AN ANALYSIS OF THE POTENTIAL FOR AQUACULTURE OF SPOT PRAWNS (*Pandalus platyceros*) IN COASTAL BRITISH COLUMBIA.

by

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PROFESSIONAL PAPER SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF AQUACULTURE

in the Department

of

Biological Sciences

SIMON FRASER UNIVERSITY

June 1997

0-612-24173-4

ABSTRACT

Shrimp farming is one of the largest aquaculture businesses throughout the world. There are thousands of shrimp farms world-wide that produced almost 700,000 tonnes of shrimp in 1996 making it the most widely traded seafood. The local spot prawn (*Pandalus platyceros*) is presently being investigated as a potential subject for net pen mariculture in British Columbia. A review of the biology, markets and culture operations of *P. platyceros* was performed as well as an economic analysis of the proposed farming method. Biologically *P. platyceros* has been successfully reared in confinement but factors such as poor feed conversion and relatively slow growth significantly increase costs, making the likelihood of large scale operations tenuous. The economic feasibility of commercial spot prawn culture is marginal. Attempts to grow these shrimp for profit would require large scales of economy and any failure would result in considerable financial setback. Unless these factors are overcome, it is unlikely that commercial success of spot prawn culture will be achieved. It is therefore recommended that a pilot project should be established to research the dynamics of a large scale culture operation of *P. platyceros*.

Dedication

To my parents and Andrea. Thank you for all your support and patience.

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1. INTRODUCTION

1.1 Introduction

The spot prawn (*Pandalus platyceros*) is the largest shrimp species in Canada and one of the most valuable on a per weight basis (Jamieson and Francis, 1986). It is one of 85 known shrimp species in British Columbia of which only 6 are harvested commercially or for sport. The average annual wild harvest of *P. platyceros* is well above one million pounds and its value has continued to increase over the past several years. The wild stocks are recently showing signs of being overfished and the effort required to catch these animals is increasing at a rate greater than increases in catch. There is a very well established market for the cold water shrimp and demand is continuing to increase.

The culture of various shrimp species has been practised in tropical countries for centuries and today they are one of the most successfully cultured groups of marine animals in the world. The high value of shrimp and prawns has motivated researchers to develop tropical crustacean culture techniques over the past several decades and more recently this research has begun in temperate climates. There is no commercial production of *P. platyceros* at this time but research in the area has been ongoing for at least 30 years in both the United Kingdom and the United States. Over the past few years there has been co-operation between several companies in British Columbia in the pursuit of developing a feasible culture system for the spot prawn. The coastal environment of B.C. is suitable for the culture of these animals and the life cycle has been determined such that several groups of animals have been grown to maturity in captivity. The animal does appear capable of being domesticated but there are some problems which will need solving before a commercial operation will be profitable. There has been a lot of cannibalism observed with these animals and an affordable commercial feed has yet to be developed. The spot prawn is also slow growing, compared with other cultured shrimp, which considerably increases the cost to grow them to market size. *P. platyceros* can be raised profitably but with these drawbacks it is unlikely that many entrepreneurs will consider them attractive as an investment. It may however be feasible for established shellfish growers who already have some of the infrastructure in place to culture them as a means of increasing their profit margin.

This paper attempts to provide the necessary background information that a potential farmer of *P. platyceros* would need as well as an economic analysis to present the financial aspects and risks to an entrepreneur or investor. Throughout the paper *P. platyceros* has been compared with other shrimp species commonly grown in order to analyse its suitability for culture.

1.2 An Overview of Aquaculture

1.2.1 World Aquaculture Status

Aquaculture can be dated back thousands of years in ancient China with the production of carp as a food source for local populations (Anonymous, 1996). It is only in recent years that aquaculture has become big business (Emery, 1991). The top five producing countries in the world as of 1994 were China, India, Japan, Korea and the Philippines, accounting for approximately 80% of the total world production (Anonymous, 1996). North America, South America, former USSR, and Africa follow well behind their Asian counterparts with Canada placing a distant 27th in terms of production (Anonymous, 1995a). World production from aquaculture in 1994 totalled $39.83 billion (U.S. dollars at 25.5 million tons) up 10.3% (11.8% weight increase) from 1993. If this growth continues it will result in a production value of approximately 40 million tons by the year 2010 (Anonymous, 1996). In the United States, aquaculture is the fastest growing segment of agriculture. As new people enter the aquaculture industry and technology improves the world rate may well increase.

1.2.2 Aquaculture in Canada

Aquaculture in Canada began over 100 years ago with the federal government operating a number of salmon and trout hatcheries for restocking purposes. Large scale commercial production began in the 50's with oyster farming in B.C. and trout farming in both B.C. and Ontario (Emery, 1991). Aquaculture was considered to be in the developmental stage in Canada until the 80's when huge growth in the industry began (Figure 1-1, page 3) and the number of species increased to include several different varieties of finfish, molluscs and even some aquatic plants (Anonymous, 1996). Since then there has been a dramatic increase in both quantity and dollar value of aquaculture production, but this still pales in comparison with production from Asian countries, Norway and Chile (Anonymous, 1995b; Emery, 1991; Anonymous, 1996). Emphasis in

Canada has been to raise profitable species resulting in aquaculture producing 17% of the total landed value and 6% of the weight of Canadian Fisheries in 1993 (Anonymous, 1996). As well as providing direct financial benefits to the Canadian economy, there is also $266 million produced annually from the supply and service sectors of aquaculture (Anonymous, 1996).

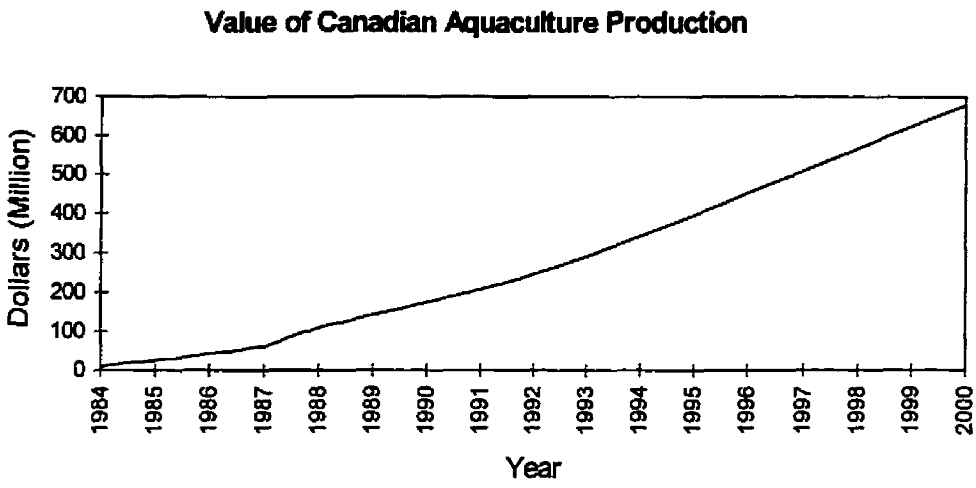

Figure 1-1: Total Value of Past, Present and Future Aquaculture Production in Canada. Anonymous, 1995; Emery, 1991; Anonymous, 1996.

The success of the past is considered to be part of the first wave of aquaculture development and the various levels of governments are trying to plan how best to proceed with the second wave. Producing less than 0.3% of the world aquaculture production, the government wishes to move ahead making use of its highly skilled professional work force to become a leader in aquaculture and develop a sustainable productive industry (Anonymous, 1996). With the declining fisheries in Canada there are very good reasons for increasing aquaculture operations and production. There is a serious need to provide economic growth in rural areas of the country where opportunities are limited and there is also the need to make up for the shortfall of the fishery (Emery, 1991). In order to be competitive within the aquaculture industry, Canada must continue to increase the production of successful species as well as others which are not commonly cultured (Emery, 1991). It is also important to determine the aquaculture potential of new species for future possibilities. The Federal Government recognises these aspects of aquaculture and realises that by promoting them, they will facilitate long-term sustainable growth (Anonymous, 1995b). In 1995 the Federal Aquaculture Development Strategy was published to present how the federal government will take aquaculture into the next century (Anonymous, 1995b) but it remains to be seen if their plans will be carried out to their full extent.

1.2.3 Aquaculture in British Columbia

British Columbia has 27,000 kilometres of coastline with a climate well suited for aquaculture (Anonymous, 1987). The aquaculture industry in B.C. took off in the 1980's with the influx of foreign capital (Warton & McDougal, 1991) and within ten years production levels and the number of operations have changed considerably. British Columbia is the leader of Canadian aquaculture in terms of its size and production. Aquaculture output from B.C. accounts for over 50% of both the quantity and dollar value of all aquaculture products in Canada (Anonymous, 1996; Anonymous, 1995b). The majority of these products are salmon, oysters and clams (Anonymous 1995b). Other shellfish and freshwater fish make up only a small part of the total production. Increasingly, producers in B.C. are gaining interest in the culture of new species including geoduck, abalone and the local spot prawn *Pandalus platyceros*.

British Columbia has a wide range of resources available to assist setting up an aquaculture operation. The Ministry of Agriculture, Food and Fisheries is the lead department of the provincial government to promote aquaculture. There are also other departments involved such as the Ministry of Crown Lands, who are responsible for land allocation, and the Ministry of Environment, Lands and Parks (MOELP). It is in the hands of the latter to ensure farms operate responsibly with regards to environmental aspects (Anonymous, 1990). Within the province there are several institutions actively taking part in aquaculture research such as the Pacific Biological Station (DFO), Bamfield Marine Station, Malaspina College and other educational institutes that are setting up aquaculture programs. A few private firms operating independently or with the assistance of public money are actively researching opportunities for new culture methods and species to pursue. Several financial assistance programs are available from both the federal and provincial governments but are constantly changing and require investigation when needed.

1.2.3.1 Drawbacks for culturing in B.C.

Although the government officially promotes aquaculture in this country there are several problems which can make setting up a net pen operation in B.C. difficult. Salmon farming in B.C.

is presently undergoing a lot of scrutiny. The Provincial Government is in the process of preparing an environmental assessment which the local aquaculturists are awaiting in anticipation. This report can possibly limit further growth of this industry if its findings are negative. It is also under attack from various special interest groups and environmental agencies who feel that salmon farming is polluting the waters both chemically and genetically and that its activity should not be allowed to continue without major changes. These groups are blaming salmon farming for environmental damage and the loss of indigenous animal populations that once inhabited these localised coastal areas (Morton, 1997).

Salmon farming in B.C. is worth twice the value of the commercial salmon fishery and farmed salmon is the provinces largest agriculture export, yet it is gradually losing its market share due to the inability of established farmers to expand and take advantage of economies of scale. Over the past 14 months over $26 million of investment and 500 jobs have been passed over for Scotland and Chile instead of B.C. (D'Avignon, 1996). Local companies are forced to invest in other provinces or countries since they are unable to pursue local expansion. The regulatory impediments have been ongoing now for five years and it is hoped that with the release of the assessment, the ban on expansion will be lifted.

Governmental impediments are certainly not new to the industry. Eleven years ago in 1986 the fisheries minister agreed to develop a one stop licensing and leasing office for aquaculture ventures as well as to develop Federal-Provincial co-operation to promote the orderly development of the industry (Emery, 1991). To date, neither of these have come to pass. Aquaculture can in fact be considered an over regulated industry. Many of the regulations are policies designed for the wild catch fisheries and not for growers of private stocks. Recently the aquaculture industry was not included with the agriculture industry which was desired because policies could have been made that are more relevant for the participants (pers. comm. Judith Reid). There are presently too many different departments that a grower must deal with and the lack of co-operation, even within the same level of government has been a point of frustration for many. The policies can also be quite confusing. For example, sturgeon culture is not allowed to be carried out in any river where there is no natural stock to prevent the introduction of a foreign species. Yet, it is also not allowed to be performed near a river where there is a natural stock for fear of genetically altering the existing stock (Down, 1996). The definition of aquaculture in the province has caused problems in the past for farmers wishing to grow finfish other than salmon, as they were not included and therefore not entitled to certain tax relief benefits (pers. comm. Bill Bennett). Officially the government is trying to make aquaculture work in this country. However, there are still a lot problems to solve before it is as accepted as the agriculture industry.

1.3 A Review of Shrimp Farming

1.3.1 Shrimp Production

There are an estimated 113,005 shrimp farms and 4,992 hatcheries throughout the world with over 80% of the production being of three species; *Penaeus monodon*, *P. vannamei* and *P. chinensis* (Jory, 1996a). The majority of production is from the eastern hemisphere which produces up to 80% of the global quantity. Although the total quantity farmed in the west is much less, the average weight produced per hectare of farmed land (kg/ha) is almost twice that of the eastern countries due to differing culture methods. The cultured shrimp industry saw an increase of 300% between 1975 - 1985 and 250% between 1985 - 1995 and may make up to 57% of the world shrimp supply by the year 2005 (Jory, 1996a).

Crustacean aquaculture is centuries old with typical farms consisting of large earthen ponds and warm water species. World production has increased since World War II due to increased demand, especially in the U.S. and Japan. From 1983 - 1990 penaeid prawn farming increased six fold and freshwater prawn farming has increased even greater (Laubier & Laubier, 1993). Early techniques in south east Asia caught wild juveniles from the estuaries and raised them in fish ponds. Increasing knowledge of crustacean biology in the late 1800's and early 1900's led to restocking attempts of depleted fishing grounds. It was not until the early 1960's that successful rearing of large numbers of shrimp (*Penaeus japonicus*) was achieved in the laboratory and later in nutrient enriched ponds. The technological constraints have been for the most part the control of broodstock and seedstock (Laubier & Laubier, 1993) but with scientific advancements these are now better understood and shrimp farming may see further increases in production.

1.3.1.1 Experiments in Alternate Climates

Traditional shrimp farming occurs in tropical countries but recently there has been a growing interest in shrimp culture in countries with temperate climates. For at least three decades researchers in the United Kingdom have been studying the possibility of growing both warm water and cold water shrimp. They have worked on the assumption that closed systems would be the best system since warm water species would need a high degree of environmental control (Forster and Beard, 1974). They also suggested that fast growing prawns, stocked at high densities would be the most suitable. This method in the U.K. (and here in B.C.) would result in a very high cost of space and heat, which together can range from 44.6 - 84.7% of the total cost of production (Wickens & Beard, 1978).

Macrobrachium rosenbergii, the freshwater prawn, has been the subject of investigation in the U.S. for a number of years to determine if they are suitable candidates for cultivation in temperate climates. (D'Abramo et al, 1989; Tidwell et al, 1996). Positive results have been found for *M. rosenbergii* and other species, such as *Penaeus monodon*, in that mean growth rates remained the same or increased and Feed Conversion Rates (FCR) were within acceptable ranges in temperate climates (Tidwell et al, 1996; Lumare et al, 1993). Researchers in the U.S. were able to take advantage of the well established infrastructure and pond systems that were constructed for catfish culture (D'Abramo, 1997) thereby making their job easier. These experiments show that shrimp culture need not be limited to those countries possessing the ideal climates for the commonly grown species of shrimp and that there is some flexibility with regard to required environmental conditions.

1.3.1.2 Alternate Grow-out Methods

There have also been some experiments performed to test alternate methods for culturing shrimp in various regions. Most of the testing is done intensively, in an attempt to decrease the amount of land required to profitably grow these animals to market size. This is particularly important in countries such as North America where water front land is expensive. Recirculating raceways have been used in Texas to successfully grow *P. vannamei* (Reid & Arnold, 1992) and in Illinois, artificially created salt water along with natural gas heating has been used to grow *P.*

vannamei (McCoy, 1986; Rosenberry, 1982). Cage culture has been successful for raising *P. monodon* through the nursery stage in the Philippines (Rodriguez et al, 1993) and for the raising of *Pandalus platyceros* in Washington state (Rensel & Prentice, 1979). These experiments have shown that shrimp are somewhat flexible in their ability to adapt to different substrates for habitation and it is possible to raise them outside the established normal methods.

1.3.2 Culture of Pandalus platyceros

There is presently no commercial production of *P. platyceros* but experiments have been performed for at least 30 years in the U.K. In 1970 the Department of Fish and Game's marine culture laboratory (California) selected the spot prawn as one of their first invertebrate species to investigate for its culture potential (Kelly et al, 1977). The National Marine Fisheries Service in the U.S. later selected the spot prawn as a potential species for culture in 1975 (Rensel & Prentice, 1979). In British Columbia the spot prawn has been considered a potential aquaculture candidate for many years. In 1981 the Ministry of the Environment published "Shrimps & Prawns: potential subjects for Mariculture in British Columbia" (Neilson, 1981). At this time *P. platyceros,* was deemed unsuitable for culture but it was suggested that it may be feasible in the future should technology develop (Neilson, 1981; Gunn et al, 1983). It was also suggested that it would be suitable for culture if grown in a polyculture environment with salmon or shellfish (Rensel & Prentice, 1979; Kelly et al, 1977; Hunt et al, 1995). This may still be the best economical method for the cultivation of *P. platyceros* for commercial purposes and should be further researched.

