank has stabilized, a constant flow of about 1.2 L/min for both the inlet and outlet should be maintained in order to

completely replace the rearing tank's water 2 times a day. The operator can adjust the flow with the gate valves at the inlet and outlet until a steady state flow has been obtained. In order to simplify operations, operators can instead fully replace the rearing tank's water twice a day by allowing half of the storage tank volume (1,000 L) to flow through the rearing tank at two different times in a day. Operators will have to measure the salinity of the water in the storage tank before replacing water in the rearing tank to ensure that the water entering the rearing tank has a salinity of about 12 ppt. While larvae are in the rearing tank, operators should keep the following in mind:

- Do not suddenly change temperature or salinity in the rearing tank because the shock can cause mortality.
- Maintain almost constant aeration of the rearing tank. Aeration should only be turned off temporarily during larval observation, tank cleaning, and larval feeding.
- The storage tank should be kept full in case there is a pump failure, so flow to the rearing tank can be maintained until the pump can be fixed or replaced. A backup pump should also be on site in order to easily replace the pump.
- Healthy larvae swarm near the water surface while unhealthy larvae accumulate near the bottom or along the sides of the tank.

Part of the initial viability test for *M. rosenbergii* aquaculture will be to determine adequate feeding regimens. The hope is that the relatively low larval stocking density, high flow-through rate, and the natural feed in the water source will be sufficient to sustain the larvae. Underfed larvae will result in poor growth, extended culture cycle, and larval cannibalism. If the operator sees larvae accumulating near the bottom or sides of the tank, resorting to cannibalism, or growing slowly, then it may be appropriate add additional feed. The larvae's diet can be supplemented with local feeds such as leftover fish and shellfish scraps or fish organs that are removed while cleaning fish. However, it is important not to allow these scraps to accumulate in the tank as it can cause the water quality to deteriorate (New et al. 2010).

By day 35, a majority of the larvae should have metamorphosized into PL. In preparation to transfer the PL from the rearing tank to the grow-out pond, the salinity in the rearing tank should be slowly adjusted from 12 ppt to freshwater with a salinity of 0

ppt over a 12-hour period. Once the salinity has been changed, the water level in the tank can be reduced to about 35 cm. Then, the PL can be removed from the rearing tank using dip nets and transferred to the grow-out ponds in buckets. Maintaining sufficient DO concentrations is important throughout this process, so operators should keep the aerators on up until they attempt to use dip nets to remove the PL and PL should not remain in the buckets for longer than a few hours (New 2002).

4.2 Grow-Out Ponds

Grow-out ponds are earthen structures where the adult *M. rosenbergii* grows to full size before being harvested and sold. Many prawn farms have a nursery phase in between the hatchery and grow-out phases where PL grow to full adults in separate ponds, but to simplify operations, it is recommended to transfer PL directly from the hatchery to the grow-out ponds. Initially, there will be three grow-out ponds with dimensions of 30 meters by 20 meters.

4.2.1 Culture Types

There are three main categories of grow-out pond cultures: extensive, semi-intensive, and intensive (New et al. 2010). These categories are described in the table below:

Table 2 Grow-Out Pond Culture Types (New et al. 2014)

Type of Culture	Stocking Density (PL/m ²)	Feed	Technology Level Used	Yield (t/ha/yr)
Intensive	> 20	Artificial	High	> 5
Semi-Intensive	4 – 20	Supplemental	Varied	0.5 – 5
Extensive	1 – 4	Natural	Low	< 0.5

Intensive cultures are kept in artificial tanks where all water quality parameters are carefully controlled to optimize the yield. Typically, an extensive culture is a sectioned off area in a natural stream or river where wild stock are placed to grow. Semi-intensive cultures vary in the amount of technology used, from simple earthen ponds with natural water flowing through them to series of concrete ponds with treated water. The

recommended design in this paper uses a hatchery to produce PL and dedicated, man-made ponds for the grow-out phase similar to semi-intensive cultures. However, the design calls for a stocking density of 1 PL/m², which fits in the range of extensive cultures.

