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MUSSEL FARMING IN THE STATE OF SARAWAK, MALAYSIA: A FEASIBILITY STUDY

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ABSTRACT

The purpose of this study was to identify whether it is possible to grow green mussel in the state of Sarawak based on the evaluation of available biophysical parameters, economic and market opportunities. Site suitability rating systems are developed to assess the environmental parameters of the sites. The biophysical parameters such as salinity, temperature, dissolved oxygen, pH, turbidity, water current and depth of the site in three rivers including Sungai Santubong, Sungai Gerigat and Sungai Oya were collected from secondary data, rated and finally categorised. The profitability model of raft and long line culture methods was considered in this study based on assumptions and data collection by reviewing printed and electronic articles from research publications. Investment indicators net present value (NPV), internal rate of return (IRR) and sensitivity analysis on sale price, cost of seeds and harvest weight are determined. The biophysical evaluation results shows that Sungai Santubong is categorised as 'good' whereas Sungai Gerigat and Sungai Oya are categorised as 'medium' sites for growing green mussel. Profitability models for both culture methods indicate a positive NPV and acceptable IRR. However, the model is highly sensitive to changes in sales prices and harvest weights. The long line culture requires less capital investment than raft culture.

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CERGIS - Coastal Environmental Resource Geographic Information System
DOF - Department of Fisheries Malaysia
FAO - Food Agriculture Organisation of the United Nation
KM^2 - Kilometres square
MOA - Ministry of Agriculture and Agro-Based Industry Malaysia
MT - Metric tons
RM - Ringgit Malaysia (Currency of Malaysia)
SEAFDEC - Southeast Asian Fisheries Development Centre
USD - Dollar of United States of America
m - Metre
ppt - Part per thousand
°C - degree Celsius

1 INTRODUCTION

Aquaculture plays an important role in Malaysia by providing an alternative means of increasing fish production, contributing to the protein food supply and contributing to the socio-economic development of the nation. Aquaculture production increased by 77% in the past 10 years from 105,000 mt in 1993 to 186,000 mt in 2003 while in terms of value it increased by 116% from USD 113 million to USD 302 million. Capture fisheries increased by 28% from 1.2 million tonnes in 1993 to 1.5 million tonnes in 2003 (FAO 2005). Increased aquaculture production is due to the commitment of the government to increase food production in the country.

The Third National Agriculture Policy (1998 – 2010), sets aggressive development goals for aquaculture to supplement production from capture fisheries, as well as to cater for exports. It was forecasted that the aquaculture production would increase to 601,000 tonnes by 2010 (MOA 2004). About 20,000 people are directly involved in the aquaculture industry.

Basically, aquaculture in Malaysia consists of freshwater and brackish water production. Brackish water aquaculture dominates the production with 136,000 tonnes valued at USD 236 million (FAO 2005). The main species of brackish water aquaculture are marine finfish, black tiger shrimp and shelled molluscs.

Aquaculture operations are located in most parts of the country, depending on the suitability and potential of the area. Pond culture of fish and shrimp is located along the west coast of Peninsular Malaysia, mainly in the states of Perak, Selangor, Kedah, Penang, Negeri Sembilan and Selangor, on the east coast of Peninsular Malaysia in the states of Trengganu and Pahang and the states of Sabah and Sarawak in East Malaysia (Figure 1). Marine finfish cage culture is mainly located in the states of Penang, Perak, Kedah and Johor. Shell mollusc culture such as cockles is mainly found in the state of Perak and the culture of oysters in the state of Trengganu. Green mussels are mainly cultured in the states of Johor, Melaka, Negeri Sembilan, Selangor and Perak. Currently the major culture systems used are brackish water culture of shrimps and marine fish in ponds, marine fish in floating net-cages, mussel culture in rafts and oyster culture in rafts and racks.

Culture of the green mussels, *Perna viridis*, holds considerable potential in Malaysian coastal waters (Marzuki 1998). The production increased to 7702 mt in 2003 from 5785 mt in 2002 (FAO 2005). Most of the production is in the western part of Peninsular Malaysia in the states of Johore, Melaka, Perak, Selangor, Negeri Sembilan and Penang and a little in the state of Sabah in East Malaysia (DOF 1996). In the state of Sarawak, there is no production record of green mussel. The brackish water aquaculture in Sarawak is black tiger shrimp culture in ponds, marine fish culture in floating net cages and crab culture in pens. However, it is reported that shellfish such as giant clams, razor clams and white clams are found naturally and are becoming important for commercial, recreational and subsistence activities in Sarawak (Oakley 2000). Green mussel appears to be already consumed in Sarawak and the import of this product increased from 1 mt in 1996 to 7 mt in 2000 (Pada Bijo, personal communication). On the other hand, Malaysia was importing 491 mt of mussel in 2003 even though the green mussel production in that year reached 7700 mt (FAO 2005). Thus, the introduction of green mussel farming in state of Sarawak could meet local demand as well as contribute to the balance of trade or export earnings of the nation.

Figure 1: Geographical location of the state of Sarawak in the Federation of Malaysia (World factbook 2002).

The aim of this study is to evaluate the potential for introducing green mussel farming in the state of Sarawak using existing biophysical and economic information. The study is a descriptive analysis using information from websites and correspondence, and a site visit to a mussel farm in Iceland for technological and economic information.

The research question is related to the main topic of the project, and asks whether green mussel farming in the state of Sarawak is feasible? :

The findings of the study will strengthen the understanding of the concept, principle and approach of how to formulate a framework and prepare a plan of action for introducing a new aquaculture programme, projects or species to a new area. Furthermore, the study should:

a) Increase understanding of decision-making processes through a structured feasibility study.
b) Provide additional information that benefits the development of the aquaculture industry.

2 BACKGROUND

2.1 World mussel production

World mussel productions of all types increased at an average of 5% per year during 1950-2003 (Figure 2), reaching about 1.6 million tonnes in 2003 constituting 13% of the 12.3 million tonnes total mollusc supply (FAO 2005). The worldwide combined total farm gate value of mussels in 2003 was estimated at roughly USD 996 million (FAO 2005). Over 40 countries worldwide are listed as significant producers of mussels. The top five producing countries, China, Spain, Italy, Thailand and New Zealand, account for 82% (1.2 million tonnes) of the total mussel landings (Table 1). The blue mussel, *Mytilus edulis*, and the Mediterranean mussel and currently green mussel form the bulk of the total world production. Green shell mussel, *Perna spp*., a tropical and subtropical genus, shows significant increases of production in some countries such as New Zealand and Thailand. The green mussel in the tropics is mainly *Perna viridis*, which is cultivated in India, Indonesia, the Philippines, Singapore, Thailand and Malaysia (Spencer 2002).

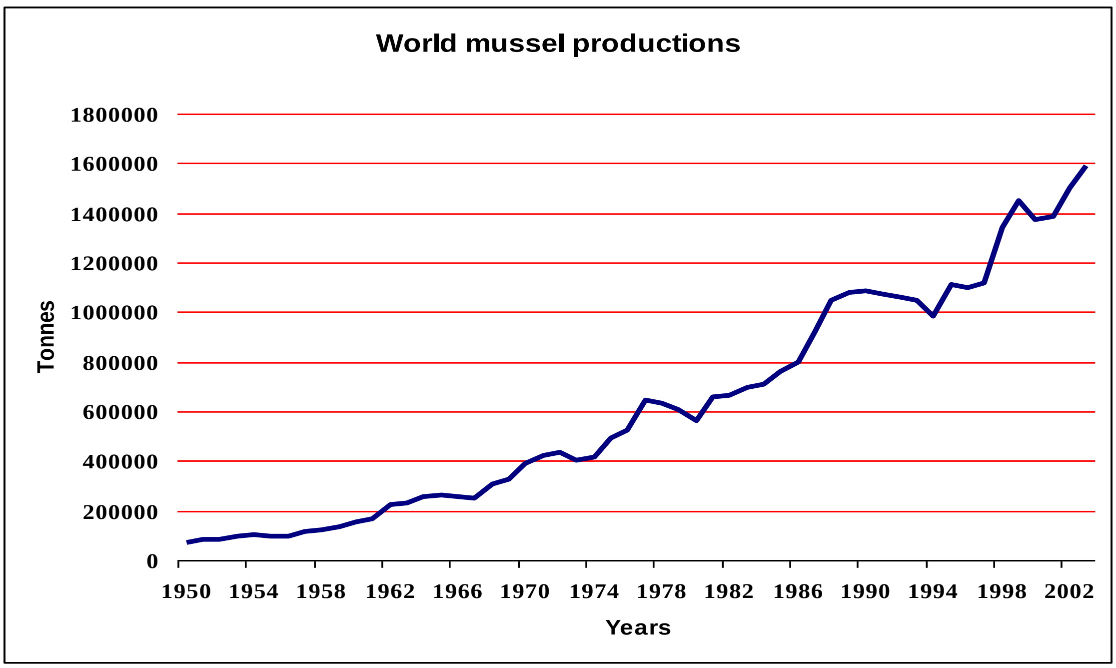

Figure 2: Estimated world production of mussels of all types in the period 1950-2003 (FAO 2005).

Table 1: World mussel production in 1993 and 2003 (FAO 2005) showing an increase by countries (modified from Spencer 2002).

Species	Common name	Country	Thousands of tonnes	
			1993	2003
Mytilidae	Sea mussel	China	509.6	683.2
Mytilus edulis	Blue mussel	Spain	91.5	248.8
		Netherlands	66.0	56.2
		France	55.0	55
		Germany	24.7	28.6
		Ireland	13.7	39.3
		UK	4.2	19.2
		Canada	5.1	20.5
M.galloprovincialis	Mediterranean mussel	Italy	40.0	99.0
		Greece	16.7	31.5
		France	15.0	13.0
M.smaragdinus	Green mussel	Thailand	24.4	89.0
		Philippines	25.1	13.5
Perna viridis,	Green mussel	Malaysia	1.2	7.7
Perna canaliculus	New Zealand mussel	New Zealand	47.0	78.0
M.chilensis	Chilean mussel	Chile	2.9	56.5
M.coruscus	Korean mussel	Korea Republic	55.1	15.8
M.planatulus	Australian mussel	Australia	0.6	2.9
Perna perna	South American rock mussel	Brazil	0.0	17.2
	World total		1048.2	1589.5

2.2 Green mussel farming in Malaysia

The mussel farming is considered to hold considerable potential in Malaysian coastal waters (Mazuki 1998). The production increased from 1200 mt in 1993 to 7700 mt in 2003 (Table 1and Figure 3). Nevertheless this production (Table 1 is still below that of the neighbouring countries such as Thailand and the Philippines.