Recently there has been renewed interest in the culture of these prawns in British Columbia. Research is presently being carried out by Island Scallops and the Cultured Crustacean Company on Vancouver Island as well as DFO's (Department of Fisheries and Oceans) Pacific Biological Station and Malaspina College. Moore-Clark and Rangen have experimented with diets and Sea Plus Marketing and TriStar Seafood Supply are providing ovigerous females for broodstock (Chettleburgh, 1996; pers. comm. Chris Campbell; pers. comm. Ray Leitch; pers. comm. Greg Nelson). There has been mixed success to date but overall the experiments appear successful and the involved parties are positive about the project's future. The goal is to grow the adults in sea pens using vertical inserts to increase surface area which can be used by the shrimp as substrate (Chettleburgh, 1996). The inserts also act as added surface for fouling organisms to settle thereby providing an increased natural feed for the shrimp (Rickards, 1971). Research is still ongoing in this field and it is hoped that pilot projects will be started within the next few years (pers. comm. Chris Campbell).

1.4 Scaling Up from Research to Commercial systems

All culture of *P. platyceros* to date has been experimental with small numbers of animals in various systems and at various densities. Methods have been variable, using monoculture and polyculture systems and much of the feed used has been inappropriate for commercial purposes due to their cost. Many important parameters have been determined such as temperature, salinity, dissolved oxygen and others while some factors need further investigation such as density, types of feeds and more. The economic feasibility has been neglected in the literature and various questions are in need of answering such as whether to build a hatchery, how large should the grow out facility be, how many employees are required and more.

Various aquaculture ventures have failed due to the problems of scaling up systems to a commercial size (Huguenin & Webber, 1981). Dykes have failed allowing seawater and animals to escape entrapment, excess biofouling has caused freshwater to enter and dilute saltwater systems resulting in disaster. Failures have also been attributed to poor site selection, planning, designs, equipment and lack of money as well as management that hadn't been able to factor in all possible problems. Lack of communication between scientists and practitioners is common and problematic. Many difficulties are the result of ignoring basic problems and the biggest may be that scaling up from research to commercial projects is often thought to be a low risk linear bio-engineering project. Rather than the proper use of a pilot phase, many people have gone straight to a commercial scale resulting in failure (Huguenin & Webber, 1981).

There is a need for pilot projects and large scale operations to research the design, economics and operations of the animal and large scale facility. The pilot project should be a test facility for a commercial operation and not just a larger research station. The pilot plant and large scale project can then supply information back to the scientists performing basic experimentation for further studies on the animal (Huguenin & Webber, 1981). Since laboratory research generally holds many factors constant, which is not the case in the culture environment, results can not often be extrapolated directly to commercial conditions. Typically, research does not provide for easy scaling up of facilities and the biological complexities alone may cause major problems (Huguenin & Webber, 1981). With regards to the economics of scaling up there are many factors, one of which is the scale of economies. For any size facility there will be basic services and equipment that will be needed so it must be determined what is the minimum size facility that will be profitable. Huguenin & Webber (1981) point out that public funding has been crucial in the development of the agriculture industry throughout the decades and without the collaboration of academia, industry and government, aquaculture may not develop to its full potential. Finally, it must be realised that aquaculture is a business and must be dealt with as such. It is evident from such gatherings as the "World Aquaculture 97" and aquaculture news groups that economic and business aspects are often omitted from aquaculture discussions. More importantly many people don't even care for these topics (Wade, 1997). Aquaculture can not thrive on research and grant money which, although crucial, is not adequate to develop a sustainable industry. More emphasis must be placed on these matters or the industry will not be viable and it will be known as an industry of failures.

1.5 The Fishery

1.5.1 History

The early history of the prawn fishery is not well documented. A shrimp fishery was present before 1890 near Victoria, (Butler, 1968) but the prawn fishery probably began after World War I in Howe Sound and was relatively insignificant until after World War II. The main market at this time was for frozen product in Vancouver (Butler, 1970). *P. platyceros* inhabit rocky terrain necessitating the use of traps for capture. Recruitment takes place after about 1½ years when the animal is between 12 - 15 grams (Butler, 1970). The vessels used range from 5 - 35 m in length utilising anywhere from 400 - 1500 traps. There are 30 different types of traps used, varying in the number of tunnel entrances, tunnel sizes, entrance ring size and mesh size. Six different baits are used in the traps, which are left in the water from 3 - 96 hours at depths ranging between 15 - 250 metres (Jamieson and Francis, 1986; Boutillier, 1985). The spot prawn is the most popular species for sport fishers who are allowed to use 4 traps at a time (Jamieson and Francis, 1986). Trapping began in the early 1950's, with Knight and Kingcome inlets being the leaders in prawn production until about 1970. In 1960, 1260 traps were fished, later expanding to 2710 traps in 1965 which were spread through various regions in the Strait of Georgia. At this time, the fishermen also took advantage of their diel migration and set traps in shallower water overnight to decrease fishing effort (Butler, 1980; Boutillier, 1985). In 1979 the prawn trapping was concentrated in the south coast region but in the late 70's increased markets, overcrowding and positive results from exploratory prawn surveys led to the development of the northern fishery (Jamieson and Francis, 1986). This resulted in the number of vessels increasing from 50 to 300 between 1979 and 1984 (Jamieson and Francis, 1986; Boutillier, 1985). Over the years the proportion of prawns in the total numbers of shrimps landed increased to 56% in 1980 and 78.2% of the value (Whyte and Carswell, 1982). Figure 1-2 (page 12) shows the catch of prawns from traps as well as the effort required to make these landings. In recent years there has been a dramatic increase in the amount of prawns caught and it is clear that this increase in catch correlates with an increase in the effort put into the trap fishery. However the effort has increased twenty six fold since 1972 whereas the catch has increased only twenty fold. If this trend continues it will become increasingly less profitable to obtain these prawns in the traditional method. As the effort increases greater than the catch, the cost of each prawn caught rises thereby diminishing the fishers' profit margin.

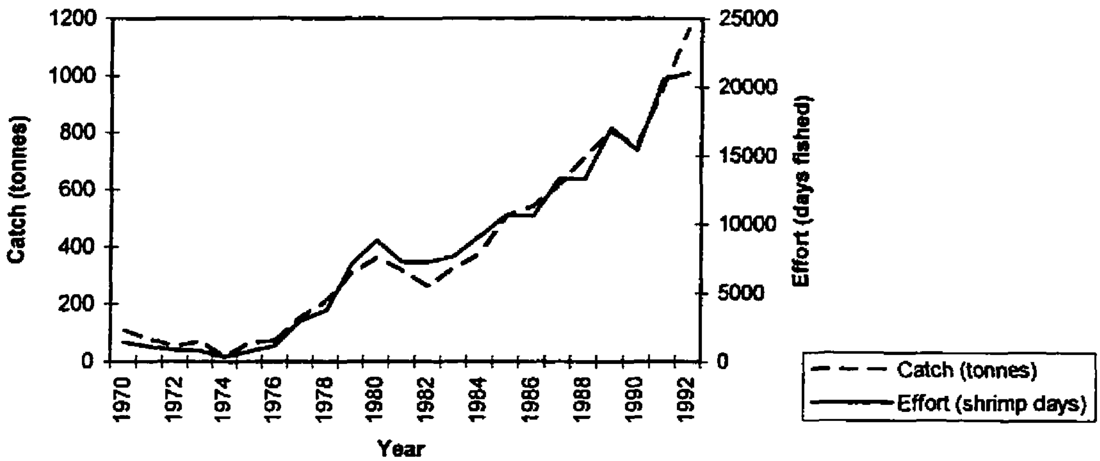

Figure 1-2: Catch and Effort for Prawn Trap Fishery.
(B.C. Catch Statistics 1980 - 1990)

The crustacea (shrimp, prawn and crab) fishery is proportionately small in B.C. In 1981 the prawn fishery accounted for about only 2.5% (0.5 mill lb prawn/20 mill lb invertebrates) of the total invertebrate fisheries in the province (Pearse, 1981). In 1981 it was estimated that 0.5 million pounds of prawns was close to the maximum sustainable yields. Even then, certain grounds such as Howe Sound were already overfished and there appeared to be little scope of increased yields in the future. Although the fishery is relatively small, the increase in value of landings has increased at a much higher rate than the landings of invertebrates themselves. A two fold increase in landings from 1970 to 1980 (to 20.4 million lbs) saw almost a 7 fold increase in value to $11 million (Pearse, 1981). Figure 1-3 (page, 13) shows the relative change in the catch, effort exerted and the value of the catch from 1980 to 1990. It can be clearly seen that though the catch and effort increases only 2 fold over the ten year period, the value of that catch has increased over ten fold. These price increases reflect the effects of fluctuating markets and product supply.

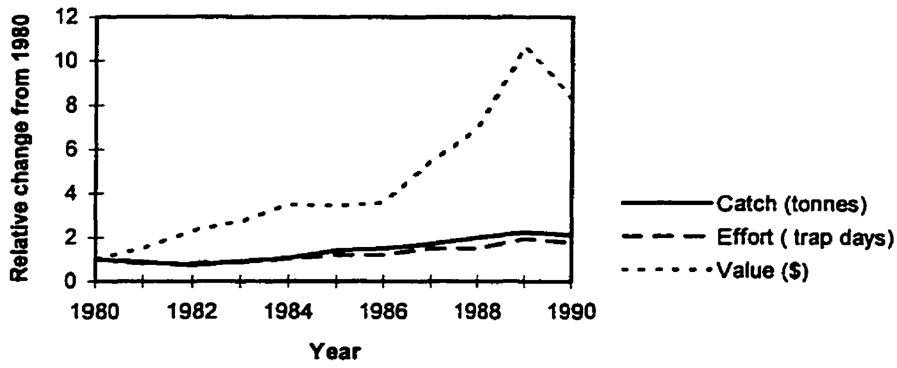

Figure 1-3: Relative Change in Catch, Effort and Value from 1980.
(B.C. Catch Statistics 1980 - 1990)

1.5.2 Monitoring and Control

The fishery policies are made with the emphasis on properly protecting the stocks and enhancing them whenever advantageous. Careful regulation of the level and form of harvesting, both the species in question and those lower on the food chain, is necessary in order to maintain the resource. There is therefore the need for institutional and financial arrangements to take advantage of opportunities for enhancement, to acquire data, and for research to carry out these objectives effectively (Pearse, 1981).

Commercial fishing vessels were, for the first time, required to purchase licences for all fisheries in 1966. There was to be a minimal annual renewal fee and each vessel would receive a permanent licence number. In the late 1970's the prawn fishery saw a rapid expansion, necessitating the development of management and control systems (Adkins, 1993). The management of shrimp and other minor species has been a difficult one as it is based on sparse information about stock size and productivity (Pearse, 1981). Management of the fishery is accomplished by determining the catch per unit effort value for female spawners and comparing it to an acceptable monthly spawner index (Jamieson and Francis, 1986; Adkins, 1993). When observed catch values decline to the level of or below the expected monthly index, the area is closed until the end of the egg bearing period (around March). It is a difficult method to effect but is considered to be conservative (Jamieson and Francis, 1986). Limits were placed on the minimum size prawns caught and size selective traps were required in the mid 1980's to prevent overfishing. Seasonal closures were also implemented during the larval hatching period at this time and in 1990, entry to the fishery was limited to further control fishing effort (Adkins, 1993). Figure 1-2 (page 12), however, shows that although entry was limited, the effort implemented for trap fishing continued to increase with an accompanying increase in catch. If stocks are to be conserved, there needs to be a limit placed on catch per fisher or demise of the fishery may follow, as it has with other species.

1.6 Markets

1.6.1 General Shrimp Markets

Demand for fish and seafood is expected to reach 120 million tonnes early next century while the total wild catch has peaked at about 100 million tonnes and is declining (Anonymous, 1995b). The world market for shrimp is approximately 2.2 million tonnes of which the majority is consumed by Japan, U.S. and Europe (Anonymous, 1991a). It is estimated that by the year 2000, shrimp farming will supply 50% of the world's shrimp (Jory, 1995). Shrimp is the fastest growing seafood in the United States, jumping from a per capita consumption of 1.5 pounds in 1982 to 2.5 pounds in 1992 (Anonymous, 1993a). Total imports to the U.S. have increased from 103,428 tons in 1977 to 244,758 tons in 1991 and Japan's imports increased from 124,780 to 284,493 tons over the same time period. The European consumption is also rapidly increasing as imports rose 233,000 tons from 1981 to 1991 (Anonymous, 1993b). Shrimp is also enjoying the benefits of being a healthier food option, therefore demand is continuing to increase in both the U.S. and Europe (Anonymous, 1991b). Shrimp have a long and successful history in the market and now, with aquaculture, the prices are more stable and they are available to a larger market since they are no longer considered a luxury item to many. In fact without aquaculture it is estimated that shrimp prices would be 70% higher (Anonymous, 1993b). Other, non traditional markets are also increasing; China now consumes half its production and Hong Kong, Malaysia, Singapore and Taiwan are quickly becoming consumers (Anonymous, 1993b). Shrimp is so important to the marketplace that it can affect the way seafood is sold. Safeway (in the U.S.) requires $5,000 in sales per week at their full service counters in order to maintain them. Shrimp sales comprise a large proportion of this financial requirement so if sales drop dramatically, the limit may not be met, thus jeopardising the sustainability of these counters (Johnson, 1997).

1.6.2 Cold Water Shrimp Markets

There are several well established seafood wholesalers in B.C. who are experienced with shrimp trading as a result of the long running shrimp fishery. Cold water shrimp are generally smaller and sweeter that the warm water shrimp (Anonymous, 1992). The major suppliers of cold water shrimp are Greenland, Norway, Denmark, Iceland and Canada (Anonymous, 1993b). Japan, the largest seafood consumer in the world, has recently been increasing their import of cold water shrimp because it has been discovered to have a higher presentation value at sushi bars. From 1984 - 1991 Japanese imports increased from 10,232 tons to 31,115 tons (Anonymous, 1993b). Japan is presently having problems with its Yen which is affecting the market and quantity of imports resulting in a smaller market than in recent years (pers. comm. Ray Leitch). In 1980 most shrimp and prawns caught were sold within Canada (Pearse, 1981). Presently most spot prawns are shipped to Toronto, the United States, Japan and Hong Kong. Figure 1-4 (page, 16) shows the exports of shrimps and prawns from Canada to the three largest markets. It is clear from the graph that the demand for shrimp in Japan has risen dramatically over the past seven years. Wholesalers in Vancouver can handle 3000 - 4000 lbs of prawns per day of which approximately 35% is sold in the lower mainland market place (pers. comm. Greg Nelson). The animals are sold either live or frozen and often wholesalers specialise in one form or the other. Frozen product is often packed with heads on since the animal is approximately 50% head, the price per pound at the consumer level would double if packed without heads. This affects sales and suppliers would not make up the added processing costs (pers. comm. Ray Leitch). The market seems willing to pay the lower cost for heads on shrimp rather than the higher cost of processed tails only product.

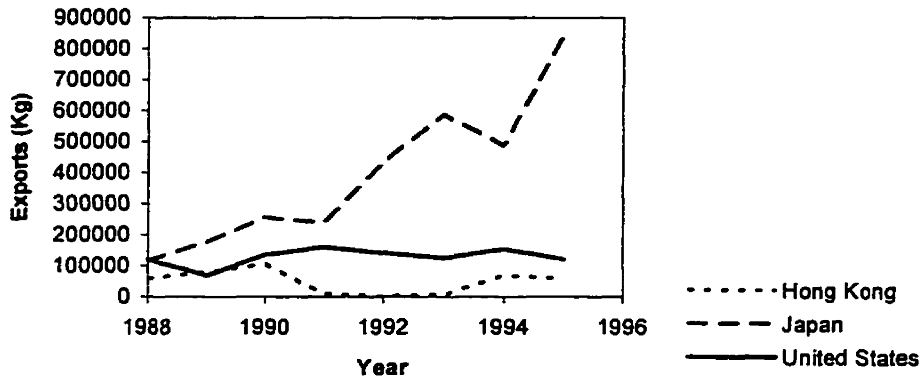

Figure 1-4: Exports of Shrimps and Prawns from Canada.
(Statistics Canada)

The main fishing season is from May to September when prices range from about $4.50 - $7.50/lb (pers. comm. Greg Nelson & Ray Leitch). Wholesalers have expressed interest in prawn farming and would be keen to assist by supplying broodstock to hatcheries in return for loyalty with sales. The price for live prawns is variable with supply, ranging from $6.75 - $8.50/lb when supply is relatively consistent. If harvesting is performed in the off season (October - April), prices can be expected to be $1.50 - $2.00/lb higher for live product than in the peak fishing months (pers. comm. Greg Nelson). Table 1-1 (page 16) presents the market value of *P. platyceros* at various sizes. These values are at present market prices and will fluctuate with supply and demand but they are useful for determining an estimate of profit that can be obtained from the product.

Table 1-1: Wholesale Price and Size of Frozen *P. platyceros.*
(pers. comm. Greg Nelson & Ray Leitch).