4.2.1 Ponds

Each pond will be 20 m wide, 30 m long, and have an average water depth of 0.9 m. There should also be a 0.3 m freeboard. In order to create a 0.5% slope, the side where the water flows into the pond will have a depth of 1.05 m and the side where the water flows out of the pond will have a depth of 1.35 m (see Figure 4.5). The internal slope of the pond's bank should not be any steeper than 3:1. In addition, the bank can be lined with vegetation such as grass, taro, or banana trees in order to maintain its structural integrity (New 2002).

Figure 4.5 Cross-Section of a Grow-Out Pond.

4.2.2 Water Distribution

As shown in Figure 4.2, initially there will be three grow-out ponds that are fed by one of the streams on either side of the chosen site. It is important that the stream feeding the ponds is not the same stream that is used as the water source for the hatchery, so as not to decrease the water quality at the intake for the hatchery. Each pond will have an inlet pipe from the water source to the pond and an outlet pipe from the pond to downstream of the water source. Each of the inlet and outlet pipes will have a gate

Figure 4.6 Representations of Rippling and Cascading to Induce Aeration. Taken from New 2002 (for permission see Appendix B).

valve near the pond so that operators can control the flow into and out of the grow-out ponds. The pipes will be made of flexible HDPE like the pipes used in the hatchery.

The following formula will be used to determine the flow into each pond, using the parameter that there will be enough flow to replace 25% of the water in the pond each day.

$$\text{Flow} \left(\frac{L}{s} \right) = \frac{0.25 * \text{Volume of the Pond (L)}}{\text{Seconds in a day (s)}}$$

With a pond volume of 540,000 L, the flow through the pond will be 1.6 L/s. In order to reach steady state flow through the pond, the outlet will also need a flow of 1.6 L/s. The ponds will be placed in order to have at least 1 meter of elevation head so that water can flow

by gravity. A 100 m inflow pipe with a nominal diameter of 63 mm would have a flow of about 9.8 L/s (see Appendix A for the calculation), which would be more than sufficient to provide the necessary flow. Considering that some water will be lost to evapotranspiration and seepage, operators can use the gate valve to adjust the inflow and the outflow to each pond until the flow is at steady state flow rate of ~1.6 L/s. The ponds should be shaded and lined with clayey soil (which is readily available on Aneityum). The outlet from the pond will need crude screening, with openings no larger than 5 mm so as not to allow PL to escape the pond through the outlet.

Aeration of the inflow can be induced by either rippling or cascading (as shown in Figure 4.6). Rippling occurs along a short open channel where water flows over stones or weirs, causing turbulence and aerating the water. To cascade the water, the inflow is injected into a bore pipe, forcing air to the bottom of the pond. It is recommended to use rippling because it is simpler to construct and the materials are locally available (New 2002).

4.2.3 Operations

The grow-out ponds should be operated with a semi-batch approach in which PL are put in the ponds all at once and harvested as needed to be sold on Mystery Island. Prior to filling the pond, the pond should be left dry for 2 – 3 weeks. If necessary, sediment build-up on the bottom of the pond should be removed during this time along with making any necessary repairs to the banks of the pond. The pond should be stocked immediately after filling the pond with water at a stocking density of 1 PL/m², which with pond dimensions of 30 m by 20 m, should be about 600 PL (New 2002).

As with the hatchery, the hope is that the relatively low stocking density and high water exchange rate of the pond from natural waters containing natural feeds will minimize or eliminate the need to apply regular feed to the pond. If the health of the prawns declines

or their growth rate is impaired due to malnutrition, the prawns' diet can be supplemented with fish and shellfish scraps, corn, oranges, carrot tops, brewer's yeast, rice or peeled sweet potatoes which are all readily available on Aneityum (New 2002). There are two important factors to keep in mind while supplementing the prawn's diet with additional feed:

1. The feed needs to be broken into small enough pieces for the prawns to consume. Shred or grind the feeds when necessary.
2. Operators should not allow feed to accumulate in the pond because the decomposition of the feed can cause the water quality to deteriorate (New et al. 2010).