Green mussel, *Perna viridis* (Appendix V) is the main species for aquaculture operation in Malaysia (Ong and Rabihah 1989). The culture activity started in the Johore Straits in the southern coast of Peninsular Malaysia due to availability of natural seed. It spread to the western coast of Peninsular Malaysia especially the state of Melaka where natural spat are available and Perak by obtaining the seed for transplantation from Johore and Melaka. With the development of culture systems through work done by Fisheries Research Institutes and the initiative of the government the mussel culture is now spreading to other parts of Peninsular Malaysia by transplantation of young mussels collected on polypropylene ropes from sites with natural spat (Choo 1979). There are more than 250 culturists managing over 370 rafts (78,000 $m^{2)}$ located in the states of Johor, Melaka, Perak, Negeri Sembilan, Selangor, Penang and Sabah (DOF 1996).

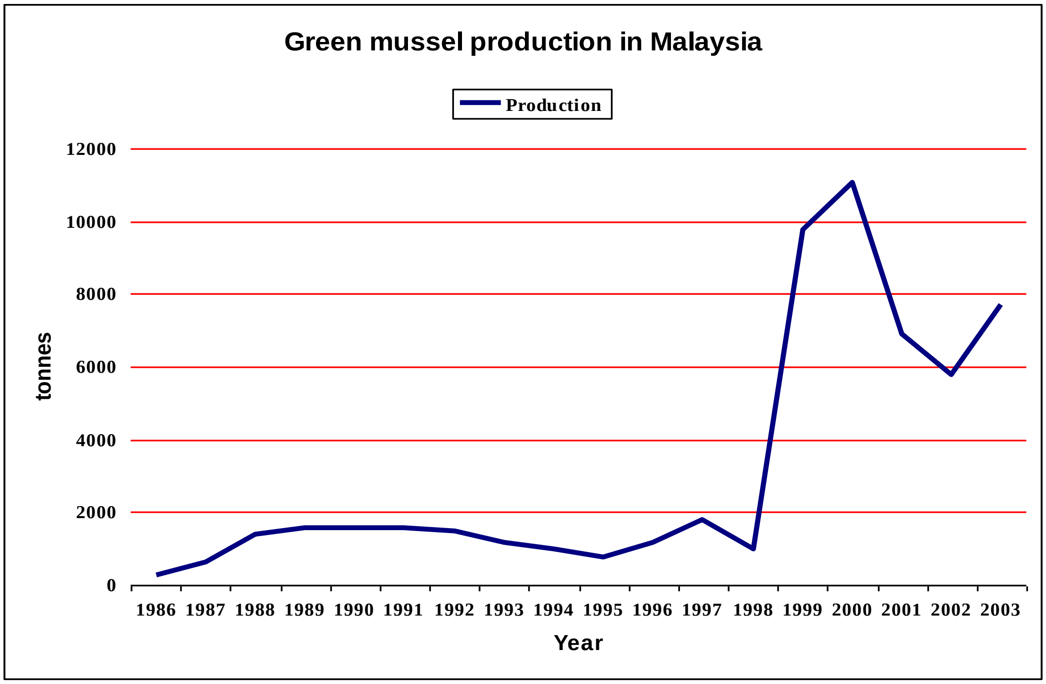

Figure 3: Production trends of green mussel in Malaysia 1986 – 2003 (FAO 2005).

2.3 Biology of the green mussel, *Perna viridis* (Linnaeus, 1758)

The green mussel also called green lipped mussel, Philippines green mussel, *Perna viridis* belongs to the family Mytilidae (GSFMC 2005). *Perna viridis* is native and widely distributed in the coastal areas of the Indo-Pacific region. It has been introduced around the world through ship ballast, hull fouling and experimental farming. Other members of the genus *Perna* are found in New Zealand (*Perna canaliculus*) and in coastal South America and Africa (*Perna perna*).

The green mussel is a comparatively large mussel, the average size is 80-100 mm in length and it has been reported occasionally to achieve a length of 150 mm – 165 mm (FIGIS 2005, NIMPIS 2002). It has two identical shell valves, a pear-shaped and smooth exterior surface characterised by concentric growth lines and a slightly concave ventral margin.

Spawning occurs in response to environmental triggers such as high food levels, temperature fluctuations, and physical disturbance. The stages after fertilisation start with the formation of free swimming larvae or trocophore larvae after 7 – 8 hours, and growing to last larvae stage, veliger larval with the development of ciliated velum after 16-19 hours and complete metamorphosis in 8 – 12 days (Tan 1975). At metamorphosis, an eye spot and extended foot develops, withdraws the vellum and secrets byssal threads as aids to selection of site for settlement. This occurrence is generally referred to as mussel spat fall. Once selected the larvae which are about 2 – 5 weeks old and of 0.25 – 0.3 mm in size (Aypa 1990) attach by anchoring with byssus thread (Spencer 2002). The young mussels, generally referred to as juvenile mussels, then grow rapidly and achieve 3

– 4 mm shell length within 4 – 8 weeks (Aypa 1990). The spawning season occurs twice a year between early spring and late autumn (Rajagopal *et al.* 1998). Sivalingam (1977) found that the spawning of mussels in Malaysia is closely related to the monsoon seasons and occurs twice a year during March and April and October and November. However, spawning occurs throughout the year in the Johore Straits, Malaysia (Choo 1979).

Growth and feeding habits:

The growth rate of green mussels is high compared to other species of mussel (Shafee 1979). The maximum growth occurs 2 m below the surface due to increased water productivity and narrow fluctuation of temperature and salinity (Sivalingam 1977). The growth rates are influenced by environmental factors such as temperature, food availability and water movement. First year growth rates vary between locations and range from 49.7 mm/yr in Hong Kong to 120 mm/yr in India (NIMPIS 2002).

According to Spencer (2002) mussels have a number of attributes that contribute to success in cultivation such as high fecundity and free-swimming larvae that ensure a wide distribution of the offspring. In addition, mussels easily settle and attach through the byssal attachment mechanism on rocky shores, intertidal and subtidal in estuaries and bays, often at high densities and have rapid growth rates. Mussels are efficient feeders. They feed by actively filtering particles from the water, which pass into and out of the mantle cavity through the frilled siphons (Figure 4). Phytoplankton cells constitute the main source of food, while other sources of carbon such as macrophytes or resuspended detritus may also supplement their diet.

Habitat:

Green mussels are widely distributed in the coastal areas of the Indo-Pacific region. In the wild, green mussels are mostly found in the littoral zone, attached in clusters on various substrates. Green mussel has the ability to disperse to another area through several methods. It is reported that green mussel has increased its geographical distribution by step-wise larval dispersal, or “island hoping” (GSFMC 2005), or by mode of prevailing current (Agard *et al*. 1992). It is distributed on a variety structures including vessels, wharves, mariculture equipment, buoys and other hard substrates (NIMPIS 2002).

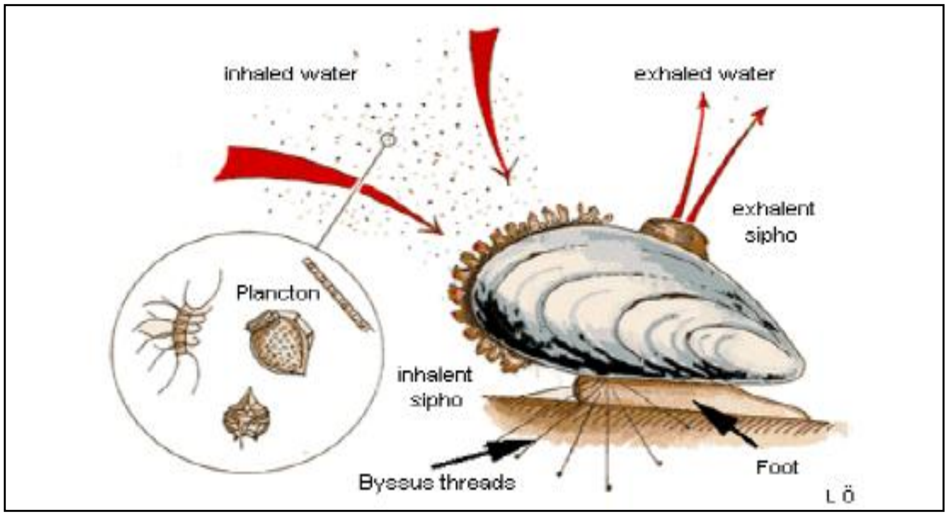

Figure 4: Mussel feeding and respiration (Aquascope 2000).

2.4 Culture aspects of green mussels

There are various characteristics that contribute to the potential of mussels in aquaculture, which are highlighted by (Hickman 1992). The high fecundity and a mobile free-living phase contributed to the widespread distribution of the relatively few mussel species, and at the same time have greatly influenced the technology and practice of mussel farming. The natural availability of seed, without the need to resort to hatchery production, has been a significant positive factor in the development of mussel farming. The green mussel is also a good candidate for cultivation because reproduction can be induced throughout the entire year (Sivalingam 1977). Furthermore, the rapid growth rate, which enables wild mussels to compete successfully against other benthic organisms, also ensures that a commercial sized product can be reared in a short time period under farming conditions. At the same time the natural ability to live in dense beds in the wild makes it readily adaptable to the high population densities necessary for an economically viably farming system. *P. viridis* is commercially important because of its rapid growth rate and high population densities (Rajagopal *et al*. 1998). The green mussel can form dense populations of 35,000 individuals per m^{-2} on a variety of structures (NIMPIS 2002). And this could contribute to the easy collection of seed for cultivation.

The ideal aquaculture candidate should be cheap to feed and resistant to disease. The mussels don’t need additional feed, as filter feeders primarily utilising phytoplankton, require only a continuous supply of high productivity seawater to grow. It also seems to be relatively free from mass mortality due to diseases that often affect other molluscs.