Size	Animals/lb	Average Weight (g)[1]	$/lb (average)
Small	> 20	18	< 6
Medium	16 - 20	23	6.00 - 6.25
Large	12 - 15	30	7.50
Extra Large	7 - 11	41	8.00
Jumbo	< 7	65	8.25

The target market is also changing from the high priced restaurants to shrimp packaged for consumption at home (Saulnier, 1991). They are sold in a variety of ways such as frozen, fresh, canned or dried just to name a few (Lee & Wickens, 1992). The supermarket trade is therefore moving away from stocking high priced fresh product to more affordable frozen product as the

[1] Values were obtained using the most conservative number whenever possible. The average was obtained using 25, 20, 15, 11 and 7 animals/lb for small, medium, large, extra large and jumbo respectively.

amount of loss due to spoilage is dramatically decreased. Farming in B.C. has the benefit of many established coastal processing facilities so the harvest can be quickly transported to these facilities or directly onto freezer boats for shipment to Vancouver. The minimum market size mentioned in the literature is 8g but this does not appear to be a size desired by local wholesalers. There is a baitfish market for the smaller shrimp such as those that do not grow to market size. Wholesalers dealing with bait fish will pay about $1/lb for the small animals (pers. comm. Al Edwards). Although it is not economical to raise animals for this market it will provide some financial return from the slow growing animals. Market size warm water shrimp (marine penaeids) range anywhere from approximately 4 - 33g (Lee & Wickens, 1992) which they generally reach within a year. One of the challenges of setting up a culture operation for new species will be to determine what is the best size to harvest the animals for the best return. The markets are well established for *P. platyceros* and the infrastructure is in place. Determining whether to culture the animal or not will basically depend on the biological and economical limitations.

1.6.3 Competition

There is a lot of competition for the shrimp market on a whole. The natural fishery is still the main supplier of shrimp and price fluctuations reflect the supply from this source (Lee & Wickens, 1992). There are also a number of large, well established farms producing vast quantities of shrimp throughout the world. The commercial shrimp fishery is decreasing everywhere with fishing effort increasing greater than quantity harvested. The wild fishery is also very seasonal with catches only allowed during certain times of the year.

There are a number of shrimp and other crustacean species that are direct competitors to *P. platyceros* but, as mentioned, desire for cold water shrimp is on the rise. The majority of the competition will be from other countries. The proximity of B.C. to the Pacific Rim market enables it to provide product to various markets with relative ease and affordability.

There are a number of products which can be thought of as indirect competitors such as lobster, abalone and other shellfish. The first two can still be considered a luxury item as supply cannot keep up with demand and the cost of each is presently high. Certain shellfish such as scallops and clams may be considered indirect competitors as they are an affordable alternative to shrimp and aquaculture of these animals is decreasing the prices seen in supermarkets. Overall the market for shrimp is still strong and local wholesalers can still sell all that suppliers can provide (pers. comm. Greg Nelson).

Potential Aquaculture of *P. platyceros*

There are several questions which must be contemplated before starting an aquaculture operation, especially one that will be growing a species never before cultivated on a commercial level. Is the technology available for cultivating that species, have the biological requirements been adequately determined, are reproductive methods successful, is the animal hardy enough to withstand the unnatural growing conditions, can optimum growth be attained and what are the Feed Conversion Ratios (FCR) and survival for the animal (Avault, 1996)? There are also a range of economic questions which must be answered such as: is feed available and economical, can they be grown cheaply, is there a market and will the entire operation be profitable (Avault, 1996)? These are just a few of the considerations which must be addressed before setting up an operation.

To determine whether to culture a new species for profit one must decide the level of production that is suitable for the species in question. When considering the culture possibilities of *P. platyceros* there are three possibilities: 1. Collecting the juveniles from the wild and growing them to maturity for harvesting; 2. Developing a broodstock for breeding, hatching, larval rearing and growing out or 3. Hatching the eggs of gravid females and releasing them at a stage in their early life cycle for enhancement of wild stocks. The first two methods are for the purpose of raising the animals to a size accepted in the market place, whereas the third method is to enhance the stocks for fishers at a later date.

There are several requirements or traits that must be met in order for a species to be considered suitable for culture.

- There must be a good market and demand, preferably one that fishing efforts are unable to meet,
- There should be a good supply of local broodstock,

- Larvae which hatch at a larger, more advanced stage are better suited because of their acceptance of a wider variety of food and fewer molts required before metamorphosis. An abbreviated larval development is beneficial as mortalities and problems associated with feeding are often minimised,
- Larvae and Megalopa (commonly called Post Larvae) should not need specialised care for high survival rates,
- The animal must be hardy such that it will be readily adaptable to general mass culture techniques,
- The species should exhibit minimal cannibalism,
- The species should be tolerable to a wide range of temperatures and salinity such that minor fluctuations have minimal effects,
- There should be a high survival rate,
- The species must be easy and affordable to raise on a large scale.

(Williamson, 1968; Kelly, Haseltine and Ebert, 1977)

P. platyceros meets many of these requirements indicating that they may be a suitable candidate species for culturing, but there are a few drawbacks. The positive and negative attributes of their biology and its relation to the above list will be discussed throughout this paper. Generally they are considered to be a fast growing shrimp, but when compared to the tropical shrimp they are much slower to reach market size (Wickens, 1972). These and other factors are very important when making an economic analysis for the animal's potential as it will take longer to see a return on investments made.

2. Biology of *Pandalus platyceros*

In order to cultivate a species for financial profit, one must understand the basic biology of the animals so that the operation can be built to meet its needs. One of the difficulties with farming any aquatic species is the lack of information on its biology and hence the difficulty either meeting its needs or domesticating the animal to grow in a culture environment. This section presents the basic biology of *P. platyceros* one should know when considering its culture.

2.1 General Biology

There are 85 species of shrimps living off the coast of British Columbia, occupying a variety of habitats and locations. Shrimp are an important part of the marine ecosystem as food for fishes and mammals as well as being predators themselves (pers. comm. Jeffrey Marliave). Of the 85 species only 6 are of commercial interest and of those, *P. platyceros* is the most valuable. *P. platyceros*, commonly known as prawn, spot prawn or spot shrimp, was first described by Y. J. Brandt in 1851. In the Strait of Georgia, B.C. they inhabit waters ranging from 7.61 - 10.97°C and 26.42 - 30.83‰ salinity. The males reach a carapace length (CL) of 48.1 mm and a total length (TL) of 230 mm and are smaller than females that reach a CL of 61.1 mm and a TL of 253 mm (Butler, 1980). They range from Unalaska Island, Alaska to San Diego, California as well as off the coasts of Japan, Korea and Russia inhabiting depths anywhere from 2 to 266 fathoms (Butler, 1964).

P. platyceros are protandric hermaphrodites, functioning as mature males when young, then later becoming mature females. Breeding occurs in the fall and the female lays her eggs, attaching them to her abdominal swimming legs. They remain there until the next spring when they hatch and spend the first two to three months as free swimming larvae before they settle to the bottom as juvenile shrimp (Jamieson and Francis, 1986). The first two larval stages are commonly found in deep water and the following larval stages are found in shallower water where they undergo metamorphosis to the juvenile stage (Butler, 1964). Their life span is about four to five years spending approximately half as males and half as females (Jamieson and Francis, 1986; pers. comm. Jeffrey Marliave).

Pandalus platyceros has a stout compressed body with a thick shell, smooth abdomen and a pubescent carapace. The adult has an overall colour of "washed out" red which is darker on the carapace due to pubescence. There are three or four lateral white stripes on the carapace with the longest being from the antenna down most of the length of the carapace. The name spot prawn stems from the pair of round white spots on the dorsolateral surface of the first and fifth abdominal somites. Juveniles usually inhabit shallow water among *Agarum* kelp beds (pers. comm. Jeffrey Marliave). The colour of the shrimp enables them to blend in with their surroundings becoming almost invisible to predators. Adults are found in rocky areas of the bottom of the ocean floor in crevices, on rock faces or in lairs under boulders. They have also been seen to exhibit a diel migration behaviour pattern moving to shallower water to feed at night (Butler, 1980).

2.2 Life Cycle

To successfully culture any animal one must fully understand the life cycle so that the biological and environmental requirements can be met. When this is understood diets can be determined and the entire operation can be designed to meet the needs of the animal at its different stages. An aquaculture facility usually consists of a hatchery, nursery and growout site, each of which must be constructed to best meet these needs so growth and survival can be maximised.

Caridean shrimp larvae hatch at a much more developed stage than do other shrimps currently being cultured around the world such as the penaeids. They also have a much longer incubation period through which the eggs are attached under the female's tail. The nauplius stage is passed over in Carideans, becoming an embryonic stage within the egg, resulting in larvae hatching as protozoea or zoea. Figure 2-1 (page 22) presents the general lifecycle of *Pandalus* prawn.

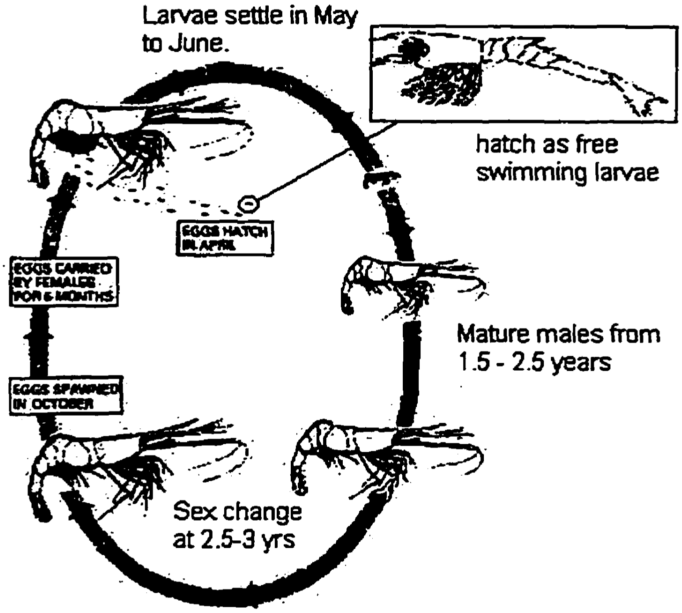

Figure 2-1: Lifecycle of a *Pandalus* Prawn.
(Modified from Iversen et al, 1993 and Butler, 1970.

The larvae generally feed on phytoplankton and zooplankton and as adults they are predators unlike some other shrimp (pers. comm. Jeffrey Marliave). Spawning is usually completed by the end of October and the ovigerous period lasts for about 5-5½ months. The larvae hatch in March or April at depths of 70-90 m. The free swimming larvae will then move with the water currents to shallower (54m or less) regions, often near shore where they settle during the months of April and May (Butler, 1980). In southern British Columbia they will predominantly settle in the kelp beds of *Agarum* sp. (such as *fimbriatum* Harvey and *cribrosum* Bory) using these areas as nurseries. They will usually emigrate to deeper water in the fall when the CL is between 16-20 mm but will overwinter if they are not large enough. Settlement is inconsistent between years depending on variables such as strength of the year class and the state of the kelp beds. Stronger year classes may overwinter more so than weaker ones since there may be a larger proportion of slow growers. The shrimp which overwinter will then migrate to the deeper water during the summer or when they reach a CL of 20 - 22 mm (no matter what the season). The average growth of shrimp that emigrated as underyearlings were seen to be as much as 3 mm per month but for those that overwintered the average was only 1 mm per month indicating a reduced growth rate due to seasonal variation. (Marliave and Roth, 1995).

The eggs are eyed with a mean length of 2 mm and diameter of 1.5 mm changing from a dark orange to a brown colour at the time of hatching (Butler, 1970). Females hatch their larvae mostly at night with vigorous beating of their pleopods liberating large numbers at different intervals. Hatching all the larvae can take 7-10 days. The shrimp hatch as an advanced large bright coloured zoea 7.8 - 8.2 mm total length. Upon hatching they are at a more advanced stage of development than many other local species of shrimp as well as other commonly cultured shrimp. There are generally only four molts, which take 15 - 29 days, through which they must pass before they are considered post larvae. Other species such as *Macrobrachium rosenbergii* and *Palaemon serratus* take 6 - 11 molts (Wickens, 1972). Their means of locomotion as larvae are through rapid movements of natatory exopods on the maxillipeds in stage I. In later stages they use the first three pairs of pereiopods (Wickens, 1972). During the first four stages they swim backwards and upside down (Price and Chew, 1972) whereas post larvae and adults swim forwards using the abdominal pleopods for swimming and their pereiopods for walking (Wickens, 1972). *P. platyceros* are sensitive to light being positively phototrophic during the zoeal stages and then decreasingly so as they develop, eventually becoming negatively phototrophic as they become adults (Price and Chew, 1972). During the first three zoeal stages they are found swimming actively throughout the water column but at the fourth stage they start descending to the bottom where they can find dark protective habitats (Kelly, Haseltine and Ebert, 1977; pers. comm. Jeffrey Marliave). The duration of intermolt increases with age, starting at about 5 days at three weeks, increasing to 37 days after seven months (Wickens, 1972).

Berkeley (1930) first described *P. platyceros* from animals caught in the wild, Price and Chew (1972) later described larval stages I through IX in great detail. Table 2-1 (page 24) briefly describes the first five stages of P. platyceros. At stage five the animal is considered to be megalopa or post larvae because abdominal propulsion is now obvious (Williamson, 1969).

Table 2-1[1]. Brief description of *P. platyceros* larval stages.

Stage	Size (mm) TL	Brief Description
I	8.1	Immobile eyes, bright colour with numerous orange-red chromatophores, mouth parts & internal organs bright orange-red; visible yolk (orange-yellow globules) through carapace.
II	10	Uniform light brown, no large chromatophores, stalked eyes, antennule now segmented, spines on antennal and pterygostomian now visible. Prominent supra-orbital spine is now visible.
III	11	Brightly coloured, body orange-red, individual orange-yellow chromatophores on pereiopods and mouth parts,
IV	11.5 - 12	Pale brown or greenish hue; small groups of chromatophores remain on base of antennae, eye-stalks, lateral margins of carapace and pereiopods; antennal spine equal in length to pterygostomian spine.
V	12 - 13	Light brown to light green with scattered chromatophores all over body. Carapace has large chromatophore near base of eye-stalk and large white spot in hepatic region; white spots on 1st & 2nd abdominal segments with chromatophores which all form an X shape. Antennal spine longer that pterygostomian spine and supra-orbital spine is gone. Antenna is 3/4 body length. The animal is adult-like in many ways.

Between the post-larvae and the adult form they pass through a period where they are considered to be juvenile shrimp which is defined as a young form usually small and sexually immature, showing general resemblance to adults (Hart, 1971; Williamson 1969). With the culture of P. platyceros, this period may be considered to be from post larvae to approximately one (as defined by Rensel & Prentice, 1979) to 1.5 years when they reach sexual maturity. During the second autumn the prawns mature as males functioning as such for another year. Sex change to females is complete by the end of the third year and within one year post hatch all females (38 mm CL and larger) are believed to leave the rocky area and die (Butler, 1964).

2.3 Fecundity

The fecundity of the animal is important to enable the aquaculturist to determine the size of broodstock required to provide an adequate number of shrimp for a profitable harvest. Fecundity in *P. platyceros* is lower than in most other shrimps (Table 2-2, page 25) cultured throughout the world today but according to Williamson (1968) it is adequate.

[1] Descriptions in this table are very brief and only those considered easily visible are listed. For a more thorough description of larvae stages please consult Price and Chew (1972).

Table 2-2. Reported Fecundity of *P. platyceros* compared to some cultured shrimps.

Species	Fecundity Range	Average	Reference
Pandalus platyceros	1393 - 3162		Butler, 1970
Pandalus platyceros	2500 - 4500		Wickens, 1972
Pandalus platyceros	2628 - 4669	3483	Kelly, Haseltine and Ebert, 1977
Pandalus platyceros	-	2028	Butler, 1980 (Strait of Georgia)
Pandalus platyceros	-	3900	Butler, 1980 (Alaska)
Macrobrachium rosenbergii	-	80,000	Lee and Wickens, 1992
Penaeus vannamei	-	80,000 - 250,000	Lee and Wickens, 1992
Penaeus monodon	-	150,000 - 300,000	Lee and Wickens, 1992

Decapod Crustacea undergo an abbreviated development resulting in a lower mortality rate and cost to rear from egg to post larvae stage so they are more attractive to culture (Williamson, 1968). Once the level of production required has been determined, the grower can work backwards (taking expected mortalities into account) to determine the number of adult shrimp required as broodstock. Butler (1970) related fecundity to carapace length with the formula Log F (number of eggs) = 3.3967 * Log L (carapace length) - 2.0564. This equation could be used to estimate the number of eggs expected from the females thereby enabling the grower to forecast expected production and plan accordingly.

2.4 Reproduction

The hermaphroditic spot prawn matures as a male after 1.5 years and may breed one or more times before it passes through a transitional phase to a female approximately a year later. It generally takes at least 24-36 months before they are ready for spawning as females (Butler, 1970; Wickens, 1972). It was thought that the spot prawn spawned only once as a female before it left its habitat to die (Butler, 1964) and only rarely spawned a second time. Rensel and Prentice (1977) however, showed that the female prawn can reproduce more than once in a lifetime. They held spawned females and male prawns in either the laboratory, floating net pens or benthic cages at different densities from August to October. It was seen that the density was not a factor for survival but prawns in the benthic cages (3.8 prawns/m^2) and laboratory tanks (16.7 prawns/m^2) had a much higher survival rate, 80% and 75% respectively. Eighty-five point four percent of the surviving females spawned a second time. The eggs were viable and developed normally but the fecundity was only 10 - 100 eggs per female. It was suggested that the low fecundity was a result of nutritional deficiency, environmental factors or that the females removed them from their abdomens. Further experimentation could prove whether or not the second spawning is useful for developing a laboratory bred broodstock for aquaculture.