Harvesting full grown *M. rosenbergeii* will be on an as-needed basis. On days when cruise ships anchor at Mystery Island, a sufficient number of prawns can be caught and put on boats to be cooked and sold to tourists. When larger numbers are needed to be sold, or the last of the prawns in a pond are to be sold, a pond can be drained to make capturing the prawns easier.

4.3 Modular Expansion

Productivity of the prawn aquaculture can be increased by either making the hatchery process and grow-out ponds more efficient or by expanding available infrastructure. Efficiency will increase as the operators gain experience and push the limitations of the system to maximize production. Expanding infrastructure, on the other hand, will require capital investment. However, the process of expanding can be modular, increasing the hatchery capacity and number of grow-out ponds piece by piece.

To expand the hatchery, each additional rearing tank will need piping carrying inflow to the storage tank, a storage tank, aeration blowers with a solar panel and battery, and piping carrying the outflow away from the hatchery. There are hundreds of streams and rivers on Aneityum, so the additional rearing tank can be placed near the initial hatchery or in another location, depending on how the people on Aneityum want to expand.

As a general rule, every additional rearing tank will need three grow-out ponds to accommodate the PL produced. The initial site will not have enough water for additional

ponds, so the additional grow-out ponds will have to be placed in other locations. Again, the distribution of the ponds and labor will need to be decided by the people of Aneityum.

4.4 Advantages and Disadvantages

The main disadvantages of using *M. rosenbergeii* stem from the fact that the species is not native to Vanuatu. Initial broodstock will have to initially be imported, and although future broodstock can be taken from the grow-out ponds, if complete mortality of the grow-out ponds and/or hatchery occurs due to disease, natural disaster, or poor management, broodstock will have to be imported again. Also, since *M. rosenbergeii* is an exotic species, any specimens that escape from the grow-out ponds would risk becoming an invasive species.

Another disadvantage is that *M. rosenbergeii* aquaculture will require a viability test on Aneityum. Specifically, the assumption that the natural waters of Aneityum have sufficient nutrition and water quality for *M. rosenbergeii* to survive across all of its stages of life needs to be tested. If additional feed needs to be applied to either the hatchery or grow-out ponds, a feeding regimen will also need to be determined. During the viability testing, there is a significant chance that there will be complete mortality due to poor management which, as previously stated, would require importing additional broodstock to continue prawn aquaculture on Aneityum.

Despite the disadvantages, *M. rosenbergeii* is the most farmed freshwater prawn because of the species' natural advantages. Due to its size and quick maturation rate of about 35 days, *M. rosenbergeii* has shown to be the most productive culture of freshwater prawns. *M. rosenbergeii* is also the most well-studied freshwater prawn. Almost all of the established guides and methods for freshwater prawn aquaculture are for *M. rosenbergeii*, so using other species of freshwater prawn would require research and adaption of those guides and methods.

Chapter 5 – Locally Sourced *Macrobrachium lar*

Macrobrachium lar is the main *Macrobrachium* species native to Vanuatu, and wild broodstock are readily available throughout Aneityum. Although the grow-out process has proven to be successful in various settings, including in Vanuatu, grow-out ponds have always been stocked with PL caught in the wild because the hatchery process has yet to be proven viable (Gereva 2014).

5.1 Hatchery

In order to maintain *M. lar* aquaculture on a scale beyond subsistence farming, it will be necessary to develop the hatchery process for *M. lar* because consistently catching wild PL to stock grow-out ponds could adversely affect their native population. The hope is that using the untreated water that *M. lar* larvae naturally lives in as a water source will eliminate the process of finding the exact water quality parameters needed to successfully rear *M. lar* larvae.

The proposed hatchery design for rearing *M. lar* larvae is nearly identical in layout to the one described in Chapter 4 for *M. rosenbergeii*. However, there are a few significant differences in the operations of the hatchery.