The green mussel is located at the lower level of the food chain, has fast growth rates, a sturdy nature and is resistant to catastrophic mass mortalities. These characteristics make it possible to be produced in large quantities at a very reasonable price. The ability of these species to attach to substrates with the byssus, makes it an ideal aquaculture species using different culture systems. Bardarch *et al*. (1972) demonstrated that mussel culture is the most productive form of saltwater aquaculture.

Transplanting:

As mentioned before, the mussels are able to attach themselves by means of byssus threads to any firm substrate and more importantly, they are able to reattach again and again with minor self adjustment whilst attached. This characteristic makes it possible to grow through transplantation to other sites where its natural seed is not available and has influenced mussel farming practices and technology that has been developed throughout the world. The mussel can also be transplanted from one environment to another with few adverse effects (Parulekar *et al*. 1982)

2.4.1 Site selection for green mussel culture

The proper selection of culture sites is important when considering green mussel culture. Several factors should be carefully considered which could be grouped as primary and secondary factors (Lovatelli 1988). The primary factors, physical, ecological and biological, are the most important in the selection of a suitable culture site, while factors such as risks and economics are usually considered secondary in terms of importance (Figure 5).

PRIMARY FACTORS	SECONDARY FACTORS
• Area location	• Environmental pollution
• Substrate	• Resource competition
• Water depth	• Economic considerations
• Exposure	• Poaching
• Water movement	
• Turbidity	
• Salinity	
• Temperature	
• Dissolved oxygen	
• Water pH	
• Food availability	
• Sources of seed	
• Predators potential	

Figure 5: List of primary and secondary factors, which require consideration when selecting sites for mollusc culture (modified from Lotavelli 1988).

According to (Aypa 1990) the site for mussel cultivation should be well-protected or sheltered coves and bays rather than open un-protected areas. Sites affected by strong wind and big waves must be avoided because this causes damages to stocks and culture materials. The sites must be clear from serving as catchments basins for excessive flood waters. Flood waters would instantly change the temperature and salinity of the seawater, which is detrimental to the mussels.

Water depth:

The water depth for mussel farming should be at least below 1 m mean tide level. Culture methods vary with different water depths. Bottom culture can be practiced in areas where the mean tide level is less than 1.5 m (Lovatelli 1988). For off bottom culture, methods such as raft and long line usually need a minimum water column height during low water spring tide. The hanging ropes with mussel seeds of these culture methods should be at least 1 m above the sea floor during extreme low water spring tides (Lovatelli 1988) to prevent ground predators, seabed high water turbidity and friction with the bottom. (Aypa 1990) suggested that a favourable water depth for both seed collection and mussel cultivation is 2 m or more.

Water current:

As filter feeders, mussels need water movement or currents for providing adequate food supply as well as dissolved oxygen. However, a very strong current can cause high turbidity and thus difficulties for young mussels to attach to the substrate and drag on ropes or lines. Moderate or suitable current speeds within the range of 0.1 – 0.3 $msec^{-1}$ have been reported to be potential sites for mussel farming (Lovatelli 1988). Slow water movement usually results in slow growth of the mussels and also promotes the settling of organic and inorganic particulate materials on the cultured organisms. (Aypa 1990) reported a water current of 0.17–0.25 $msec^{-1}$ during flood tide and 0.25–0.35 $msec^{-1}$ at ebb tide should be observed.

Turbidity:

The turbidity level of water determines the presence of suspended, organic and inorganic matters in the culture area. High levels of these materials have ill effects on mussel culture due to failure of filtering activity and reduced penetration of sunlight in the water column, which will result in low primary productivity. As a result, the cultured species may face slow growth rates due to limited food availability. A practical method for determining the turbidity level is the use of the Secchi-disc. Lovatelli (1988) reported that a site having a disc reading of less than 25 cm should be considered unsuitable for mussel culture.

Salinity:

Green mussel is reported to tolerate a high range of salinity. (Sivalingam 1977) observed that the species has 50% survival salinity tolerance at 24 ppt and 80 ppt for a period of 2 weeks in a laboratory experiment. (Hickman 1989) reported that tropical green mussel occurs typically in estuarine or coastal water that is rich in plankton, has high salinity (27 ppt to 33 ppt) and warm temperature (26°C to 32°C). The green mussel shows a good growth performance in estuarine habitats with salinities ranging from 18 ppt to 33 ppt and temperature from 1°C to 32°C as reported in (FIGIS 2005) and this species shows a broad salinity and temperature tolerance in experimental testing. According to (Aypa 1990) the water salinity of 27 ppt to 35 ppt is ideal for mussel farming. Studies done by (Rajagopal *et al.* 1998) show the green mussel can grow in water salinity ranging from 5.2 ppt to 39.8 ppt.

Temperature:

Water temperature also affects the growth of green mussel. Sivalingam (1977) demonstrated the green mussel has 50% survival temperature tolerance from 10°C – 35°C under experimental testing. It was reported that the optimal temperature for green mussel ranges from 26°C to 32°C (Hickman 1989), 27°C to 30°C (Aypa 1990), 25.3°C to 34.6°C (Rajagopal *et al.* 1998). It also tolerates a range of temperature 11°C to 32°C (FIGIS 2005).

Food organisms:

As filter feeders, green mussels mainly feed on a wide range of phytoplankton species, small zooplankton and other suspended fine organic materials. High primary productivity areas lead to high productivity and biomass of mussels. Rajagopal *et al.* (1998) observed the chlorophyll-α distribution range from 0.7 mg m^{-3} to 17 mg m^{-3} in potential green mussel cultivation.

Source of seeds:

The source of seeds may affect site selection decisions. The initial mussel culture in most parts of the world is confined to the availability of natural seed within the vicinity of the culture site. Mussel farming in Malaysia started in the state of Johore where natural seeds are available (Ong and Rabihah 1989). However, in suitable culture sites where natural seed are not available, the transplantation of young mussels collected usually on polypropylene ropes, ensures the success of the farming industry in most part of the world. Green mussel farming in the western coast of Peninsular Malaysia mostly depends on seed supply from the state of Johore (Ong and Rabihah 1989).

Economic considerations:

Assessment of the economic aspects of mussel farming should also be considered when a culture site is selected. Different levels of investment depend on the suitable and preferred culture methods, the scale of production and the complexity of the culture system itself. Vakily (1989) concluded that mussel farming is economically viable if appropriate technology is applied.

2.4.2 Culture methods

Aypa (1990) describes three main categories of culture methods for mussel cultivation, bottom culture growing mussels directly on the bottom, intertidal and shallow water culture in the intertidal zone, and deep water culture. These are then divided into a variety of culture methods as practiced in many countries, based on the prevailing hydrographical, social and economic conditions. The RAS (1991) describes the three culture methods currently in use for the culture, *Perna viridis*; raft, stake and rack methods. All the methods in the cultivation of mussels can be assigned to one of two categories; they are either on bottom cultivation or off-bottom cultivation.

2.4.2.1 On-bottom culture

On-bottom culture or seabed culture is largely practiced in Europe especially in the Netherlands, Germany, Ireland and the United Kingdom (Spencer 2002). Bottom culture is based on transferring wild mussels to a sheltered culture plot where the density is reduced to improve growth and fattening. Aypa (1990) mentioned in this culture system a firm bottom is required with adequate tidal flow to prevent silt deposition, removal of excreta, and to provide sufficient oxygen for the cultured animals. In the Netherlands, a bottom method is extensively practiced and completely depends on natural seeds. When the natural seeds are unsatisfactory for growing, the seedlings are often transferred by the farmers to richer ground until the marketable size is attained. Farmers in a certain locality of the Philippines practice a bottom method, which is used in shallow areas from 0.6 m at low tide and 3.6 m at high tide. The mussel seeds are collected from the bay using bamboo poles and after one or two months, the mussels are removed from the bamboo poles and laid at the bottom of estuary near the farmers' residences.

2.4.2.2 Off-bottom culture

The culture methods under this category are practiced in intertidal zones and/or mussels are grown above the seabed and can be used to describe all other types of mussel farming, encompassing the whole spectrum from cultivation on stakes or poles, through to methods of utilising ropes or lines suspended from the sea surfaces. Spencer (2002) describes three principle methods of off-bottom culture, namely pole, raft and long line and, (Aypa 1990) categorised the farming into another three subcategories of methods namely fixed suspended cultivation, floating suspended cultivation and deep water cultivation based on local needs as explained below:

a. Fixed suspended cultivation

There are five culture methods under this subcategory namely rack culture, tray culture, wig-wam culture, rope-web culture and pole cultivation. All these methods are practiced in the Philippines except pole culture, which is practiced in France. All the methods are described by (Aypa 1990). Basically, these methods of cultivation require a fixed platform or structures for settlement and growth of the mussels. Furthermore, the cultivation occurs in soft and muddy seabeds, narrow tidal range, and water depths of 2-3

m. The collected spats grow to marketable size, 5 – 10 cm in 6 – 10 months. Aypa (1990) observed, about 2,000 – 3,000 seeds attached on 1 m of stake, 1 – 2 m below low water level through the rack method.

The pole cultivation or 'Bouchot' culture method is the most significant culture practiced under fixed suspended cultivation (Figure 6). It was considered to be the original method for farming mussels (Gosling 1992) and produces more than 40,000 tonnes annually of France's farmed mussels (FAO 2005).