2.4.1 Mating Behaviour

The mating behaviour is said to be similar to *Pandalus danae* (Butler, 1970). Mating generally occurs when the female has recently moulted and her shell is soft (Lee & Wickens, 1992; Needler, 1931). The female moults at night and develops long setae on the pleopods. Within 36 hours mating (perhaps stimulated by a secretion) and oviposition occur. The male runs up the back of the female and assumes a position with the anterior of his abdomen under the posterior part of her cephalothorax. The female is left with a loose mass of spermatozoa and oviposition takes place while resting on the bottom aided by the movement of her pereiopods. The eggs are passed from the oviducts between the pereiopods, where the spermatozoa is held, to the abdomen where they become attached to the pleopods and remain until they hatch. The eggs become fertilised as they pass over the sperm, which has a sharp head and sticks to the egg (Needler, 1931).

P. platyceros is included with those shrimps that require environmental or hormonal manipulation to breed reliably (Lee & Wickens 1992). Eyestalk ablation, a commonly used method to promote spawning of shrimp, tends to delay the change of sex in *P. platyceros* (Butler, 1980). Since males may reproduce more than once this method may enable one to manipulate an animal with desired attributes such as quick growth to provide a better quality of shrimp. Environmental factors such as changing water temperature or hormone injections are also used to promote spawning of various cultured species, so reproductive experimentation should concentrate on determining the best method for enhancing mating success. If certain secretions from the female promote mating as suggested by Needler (1931) then it would be very beneficial to determine their nature so they too can be utilised. Success in this area is essential to develop a productive broodstock and hatchery.

2.4.2 Sexing

To develop a self sustaining broodstock it will be necessary to distinguish between male and female. The male is generally smaller and more slender than the female with a relatively longer rostrum and antennular flagella and the chelae of the first pereiopods are longer and stouter as well. The spot prawn can be sexed by a couple of different means. The most obvious of which is the presence of eggs on the pleopods of the females. However female caridean shrimps are ovigerous only part of the year and if infected with parasites they may not carry any eggs at all. The most definitive method is to examine the endopods of the first two pairs of pleopods: (Butler, 1970 & 1980)

- Females: On the second pleopod, the female has a single process branching from the inner margin with minute hook-like setae on the distal end of the endopod (the appendix interna). The endopod on the first pleopod of the female is tapered and nib-shaped (Butler, 1980).
- Males: On the second pleopod of the male, there is another structure, the appendix masculina, between the appendix interna and the inner margin of the endopod. The appendix masculina is longer than the appendix interna bearing spines or spinules on the tip or laterally. Analysing the first pleopod is a quicker method by observing a clump of minute hook-like setae on the tip or inner lobe (if bifid) of the distal end of the endopod if male. The endopod is also tapered with a shoulder or protusion (Butler, 1980).

The openings of the paired ducts from the ovaries (oviducts) and testes (vasa deferentia) are located on the inner margins of the coxae of the third and fifth pairs of pereiopods respectively. The external changes from male to females take about five moults but the internal changes start before these are visible (Butler, 1980).

2.5 Disease

One of the many problems with farming any species is the potential of losing stock as a result of disease. Disease may be viral, bacterial, fungal or parasitic and could take control at any time in the life cycle of the animal. In culture conditions, stress resulting from various factors such as crowding, water quality, poor feed (or lack of), transferring stock and others, weaken the animals, making them prone to diseases. Most of the species being cultured world-wide have at one point in time been negatively influenced by disease, resulting in loss of stock and even financial ruin for the farmer. Shrimp farming has been successful for a long time but over the past few years farmers have reported numerous losses due to viral, bacterial and parasitic diseases. This has led to the development of SPF shrimp or Specific Pathogen Free shrimp as many countries have banned the importation of live shrimp for the purpose of culture. There is however no guarantee that SPF shrimp will not become exposed to a disease from the hatchery water supply or once they are transferred to pens in the ocean as proposed in this paper.

There are 11 different parasites which affect at least 50 different species of shrimps in BC however few are known to affect *P. platyceros* (Butler, 1980). Although the list of infectious diseases for *P. platyceros* is small, latent pathogens may become virulent if culture becomes commonplace due to increased stress of the situation (Wickens and Beard, 1978). Mortalities of *P. platyceros* due to diseases usually occur in the night during ecdysis making it difficult to observe signs (Wickens and Beard, 1978). Good husbandry techniques, water quality and nutrition are essential to minimise the loss resulting from disease especially in intensive systems where disease transfer is very rapid.

Wickens and Beard (1978) listed several general diseases which were either seen or were known to commonly occur:

- Septemic Fungus disease - blackened areas on the cuticle, usually associated with a wound, surrounded by a zone of reddening and extensive ramification of fungal hyphae in the body tissue. Progressive paralysis occurred and death followed shortly.
- Shell disease - brown black spots on the cuticle which decrease the market value of the animal but is not generally lethal to the prawn or humans
- White syndrome - individual prawns turned opaque white and muscular necrosis occurred afterwards
- Vibrio - not seen in *P. platyceros* yet but may possibly infect these shrimp. This disease is accompanied with a high mortality, 60 - 70%. The appendages erode and there is a loss of shell colour and reddening of the gills
- Filamentous growth on the gills - again this was not seen with *P. platyceros* but may be of concern in the future. There is a slight to heavy growth of filamentous micro organisms on the gills

Larvae of two trematodes and four nematodes have been observed in different local shrimp and although it has not been stated that they infect *P. platyceros* it is possible that under culture conditions the shrimp may be susceptible (Butler, 1980).

Wickens (1972) noticed that several of his shrimp showed symptoms similar to a mycotic disease and all specimens died at a length greater than 75 mm. There was severe damage to the pleopods and uropods that was characterised by thick blackened areas in the cuticle surrounded by a zone of reddening. There were also extensive ramifications of fungal hyphae. Wickens (1972) noted that the incidence of disease increased as winter set in and moult frequency declined with temperature. It was suggested that stress caused by low temperatures had reduced resistance to the pathogens and/or the longer intermolt periods of adults allowed time for pathogens to colonise and penetrate damaged areas of the cuticle.

Rensel and Prentice (1980) noted that mortalities were very high when there was a rapid increase in temperature and noted that plankton blooms were the primary cause for death with the prawns becoming covered with fouling organisms (*Obelia* sp. and the suctorian protozoan *Ephelata gemmipara*). Heaviest fouling occurred at the periopods and the ventral edges of the cephalothorax but the gills were unaffected. Many of the survivors were lethargic and did not feed or molt. They treated the prawns with a formaldehyde/malachite green dip 25 to 0.1 PPM for eight hours but the benefits were temporary, lasting only a few days. This is very relevant to any net pen prawn culture which may take place in British Columbia since the local salmon farmers experience heavy plankton blooms occasionally and must relocate the pens to maintain the health of the animals. Rensel and Prentice (1980) found that instead of moving the nets to a different location, which is time consuming and costly, they could lower the nets to colder, less lighted depths below the influence of the plankton bloom. This did not completely rid the animals of fouling organisms but their activity increased and moulting occurred within two days. Lowering the nets below the blooms increased survival to 92% compared with 100% mortality of prawns in the nets which were left on the surface. Lowering nets may be better than moving locations as stress on the animals would be minimised, allowing quicker recovery at a lower cost.

Most culture facilities will have viruses, bacteria or protozoans present no matter how stringent the management practices. Whether the animals develop a disease or not is usually a result of stress that has pushed them past the point where they can recuperate. Some diseases however have been spread by the shipment of stock between farms and countries leading to numerous problems world-wide (Bower et al, 1994). Presently the species *Macrobrachium rosenbergii* is under investigation for culture in B.C. (pers. comm. Bill Bennett) and one of the factors which must be considered is the possibility of disease transfer to the local wild crustacean stock. The farmer should learn to recognise signs of disease and stress such as a decrease in appetite, abnormal swimming or postural behaviour, a continuous level of mortality, infestations of epibiotic growths on the cuticle or eggs, increased cannibalism and moulting difficulties, discoloration, lesions and mass mortalities. Many illnesses are preventable by good management and husbandry practices including proper site selection. All efforts should be made to keep any stresses minimal and if necessary anti bacterial agents may be used although these may kill beneficial bacteria as well. Sometimes if the disease is serious enough the crop must be destroyed and the system thoroughly cleaned (Lee & Wickins. 1992).

3. Considerations for Culturing *P. platyceros*

There are several considerations which must made when preparing to culture an animal. Many of these are directly related to its biology but when animals are grown in artificial conditions, factors such as density, feed, environmental properties and others must be manipulated to ensure successful and profitable aquaculture. This section deals with some of those factors, including experiments which have already been performed to test the suitability of *P. platyceros* for culture and others which must yet be considered.

3.1 Broodstock

Most of the broodstock used in past experiments were obtained from the wild, often from local fishermen. Appendix I shows the various sites where prawn fisheries are active in British Columbia from which broodstock may be obtained. The gravid females are gathered and transported to the laboratory where they are incubated at appropriate conditions to hatch their eggs. This is suitable for experimentation and small culture operations, but is not the best method for supplying large commercial operations. Obtaining broodstock from the wild is an insecure method for a number of reasons. Year classes recruited into the nursery are inconsistent as shown by Marliave and Roth (1995) and low quantities in the nursery may indicate that the supply of mature broodstock will be limited in 2 - 3 years. The supply is also dependant on fishers' catch and if fishing is restricted for a year or more, the brood supply is eliminated. Disease is another factor that may occasionally be dominant in the wild, making any caught animals poor candidates for the production of successful stock in stressful farm environments. Pollution is another reason for developing a reliable broodstock. Over the past few years approximately half of Howe Sound was closed to fishermen due to dioxin and furan contamination (Bower et al, 1996), eliminating the possibility of broodstock from these areas.

Presently there is little published on the reproductive triggers for the spot prawn as with other species. Some species do not mature regularly so they are induced to mature sexually through eyestalk ablation which removes several glands that inhibit gonad development (Liao & Chen, 1983). For successful shrimp culture in Canada it is important for the industry to develop scientific methods to promote reproduction in the laboratory so that a reliable source of broodstock can be developed. Maturation of animals for breeding is routinely done in indoor tanks at low densities (6-10/m^2) with a high degree of control over environmental factors such as temperature, salinity and water quality. They are also fed a very high quality diet such as mussels or clams to help develop a good supply of healthy larvae (Lee & Wickens, 1992).

Another important factor when choosing a species to culture and developing a broodstock is the time to maturity. Animals which take a long time to mature should receive special attention until they are ready to be bred. A disadvantage of *P. platyceros* is that it takes three to four years before they mature (pers. comm. Jeffrey Marliave) and since harvesting is expected to take place sometime prior, several specimens will have to be kept under special care for several months. Many other species such as the penaeids take less than one year before they mature and have a higher fecundity (Lee & Wickens, 1992) so they are easier and cheaper to maintain as broodstock. Care must be taken as well to ensure that an alternative supply of animals is available. If all the broodstock are kept in the same hatchery, any problem that causes mortality in the lab can wipe out the entire broodstock.

3.1.1 Transportation of Broodstock

Broodstock obtained from the fishing grounds must be properly transported to the hatchery with minimal stress and shock to prevent damage to the females and their eggs. Traps are the best method of fishing for brood since the trawl method of fishing tends to crush many of the animals. For short distances, styrofoam or plastic live-holding containers filled with seawater (Price and Chew, 1972; Kelly, Haseltine and Ebert, 1977) are adequate. Wickens (1972) transported adult ovigerous prawns from B.C. to England in sealed polythene bags filled with half seawater, half air (or oxygen) and obtained high survival rates (>90%). For the 7 hour drive that followed the flight, they were transferred to 40 litre bins (containing water at 8°C and 35‰ salinity) with baffles to reduce splashing and a supply of oxygen. Whyte and Carswell (1982) determined that for live holding of P. platyceros, salinity ranges should be between 25 - 35‰ (30‰ optimum), with a minimum temperature and oxygen level of 5°C and 3.5 mg/litre respectively. The population density should also be minimised for transportation as increasing the density from 1 - 4 prawns/100cm^2 can increase mortality to 27.7% (Whyte and Carswell, 1982). Keeping the animals starved throughout the transportation period is also advised since their metabolism will decrease (Whyte and Carswell, 1982), making them less prone to injury from physical activity. It is very important to get the prawns to the hatchery with minimal stress to assure a healthy supply of eggs for culture, so strict guidelines should be developed and followed.

3.2 Density

To ensure economic success for the project, the minimum density must be determined so that each net pen produces an adequate number of prawns to cover all incurred costs and make a profit. However the carrying capacity of the operation and biology of the animal must be balanced to establish a feasible operation with minimal stress. Increasing the densities in any captive situation will increase stress on the animals. This in turn can result in the development of diseases, decreased growth rates, poor food conversion ratios, cannibalism and a lower water quality. There are four general levels of shrimp farming which describe the relative densities in which animals are cultured (Lee and Wickens, 1992):

- Extensive Culture - this is a low density culture method often used in polyculture situations. Water exchange is minimal or nil and the supply of animals is usually from the wild. Annual yields are up to 1000 kg/ha, with each pond being harvested up to three times a year. The food supply for this method is often from natural production within the ponds and may be enhanced with fertilisers or manure.
- Semi-intensive Culture - the animals are held either in mono or polyculture scenarios at moderate densities producing between 500 - 5,000 kg/ha annually. The animals are supplied from either the wild or from the hatchery. Water exchange is again low and feed is supplied through natural productivity, often supplemented with low quality artificial feed. Aeration is sometimes necessary at these levels to prevent asphyxiation.
- Intensive Culture - This is a high density monoculture operation. Water exchange is essential and at high percentages daily. The animals are supplied mainly through hatchery and nursery reared stocks and yields range from 5,000 - 15,000 kg/ha. They are fed an artificial diet with occasional supplements of fresh meat (fish or mussels). Aeration is essential and regular.

- Super-intensive culture - this is a very high density operation with yields of 10,000 - 30,000 kg/ha possible. This method is completely dependant on artificial feeds and enclosed systems such as tanks or raceways so the operator has a high degree of control over water quality and flow. Water is exchanged continuously at a high rate and aeration is usually constant. The shrimps are all hatchery reared and fed artificial diets to express maximum control over the animals well being.

Tropical shrimp farming operations use large earthen ponds or man made tanks that allow water flow and quality to be easily monitored and controlled. This control makes it easier to study and understand the animal in order to develop systems capable of carrying greater densities of shrimps. This will not be the case of net pens used to rear *P. platyceros* in BC as the grow out sites will be exposed to natural environments. Research has not yet established a maximum density for *P. platyceros* to grow well without high mortalities. The prawn, is however, a hardy species and fishers commonly keep them alive in overcrowded netpens or benthic cages for up to ten days with no mention of ill effects (Butler, 1970). Early attempts to grow *P. platyceros* for commercial harvest would most likely start as an extensive or semi-intensive operation until the animals are domesticated allowing increased densities. Table 3-5 (page 43) presents the densities of some successful experiments. From one year of experimental culture, Rensel and Prentice (1979) obtained 74 g/m^2 of *P. platyceros* from nets to which no feed was added (for the shrimp) and 155 g/m^2 from nets in which mussels were fed to the shrimp. These yields are favourable when compared to those of extensive culture operations, which have a suggested yield of up to 100 g/m^2 (Lee and Wickens, 1992) and the lower scale estimation of semi-intensive systems of 50 g/m^2 and up (Lee and Wickens, 1992). It seems likely that *P. platyceros* can be grown in sufficient densities to produce harvest levels which other shrimp farmers find suitable. Table 3-1 (page 35) compares the harvest yields of *P. platyceros* raised by Rensel and Prentice (1979) to those of some other species raised in extensive to semi-intensive systems.

Table 3-1. Comparison of yields from some low density shrimp cultures.

Species	Annual Yield (g/m^2)	Live Weight (g)	Reference
P. platyceros	74 - 155	7.3 - 8.6	Rensel & Prentice, 1979
Penaeus vannamei	115 - 173	15 - 25	Lee & Wickens, 1992
M. rosenbergii	140 - 221	> 30	Lee & Wickens, 1992
Penaeus monodon	100 - 150	26 - 39	Lee & Wickens, 1992

This comparison indicates that the density in which *P. platyceros* have been experimentally raised may be suitable for commercial growth and, with further research, farmers may be able to increase the density to more profitable levels. Wickens (1972) obtained a yield of 492 g/m^2 from a stocking density of 185 prawns/m^2 over 23 weeks. This compared quite favourably with other species tested but conditions were ideal, being in the laboratory using expensive fresh feeds, which are not practical for commercial farmers. There are other factors which have to be considered that are directly related to density and production values such as the size of the shrimp produced and what impact that will have on their marketability. Table 3-1 (page 35) also shows that the size range of *P. platyceros* produced is much smaller than the others, making them less desirable and profitable in the market place. Generally the lower stocking densities result in larger, higher valued shrimp (Lee & Wickens, 1992). So even though yields appear to be adequate, the value may still not cover the cost of production. Density of a second species in the net must also be considered if prawns are to be grown in a polyculture system. In the polyculture system of Rensel and Prentice (1979), *P. platyceros* (9.3 animals/m^2) shared net pens with coho salmon at a density of 82 animals/m^3. These results are very positive but some common husbandry practices of salmon farming were not followed such as the removal of morts. They remained in the net pens and were used by the shrimp as feed. This practice would most likely not be embraced by salmon farmers in a polyculture situation for fear of spreading disease to the rest of their stock. It must also be determined whether decreasing the density of one species in order to grow a second in the same cage is the best economical move to make. The combination of species should have some distinct economic benefit over monoculture of either species alone. Combining two species together in culture conditions is very risky. Each species must be thoroughly understood and the benefits of polyculture must outweigh the added risk.