- *M. lar* larvae require salinities of 30 – 35 ppt (ocean water) instead of the 12 ppt needed for *M. rosenbergeii*. Therefore, after the larvae hatch, the salinity in the rearing tank will need to be adjusted from ~5 p.p.t to 32 – 34 ppt over a 12-hour period (Lal et al. 2014). The proposed design for the hatchery for *M. lar* therefore only needs two intake locations: one providing freshwater with a salinity of 0 ppt, and one providing ocean water.
- The stocking density of the rearing tank will be experimental. Berried females can produce up to 20,000 eggs, so it is recommended to initially use a single specimen as broodstock for the rearing tank (Gereva 2014).
- The larval stage of *M. lar*, and therefore a hatchery cycle, can range from 77 – 110 days, which is much longer than the larval stage of *M. rosenbergeii* (Lal et al. 2014).

Like the operations of the *M. rosenbergeii* hatchery, the hope is that naturally available nutrition in the water source will be sufficient to sustain the larvae. However, if it does not appear to be sufficient based on observations, it may be necessary to supplement the larval diet. Less is known about *M. lar* diet, so both the types of feeds and the feeding regimen will be experimental. However, it is recommended to start by using the same regimens described for *M. rosenbergeii*.

5.2 Grow-Out Ponds

Like the hatchery, the layout for grow-out ponds for *M. lar* is identical to those described in Chapter 4 for *M. rosenbergeii*. A major difference in operations is the stocking density which affects the number of ponds needed to accommodate the PL produced in the hatchery. The number of PL produced in the hatchery is uncertain because hatcheries of *M. lar* have yet to be successful. However, if a maximum of 20,000 eggs are introduced to the hatchery, 50% of the eggs hatch into viable larvae, and a maximum survival rate of the larvae to metamorphosis is 10% (the best survival rate shown has been 0.08%) is assumed, then the hatchery will produce 1,000 PL. A 20 m by 30 m grow-out pond would therefore have a stocking density of 1.7 PL/m². PL stocking densities for *M. lar* in grow-out ponds have been shown to be viable from 5 – 18 PL/m². Therefore, a single 20 m by 30 m grow-out pond should be sufficient to accommodate all the PL produced in the hatchery.

M. lar is capable of moving over land. Local people on Aneityum who have made trial grow-out ponds for wild caught *M. lar* have noted that their stock have escaped from the ponds by travelling over land and back into the nearby streams and rivers. In order to prevent stock from escaping grow-out ponds, a 1 m tall barrier of plastic sheeting should be set up around the perimeter of the pond.

5.3 Advantages and Disadvantages

The main disadvantage of using *M. lar* rather than *M. rosenbergeii* in the hatchery process is that the hatchery process for *M. rosenbergeii* has been well documented and proven successful, while the hatchery process for *M. lar* has yet to be proven viable. In practice, this means that many of the parameters and guidelines, such as stocking

densities and feeding regimens, are still experimental. *M. lar* is also a smaller species, has a slower maturation rate, and a worse natural survival rate to PL than *M. rosenbergeii*, which ultimately means that even if a successful hatchery process is determined, *M. lar* aquaculture will not be as productive as that of *M. rosenbergeii*.

However, *M. lar* aquaculture's advantages stem from the fact that the species is native to Aneityum. New broodstock for the hatchery can be easily caught in local streams and rivers, and if specimens escape from the grow-out ponds, there is no risk of introducing an invasive species into the ecosystem. Despite many of processes of *M. lar* aquaculture being experimental, the abundance of locally caught broodstock means that complete mortality of larvae or grow-out pond stock is not nearly as problematic as with *M. rosenbergeii*, which would require additional broodstock to be imported.

Chapter 6 – Conclusion

Aneityum has an easily accessible market to sell freshwater prawns because tourists arrive by the thousands on cruise ships to Mystery Island, just south of Aneityum. However, catching wild prawns or filling grow-out ponds with wild stock is not viable on a large scale because these practices could devastate the local populations of prawns over a long period of time. The alternative is to use freshwater prawn aquaculture to rear prawns from larvae in a hatchery to adults in the grow-out pond.