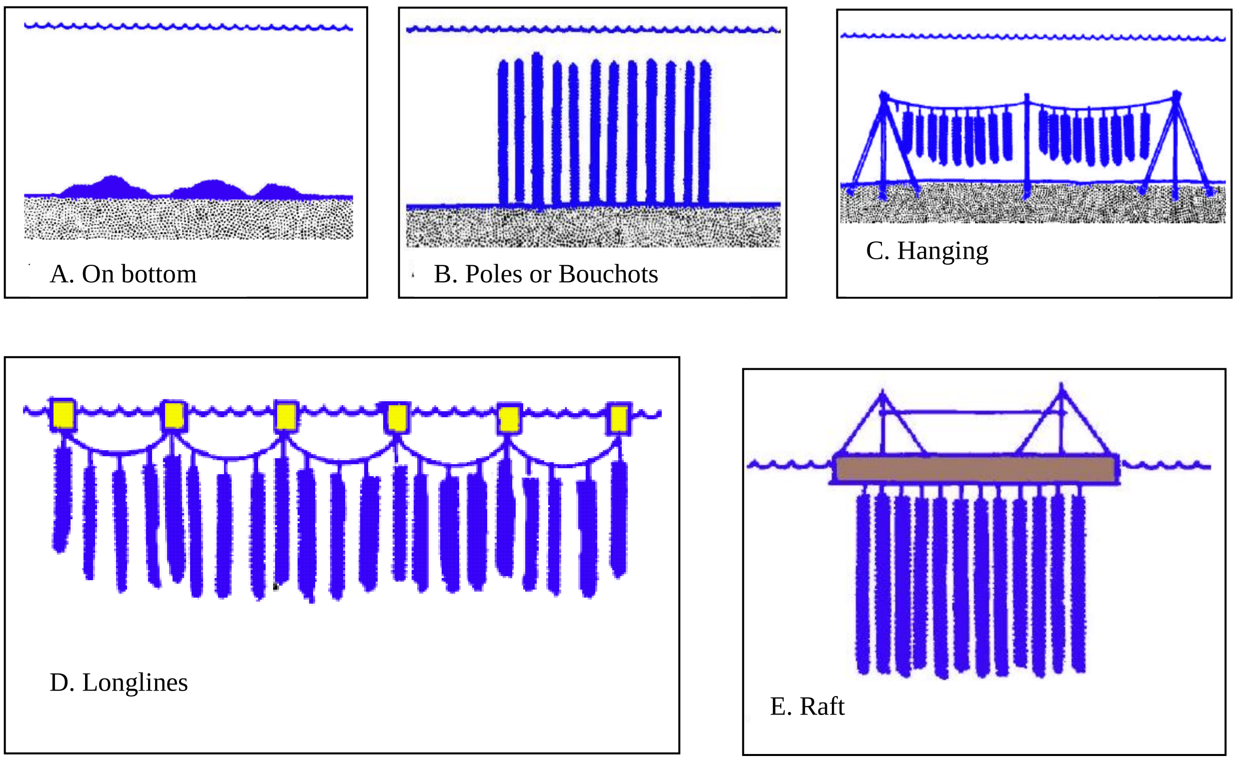

Figure 6: Diagrammatic representation of various culture methods (Gunnarsson *et al.* 2005).

b. Floating suspended cultivation

The development of floating suspended systems allows the mussel culture deeper coastal waters and more effectively exploits the high primary productivity of these areas. There are two main methods under this category, namely the raft culture method and the long line culture method (Figure 6). The raft culture method is carried out largely in Spain and is also popular in many other countries, notably Australia, China, Chile, Canada, USA, India, Ireland, Malaysia, New Zealand, Scotland, and Venezuela (Spencer 2002). With this method of culture, the mussels are grown attached to suspended ropes, which are tied to a raft. The raft is made of various types of structures. An old wooden boat with a system of outriggers built around it could be the raft. The other types could be a catamaran-type boat carrying some 1000 rope hangings, or an ordinary plain wooden raft with floats and anchors. With time, specialised rafts were developed especially in Europe, the floatation made of plastic and wooden materials are encased with a thin outer glass fibre layer to protect them from attack by marine boring organisms. The Spanish raft, measures 27 x 20 m is made of eucalyptus timber and can accommodate 850 synthetic ropes 8-10 m long. The raft is located in relatively sheltered locations with a water depth of 3-5 m. In Scotland the culture period takes 5-10 months to grow from a mean size 2 cm to a marketable size of 5-6 cm. In good culture sites it takes from 4-6 months to reach marketable size. Generally, larger mussels are removed to allow the smaller ones to grow longer. It has been estimated that the yield from raft culture of mussels (based on 350 raft/ha and 2 cycles of 450 kg per raft per annum) is 315 tonnes of shell-on mussels per ha per year. A long line structure supported by a series of small floats joined by a cable or chain and anchored at the bottom on both ends is employed. Collected mussel seeds on ropes or string are suspended on the line. The seeds for mussel culture are obtained from natural spat. The nylon net, polyethylene net and mangrove poles are used as a collector of natural seed. Each collector or rope (1 meter long) can collect 800 to 3000 spat. The collector is then transplanted from the natural area to the culture site. The stocking density, which is commonly used is 3 to 5 strings m^2. Jeffs *et al*. (1999) reported that a typical mussel farm of 3 ha in New Zealand contains 10 long lines running parallel to shore. Each long line consists of 30 to 40 large plastic buoys supporting two 110 m backbones that run side-by-side.

3 METHODS

3.1 Data collection and main assumptions

This work is based on collection of secondary data and information on the physical and biological parameters of the main estuaries or river basins in Sarawak. The information was collected by reviewing both print and electronic research publications. Other information was also derived from the personal experience of the author in aquaculture farming in the state of Sarawak.

3.1.1 Biophysical evaluation

Biophysical parameters are generally the most critical in site selection for mussel farms. The site selection for farming is normally based on the examination of a range of biophysical parameters, which represent the environmental conditions of the site. It is not feasible to assess every parameter. Thus a simple weighted system was developed to assess potential sites. Through weighted assessment the site could be evaluate based minimum requirements of environmental parameters. Parameters such as water temperature, pH, dissolved oxygen, salinity, transparency, water movement and water depth are given a weighted value range from 0.00 to 0.90 based on the how it affects the growth or survival of the cultured species. The total weighted value of the parameters is 1.00 (Table 2). Then the physical parameters of the potential site will be rated based on its suitability for green mussel culture from 1 (unsuitable) to 10 (optimal) as illustrated in Table 3. Since the physical parameters of a site are always read as a range, the maximum and minimum will be graded based on the rating system in Table 3. The final rating score of a particular parameter is the average of its minimum and maximum. Finally the rated value of each parameter of the studied site is multiplied with the weighted value for the parameter to get the parameter weighted value of the site. The total of the parameters weighted value will be used to categorise the suitability of the site. If the parameters weighted value is high the site is considered suitable for green mussel farming and *vice versa*. The rating of site suitability is shown in Table 4 .

Table 2: The assumption weighted value is given to biophysical parameters based on the degree of importance.

Environmental factors	**Assumption weighted value**	**Remarks**
A. Environmental factors which directly affect growth/survival of green mussel.		
1. Salinity	0.15	
2. Dissolved oxygen	0.15	
3. pH	0.10	
Sub Total	0.40	
B. Environmental factors which directly affect growth of green mussel.		
1. Temperature	0.15	
2. Turbidity	0.15	
Sub Total	0.30	
C. Environmental factors which directly affect survival of green mussel.	0.15	
1. Water movement	0.15	
2. Depth	-	
3. Tide	-	No value given for item number 3,4,5,6 due to lack of information.
4. Suspended sediment	-	
5. Disease	-	
6. Fouling potential		
Sub Total	0.30	
Total weighted value	1.00	

Table 3: Assumptions of rating points for the range of physical parameters for mussel farming based on gathered information from (Sivalingam 1977), (Lovatelli 1988), (Hickman 1989), (Aypa 1990), and (FIGIS 2005).

	Rating point									
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Salinity (ppt)	27- 32	25 – 33	24 – 34	23 – 35	18 – 36	15 – 40	12- 45	10 – 50	5 – 55	0 – 65
Dissolved oxygen (mg l^{-1})	> 8	7-6	6-5	5-4	4-3	-	-	3-2	2-1	-
PH	7.9-8.2	7.8-8.3	7.7-8.4	7.6-8.5	7.5-8.6	7.4-8.7	7.3-8.8	7.0-8.9	6.9-9.0	6.8-9.1
Temperature (°C)	26-32	25-33	24-34	23-35	22-36	21-37	20-38	19-39	18-40	17-41
Turbidity (cm)	25-22	26-21	30-19	35-17	40-15	45-13	50-12	55-10	60-8	65-7
Water movement (m sec^{-1})	0.1-0.3	0.15-0.35	0.2-0.4	0.25-0.45	0.3-0.5	0.35-0.6	0.4-0.7	0.6-0.9	0.9-1.5	>1.5
Water depth	>8	8	7	6	5	4	3	-	-	1

Table 4: The category of the site based on assumed weight (modified from Kingzett and Salmon 2002).

Weighted category	**Site evaluation**	**Recommendation**
1.00 – 2.50	Not advisable	Site not suitable for green mussel farming and cannot support the culture
2.60 – 5.00	Poor	Site may support green mussel but not recommended.
5.10 – 7.50	Medium	Site is capable and moderately suitable for green mussel farming.
7.60 – 10.00	Good	Site is suitable for green mussel farming and highly recommended.

3.1.2 Green mussel culture technology

Two culture methods were considered based on the basic information of environmental conditions in Sarawak. The raft method and the typical floating long line method, which is suitable in shallow water and sheltered areas, were considered and compared for their economic viability. All assumed values are based on references discussed in the text and the author’s experience. The main assumptions for the production model are described in Table 5. Photographs of the two culture methods are shown in Appendix VI.

Raft technology method/model:

Based on the assumptions in Table 5, a raft module (50 rafts) production model was developed. 50 units of 7 m x 7 m rafts will be built and arranged so that 5 units form 1 module, 10 modules in all. Each raft consists of about 200 ropes. The ropes attached with seed sizes of 0.5 cm – 1.00 cm will be bought from farmers in Johor of Peninsular

Malaysia. Each rope of seed is 2-4 m long and weighs 5 kg. The seed will be transported to the farm under controlled temperature to reduce stress and installed to the raft immediately upon arrival. The green mussel farm will be protected from predators. At the same time water parameters such as salinity, temperature, turbidity and current will be monitored daily as any abrupt changes with the water parameters could affect the growth of the green mussels. After 10 months the green mussels are harvested and sold at RM 1.50 kg^{-1}(USD ≈ 0.40). The main cost incurred during the operation were calculated and subtracted from revenue at the end of the production period, see further Appendices I and II.

Table 5:The main assumptions used in the development of a production schedule for a green mussel farm in the state of Sarawak, Malaysia.