3.3 Dissolved Oxygen (DO)

There is little discussion in many of the experiments performed on the oxygen requirements of *P. platyceros*. The dissolved oxygen can be monitored in the hatchery using detectors available from a variety of aquaculture suppliers and adjustments can be easily made. In floating net pens in the open ocean there is little control over many variables including DO. Dissolved oxygen levels must be monitored as large variations may cause undue stress and increase mortalities. Decreases in the DO can be caused by such natural occurrences as plankton blooms or by an increase in biochemical oxygen demand (BOD) often associated with pollution. If severe decreases in DO occur, it may be necessary to move the pens, as done with salmon nets inflicted with severe plankton blooms, or lower the pens to depths unaffected by the causative agent as suggested by Rensel and Prentice (1980). If low DO levels can be anticipated, such as with the case of some plankton blooms, then a proactive measure should be taken to minimise stress on the animals.

Whyte and Carswell (1982) determined that the critical ambient oxygen level was between 3.5 to 4.0 mg O_2/l (at 30‰). Below this level, metabolism of the prawns decreased, eventually leading to asphyxia when levels declined to 0.5 mg O_2/l. The critical level of oxygen concentration increased to 5 mg O_2/l when the salinity was lowered to 20‰ at 5°C and asphyxia occurred at 2.25 mg O_2/l. Inadequate DO in the water at these conditions may be partially responsible for deaths seen in various experiments (Whyte and Carswell, 1982).

Rensel and Prentice (1980) noted that the DO levels for their net pen sites ranged from 5 - 11 PPM throughout the experiment. The lowest level lasted only a few hours during some tides and did not seem to affect the prawns. Though there was a major problem with plankton blooms at one of their experimental sites, there were no problems associated with low DO. This observation does not diminish the need to monitor DO levels both in the hatchery and in the net pens as fluctuations in this variables can be rapid and detrimental.

3.4 Temperature and Salinity

Temperature and salinity are very important variables that need to be determined prior to setting up a hatchery and grow out operation. Survival and growth can both be affected by changes of these variables. British Columbia's temperate climate limits the number of suitable species for culture to those that grow well in cold water. The farmer could opt to heat the water supply to suit an animal with a proven background but this raises the cost of production considerably. *P. platyceros* is an encouraging species because of their lack of rigid environmental requirements, meaning that minor changes in climatic variables may not be immediately detrimental (Wickens, 1972). Poor water quality, including variations in temperature and salinity can stress the animals being reared resulting in disease and possibly high mortalities. In the natural environment the salinity range is 26 - 31‰ with the adult population preferring temperatures between 7 - 11°C while the larvae and early post larvae inhabit waters with ranges of 0 - 18°C (Wickens, 1972). Culturing shrimp usually requires holding them through more than one stage so it is important to understand the requirements for each level of the system.

3.4.1 Transport of BroodStock

Whyte and Carswell (1982) determined that the transportation of live animals should be performed at 5°C and between 25 - 35‰ salinity.

3.4.2 Incubation Period

The temperature at which females are held during the incubation period will affect the viability of the larvae once hatched. Wickens (1972) showed that the time of incubation could be shortened by increasing the incubation temperature but the number of larvae successfully metamorphosing to PL decreased (although not statistically significant). He also found that the proportion of PL that developed was affected by the length of incubation at a certain temperature. The highest percentage of PL which developed were those held at 11.0°C for 45 days (51.1% survival to PL). The percentage of survivors decreased as either the temperature or days of incubation were varied. This agrees with the findings of Price and Chew (1972) who determined that the eggs of females incubated at 11.0°C produced better larvae than those at 13 - 15°C. Although the time required to hatch at lower temperatures was longer, it is more important to produce a healthy larval population with better survival rates than try to decrease incubation time.

3.4.3 Larvae

Increasing the temperature at which the larvae are held will increase their development rate thereby decreasing the time spent as larvae. Table 3-2 (page 38) shows that by increasing the temperature the survival of the animals is only minimally affected and the time to metamorphosis is decreased by several days. Wickens (1972) determined that the best rearing temperature for larvae is between 14 - 15°C.

Table 3-2. The effect of temperature and density on survival and development of *P. platyceros* larvae.

Density (#/l)	Temperature (°C)	Total Survival (%)	Days until 50% are PL
5	13.0	90	25
	15.0	90	22
10	11.0	77	29
	12.5	73	20
	15.5	80	15
15	12.7	35	26
	15.2	15	21

(Wickens, 1972)

The salinity for incubation period, larvae and post larval stages is generally kept around 30‰. *P. platyceros* larvae have been grown in salinitys ranging from 26 to 30‰ with no ill effects (Wickens, 1972).

3.4.4 Post Larvae and Adults

Varying the water temperature used to rear PL, Wickens (1972) determined that the optimum salinity and temperature was 30‰ and 18°C respectively. Survival decreased when the salinity dropped below 26‰ and growth decreased when the temperature rose to 20°C or more. Growth rates generally decline with a drop in temperature but with a sustained increase in temperature (23°C for seven to eight days) there is also decreased growth accompanied with an increase in disease and prawn mortality (Wickens, 1972). Prawns raised in outdoor tanks grew well in water temperatures ranging from 0 - 24°C reaching a mean weight of 4.9 g (73% survival rate) in a six month period but then they began showing signs of disease. The conditions above are comparable to those of other experiments performed. Whyte and Carswell (1982) determined that the lower lethal temperature is about 3°C and the lower salinity level is 21.3‰. Kelly, Haseltine and Ebert (1977) showed that mortalities increased from 20 to 100% between 21.3 and 26.0°C and that the LD_{50} (48 hour test period) for temperature was 22.9°C. They also showed that the 48 hour LD_{50} for salinity was 20.4‰ and that in general mortalities increased dramatically below 22‰.

Water temperatures in B.C. at depth rarely get high enough throughout the year to be a problem but if prawns are kept at the surface or inside greenhouses for their early development, as are some species, water quality monitoring may be crucial to prevent any temperature related deaths, growth restriction or disease developments. Salinity must also be monitored in the hatchery environment or in greenhouses since water evaporation from the tanks will alter the salinity, potentially leading to health problems. Salinity levels may also fluctuate in the net pens as winter runoff or heavy autumn rains may decrease the surface salinity, leading to osmotic problems or fungal infections (pers. comm. Jeffrey Marliave). It is evident that these qualities must be maintained as constant as possible to obtain optimum survival and growth rates for the successful operation of any commercial culture operation.

3.5 Growth and Survival

The growth rate of the animal under consideration for culturing is one of the most important variables when determining its suitability to be raised for economic gain. Over the last decade or so there has been an oversupply of small to medium shrimp that are of lower value and not as profitable for the shrimp aquaculturist (Lee & Wickens, 1992). Faster growing larger animals are much more desirable because the return on investment is realised quicker as will recovery from any crop failure (Lee & Wickens, 1992). In the wild, juvenile shrimp more than triple their weight in the first year and then grow as much as another 155% in the second year. The rapid growth may be explained by the amount of feed readily available after late summer and autumn plankton blooms (Butler, 1964). Wickens (1972) suggested that they may be able to reach market size (8 - 10 g) in one season. In fact, edible size is considered to be about 5 g which is obtainable in less than one year. In southern BC they are recruited into the trap fishery after one and a half years which would make them approximately 12 - 13 g (Butler, 1970). Growth of *P. platyceros* tends to follow a seasonal pattern with fastest growth occurring during the summer and early fall, then slowing down over the winter months (Butler, 1964; Marliave and Roth, 1995).

Shrimp farms often have three different stages where growth and development are monitored: the hatchery, nursery and grow out site. The hatchery is designed to suit the needs of the animal from hatching to the post larvae stage or some time shortly thereafter. The PL are then transferred to a nursery site where they are raised to a juvenile stage, weighing between 0.1 - 2 g (depending on the species) before they are transferred to the grow out ponds or cages (Lee & Wickens, 1992; Williamson, 1968). They remain in the final site until they are harvested for market. Densities are usually lowered in each successive step to suit the needs of the growing animal and to provide conditions suitable for the best returns. *P. platyceros* hatch at a more advanced stage than most cultured penaeids so it may be possible to combine the hatchery and nursery rather than having three distinct structures (Williamson, 1968). There will also be a certain percentage mortality in each stage of the operation which must be accounted for and as with any population there will be a range of sizes at any one time. Populations of all cultured animal consist of quick growers that can be harvested early, groups that follow the normal mean growth patterns and runts which should be weeded out to prevent them from slowing the rest of the population by consuming food and space. There has been very little work reported in the literature that deals with variable growth rates in coldwater shrimp. It may be worthwhile investigating this area to determine the percentage of animals which will not reach market size. Understanding the growth patterns of these animals in captivity will enable one to know whether it is necessary to grade the animals and if so, how often.

3.5.1 Larval Growth

The larvae of *P. platyceros* remain in the hatchery for at least 15 - 35 days at which time they all should reach stage V when they are considered to be PL (Kelly, Haseltine and Ebert, 1977; Wickens, 1972). They measure only 2.4 - 3.0 mm carapace length (CL) (mean 2.74 mm) and weigh less than one gram (Kelly, Haseltine and Ebert, 1977). The largest percentage of mortality occurs during the first two weeks during ecdysis from stage I to II (Kelly, Haseltine and Ebert, 1977). Kelly et al found an average of 46% survival (0.11 larvae/cm^2) to stage V while Wickens (1972) obtained 81% survival (25 larvae/l) when the seawater was filtered. Many experimenters kept the larvae in the same tanks until at least stage IX when their average size range would be approximately 4.9 - 5.5 mm CL. Mortalities can be high in the hatchery but proper planning can assure that there will be the required number of animals for harvesting. Relatively little time and energy has been expended during this period, and by calculating the overall expected percentage survival, the hatchery can provide the necessary supply to the nursery.

3.5.2 Nursery Growth

There is little mentioned in the literature about the use of separate nursery systems for the culture of *P. platyceros*. Most researchers grew the prawns wholly in the laboratory or transferred them to net pens in the first July post hatching at which time they averaged 5.3 mm CL (< 1 g) (Rensel & Prentice, 1980). Table 3-3 (page 41) compares the nursery stage of four different cultured crustaceans.

Table 3-3. Survival and Growth Comparison of four different crustaceans in the nursery.

Species	Period (days)	Survival (%)	Growth (g)	Reference
Penaeus monodon	14	100	0.15 to 1.27	Forster & Beard, 1974
Penaeus vannamei	45 - 50	> 60	PL5 to 1 g	Lee & Wickens, 1992
M. rosenbergii	60 - 120	17 - 76	PL5 to 1 g	Lee & Wickens, 1992
P. platyceros	60	98	0.63 to 2.8	Oesterling & Provenzano, 1985

It shows that *P. platyceros* grows reasonably quickly from PL to a juvenile, taking only two months, and compares well to species which have an established history of commercial culture. It is likely that the technology used in nurseries of other species could be transferred and used for *P. platyceros* or some combination of nursery/growout site could be developed.

3.5.3 Growout

This is the most important stage for growth and the most expensive for the aquaculturist. It is in this stage that the animal will remain until it is harvested for market. Cultured animals are usually fed more expensive feeds and more man-hours are spent at this stage, therefore mortalities are more costly. This stage provides the most serious drawback in the argument for using *P. platyceros* as a culture species. As shown in Table 3-4 (page 42) the time for *P. platyceros* to reach a size comparable to that of other commonly grown species is much longer. Whereas the turnover rate for the other species is short, growers of *P. platyceros* must wait longer before harvesting, therefore making it more difficult to recover losses.

Table 3-4. Survival and Growth Comparison of four different crustaceans in the growout site.

Species	Period (days)	Survival (%)	Growth (g)	Reference
Penaeus monodon	80 - 225	30 - 80	21 - 33	Forster & Beard, 1974
Penaeus vannamei	67 - 164	40 - 90	7 - 23	Lee & Wickens, 1992
M. rosenbergii	90 - 150	40 - 60	25 - 45	Lee & Wickens, 1992
P. platyceros	540	10 - 85	10 - 18	Oesterling & Provenzano, 1985

Experimenters, using a variety of conditions and environments have been able to meet or exceed the growth rates that are seen in the wild. Although it has been determined that the animal reaches consumable size within one year, the best size to harvest them must be based on an economic analysis. It may be more profitable to grow them for a longer period of time if the consumer is willing to pay more for a larger animal.

Figure 3-1 (page 42) presents the growth rates of *P. platyceros* achieved in some experiments and compares them to the growth rate found in the natural environment. Some of the experimental conditions in which the animals were held for these trials are shown in Table 3-5 (page 43) and can be directly related to the graph (Figure 3-1, page 42).

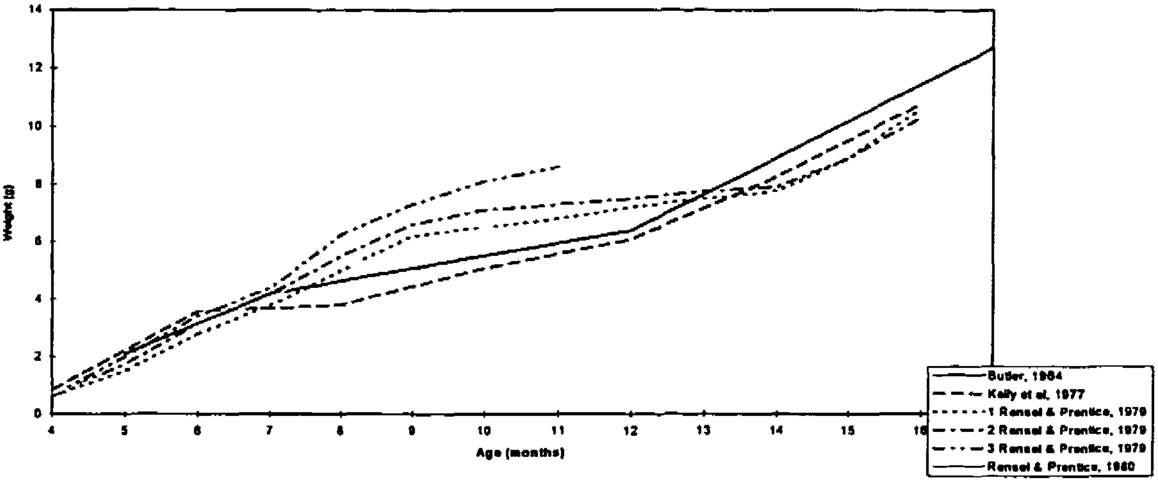

Figure 3-1. Growth Comparison of *P. platyceros* under different Experimental conditions.

Table 3-5. Experimental Information for Figure 3-1 (Page 42).

Temperature	Salinity	Survival (%)	Feed	Density (#/m)	Reference
7.61 - 10.97	26.42 - 30.83	NA	NA *	NA	Butler, 1964
9.5 - 21.0	34	≥ 80	Varied **	4.4	Kelly et al, 1977
NA	NA	69	Mussel	30.8	2 Rensel & Prentice, 1979
NA	NA	64	Salmon	30.8	1 Rensel & Prentice, 1979
NA	NA	93	Unsupplemented***	9.3	3 Rensel & Prentice, 1979
16.5	28.4 - 31.0	79	Mussel	7.1	Rensel & Prentice, 1980

* Wild Populations

** Experiments were performed with various diced foods.

*** No feed was given directly to the shrimp. Food consisted of whatever they could obtain including: Salmon Mortalities, uneaten fish feed, salmon faeces and net fouling organisms.

1 & 2. Prawns were grown in a monoculture system.

3. Prawns were grown in a polyculture system with coho salmon ($82/m^3$).

The results of Rensel and Prentice (1979 & 1980) are most interesting as they best represent the environmental and culture conditions of those being considered for growing *P. platyceros* in B.C. They cultured their animals both in the laboratory and in net pens at different sites in Washington state. Since the use of net pens is the most likely method for culture in B.C. it best represents what may be found in similar operations here. Rensel and Prentice (1979) found that prawns fed diets of fresh mussels or salmon grew significantly slower in the laboratory than in net pens in the ocean and that there was no significant difference in survival in either of the two experimental groups. This was probably because the presence of fouling organisms in the net pens provided essential nutrients absent in the laboratory diets (Rensel & Prentice, 1979). They also managed to achieve growth rates which exceeded that experienced by the wild populations until late in the year when growth slowed and the wild population overtook the experimental populations. The decline in growth corresponds to that seen in the natural population and may be associated with decreased water temperatures and a decline in food availability. The natural environment for these animals is deep on the floor of the ocean where they may be less susceptible to food shortages and fluctuations in temperature and salinity than at the surface in net pens, which may explain the more dramatic decline in growth. Kelly et al (1977) also found that growth rates were slower in the lab than those in the wild (Butler, 1964) even when the animals were fed a variety of diets. The most significant result is probably the experiment which cultured *P. platyceros* in the same net pen as coho salmon (Rensel & Prentice #3, 1979). Growth rates were very fast, over 7 grams in 7 months with very little mortality and their final weight exceeded other experiments by more than one gram through the same time period. These animals were not fed any diet directly but allowed to scavenge what they could from their environment. They were determined to have consumed a diet consisting of salmon mortalities, uneaten fish pellets, salmon faeces and net fouling organisms (Rensel & Prentice, 1979). The percentage survival for other experimental groups was lower than with the polyculture experiment but they were grown at higher densities and for a considerably longer period of time. It is unknown whether there were periods of higher mortality or if losses were consistent throughout the duration of the experiments. Minimum survival in the growout phase was 64%, which may be a bit low for commercial purposes, but with more research and with domestication it may be possible to achieve higher survival rates, as demonstrated by some of these experiments.