When it comes to freshwater prawn aquaculture, *M. rosenbergii* is the standard species used in most places around the world. The majority of experience, research, and production revolve around *M. rosenbergii*. However, as an exotic species to the remote island of Aneityum, importing initial broodstock is difficult and consistent deliveries of PL or broodstock is near impossible. The hope is that broodstock can be taken from grow-out ponds after the prawns have matured, but this puts the operation in a precarious position. Complete mortality of the hatchery or grow-out ponds would result in a halt to operations until new broodstock could be imported.

M. lar is an interesting alternative to *M. rosenbergii* because despite its smaller size and slower maturation rate, it is native to Aneityum and broodstock is readily available in the local streams and rivers. However, the hatchery process for *M. lar* has yet to be proven viable. Since catching wild stock to fill grow-out ponds is not sustainable at a large scale, the hatchery process would require trial and error with the hopes that a viable hatchery process could be discovered.

For both species of prawns, the initial capital investment will be relatively high to build the hatchery and grow-out ponds. Initial investment will most likely need to come from either aid organizations or the VFD. However, the upkeep cost will be low since high quality water is readily available, electricity is powered through solar panels, and there are no regular purchases to maintain operations. The market price for *M. lar* in Vanuatu is 1,000 – 1,500 VT/kg (\$8.69 - \$12.96) while the market price for *M. rosenbergii* is ~2,000 VT/kg (\$17.06) (VFD 2008). However, since on Aneityum, the prawns would be sold directly to tourists, they can expect to sell the prawns at higher prices. The designs

laid out in this paper are to test the viability of freshwater prawn aquaculture for both species. Therefore, they are not designed to maximize productivity. After freshwater prawn aquaculture is proven viable, the hope is that operations can then be improved to maximize productivity and therefore increase profits.

The proposed layout for the hatchery and grow-out ponds for both *M. rosenbergeii* and *M. lar* are nearly identical. The only two differences are:

1. The hatchery for *M. lar* only needs two intake locations to pump water to the storage tank, while the hatchery for *M. rosenbergeii* needs three.
2. *M. lar* will only need a single 20 m by 30 m grow-out pond to accommodate the PL produced by the hatchery, while *M. rosenbergeii* will need three.

Therefore, the proposed hatchery and grow-out pond design for *M. lar* require less materials and construction than for *M. rosenbergeii*, and the broodstock to start the hatchery can be easily acquired from local streams and rivers. It is recommended to start trials of freshwater prawn aquaculture with *M. lar*. If a viable hatchery process cannot be discovered or the production rate is not satisfactory, then the facilities can easily be added to and the operations adjusted to accommodate *M. rosenbergeii*. If *M. lar* cultures prove successful, but the people of Aneityum also want to also experiment with cultures of *M. rosenbergeii*, the facilities can be expanded in modular fashion to accommodate cultures of both species.

References

- Amos, Moses John. 2007. "Vanuatu Fishery Resource Profiles." Global Environment Facility, United Nations Development Programme, and Pacific Regional Environment Programme.
- Amos, Moses John, Ruth Garcia, Tim Pickering, and Robert Jimmy. 2014. "Study on the Potential of Aquaculture in the Pacific." Secretariat of the Pacific Community.
- CIA Factbook. 2019. "The World Factbook: Vanuatu." Accessed August 18.
<https://www.cia.gov/library/publications/the-world-factbook/geos/nh.html>
- Comparative Constitute Project (CCP). 2019. "Vanuatu's Constitution of 1980 with Amendments through 1983." Constituteproject.org.
- Gereva, Sompert. 2014. "An evaluation of the culture performance of two *Macrobrachium* species in Vanuatu: the exotic *M. rosenbergeii* and the indigenous *M. lar*." Queensland University of Technology.
- Historie, Rijksmuseum van Natuurlijke. 1980. "Vol. 1 – Shrimps and Prawns of the World." FAO.
- Lal, Monal M, Johnson Seeto, and Timothy D Pickering. 2014. "Complete larval development of the Monkey River Prawn *Macrobrachium lar* (Palaemonidae) using a novel greenwater technique." Springer Open Journal.
- New, Michael B. 2002. "Farming Freshwater Prawns: A Manual for the Culture of the Giant River Prawn (*Macrobrachium rosenbergeii*)." FAO.
- New, Michael Bernard, Wagner Cotroni Valenti, James H. Tidwell, Louis R. D'Abramo, and Methil Narayanan Kutty. 2010. "Freshwater Prawns: Biology and Farming." Blackwell Publish Ltd.
- Smithsonian Institution. 2013. "National Museum of Natural History Global Volcanism Program: Aneityum." Accessed August 21.
<https://volcano.si.edu/volcano.cfm?vn=257110>