Characteristics	**Assumed value**	
	Raft Method	Long line method
Farm size	50 rafts	50 lines
Size of 1 raft or1 line (m)	7 x 7	100
1 raft or line	200 ropes	
1 ropes (2-4 m)	5 kg seed	
Initial seed size (cm)	0.5-1.0	
Cost of seed (RM/ropes)	13.0	
Transportation costs (RM/rope)	3.0	
Harvest weight per ropes (kg) 1st year 2nd year onward	 30 35	
Production cycle	12 months	
Green mussel sale price	RM 1.50/kg	
Cost of raft/long line	RM116000	RM105000
Boat and equipment	RM30000	
House	RM10000	
Interest on loan	4 % per annum	
Amount of loan	90 %	
Loan repayment	7 years	
Depreciation	7 years	

Note: RM 1.00 ≈ USD 0.40 (RatesFX 2005)

Long line technology method/model:

Typical floating long line is the second model evaluated for an operation of green mussel farming in Sarawak. This long line method is different from the long line used for the culture of blue mussel in European countries, which is submerged to a certain depth to avoid heavy waves. The long line is 220 m long and 30 mm diameter tied with 25 floats to form two 100 m long lines. The floating long line is anchored at each end. Each float can support 700 kg of green mussel. Ten long lines will be constructed all together. The 2-4 m seed ropes are tied to the long line at 0.5 m intervals so that each long line will have 200 ropes. The farm operation is the same as in the raft method and harvest will be after 10 months.

After harvesting the raft or long line will be checked for maintenance within 1 month before restocking. In order to evaluate economic feasibility of the different methods, the production schedule is projected over a period of 10 years. The purpose is to find out the differences in terms of the economic returns of each method.

3.1.3 Culture operation

The two methods model above will be tested or evaluated for economic returns in production. The profitability model was used to plan the production and cash flow over a 10 year period. The investment and finance indicate the amount of capital needed for the culturist to start the farming. The net profit will be obtained after subtracting the costs Table 6 from the revenues of the operation. The production plan also indicates other component of the economic evaluation including surplus (losses and/or gains), net profit after depreciation and interest, and calculations of net present value (NPV) and the internal rate of return (IRR). The net present value of the profits and the internal rate of return for each model were calculated for a period of 10 years under the discount rate at 10% and 15% using Microsoft Excel functions. In the production cycle, certain elements such as cost, quantities and price may be variable which has an effect on the net return. Sensitivity analyses were done by manipulating the cost of seed, size of harvest, and ex-farm price to determine which values in the production model have the greatest impact on net returns.

Table 6: Estimated financial outlay for culture of green mussel *P. viridis* in raft and long line culture methods.

Items	**Value (RM) for raft method**	**Value (RM) for long line method**
Investment		
Raft 50(7 mx7 m)	100000	
Longline 25(2 x 100 m)		35000
Float (125 pcs)		50000
Anchor	160000	20000
Ropes (10000 of 2-4m ropes)		
Sub total	116000	105000
Equipment		
Boat	30000	30000
House	10000	10000
Sub total	40000	40000
Variable		
Seed cost 10000 ropes	130000	130000
Transportation (RM3.00/ropes)	30000	30000
Manpower (Manager)	36000	36000
Assistant	22000	22000
Labour (3)	22000	22000
Fuel	36000	36000
Maintenance	6000	6000
Miscellaneous	12000	12000
Sub total	294000	294000

Note: RM 1.00 ≈ USD 0.40 (RatesFX 2005)

4 SITE SUITABILITY OF GREEN MUSSEL FARMING IN SARAWAK

4.1 Coastal environment in the state of Sarawak

The confederation of Malaysia consists of 13 states and three federal territories with 11 states and two federal territories on Peninsular Malaysia or West Malaysia, and the state of Sabah, Sarawak and Federal Territories of Labuan in East Malaysia (Figure 1). These two regions are separated by the South China Sea. The state of Sarawak is the biggest of the 13 states and has a total area of 124,500 km^2. The government of Malaysia has identified the state of Sarawak as having great potential for aquaculture development. It is reported that the total area of 1539 km^2 has potential for brackish water aquaculture development.

The coastal waters of Sarawak are located between the latitudes 1° 30' and 7° 07' N and longitudes 109° 38' to 114° 05' E. The continental shelf off Sarawak extends up to 220 nautical miles (nm) at its widest span north of Tanjong Po in the south, and its narrowest span is 30 nm north of Tanjong Baram in the north (Abu Talib *et al.* 2003). The state of Sarawak borders the South China Sea.

The state of Sarawak is drained by a network of rivers and streams. The state government has gazetted these rivers and streams into 21 river basins (DID 2005), which drain into the South China Sea. Some of the rivers and streams in the river basins are affected by seawater for several kilometres and are suitable for brackish water aquaculture. Currently marine fish cage culture is operated in the Lawas river basin, Sungai Salak in the Sungai Sarawak river basin and Sungai Gerigat in the Krian River basin (Appendix III).

Sarawak lies entirely in the equatorial zone and the climate is governed by the regime of the northeast and southwest monsoons. The northeast monsoon blows from October to March and brings a lot of rain. The southwest monsoon occurs between May and September, and is drier. The average temperature throughout the year is 26°C, and annual rainfall in 2003 ranged from 513 mm to 1074 mm (Appendix IV).

An assessment of the fisheries resources in the South China Sea, especially in the coastal waters of Sarawak, is done by the Southeast Asian Fisheries Development Centre (SEAFDEC), which maintains a database on the fishery and oceanographic and marine environmental conditions of the Sarawak coastal waters. The data could be useful for analysing the suitability for mussel culture. The general information that can be gathered is illustrated in Table 7.

Table 7: Environmental parameters of the South China Sea where the readings are taken near the coast of Sarawak based on a survey by SEAFDEC in 1997 (SEAFDEC 1997a, SEAFDEC 1997b, SEAFDEC 1997c).

Parameter	South China Sea near coastal waters of Sarawak
Temperature (°C)	24.49 – 30.65
Primary productivity (g C $m^{-2}day^{-1}$)	0.13-0.88
PH	7.7-8.2
Salinity (ppt)	31.8-34.6
Current velocity (ms^{-1})	0.1 – 0.3

4.2 Biophysical evaluation of the site

The biophysical parameters of three rivers Sungai Santubong, Sungai Gerigat and Sungai Oya were obtained from the Technical and Monitoring Unit (TEMU) of the Fisheries Development Authority Malaysia (LKIM) Sarawak (Pada Bijo, personal communication). These data were collected in March 2005 during a survey of possibilities for cage culture farming. All the data were collected at the river mouths or estuaries. The results of the survey are shown in Table 8. Sungai Santubong located at Sungai Sarawak river basin, Sungai Gerigat located at Krian river basin and Sungai Oya located at Oya river basin (Appendix III)

Table 8: The environmental parameters of three different sites where readings are taken in the estuary (Pada Bijo, personal communication, DID 2005).

Parameter	Sungai Santubong	Sungai Gerigat	Sungai Oya
Salinity (ppt)	28 - 31	24 - 29	7 – 17
Dissolved oxygen (mg l^{-1})	4 - 5	4 - 5	3 – 4
PH	7.99 - 8.01	7.89 - 8.29	7.0 - 7.3
Temperature (°C)	31.9 - 32.3	29.8 - 32.4	27.9 - 31.24
Turbidity (cm)	25 - 30	45 - 55	40 – 50
Water current (ms^{-1})	0.07 - 0.10	0.23 - 0.30	0.22 - 0.30
Depth (m)	6 - 5	6 - 5	4 – 3
Tide (m)	0.02 - 5.53	0.02 - 5.53	0.23 - 2.69

The lowest tide 0.02 m and maximum tide 5.53 m is in Kuching, the southern part of the state, while in the middle of the Sarawak coast the tide is lowest at 0.23 m and highest at 2.69 m. The tide fluctuations are lowest 0.09 m and highest 2.18 m in the northern part of the state (Appendix IV).

Table 9: Rating points and weighted assessment of the three different sites.

Biophysical and environmental parameters	**Weighted (a)**	**Sungai Santubong**		**Sungai Gerigat**		**Sungai Oya**	
		Rating point (b)	**Weighted achieved (a * b)**	**Rating point (b)**	**Weighted achieved (a * b)**	**Rating point (b)**	**Weighte d achieved (a * b)**
Salinity	0.15	10.0	1.50	8.0	1.20	2.0	0.30
Dissolved oxygen	0.15	7.0	1.05	7.0	1.05	6.0	0.90
PH	0.10	10.0	1.00	9.0	0.90	3.0	0.30
Temperature	0.15	9.5	1.43	9.5	1.43	10.0	1.50
Turbidity	0.15	9.0	1.35	4.0	0.6	5.0	0.75
Water movement	0.15	10.0	1.50	9.0	1.35	9.0	1.35
Depth	0.15	6.5	0.98	6.5	0.98	4.5	0.68
Total			8.81		7.51		5.78
Weighted category			Good		Medium		Medium

Based on the assumptions in Table 2, Table 3, and Table 4 an attempt was made to evaluate the three sites as in Table 8. The results of the site evaluation are shown in Table 9. The biophysical environmental properties enable Sungai Santubong to be categorised as ‘good’ while Sungai Gerigat and Sungai Oya are categorised as ‘medium’ in terms of suitability for green mussel farming. The Sungai Santubong site has optimum biophysical parameters for green mussel farming except for the depth of the site, which is rated as moderate. Apart from a low rating for turbidity all other parameters are considered optimal in Sungai Gerigat. In Sungai Oya salinity, pH and turbidity get a low rating. The highest salinity achieved in the site during this survey is 16 ppt. and the pH value is between 7 – 7.3 for Sungai Oya. The overall weighted total for Sungai Oya is 5.78 and it is considered to be a medium site and needs to do more site improvement if culture is to be done there.

5 ECONOMIC MODEL FOR MUSSEL FARMING

5.1 Production cycle of a 50 unit raft model production system

High quality natural seed will be bought from the farmers in Johore in Peninsular Malaysia. The seed will already be attached to the ropes and all terms of buoying based on ropes. Each rope averages 2 – 4 m in length and the weight is on average 5 kg. The seeds are transported to Sarawak by air cargo for 1.5 hours. The packaging and transportation of seeds to the culture site takes an average of 8 hours. On arrival the ropes of seeds will be acclimatised to the local environment by flushing with water and slowly submerged before it is tied to the raft. Water quality parameters such as salinity, temperature, pH, current and turbidity will be monitored daily. The ropes will also be checked carefully during this first culture cycle in order to assess the incidence of predators and diseases. In addition, all the structure of the raft, anchors and other components must be checked. At the end of 8 months, the mussel is expected to have grown to a harvestable size. It was suggested that a total harvest be done after 10 months. The raft and all the culture equipment then be checked and maintained before a new cycle is started. The overall production is on a yearly basis.