P. platyceros are still quite small and slow growing compared to most commercially cultured shrimp throughout the world. Comparing the grow out phase of three commonly grown crustaceans to *P. platyceros* (Table 3-4, page 42) shows that the overall survival is comparable to the others and is acceptable since most experimenters found survival rates to be towards the higher end of the range given in the table. The size harvested is also within the acceptable range of other species but the growth period is much longer than any other species and should crop failure occur towards the end of the cycle it would make financial recovery difficult. This also makes them less profitable since the cost to grow them for an extended period of time is higher. Some *Penaeus vannamei* farms harvest three crops annually resulting in a quicker return on investment than would be realised from a *P. platyceros* farm.

3.6 Food

3.6.1 Introduction

As with most species energy requirements are supplied by carbohydrates, proteins and fats (Pillay, 1990). The quality and quantity of feed is very important to maximise growth and produce a healthy, attractive animal. The frequency and time of day of feeding are also very important and must coincide with the animals physiological needs to attain maximum growth. (Robertson and

Lawrence and Castille, 1993). Nutritional requirements at the juvenile stage should be met with food similar to that which they would find in nature.

3.6.1.1 Larval Feed

Good quality food is important at this stage to achieve good survival throughout the many molts and stages that the animal must pass. The young shrimp molt often and availability of ions such as calcium and bicarbonate as well as the correct pH is crucial at this point for the mineralization of the new shells (Pillay, 1990). Larval feed is often supplied in the form of phytoplankton or zooplankton which they commonly consume in the wild. The following is an example of some food used in the culture of many crustacean species.

- Algae:

The most common algae used for shrimp feed are *Tetraselmis*, *Chaetoceros*, *Isochrysis* and *Skeletonema*. These are provided from the fifth nauplii stage to the post larvae stage and are quite often grown on the farm to ensure a good supply and quality for the shrimp. Algae are commonly used on Penaeid farms but may not be as suitable or necessary for P. platyceros as will be discussed in the following pages.

- Rotifers:

Rotifers are becoming more important as a food source for shrimp as some species are considered to be more nutritive than Artemia. They may be used as supplement or replacement for Artemia.

- Artemia:

Artemia are often used for food in crustacean hatcheries when the shrimp are in the Zoea, Mysis and Post Larvae stages and are used either fresh or frozen. Fresh Artemia provides good nutrition, the value of which can be affected by a number of factors such as the different strains, modes of harvesting, handling and hatching.

3.6.1.2 Adult Feed

The juvenile and adult shrimp are able to eat detritus and benthic micro-organisms, scavenge on non living material or feed as predators and may even become cannibalistic if overcrowded or underfed. In extensive systems and semi-intensive systems organic and inorganic fertilising of the pond promotes the growth of these natural feeds which, along with artificial feeds, can sustain the shrimp and provide a source of oxygen for the pond. The more intense the farm, the more it must rely solely upon artificial feeds since the importance of water quality increases with density.

3.6.2 Dietary requirements and development for *P. platyceros*

The nutritional requirements of any species under consideration must be understood for obvious reasons. Artificial feeds must be palatable, provide high survival rates, quick growth, a low feed conversion ratio (FCR) and must be environmentally friendly. The goal is to develop an economical diet which will enable the prawns to grow quickly to a desirable market size with the least amount of food expenditure at the lowest price possible. The quality of the food is important as in keeping with the old adage "you are what you eat", poor quality food can produce shrimp with an odd taste or texture that will reduce the market value of the final product. Understanding the natural diet of *P. platyceros* will enable one to best develop an artificial diet which will satisfy both the animal's and farmer's requirements alike. It is difficult to produce an artificial feed which is nutritionally complete. Some of these missing elements may be obtained from the natural environment, which is one of the benefits of growing prawns in ocean netpens where they are exposed to naturally occurring organism that have been shown to supplement artificial diets.

Prawns are considered messy eaters, manipulating and breaking up pieces of food outside their mouth, thereby losing much material. Pellets must be bound together chemically to decrease waste. Carboxymethylcellulose, polyvinyl alcohol, agar and guar gum are some examples of binding materials used to hold pellets together for various species of cultured animals (Wickens and Beard, 1978). A good quality food is necessary for a good FCR, which is the ratio of the weight of food consumed to the increase in prawn weight. Some experiments testing several natural food types have produced good growth but may have some disadvantages (Wickens and Beard, 1978) over pellets such as:

- rapid decomposition creating deoxygenation,
- they may have a higher cost than pellets,
- they may need daily preparation whereas pellets may be stored for later use,
- stores of natural foods may be more vulnerable to weather changes, causing them to rot,

- seasonal variation in availability and quality can limit their nutritional benefits.

Quality food is also important for moulting as Rensel and Prentice (1980) found that using clams for feed (versus an unsupplemented diet) produced a population which had a higher percentage moulting together. This would tend to somewhat limit the variability of size at harvest time. The energy levels found in food is also an important factor for growth as Wickens and Beard (1978) noted that ingestion rate decreased with a high energy diet resulting in decreased growth.

Cannibalism is one trait often seen in the culture of many shrimp, especially in crowded intensive conditions. This may cause many losses to the farmer, decreasing the overall profitability of the operation. In artificial culture conditions *P. platyceros* will sometimes eat dead relatives but generally the literature indicates that this problem is minimal. Observations of cannibalism are mixed and vary between the different stages of shrimp life but it seems that some degree of cannibalism is common. In British Columbia, researchers have found that cannibalism is a major issue causing high mortality (pers. comm. Chris Campbell). They are especially susceptible when they molt (pers. comm. Jeffrey Marliave). Ensuring adequate food provision, grading, maintaining good husbandry practices, increasing habitat complexity and minimising stress may help to minimise this behaviour.

The diet of shrimp in general is quite varied. Upon hatching the larvae can grasp and feed on minute copepods and newly hatched *Artemia* or they can live up to 11 - 13 days on their stored yolk (Price and Chew, 1972; Kelly, Haseltine and Ebert, 1977). Juveniles and adults are predators, feeding on a variety of animals preferring small worms and crustaceans (Wickens and Beard, 1978; pers. comm. Jeffrey Marliave). The nursery habitat seems to be favourable for quick growth as there is an availability of naturally occurring plankton and algae from the annual blooms as well as various scavenging organism (amphipods and mysids) on which to feed (Butler, 1964). Once on the rocky bottom at deeper depths they adapt well to feed on the epifauna and the detritus in nearby mud (Butler, 1964). The analysis of stomach contents of 24 prawns near Vancouver showed that their diet consisted largely of polychaete worms and crustaceans (Butler, 1980).

There have been several experiments to determine the best feed for *P. platyceros*. The larvae of *P. platyceros* can be fed *Artemia* right away instead of requiring algae for the first few molts as do many other shrimp species (Wickens and Beard, 1978). Wickens (1972) showed that larvae can easily catch and eat either newly hatched (0.6 mm) or partially grown (2 mm) *Artemia*. Neither growth nor survival were affected by the size of the *Artemia* used. However the cost of the algae, *Isochrysis galbana* (500 - 1000 cells/ml), used to feed the *Artemia* (Kelly, Haseltine and Ebert, 1977) would increase the overall cost of the operation so if the difference is negligible, smaller *Artemia* would be preferable. Kelly, Haseltine and Ebert, (1977) tested a number of diets on the larvae and adult prawn. They found that a combination of *Phaeodactylum tricornutum* and *Artemia salina* produced a higher growth rate than *Artemia salina* alone but there was a decrease in survival which combined with increased cost would tend to outweigh any benefits of increased growth. Combinations of *Artemia* and other algae produced higher mortalities indicating that feeding *Artemia* alone may be the best diet for larval *P. platyceros*.

Once the animal undergoes metamorphosis into the post larvae stage it must be weaned off its larvae diet of crustaceans and algae, onto a feed more suited to adult life. Wickens and Beard (1978) were able to wean their shrimp after 7 - 9 days post metamorphosis. This is a very critical phase often resulting in heavy mortalities but is also very important for the continued development of the prawns. Many of the experiments in the past tested diets unsuitable for culture due mostly to the expense of obtaining them. Feed trials with the post larvae suggested that a combination of diced sea mussel and sea urchin provided the best growth with a FCR of 5.5:1 and a good survival of 80%. This was two fold higher than feeding a diet of sea mussel alone. This FCR is still very high compared with other species and Wickens and Beard (1978) suggested that a FCR of just 2.5:1 is desirable. One must also consider the expense of the feed in the above case. A diet of sea mussel and sea urchin would be very expensive and difficult to obtain on a regular basis. Wickens (1972) fed diets of *Mytilus* flesh (gonads), frozen shrimp (*Crangon*), live worms (*Lumbricillus*) and a compounded diet of Norwegian shrimp meal. This was determined to be suitable for the experiments, producing growth to 5g within one year but again it is unsuitable for commercial mass culture of the animal. Researchers on Vancouver Island have found that feed conversion rates as low as 1.5:1 or less may be obtainable for shrimp raised in net pens (pers. comm. Chris Campbell) This may be attributed to a better artificial diet supplied to the animals and the availability of natural organisms in the water which they may consume. Lee and Wickens (1992) report FCR's from between 1.4:1 to 9:1 for different crustaceans and feed types so these findings are within reason of other reports.

3.6.3 Development of Pellets for Shrimp Feed

There are many considerations when choosing an artificial diet. Fatty acid requirements such as linoleic (18:2 n-6), linolenic (18:3 n-3), eicosapentaenoic (20:5 n-3), docosahexaenoic (22:6 n-3) and other n-3PUFA'S are important for marine shrimp. Energy supply is very important as the protein:energy ratio is critical to ingestion, utilization and growth. A ratio of 0.07 to 1.0 with a protein content of 25-35% has given good results with other shrimp. Sufficient vitamin supply is also important, for example vitamin C is required to prevent deficiency and "Black Death" syndrome in *Penaeus vannammei.* The minimum quantity of ascorbic acid-equivalent/kg is 120mg for shrimp weighing 0.1g and 90mg for shrimp weighing 0.5g. So vitamin C content of food can decrease as the shrimp grow (He & Lawrence. 1993). Diets with up to 18% shrimp by-products instead of fish meal and soybean meal have been shown to significantly increase the final weights of *P. vannamei* (Cruz-Suarez et al. 1993) and may do the same for *P. platyceros.* Feeds with a higher pH can increase food consumption by shrimp thus increasing growth, however this increase is correlated with higher food conversion ratios. This may be beneficial if the cost of the extra feed is outweighed by extra profit of larger shrimp (Lim. 1993). Adequate minerals such as Zinc are also important for growth. *P. vannamei* require about 33 mg/kg for full growth (Davis and Lawrence. 1993).

Pellets used for other shrimp species were initially tried as a basis to develop feed for *P. platyceros* but they were not readily accepted and proved unsuccessful (pers. comm. Chris Campbell). The amino acid and lipid content of the prawn has since been analysed in order to try and determine their requirements. Krill is readily accepted by the prawns and has been used in combination with various supplements to develop a feed that has proven to be successful in recent trials (pers. comm. Chris Campbell). This diet is only experimental and would not be feasible on a commercial level since the cost of krill is too expensive for large scale operations. It does however, make a good starting point from which to base other trial diets. Dominy and Lim (1990) showed that substituting fish meal with up to 28% soybean meal gave equal growth to a control diet of 53% fish meal. Soybean meal and other plant by-products are much cheaper alternatives to expensive fishmeal. The main difficulty is to find a food the animal will readily consume and then experiment with various formulas from there.

The use of feeding stimulants is becoming increasingly important in shrimp feeds as they enhance the animals response and lead to superior feed utilization. Feed conversion is often related to the feed being recognised as such by the shrimp. Chemoattractants are being used more commonly in pelleted feeds. They consist of an attractant to provoke a response in the shrimp, an incitant to evoke the initiation of feeding and a stimulant to promote the ingestion and continuation of feeding. These stimulants can be very effective at increasing growth and feed conversion rates. (Meyers. 1991)

Trace minerals are necessary for proper growth, development, and survival of shrimp and their addition to pelleted feed is essential. The amount of trace mineral required from food varies with the trace mineral concentration in the water. The amount of minerals required for maximum production is not well understood and there are also problems with their bioavailability (Murphy. 1991). Iron, Copper, Cobalt and Magnesium are all crucial and must be present in adequate quantities for survival and greater growth (Chuang. 1993).

Phospholipid supplements are also an important additive to feed as they are not all synthesized by the animal. Soy lecithin has been shown to increase feed conversion ratios and provide energy to shrimp. Lecithin is a good source of phospholipids, triglycerides and fatty acids. It mobilizes and assists in the absorption of dietary cholesterol in shrimp and provides a source of choline, inositol and unsaturated fatty acids. It also acts as a chemo-attractant which can eliminate or reduce the need for fishmeal as an attractant. Lecithin is particularly good for the young because their underdeveloped digestive tract has a limited ability to synthesize adequate phospholipids. Lecithin increases growth and survival, improves extrusion efficiency, and possesses binding capabilities. In addition to decreasing the oxidation of vitamins, it stabilizes fat soluble vitamins and reduces leaching of water soluble nutrients. (Personal communication ADM lecithin).

Knowing the dietary requirements of *P. platyceros* will assist feed companies to develop a suitable pellet. Commercial culture of this animal is still a few years away and it is unlikely that a specific pellet will be available in the near future. Moore-Clark, Rangen and individual researchers have provided experimental diets for growth trials over the past few years and continue to work on new formulas (Chettleburgh, 1996; pers. comm. Chris Campbell). With the success of trial diets and the commitment to proceed with new formulas, a suitable, affordable diet should be available if commercial culture of *P. platyceros* proceeds.

4. Shrimp Culture Facilities

The aquaculture facility consists of several different modules of operation. Typically there is a distinct separation between the hatchery, nursery and growout operation. Along with the different physical structures there are individual characteristics for each unit. This section briefly discusses these differences.

4.1 Hatchery

The hatchery consists of both indoor and outdoor tanks and may also be responsible for the production of larval food such as algae or *Artemia*. It is in the hatchery that the broodstock will be bred and matured until the eggs are hatched. It is also in the hatchery that larvae released from the female will be gathered for rearing. The larvae will be raised until they are about four or five months old (Rensel & Prentice, 1979 and 1980). The goal of the hatchery is to closely mimic the natural environmental conditions of the animal with the best possible conditions both biological and physical, yet at an affordable cost (Jory, 1996b). Due to the high capital costs of setting up a hatchery and the present shortage of customers for juvenile *P. platyceros* the production of these animals would best be from an established shellfish hatchery where the necessary equipment is in place and any added costs could be minimised. The reduced larval life of *P. platyceros* is beneficial since the hatchery does not have to accommodate as many different stages as does a Penaeid hatchery, therefore reducing costs (Lee & Wickens, 1992; Williamson, 1968).

4.1.1 Maturation Unit

The maturation and hatchery area should be isolated from other areas of the operation to reduce noise and other stresses on the animal. The room must also be dark since the adult prawns are negatively phototrophic and care should be taken not to flick on bright lights which will scare the animals causing them to jump against the tank walls, injuring themselves (Jory, 1996b). The water flow should be constant and sufficient to provide a daily exchange of 20 - 30% clean water. The water quality parameters must be strictly monitored and adhered to those previously discussed. Variations should be kept to an absolute minimum and those that are made deliberately, such as during transfer to the larval rearing tanks, should be made very gradually

(Jory, 1996b). Changes in parameters or between facilities should be made such that the acclimation rate is not greater than 1° C/min or 1ppt/15min (McVey & Fox. 1983).

Figure 4-1 (page 53) shows an example of a commonly used hatchery tank that has been modified to act as both a maturation tank and hatching tank. Combining the two would help minimise the cost of setting up the operation. Minimising costs at this point would be important because the fecundity of *P. platyceros* is lower than other commonly bred shrimp and time to maturation is longer. This means that more animals would have to be kept here for a longer time resulting in higher costs to produce larvae. Since the females carry their eggs until they hatch, the floor should be a combination of sand and rocks to better mimic the natural environment of the animal. The inlet pipe could then be run under the floor which would aid in filtering the water and provide a suitable flow for water replacement. The tanks used for Penaeids are typically round at 3 - 5m in diameter and 60 - 100 cm high. The bottom slopes towards the centre which aids in the removal of waste products. The animals should be able to stay in these tanks until hatching occurs and the positively phototrophic larvae swim to the surface and flow into the collecting tanks. The collecting tanks can either be used to raise the larvae or just to collect the larvae and concentrate them for accurate counting.