Spriggs, Matthew. 2007. "Population in a Vegetable Kingdom: Aneityum Island (Vanuatu) at European Contact in 1830." University of Hawaii Press.

Vanuatu Department of Fisheries (VFD). 2008. "Aquaculture Development Plan 2008 – 2013." Secretariat of the Pacific Community.

Appendix A – Pipe Size Calculations

To determine the diameter of the pipes feeding grow-out ponds in Chapter 4, Bernoulli's Equation was used:

$$\frac{P_{inlet}}{\gamma} + \frac{V_{inlet}^2}{2g} + z_{inlet} - h_L = \frac{P_{outlet}}{\gamma} + \frac{V_{outlet}^2}{2g} + z_{outlet}$$

Both the inlet and outlet are treated as if they are open to the air, so the pressure terms P_{inlet} and P_{outlet} are both equal to 0. The velocity at the inlet (V_{inlet}) is neglected, and the elevation at the outlet (z_{outlet}) is treated as the datum and set to 0 as well. The formula after removing those terms looks like the following:

$$z_{inlet} - h_L = \frac{V_{outlet}^2}{2g}$$

The variables are as follows:

- z_{inlet} is the height difference between the inlet and the outlet. A minimum height difference of 1 m was assumed.
- h_L is headloss over the pipe. The Headloss was determined using the website <https://www.engineeringtoolbox.com/>. A maximum of a 100 m of piping from the water source to the grow-out pond was assumed.
- V_{outlet} is the velocity of the flow at the outlet. The velocity is determined by assuming a flow and dividing that flow by the cross-sectional area of the pipe.
- g is the gravity constant of 9.81 m/s².

The variables z_{inlet} and g were treated as constants. Pipe size and flow, which affect the variables h_L and V_{outlet} , were adjusted until both sides of the equation were equivalent. The only requirement was that the flow had to be at least 1.6 L/s. A pipe with a diameter of 63 mm was large enough to provide 9.8 L/s of flow, which was determined to be more than enough to meet the requirement.

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- Figure 2.1
 - File: Vanuatu – Anatom.PNG
 - Credit: M. Minderhoud
- Figure 2.2
 - File: Mystery Island Vanuatu – panoramio.jpg
 - Credit: Ross Bate
- Figure 3.1
 - File: Washington DC Z00 – Macrobrachium rosenbergeii 1.jpg
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Figure 3.2 and Figure 4.6 are taken from FAO’s fisheries technical paper called “Farming Freshwater Prawns: A Manual for the Culture of the Giant River Prawn (*Macrobrachium rosenbergeii*)”. The author emailed FAO’s specialist on copyright and received the following response:

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Kind regards,

Radhika”

Appendix C – Bill of Materials

The following is a list of materials that would need to be purchased to set up the hatchery and grow-out ponds for *M. lar*:

- 2 pumps (as described on pg. 17)
- Solar system for pump
- 2,000-liter, closed storage tank (as described on pg. 14 – 15)
- 1,000-liter, open rearing tank with a conical bottom (as described on pg. 14 – 15)
- 2 aerator (as described on pg. 18)
- Solar system for aerator
- 5 m of 10 mm PCV pipe for aeration
- Flexible tubing for aeration
- 9 50 mm HDPE gate valves
- ~500 m of 50 mm HDPE pipe
- Pipe connections

In order to build the additional grow-out pond necessary for *M. rosenbergeii* aquaculture operations, an additional 100 m of 50 mm HDPE pipe and two extra gate valves will need to be purchased.