Table 10: Summary of production, income, operating costs and net income from 50 units of 7 m x 7 m raft and/or 50 lines of long lines of green mussel.

Item	1st year production	2nd year production
Revenue		
Sale price (RM kg-1)	1,50	1,50
Income (RM)	450000	525000
Operating costs (RM)		
Salary	80000	84000
Seeds	160000	160000
Fuel	36000	38000
Maintenance	6000	6300
Others	12000	12600
Total costs	294000	300900
Net profit (RM)	156000	224100

Note: Operating cost increase 5 % per year except cost of seeds.

The operating costs during a production cycle include the cost of seeds and transportation, salary for management staff and workers, fuel for boat, maintenance of boat and equipment, and other unexpected costs. The total costs subtracted from the revenue at the end of the production cycle gives a net profit of RM 156,000 (USD 41,700) for the first year of production and an increased net profit for the second year onwards due to an increase of forecasted production (Table 10). Further calculations for the production model include depreciation and interests of loans to get a net income before and after interest as shown in Table 11 For further details of the production plan and variables used in the production see Appendix I.

Table 11: Production plan of green mussel farming for 50 units of raft.

	Year 1	Year 2	Year 3	Year 4-10
Production (mt)	300	350	350	2450
Income (RM'000)	350	525	525	3675
Investment (RM '000)	481			156
Operating Cost (RM '000)	315	322	329	2531
Net cash (RM ' 000)	135	203	196	988
Net cash after interest (RM '000)	117	186	179	918

Note: RM 1.00 ≈ USD 0.40 (RatesFX 2005)

5.2 Production cycle of 50 lines of the long line model production system

The culture operation of the long line method is the same in the raft method except the ropes (with seeds) are tied to and hang from the long lines. Each line is 100 m long and can support 200 ropes. There are two lines in each unit, which are kept floating by 25 big floats and anchored at both ends. In this study the operating costs using the long line method was assumed to be the same as in the raft method. Thus the net profit contribution is the same when total cost is subtracted from revenue (Table 10). Further calculation of the production model includes depreciation and interest of loans to get net income before and after interest is higher for the long line method than in the raft method as shown in Table 12. For further details of the production plan and variables used in the production (see Appendix II)

Table 12: Production plan of green mussel farming for 50 lines of long line.

	Year 1	Year 2	Year 3	Year 4-10
Production (mt)	300	350	350	2450
Income (RM'000)	350	525	525	3675
Investment (RM '000)	469			145
Operating cost (RM '000)	314	320	326	2491
Net cash (RM ' 000)	136	205	199	1039
Net cash after interest (RM '000)	119	188	182	971

5.3 Sensitivity analysis

Sensitivity analysis provides an additional insight into the overall feasibility study of the operation that is important for any investment decision. In this study sensitivity analysis was used to show how sensitive the profitability is to variation as basic assumptions. The net present value (NPV) and the internal rate of return (IRR) were obtained using a profitability model developed in Microsoft Excel. The NPV was calculated with 10% and 15% discounting rate. A positive value of NPV indicates that the project venture is feasible (Figure 7 and Figure 8).

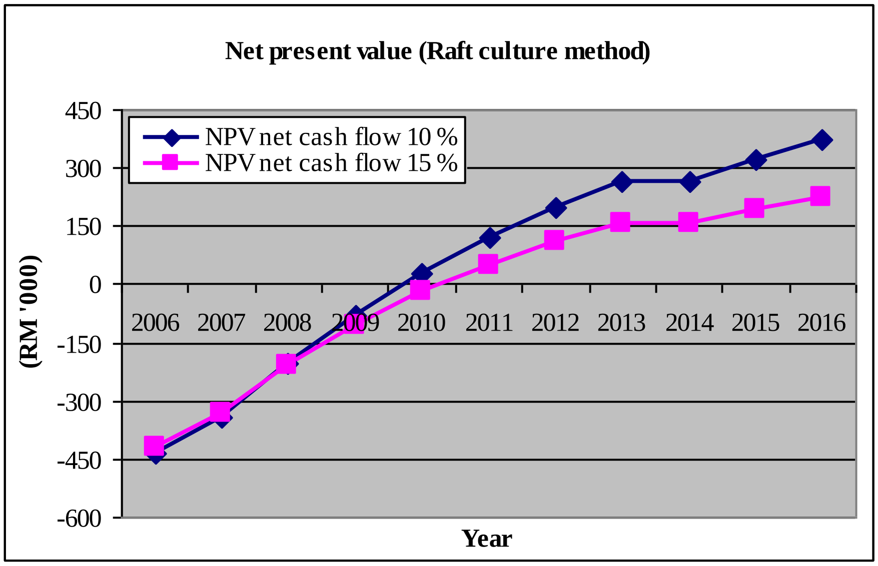

Figure 7: NPV of green mussel farming using the raft culture method.

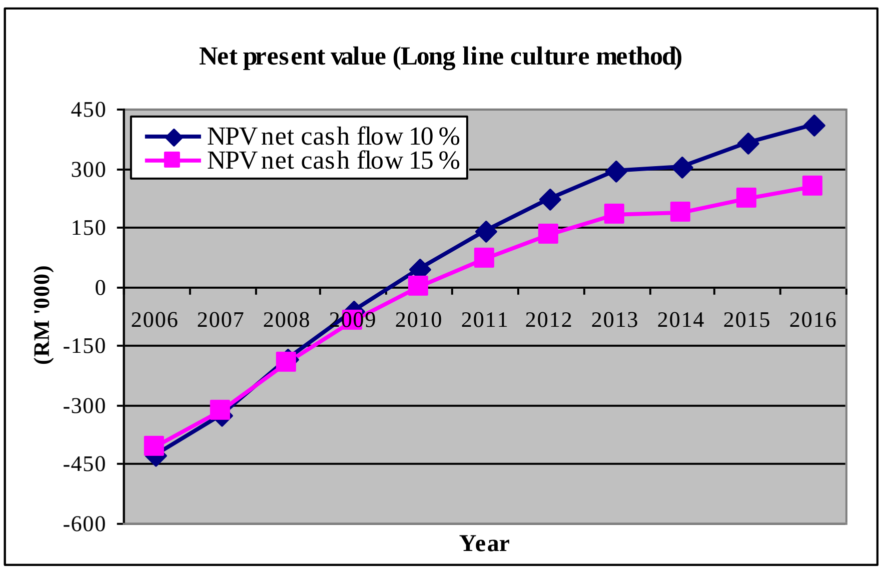

Figure 8: NPV of green mussel farming using the long line culture method.

The IRR is the discount rate when applied to the projected cash flow, which makes NPV equal to zero (NPV = 0). The IRR for a 50 7 m x 7 m raft unit and/or 50 long lines for green mussel farming is positive and above zero indicates that the venture is profitable. A planning period of 4 years is assumed (Figure 9 and Figure 10).

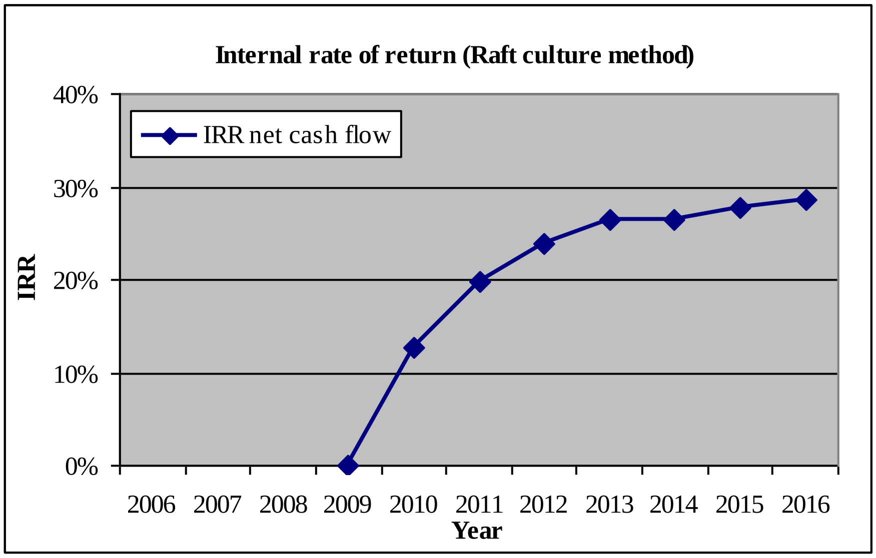

Figure 9: IRR of green mussel farming using the raft culture method.

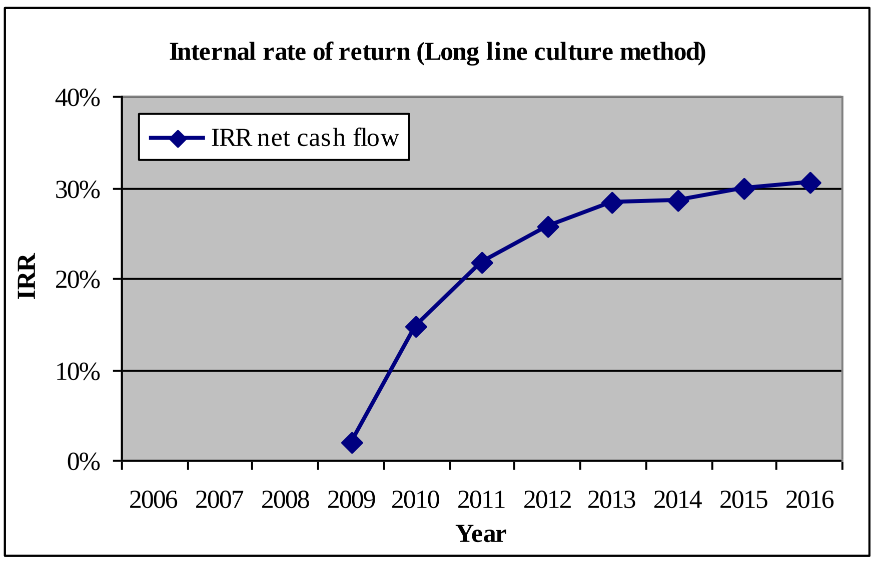

Figure 10: IRR of green mussel farming using the long line culture method.