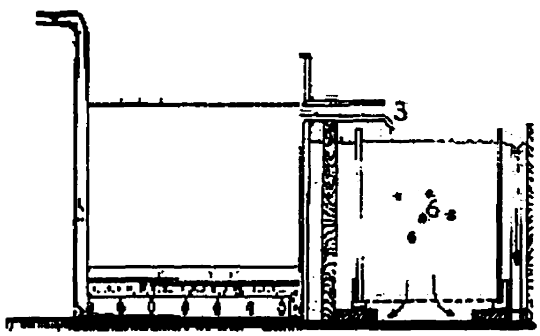

Figure 4-1: Combination of Maturation and Hatching Tank with Larvae Collecting Tank.
(Modified from AQUACOP 1983a)

4.1.2 Hatchery Methods

There are generally two methods of designing a hatchery, the Oriental method and the Western or Galveston method (Jory, 1996b). The Oriental method is generally a low density method (30 - 100 animals/l) that utilises fertilisers to promote food growth (plankton) within the tanks. The Galveston method on the other hand produces animals at a higher density (50 - 200 animals/l) with high water exchange rates combined with filtration and other treatments to provide very clean water to the animals (Jory, 1996 b&c; Lee & Wickens, 1992). With such high water quality and a strictly controlled system, it is easier to monitor the amount of feed the animals receive as well as exert disease prevention measures. One drawback of the Galveston method is that if a disease does break out it can quickly destroy all the animals because of the high densities maintained in the hatchery. Afterwards the entire unit must be thoroughly disinfected before operations can begin again (Jory, 1996b).

A combination of the two methods would probably be the best system for a hatchery of *P. platyceros* in the early stage. Since early culturing systems will be extensive and consumers for larvae will be limited there will be no need for a high density high volume output hatchery, at least until farming these animals proved financially attractive. Adequate quantities of PL can be produced by a low density operation but it is recommended to use clean water and maintain a high degree of control over the animals to monitor their health.

4.1.3 Water Supply

The water supply for the hatchery is most important since problems with either the water quality or supply can kill an entire population within a very short period of time. Not only must the water quality be monitored and treated but the tanks and pipes must be sterilised occasionally with disinfectant to prevent bacterial or viral build up in the hardware of the hatchery. A lot of time and money will be spent to provide a reliable and suitable supply of high quality water to the animals. The water supply should be from deep offshore to provide water in which the shrimp are found naturally. This may provide certain nutritional requirements that might not be included in an artificial diet. Before being supplied to the animal's tank, the water should flow through one or more filters that sequentially remove smaller particles. The water may then require ozonation and/or treatment with a UV germicidal lamp to kill bacteria. All flow systems are based on the size of the hatchery and will need to be engineered accordingly. Backup systems for all pumps and generators should also be considered since failure of pumps, aeration systems etc. can be detrimental to the survival rates (McVey & Fox. 1983).

4.1.4 World-wide Hatchery Status

Although the rapid growth in the shrimp farming industry world wide has resulted in an expansion of hatchery techniques there is still a dependence on wild caught broodstock (Jory, 1996c). Presently, maturation technology and the closing of the lifecycle is still mostly inconsistent for a large number of species but it is generally felt that this should not be the case and that shrimp can be domesticated as have other farmed animals. Hatcheries and post larval rearing are presently considered to be the low point of shrimp production with many farmers relying on wild caught larvae or juveniles. The domestication of shrimp is considered crucial for the continuation of shrimp farming and it is at this stage where most of the drawbacks presently exist. There is a lot of research being carried out, even genome mapping, to thoroughly understand the lifecycle of various shrimp species (Jory, 1996c). This would also hold true for *P. platyceros* production. Long-term success of shrimp farming in B.C. would hinge on the production of a reliable healthy supply of PL or juveniles for stocking the growout sites around the province.

4.1.5 Larval Rearing

Larval rearing of *P. platyceros* would accommodate the animals from hatching to the juvenile stage. Penaied larvae can be reared in tanks with a conical bottom, but since *P. platyceros* start to descend in their third larval stage to find dark protective areas, a flat floor would be better. The habitable surface area of the tanks could also be increased by using vertical or horizontal nets throughout the tank. These nets can act as a substrate on which the shrimp can settle (Rickards, 1971) thereby enabling higher densities of animals. The V or U shaped cylindroconical tanks are made of fibreglass and polyester resin. The shape combined with strong aeration helps prevent the accumulation of waste products and the drainage holes are covered with a fine mesh enabling water exchange without losing the larvae. Oxygen is supplied to the tanks through bubblers which are fixed onto the tank bottom (McVey & Fox, 1983).

The larvae are reared at a high density of about 100-120 larvae/litre. There is little or no water exchange in the early stages of larvae rearing since metabolite build up is minimal, but as they molt and increase in size it may be necessary to exchange up to 2/3 of the water or more daily until the post larvae are transferred to the nursery system. Water quality is very important for the larval stages as metabolites and uneaten food may build up in the tanks, promoting protozoan and bacterial growth which may be detrimental to the animals (McVey & Fox, 1983; Lee & Wickins. 1992 ; AQUACOP. 1983b).

4.1.5.1 Experimental Larvae rearing

There has been very little work done to develop a suitable system for the rearing of *P. platyceros* on a commercial level. The majority of larvae raised were all done in research laboratories providing only the quantity of larvae required for the intended experiments. Wickens (1972) used 400 L and 250 L fibreglass tanks for the post larvae, Kelly et al, (1977) used 75 - 4000 L aquarium and Rensel and Prentice (1980) also raised them in the laboratory for four months. These experiments were performed with low densities of larvae which would be unsuitable for commercial culture. Wickens and Beard (1978) reported the highest densities for mass larvae culture of *P. platyceros* but these were still low, ranging from 15 - 45 larvae/L. These densities accompanied with the reported low survival rates would not be comparable to the economic benefits of high density larval culture of penaeids. This is one area of *P. platyceros* culture which needs improvement before mass culture of the animal could be accomplished because the number of rearing tanks required to produce sufficient post larvae would increase the capital investment considerably.

4.2 The Nursery

The nursery is responsible for raising the shrimp throughout the juvenile stage which is defined as a young form, usually small and sexually immature, showing a general resemblance to the adult form (Williamson 1969). In the nursery, special care and attention can be given as the animals are weaned from larval conditions to those of the adults (Lee & Wickens, 1992). A nursery is important to produce hardier juveniles and may account for approximately 6-15% of the farm depending on the style of the operation (Lee & Wickens, 1992). *P. platyceros* may be transferred to the nursery in July, approximately four months post hatch where they could be raised until transferred to the growout pens. Rensel and Prentice (1979 & 1980) successfully raised juvenile shrimp in ocean netpens at densities ranging from 7.1 - 30.8 animals/m^2.

Penaeid nurseries are usually manmade and are constructed of cement or earthen embankments 0.04-1 hectare (ha), 40-70 cm deep with densities between 100-200 juveniles/m2. The growing animals produce increasing amounts of waste so water exchange in this style nursery must be high, ranging from ten to forty percent daily (Pillay, 1990). The high cost of water front land in British Columbia may make this method too capital intensive, especially if the nursery was to produce large quantities. Rensel and Prentice (1980) used rectangular knotless nylon net pens that had a mesh measuring 6.7 mm when stretched. The nets measured 2.16 m square (1.2 X 1.8 m) by 1.8 m deep with black plastic sheets to cover the pens protecting the shrimp from intense direct sunlight and birds. Weights were used at the corners of the net to hold the shape and a frame, constructed of polyvinyl chloride (PVC) piping, may also be used in the pen floor for this purpose. Vertical net panels were used to increase the immersed surface area from 11.5 m^2/pen to 18.9 m^2/pen. Once the animals reach a suitable size they are then transferred to the growout sites, which in the case of *P. platyceros*, will be similar to the nursery set-up. They should also be counted at this point so an accurate estimate may be made to control the density in the grow out ponds and to predict the final harvest quantities (Pillay, 1990). It has been suggested that smaller nursery nets may be placed inside salmon nets until the shrimp are three months of age (about 7 months post hatch) or about 4g (Rensel & Prentice, 1979). This would be effective if polyculture with salmon proves financially feasible, however the prawn nets would seriously decrease the amount of useful space for the fish. The area in a salmon net used by the animals is approximately 80% (pers. comm. James Manders) and any decrease will lower financial return from fish production. A second alternative may be to place the nursery nets within the growout nets used for prawns. Prawns, unlike salmon, do not utilise the water column to the same extent so inserting a nursery net will not consume valuable space and may even be beneficial since the outside of the nursery nets may be used as substrate for the yearlings. This would also be beneficial if the time to transfer the animals to the growout nets can be co-ordinated with the harvest time. Then the animals can be easily released from the nursery nets directly into the growout nets after harvesting thereby decreasing the amount of required labour considerably. This would also decrease the distance required to move the prawns as well as decreasing the amount of physical handling which adds undue stress, potentially leading to disease or high mortalities.

4.3 Growout

The growout facility for *P. platyceros* will be a similar net pen set-up to the nursery and is responsible for rearing the animals until they are harvested for delivery to the market. Typically the growout operation consists of earthen dug ponds ranging anywhere from 0.1 to 100 hectares (ha) in size and about 1 m deep. The shrimp are harvested by walking from one end of the pond to the other with a net or by draining the ponds and netting them as the water level drops (Lee & Wickens, 1992). This would be unfeasible for *P. platyceros* culture due to the amount of land required and the cost of that land within the province.

In the nursery the juveniles are smaller than the adults, therefore requiring less surface area for a specific density as well as a smaller mesh size to contain the animals. As the animals increase in size it may be necessary to transfer them to a larger net with a larger mesh size. This will aid in maintaining a constant density as well as increasing the flow rate through the net providing more oxygen and food. Rensel and Prentice (1980) raised yearlings for eight months in pens with the same dimensions as reported above (in the nursery section) but with a mesh size of 9 mm stretched and without dividers. Whether or not two different size pens are used may depend on the size at which the farmer decides to harvest the animals. If the animals are held for less than one year, they may be able to remain in the nursery size nets without transfer to a separate grow out facility as shown by Rensel and Prentice (1980). If, on the other hand it is decided to raise the prawns for more than one year it may be better to transfer them to a larger mesh net. This determination must be made based on experimental results, market surveys and the economics of either system.

4.3.1 Harvesting

Once the prawns reach market size they must be harvested and transported to wholesalers. This may be relatively easy since local salmon farmers have experience with harvesting product from net pens and may be able to provide assistance both technically and physically. It may be possible to simply raise the nets into a boat to remove the prawns or, as done on some salmon farms, by using boats that pump the animals into their hold for transport to the processing plant. The second method is the quickest and easiest way to harvest but may not be feasible since prawns are benthic and not free swimming like salmon.

There are various schedules that may be used to harvest the animals as well. The entire netpen may be harvested at once and the animals sorted, based on size and quality, for various markets such as the high end restaurant market or as bait. Partial harvesting of the net pens may be preferred to get the quick growing prawns to market when they are ready and to provide more space for the slower growers to reach market size. This may be accomplished by using a net with a certain size mesh to gather the larger shrimp at one end for removal. The reverse option may be preferred which would be to remove the slower growing animals for a low end market allowing more room and food for the fast growers. The best method must be figured out at the experimental stage based on economics and the biology of the prawn.

4.3.2 Vertical Panels

Vertical panels are not now commonly used for shrimp culture but have been proven useful in experimental trials of *P. platyceros*. The use of vertical panels may be quite beneficial for the culture of *P. platyceros* since the majority of the water column in the pens would be unused. It may also be viable to use horizontal inserts to further increase usable surface area. This may complicate daily operations however, such as feeding the animals below these inserts.

Vertical substrates may be important for increasing the surface area from which the shrimp may forage for food ultimately increasing growth, survival and yield. Rickards (1971) showed that in pond culture the growth rates and yields were significantly higher with the use of vertical substrates due in part to the increased food source in the form of fouling organisms. Rensel and Prentice (1979 & 1980) also used vertical panels to increase the surface area of the pens considerably, allowing a higher number of animals to be kept in the same size pen.

There are certain considerations that must be made when using the vertical substrates. The animals should not be restricted from moving about the net so the panels should not completely enclose certain portions. The panels should also be easy to remove for harvesting, cleaning and as otherwise necessary. The panels will also provide resistance to water flow and should be placed parallel to the direction of the normal current. It has not been determined how many panels could be used within a pen and the best distance to space the panels (Rickards, 1971). If they are too close, they may inhibit water circulation causing negative effects on the animals' growth rate. The appropriate number of panels must be determined to provide the maximum economic benefit. There are several details that need working out to determine how to best use vertical panels but it seems that it is a useful system for increasing the stocking density as well as improving survival and yield of the operation.

4.4 Site Selection

Site selection is probably one of the most important decisions that must be made prior to setting up operation. Proper site selection can prevent many potential future problems such as poor water supply, poor water quality, disease, transportation cost and a number of other expensive problems that could occur. Site selection is a major step, and there are many variables to consider before the operation commences. The Ministry of Agriculture Food and Fisheries (MAFF) publish reports and map books which present the biophysical suitability of various regions for salmonid farming in net cages (Ricker, 1989). These reports provide valuable information relevant to prawn farming since much of the data given is important for site selection of net pens and water quality. Caine et al (1987) divide the factors for site selection of salmonid cage culture into three different categories; Water Quality Factors, Physical Factors and Biological Factors. Since the culture of *P. platyceros* will most likely be in net pens these factors can be used as a basis for determining suitable locations for the grow out sites of spot prawn culture.

4.4.1.1 The Hatchery Site

In addition to the general water quality characteristics, the hatchery has some unique requirements to consider when choosing a suitable site. Since the hatchery is land based there must be a constant and adequate volume of high quality fresh and salt water available for different daily requirements. The facility must be constructed close to the water to minimise costs such as the pipe length to water supply. The site should enable a design that will prevent damage from storms and waves, yet still enable relatively easy pumping and draining of water for the tanks. A site could be chosen such that the geography of the land enables the use of gravity flow for certain aspects of the site. thus eliminating the need for at least some costly pumping (Lee & Wickens, 1992).

4.4.2 Water Quality

There are several variables concerning water quality that are important and must be researched prior to choosing a spot for culture purposes. The water must be pollution free; both chemical and biological (bacteria, parasites and protozoan content should be as low as possible). Fertiliser and sewage levels in the water as well as sediment content must be low. There should, however, be some nutrients in the water for utilisation by the animals. The supply should not be subject to algae blooms or similar fluctuations in water quality to which the B.C. coast is often prone. The annual temperature, salinity and dissolved oxygen fluctuations should also be known so that a spot can be chosen which best meets the requirements of the animal and does not have major fluctuations throughout the year. Since the amount of freshwater nearby can dramatically affect the salinity of the area, the freshwater flow for a potential site should also be known (Caine et al, 1987).

4.4.2.1 Pollution

Water quality in Canada is relatively good compared to that of some other countries and any concerns are often local rather than for a large region. The Strait of Georgia is a fairly protected region from the offshore storms that can hit the west coast of Vancouver Island. Unfortunately the increasing population in this region raises concerns for future water quality. Pollution from the Fraser River is of concern to anyone wishing to set up an operation in the southern portion of B.C. It is believed that pollution may be a contributing factor to the decline of sturgeon populations in the river (Down, 1996). Howe Sound has been closed to the prawn fishery in recent years due to pollution (Bower et al, 1996) and other areas of the coast are also subject to occasional closures. Baynes Sound, for example, is an important area to many shellfish farmers but is often subject to closures throughout the year due to high faecal counts.

There are many types of pollution which are divided into the following categories; Toxic, Organic, Nutrient (promoting algae production), Acid (pH changes), Sediment, Thermal and debris (Caine et al, 1987). In B.C. there are many point sources of pollution from industry and municipalities which cause problems for aquaculture in certain areas and must be considered before locating an operation. Sources of pollution are many and include sewage outfalls, ocean dumping, shipping wastes, inflowing water from Puget Sound, runoff from heavy rainfalls, atmospheric pollution and logging waste to name a few (Ricker, 1989). Water quality for the most part would have to be assessed on a local basis.

4.4.3 Physical Factors

These factors include currents, depth, wind and wave action, geomorphology and substrate. Currents are important in cage culture both for providing nutrients and removing wastes from the pens. Good currents for the salmon industry are considered to be between 10 - 15 cm/s with a maximum range of 50 - 100 cm/s (Caine et al, 1987). Currents specifications for shrimp culture will likely be at the very minimum of these ranges since the mesh size will be much smaller and therefore more affected by currents. Without considering fouling, it has been seen that a 5 cm mesh decreases the flow inside the net by 60% and a 3 cm mesh by 70% (Caine et al, 1987). Alignment of the pens is important when placing them in areas with a current. All pens will require a certain flow so the nets should be aligned such that some pens are not restricting flow to others. Wind is also an important factor, as surface current speeds increase with wind which could blow warm surface water (which can be above 20°C) into the pens (Caine et al, 1987). Wind may also damage net covers used to protect the shrimp from the sun. The current measurements (speed and direction) should be taken at a approximately half of the net depth (Caine et al, 1987). It is recommended that for salmon culture the depth of the site should be between 50 - 100m since greater depths are better for preventing pollution (feed and faecal wastes) from accumulating in the operation. In areas with higher currents, the depth can be decreased 5m for every 10cm/s increase in velocity (Caine et al, 1987). The ocean floor beneath the pens is best if it is sloped (>30°) and consists of rock, sand or gravel (Caine et al, 1987). The bottom should also be such that there is no restriction of seawater flow into or out of the site area to prevent stagnant water from accumulating under the nets. The shoreline should also be checked to ensure it is stable (Caine et al, 1987) since slides can force silty, dirty water into the pens of the operation and cause a lot of structural damage and mortality of the animals.