The profitability of green mussel farming is most sensitive to the sale price and the harvest weight followed by the cost of seed (including the cost of transportation). By decreasing the price by 15%, the IRR for green mussel farming for both culture methods recorded only 6% and 9% respectively. A decrease in weight by 15% will have the same effect. The IRR recorded 21% for green mussel farming using the raft method and 23% for the long line method when the cost of seed (including the cost of transportation) increased by 15% (Figure 11 and Figure 12).

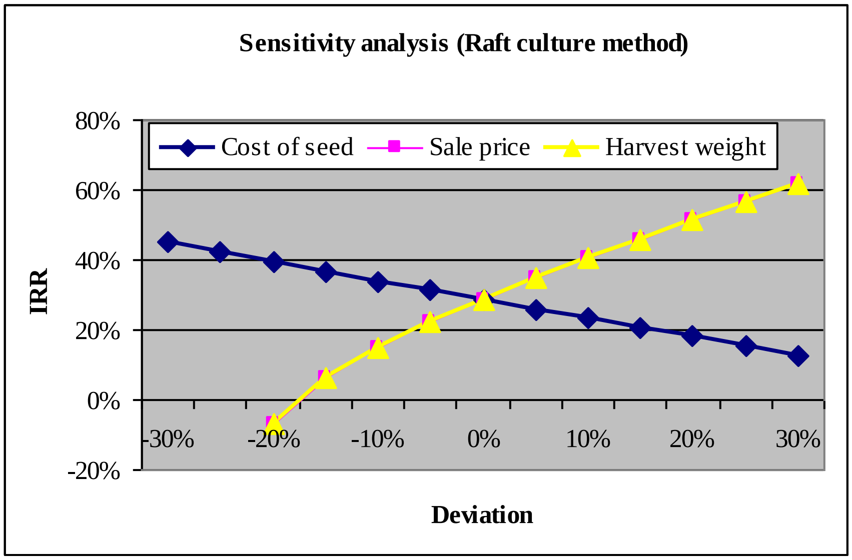

Figure 11: Sensitivity analysis of sale price, harvest weight and cost of seed using the raft method.

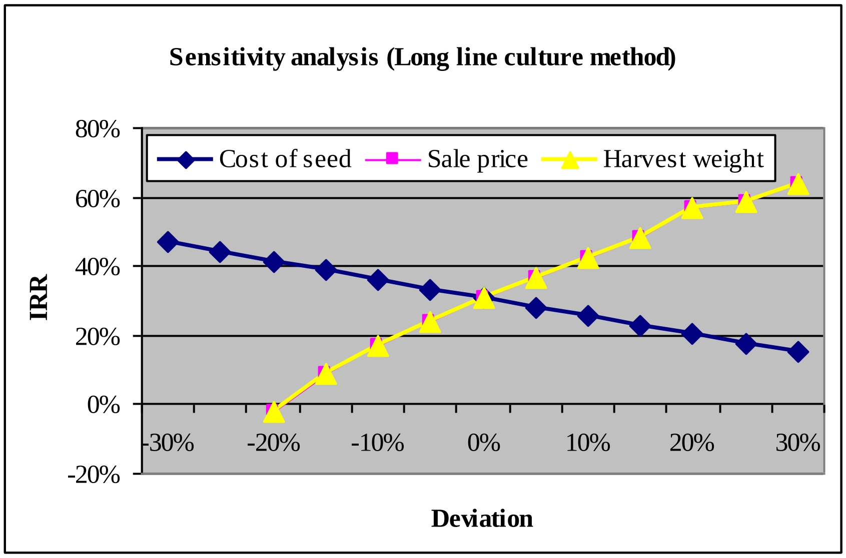

Figure 12: Sensitivity analysis of sale price, harvest weight and cost of seed using the long line method.

6 MARKETING

6.1 Domestic market for mussels

Malaysia’s green mussel market is very large. In 2003, around 8000 mt of mussel were supplied to the market (FAO 2005). In addition Malaysia also imported fresh and frozen mussel to fulfil local demand. FAO (2005) reported that the import quantity of mussel increased from 311 mt in 2001 to 491 mt in 2002 (Table 13). Some of the mussel farms in the state of Perak have already received advanced orders for their produce for the next harvest in April 2006 (Khairil, personal communication). The demands are from local buyers as well as for export to the neighbouring Singapore. Demand for mussel in the state of Sarawak itself is also evident, as import of mussel has increased from 4 mt in 1997 to 7 mt in 2000 (Pada Bijo, personal communication).

Table 13 : The production and import quantity of mussel (mt) in Malaysia (FAO 2005).

Source of supply	**2000**	**2001**	**2002**	**2003**
Cultured	11069	6880	5785	7702
Import	273	377	491	n.a

6.2 Regional trade

There is a significant demand for mussels in Malaysia’s neighbouring countries, which gives a great market opportunity. The import quantity of these countries shows an increasing trend as shown in Table 14 (FAO 2005).

Table 14: The import quantity of mussels (mt) in Malaysia’s neighbouring countries (FAO 2005).

Country		**2000**	**2001**	**2002**
Singapore	Mussel meat frozen	241	201	339
Singapore	Mussels fresh or chilled	326	274	253
Brunei Darussalam	Mussel meat frozen	53	32	148
Brunei Darussalam	Mussels fresh or chilled	3	-	28
Thailand	Mussel meat frozen	16	59	110
Thailand	Mussels fresh or chilled	4	11	12

7 DISCUSSION

The purpose of this study was to identify whether it is possible to grow green mussels in the state of Sarawak based on an evaluation of biophysical parameters, economic information and market opportunities. A site capability rating system was developed to assess the environmental parameters of potential sites. It is critical for farmers and investors to identify the most suitable sites for this aquaculture activity. Thus the biophysical evaluation system was an important tool to get fast and effective results of potential sites for green mussel farming. The profitability model of raft and long line culture methods considered in this study also becomes a valuable management tool in facilitating more market driven production management and gives an opportunity to compare culture methods. Furthermore, the information gathered will provide farmers and investors with the best information to determine the feasibility of mussel farming and can also help other related individuals or organisations to better understand site appraisal, operation and viability of aquaculture projects.

A weighted rating system was developed to evaluate environmental parameters in the estuary of three rivers in Sarawak. It is important to the farmers and investors to evaluate the biophysical parameters of the intended sites in order to know whether it is optimal for biological functions such as growth and survival of the species cultured. The environmental parameters of the sites are collected and analysed subjectively using a rating system to determine the potential of the area. Based on the biophysical evaluation it was found that Sungai Santubong is the best potential site for mussel farming whereas Sungai Gerigat and Sungai Oya are considered as moderate sites. Moderate sites for culture operation of mussels can possibly be improved by habitat modification. In Table 2 some parameters or characteristics such as tide, suspended sediment, disease and fouling potential are not taken into consideration in the rating system due to lack of information. Furthermore, characteristics such as suspended sediments, diseases and fouling potential are secondary problems arising from environmental consequences. However, the more parameters that are taken into consideration, the more precise the results should be.

The economic approach examines the profitability of the production model of two different culture methods. The purpose is to show the differences in capital investment and potential profit between these two methods. Through this analysis farmers and investors have the opportunity to evaluate the economic performance of different culture methods. It was estimated that RM481000 (USD129000) or RM469000 (USD125000) of capital investment would be required to establish 50 rafts or 50 lines of long line of green mussel respectively. The cost incurred to construct the 50 units of raft structure (including float and anchor) was RM116000 (USD31000) whereas only RM105000 (USD28000) is needed to install 50 lines of floating long line as stated in Table 6. The first year cost of operation was RM293000 (USD78000), which includes salary and fuel for the boat. Maintenance and cost of seed will increase annually due to increases in salary, the cost of fuel and maintenance by 5 % per year (Table 11 and Table 12). The difference in the cost of operations between the two culture methods is due to the differences in depreciation value (Appendix I and Appendix II). The cost of seed (including cost of transportation) contributes 50% to the cost of operation (Table 10).

Importation of seed from other parts of the country contributes to high costs of operation. The seed will be obtained from the state of Johor in Peninsular Malaysia through air freight. From the results the increase in the cost of seeds by 15% results in an IRR of total capital between 21% and 23% for the raft and long line methods, respectively. This value is considered acceptable and shows that slight changes in cost of seed do not have a great impact on the economic performance of the culture operation. The operation was found to be highly sensitive to changes in harvest weight and sales prices. A 15% decrease in sales price resulted in an IRR under 10%, which is not acceptable (Figure 11 and Figure 12). A harvest weight of 30 kg per rope estimated during the first year for both methods increases to 35 kg per rope from the second year onwards, giving an annual production of 450 mt and 525 mt, respectively (Table 11and Table 12). The estimated harvest yield of 30 – 35 kg per rope is based on mussel culture productivity information gathered by Hickman (1992). Chou and Lee (1997) estimated harvest yields of 50 kg per rope for green mussel farming in Singapore at Johor Strait.

From this study the production plan model results, operating a 50 unit raft and/or 50 lines of long line to farm green mussel could give a net cash income of RM 135000 (USD 36000) and RM 136000 (USD 36400) during the first year and RM 203000 (USD 54000) and RM 205000 (USD 54800) in the second year of production, respectively. The production plan of operation over a 10 year period is shown in Appendix I and Appendix II. The feasibility of green mussel farming in this study was determined through investment indicators such as NPV and IRR. The NPV net cash flow of 10% was positive indicating the operation is feasible (Figure 7 and Figure 8). Positive NPV indicates generation of more cash and can service debt and other requirements. The IRR for the farm was above a marginal attractive rate of return (MARR), indicating that the operation is profitable (Figure 9 and Figure 10). The current interest rate of 4% used in this study was based on the rate charged by the Agriculture Bank of Malaysia for any agricultural based operation. At this interest rate, the farmers can recover their investments in 2 years (Appendix I and Appendix II). With the reasonable interest rate the operation of mussel farming could attract those potential farmers to invest and eventually could increase supply of local agricultural products.

The demand for mussels in the state of Sarawak and in Malaysia in general is large and there has been a gradual increase in demand (Table 13). Thus the local production of mussels is highly preferred to fulfil the demand especially for fresh products. In addition, the import record of mussels in neighbouring countries (Table 14) gives a promising market for the future of mussel farming.

8 CONCLUSION

The successful introduction of new species for commercial aquaculture farming in new areas is critical for farmers and investors and several factors have to be considered. The site selection is generally the most critical step especially as it needs some biological background in assessing the site suitability. On the other hand, the economic return of the venture was the prime factor that always becomes a decision factor in all businesses. In this study the site suitability and the economic return was analysed to know the feasibility of growing green mussel in the state of Sarawak. Based on the evaluation methods used and availability of information gathered it is feasible to grow green mussel in the state of Sarawak. The site capability rating system is a useful tool and can be an important guide for the farmers to do the site selection for culture species. The two culture methods that are addressed could provide an opportunity for the farmers to make a better decision. It is important for the potential farmers to make rigorous field confirmations of the site before venturing into the business. The methodology in this study is useful as a first step only.

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APPENDIX I PRODUCTION PLAN FOR GREEN MUSSEL FARMING (RAFT CULTURE METHOD)

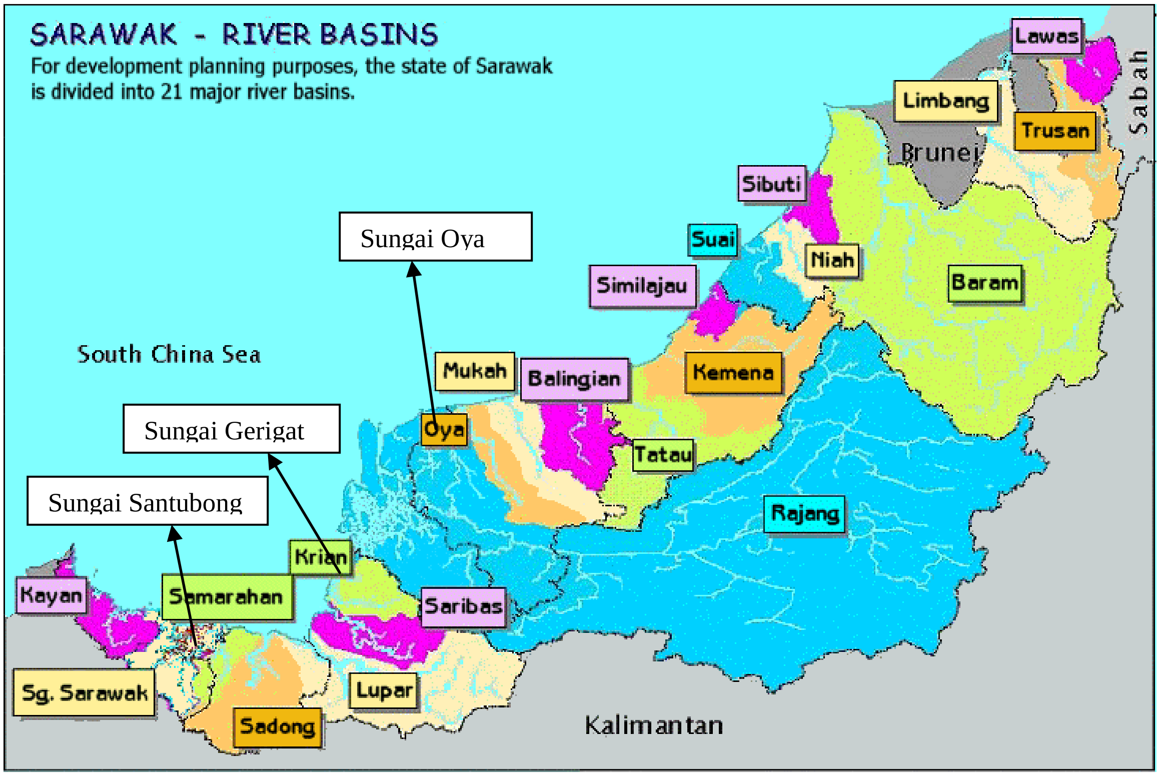
	ITEMS/YEAR	0	1	2	3	4	5	6	7	8	9	10
1.	**INCOME**											
	1.1 Number of raft		50	50	50	50	50	50	50	50	50	50
	1.2 Production (ton) @6,00/raft X 1 cycle		300	350	350	350	350	350	350	350	350	350
	1.3 INCOME		**450**	**525**	**525**	**525**	**525**	**525**	**525**	**525**	**525**	**525**
2.	**EXPENDITURE**											
	2.1 CAPITAL COST											
	2.1.1 Raft construction	100								100		
	2.1.2 Float											
	2.1.3 Anchor	16								16		
	2.1.4 Boat & harvesting equipment	30								30		
	2.1.5 Infrastructures	10								10		
	2.1.6 Operating costs	315										
	2.1.7 Management costs	10										
	Sub-total	481	0	0	0	0	0	0	0	156	0	0
	2.2 OPERATING COSTS											
	Direct operating costs											
	2.2.1 Salary Manager		36	38	40	42	44	46	48	51	53	56
	2.2.2 Salary Ass Manager		22	23	24	25	26	28	29	30	32	34
	2.2.3 Salary workers		22	23	24	25	26	28	29	30	32	34
	2.2.4 Seed		160	160	160	160	160	160	160	160	160	160
	2.2.5 Fuel		36	38	40	42	44	46	48	51	53	56
	2.2.6 Maintainance		6	6	7	7	7	8	8	8	9	9
	2.2.7 Others		12	13	13	14	15	15	16	17	18	19
	2.2.8 Depreciation		22	22	22	22	22	22	22	22	22	22
	Sub-total		315	322	329	336	344	352	361	370	379	389
3.	**TOTAL EXPENDITURE**	**481**	**315**	**322**	**329**	**336**	**344**	**352**	**361**	**526**	**379**	**389**
4.	**NETT CASH FLOW**	**-481**	**135**	**203**	**196**	**189**	**181**	**173**	**164**	**-1**	**146**	**136**
5.	**ACCUMULATED CASH FLOW**	**-481**	**-347**	**-144**	**52**	**240**	**421**	**594**	**758**	**757**	**903**	**1039**
6	**INTEREST**		17	17	17	17	17	17	17			
7	**NETT CASH AFTER INTEREST**	**-481**	**117**	**186**	**179**	**171**	**163**	**155**	**147**	**-1**	**146**	**136**
8	**ACCUMULATED CASH FLOW AFTER INTEREST**	**-481**	**-364**	**-179**	**0**	**171**	**334**	**490**	**637**	**636**	**782**	**918**

APPENDIX II PRODUCTION PLAN FOR GREEN MUSSEL FARMING (LONG LINE CULTURE METHOD)

	ITEMS/YEAR	0	1	2	3	4	5	6	7	8	9	10
	1.1 Number of line		50	50	50	50	50	50	50	50	50	50
	1.2 Production (ton) @10.0/raft X 1 cycle		300	350	350	350	350	350	350	350	350	350

	1.3 INCOME		**450**	**525**	**525**	**525**	**525**	**525**	**525**	**525**	**525**	**525**
2.	**EXPENDITURE**											
	2.1 CAPITAL COST											
	2.1.1 Long line Rope	35								35		
	2.1.2 Float and anchor	70								70		
	2.1.4 Boat & harvesting equipment	30								30		
	2.1.5 Infrastructures	10								10		
	2.1.6 Operating costs	314										
	2.1.7 Management costs	10										
	Sub total	469	0	0	0	0	0	0	0	145	0	0
	2.2 OPERATING COSTS											
	2.2.1 Salary Manager		36	38	40	42	44	46	48	51	53	56
	2.2.2 Salary Ass Manager		22	23	24	25	26	28	29	30	32	34
	2.2.3 Salary workers		22	23	24	25	26	28	29	30	32	34
	2.2.4 Seed		160	160	160	160	160	160	160	160	160	160
	2.2.5 Fuel		36	38	40	42	44	46	48	51	53	56
	2.2.6 Maintenance		6	6	7	7	7	8	8	8	9	9
	2.2.7 Others		12	12	12	12	12	12	12	12	12	12
	2.2.8 Depreciation		21	21	21	21	21	21	21	21	21	21
	Sub-total		314	320	326	333	340	347	355	363	372	381
3.	**TOTAL EXPENDITURE**	**469**	**314**	**320**	**326**	**333**	**340**	**347**	**355**	**508**	**372**	**381**
4.	**NETT CASH FLOW**	**-469**	**136**	**205**	**199**	**192**	**185**	**178**	**170**	**17**	**153**	**144**
5.	**ACCUMULATED CASH FLOW**	-469	-333	-128	71	263	448	625	795	812	965	1110
6	**INTEREST**		17	17	17	17	17	17	17			
7	**NETT CASH AFTER INTEREST**	**-469**	**119**	**188**	**182**	**175**	**168**	**161**	**153**	**17**	**153**	**144**
8	**ACCUMULATED CASH FLOW AFTER INTEREST**	**-469**	**-350**	**-162**	**20**	**195**	**363**	**524**	**677**	**694**	**847**	**991**

APPENDIX III MAP OF STATE OF SARAWAK RIVER BASIN (DID, 2005)



APPENDIX IV

The record of minimum, maximum and average of rainfall of year 2003 in three main regions of states of Sarawak (DID, 2005)

Coastal Regions	Station Names	Minimum (mm)	Maximun (mm)	Average (mm)
Southern	Buntal DID	78	1074	367.75
Middle	Mukah	78	894.5	306.25
Northern	Limbang DID	74	512.5	74

The monthly lowest and highest of tide for 2006 in three main regions of the states of Sarawak (DID, 2005)

Month	Southern (Kuching)		Middle (Mukah)		Northern (Miri)	
	Low (m)	High (m)	Low (m)	High (m)	Low (m)	High (m)
January	0.15	5.53	0.23	2.69	0.09	2.16
February	0.36	5.35	0.29	2.45	0.19	1.92
March	0.68	5.33	0.46	2.36	0.32	1.71
April	0.19	5.20	0.54	2.32	0.36	1.81
May	0.17	4.98	0.34	2.38	0.21	1.94
June	0.13	4.98	0.32	2.37	0.11	2.03
July	0.02	5.05	0.49	2.24	0.11	2.07
August	0.06	5.16	0.88	2.07	0.20	2.03
September	0.49	5.27	0.84	2.30	0.40	1.92
October	0.65	5.44	0.69	2.42	0.41	2.00
November	0.39	5.49	0.43	2.61	0.25	2.13
December	0.32	5.39	0.33	2.67	0.16	2.18

APPENDIX V

Green mussel *Perna viridis*

APPENDIX VI

Raft culture of mussel.

Long line culture of mussel