4.4.3.1 Geographical Considerations

Although the following amenities are not crucial considerations with today's technology, some may lend merit for minimising costs. Access to good roads or to larger marine vessels for harvesting and shipping product will help minimise transport costs. The ability to communicate via phone and fax is also important, especially for smaller operations. Many areas of coastal B.C. are very isolated and should the need arise for an unscheduled harvest, (as is done with some disease outbreaks) it is important to be able to contact purchasers and other people. Electricity availability and voltage consistency is important or generators may need to be purchased. Closeness to communities makes it easier for employees and for obtaining supplies. Proximity to processing facilities and markets will also affect the cost of getting the product to the end consumers and may ultimately affect the demand for the product. All these factors can dramatically affect the final return on product and financial success or failure of the operation.

4.4.4 Biological Factors

Biological factors include plankton, marine plants and fouling organisms and predators (Caine et al, 1987). Sites should be chosen which are not prone to plankton blooms, as many sites are on the Sunshine Coast (Ricker, 1989) and other areas of B.C. Plankton blooms may not be as devastating for shrimp culture in B.C. as they have been with salmon farming since prawns have been successfully lowered to depths below the effects of the bloom with very positive results (Rensel and Prentice, 1980). Dropping the nets may not always be successful. *Heterosigma* usually inhabits the top 5 - 10 m but there have been cases where it has been found at quite deep levels (Caine et al, 1987). Various predators may be a problem, such as birds, seals, and otters, so areas with particularly dense populations of these animals should be avoided. Fouling organisms can be another factor that decreases flow through the net, inhibiting the removal of uneaten feed and faeces as well as decreasing dissolved oxygen levels inside the net pen (Caine et al, 1987). At the same time it is not as crucial a factor as with salmon since *P. platyceros* have been seen to clean the nets, making use of these organisms as an extra food supply (Rensel & Prentice, 1979).

4.4.5 Suitable Sites within Georgia Strait

The report, "Biophysical Suitability of the Sunshine Coast and Johnstone Strait/Desolation Sound areas for Salmonid Farming in Net Cages" (and the accompanying atlas) from MAFF (Ricker, 1989) provides very thorough, detailed information of these areas and their suitability for cage aquaculture. Most of the Sunshine coast and southern area are generally considered poor or not acceptable due to various reasons such as pollution, dilution (mostly from the Fraser River and Squamish River), extreme weather conditions (e.g. waves and cold arctic winds), and plankton blooms. In the northern regions studied, areas deemed suitable include Redonda Islands and Desolation Sound, the south end of Quadra Island including Sutil Channel (Penn Islands, northern Cortes Island, outer Carrington Bay and the southwest Coulter Island), northernmost Waddington Channel, Rendezvous Islands, Whiterock Passage, Raza Island, Frances Bay, Church House Bight, Okisollo Channel, north of Lund harbour and portions of Malaspina Inlet. There are also numerous inlets and bays which may be determined suitable once studied individually.

It is obvious that there are many factors to consider when setting up a site. Not only do the present conditions matter but also any plans for future use of the area must be considered. If, for example, the area is to be harvested by the Forestry Industry in the future, the site may only be suitable for a few years. Site factors also change with time and the operator may need to plan alternative sites for various reasons. Once the site is chosen however, the operator can quickly commence with the application process and site set up.

4.4.6 Experimental Sites Used

Rensel and Prentice (1980) used two sites for their experiments, Clam Bay and Henderson Inlet, both located in Puget Sound, Washington. These experiments showed how important proper site selection is to the success of a culture operation. Table 4-1 (page 65) presents some of the environmental data for the two site. Although the parameters between the two sites are similar the success of the sites differed dramatically. Clam Bay proved quite good for growing shrimp whereas Henderson Inlet was unsuccessful.

Table 4-1: Environmental Data for Experimental Sites.

Site	Salinity (‰)	DO (ppm)	Temperature (°C)	Currents (knots)
Clam Bay	28.4 - 31	5 - 9	16.5 (maximum)	0.4 - 1.0
Henderson Inlet	28.4 - 31	5 - 11	19.0 (maximum)	Restricted

Rensel & Prentice, 1980.

The difference was mostly in the physical attributes of the two sites. Clam Bay was used for experimental salmon culture having good water flow and depth under the net ranging from 9 - 14 m. Henderson Inlet on the other hand, was shallow (10 m) and water exchange was restricted by the configuration of the inlet and tidal currents. This resulted in the average temperature being 2.5°C higher at Henderson Inlet and there was an increase from 11.8° - 21.9°C in just one week in June (although weekly mean temperatures never exceeded 18°C). This rapid increase in temperature along with a plankton bloom were the leading factors resulting in high mortalities at Henderson Inlet. Prawns left at the surface experienced 100% mortality whereas the ones in Clam Bay had a 66.7% survival (the lowest reported value of two replicates) (Rensel & Prentice, 1980). It is evident from these results that all factors must be considered when evaluating prospective sites for aquaculture. Those appearing to be similar may in fact be quite different in terms of their potential productivity.

5. Economic Analysis

An economic analysis is essential to determine whether it is worthwhile pursuing any species for commercial aquaculture. This section attempts to perform such an analysis for a commercial scale operation of *P. platyceros.* Since there has been no large scale culture of the animal, it was necessary to extrapolate some of the variables from methods used to grow other species and on assumptions from the literature.

5.1 Calculation of Profitability

Section 5.1 attempts to determine if a *P. platyceros* aquaculture operation can be profitable. The initial assumptions are detailed and were used in the cash flow (Appendix II) to determine if there was any possibility of profit. These assumptions were then modified to determine what changes would be required to achieve some level of economic success and are presented as the final assumptions. In order to make this determination, different factors both biological and physical were analysed.

5.1.1 Physical Characteristics and Factors Analysed

5.1.1.1 Proposed Farm Set-Up

To perform an economic analysis the proposed set-up of the operation will be based on a salmon farm in British Columbia (pers. comm. James Manders). Since the biology and habits of prawns differ from salmon, certain variations from the finfish operation will be evident. This set-up may or may not be suitable for the commercial production of *P. platyceros* depending on the results of further experimentation and biological factors. The netpens will be in sections consisting of four nets (see Appendix III) as is common and one employee can adequately maintain 3 - 5 such sections (pers. comm. James Manders). The mesh sizes will be 6.7 mm for the juveniles and 9 mm for prawns grown longer than one year as used by Rensel and Prentice (1979). One or two sections of net pen (4 or 8 nets) will be made of a smaller mesh and utilised as a nursery depending on the harvesting schedule tested. The entire arrangement of pens will be anchored by four concrete anchors, one at each corner. Each net would be equipped with an automatic feeder on a timer set to deliver less food than required by the shrimp. This enables the farmer to closely monitor feed consumption. The shape of the nets will be maintained with the use of weights at the corners and PVC piping. The nets are all interconnected with walkways to enable easy access to each and a barge will be used, providing support for a storage shed and living quarters for two employees. The site will also be equipped with an outboard boat necessary for various duties.

5.1.1.2 Initial Assumptions for the Grow out Site

The following assumptions were used as the starting point to determine the economic status of the operation. Each net will be 60m circumference by 2m deep and will have 100 sq m of vertical inserts that extended across the net such that the shrimp are not restricted in their movement about the pen. One employee will be on site at all times while three others will be available for changing nets or harvesting. Different conditions were tested within the cash flow as reported previously.

1. The boat is a 20 foot aluminium herring skiff type with a small motorised crane (Pers. Comm. Mac's Oysters).
2. The price of the motor is estimated for a diesel inboard outboard motor.
3. The cost of a floating house/storage shed will be approximately $100,000 (pers. comm. Mike Buttle).
4. The cost for netting is $735 for each nursery pen and $665 for each grow out net pen (pers. comm. Chad Ayukawa)
5. Total cost for the cages is $75,000 which includes everything except the netting and anchors (pers. comm. Allan Reid)
6. Pen covers or shade cloth are a fine mesh netting blocking about 80% of the light (based on cost of tenting mesh material). The total cost for 16 pens is approximately $900 (pers. comm. Dave Zandbergen).
7. Truck price is estimated for a second hand truck with 5 years of use.
8. Concrete anchors will be used and are included within the miscellaneous equipment cost
9. 100% of the investment is assumed to be paid in capital which is calculated as the total cost for the first year plus operating expenses for the second year.
10. Materials and fuel are calculated at 10% of the output per year.

11. The overhead for both the variable costs and the total costs are estimated to be at 10% of the respective costs. This will cover such items as repair of mechanical equipment, nets, cages etc.
12. The fixed cost labour is calculated as owner/operator salary. The variable cost salary is for a temporary replacement worker throughout the year and extra help at harvest time (@ $9.00/hr).
13. The generator is assumed to be a small output generator such as those used for motor homes to supply electricity for the small living quarters.
14. The depreciation used is a straight forward annual percentage as calculated in Table 5-1 (page 68).
15. The value of the feed is $1.25/kilo which is the price for a low oil/high fish meal content feed (pers. comm. John Wu).

Table 5-1: Capital Expense and Calculation of Annual Depreciation for Initial Assumptions.

Capital expenses	Cost ($)	Years of use	Salvage value	Annual depreciation
Floating Structure	100000	10	0	10000
Walkways (4 sections of 4)	75000	10	0	7500
Netting (16 pens)	10920	5	0	2184
Pen Covers	900	5	0	180
Boat and Engine	17000	10	0	1700
Truck	10000	5	0	2000
Generator	2000	5	0	400
Miscellaneous Equip.	1200	---	---	---
Total	217020			23964

5.1.1.3 Structural Changes

The first step was to modify the characteristics of the farm. The initial farm included metal and plastic round cages for support of the net and work crew. The housing structure for the staff and work materials was also based on size and cost of those used for salmon farming. These inclusions proved costly and impossible to realise any financial return, so the operation was altered to a more basic structure made of wooden cages on floats to support the nets. The cost of the housing structure was changed from a full sized unit, priced at retail, to an estimated cost for a smaller "home-made" version.

5.1.1.4 Final Assumptions for Profitable Model

The pen arrangement was changed from round to square nets in sections of four each measuring 15.25 m by 15.25 m by 2 m deep. The net will have four equally spaced vertical dividers which will be 3 m short of the net width to allow movement of the animals throughout the entire net. In order to study the economics of a new operation many initial variables had to be modified to suit the value of the product. The following list is of the final assumptions used in the cash flow (Table 5-2, page 70) which differed from the initial assumptions. These assumptions did show that the operation could be profitable if one takes advantage of economies of scale.

1. The cost of a floating house/storage shed will be approximately $25,000. This is the cost of the floating barge alone (pers. comm. Mike Buttle). It is assumed that the operator can build a modest abode and storage shed on a second hand barge for this value or a small land based house near the site as is the practice of several Shellfish operators.
2. The cost for netting is $1268 for the grow out pen netting and $1336 for the nursery pens. See calculations in Appendix II (pers. comm. Chad Ayukawa).
3. Total cost of four sections is $25,000 which includes everything except the netting and anchors. This calculation includes: the material costs for a wooden walkway system three feet wide (prices from local hardware stores), 10% of the original circular cages (for the mooring lines and chains), and an estimate of the cost of floatation material for the walkway (a value equal to the sum of the first two).
4. Pen cover cost for 16 pens is approximately $2858.
5. The fixed cost labour is calculated as owner/operator salary. Due to the size of the operation required at least two people would be required to act in this capacity. The variable cost salary is for a temporary replacement worker throughout the year and extra help at harvest time (@$9.00/hr).
6. The depreciation used is a straight forward annual percentage as calculated in Table 5-2 (page 70).

Table 5-2: Capital Expense and Calculation of Annual Depreciation for Final Assumptions.

Capital Expenses	Cost ($)	Years of use	Salvage value	Annual depreciation
Floating Structure	25,000	10	0	2,500
Walkways (4 sections of 4)	25,000	10	0	2,500
Netting (16 pens)	19,760	5	0	3,952
Pen Covers	2,858	5	0	572
Boat and Engine	17,000	10	0	1,700
Truck	5,000	5	0	1,000
Generator	1,000	5	0	200
Miscellaneous Equip. (5%)	2,128	10	0	213
Total	97,746			12,636

5.1.1.5 Economies of Scale

A small operation did not show any possibility of being profitable. As is the case with many aquaculture operations, they often need to be very large in order to make money. Shrimp farms can typically be 100 hectares in size. The productive area of the initial farm was 8096 sq m (506 sq m/net). This was increased to 97,152 sq m through the addition of units of 16 pens. The surface area of the farm was further increased with the addition of vertical and horizontal inserts. Initially only vertical inserts were used, however with the addition of three horizontal inserts in each net, the total area was increased by a factor of 1.38 greatly improving the productivity of each net.

5.1.1.6 Horizontal Inserts

Horizontal inserts have a big impact on the increased surface area and profitability of each net but they also impose some physical implications on daily operations. In order for the shrimp below these inserts to be adequately fed, the inserts must be either designed so portions may be raised out to enable feeding or a method must be designed to deliver the feed underneath them. This may increase necessary labour or capital cost with the purchase of modified nets or equipment. Some fish farms in Norway have used a soft feed pumped through a tube to the animals. Some variation of this method may be useful with the proposed layered system.

5.1.2 Analysis of Biological Factors

The following discusses the analysis made of stocking density and feed conversion to determine what modifications are necessary to make the operation profitable. The results are presented in section 5.3 (Sensitivity Analysis) under their respective headings. This analysis also provided the starting point of these variables for the sensitivity analysis.

5.1.2.1 Stocking Density

Stocking density was the first biological factor analysed to determine if the operation could turn a profit. The stocking density initially used was 10 animals/sq m (93% survival) which worked out to approximately 1349 kg/ha. This is low when compared to other shrimp such as *P. monodon* that can yield 4000 - 12000 kg/ha but is fairly close to yields reported for *P. vannamei* in Ecuador (Lee & Wickens, 1992). Rensel & Prentice (1979) stocked the animals to a maximum of 30 animals per sq m. Calculations were performed on densities ranging to this value. Increasing the stocking density to 30 animals per sq m is necessary to produce a profit. The operation needs to obtain a fairly high yield/hectare since harvest is only every two years and only half of the farm is available for harvesting in any one year.

5.1.2.2 FCR

Variations of FCR were also tested in the cash flow calculations. The FCR of 5.5 (Kelly, Haseltine and Ebert, 1977) is very high and adds considerably to the cost of the operation. Rensel & Prentice (1979) found very good growth rates without feeding directly and showed that shrimp utilise the fouling organisms as food. It was necessary to assume that in the open ocean, shrimp could consume much of their food from the fouling organisms on the net and that an FCR of 2.5:1 (purchased food) is realistic. Lee & Wickens (1992) suggest that FCR of <2:1 is desirable and >3:1 suggests overfeeding. Chris Campbell (pers. comm.) has calculated the FCR to be <1.5:1 in his experiments so calculations made using an FCR of 2.5:1 is not unrealistic.

5.2 Determination of Harvesting Schedule

The next step taken was to determine the best schedule to harvest the animals. Using the sample cash flow (Appendix II, page 89) alterations were made to the input of capital investment, revenue from the harvest, the output of money for fixed costs and the cost of the seed or post larvae. This was done not to determine profit, but only which schedule would return the best Internal Rate of Return (IRR), Net Present Value (NPV) and Return on Investment (ROI) based on the physical size and characteristics of the operation previously described. This analysis attempted to determine how long to raise the animals and when to harvest them. There were three trials performed using cash flows based on the example in Appendix II. Table 5-3 (page 72) outlines the factors involved in the schedules.

Table 5-3: Description of Trials used to determine best grow out method.

Trial	Nets stocked	Transferred	Harvest	Size (avg)	Sections/Cohort	$/kg (live)
1	July	May	1.5 yrs	14.5 g	2	18.74
2	July	May	2.5 yrs	24 g	1	20.95
3	July	May	3.5 yrs	40.5 g	1	23.15

All animals would be stocked in the nursery pens in July or August from the hatchery. In the following April to May they are yearlings (Rensel & Prentice, 1980) and transferred to grow out nets, distinguished by a larger mesh size, where they remain until harvest. The approximate duration of time spent in the net pens is represented by the time at harvest. Schedule one, for example would be held in nets from July until winter, 1.5 years later when they would be harvested. Harvesting is between November and March depending on demand for the product and when the best price can be obtained. The number of nets were not varied between the schedules, only the number of prawns harvested at each interval. The weight of the prawns were estimated from Figure 5-1 (page 73) which is the natural growth curve as described by Butler (1964). The sections of curve that level off represent the late fall and winter months coinciding with low supply from the wild fishery. There has been little research growing *P. platyceros* for any more than one year, but most experiments have been able to come close to the estimated natural growth so this rate was assumed. The number of sections per cohort (Table 5-3, page 72) represents the number of sections that each year class inhabits and will be available for harvest at the same time. The price per kg is the estimated price for live shrimp with the added value of being sold during these low wild harvest months.

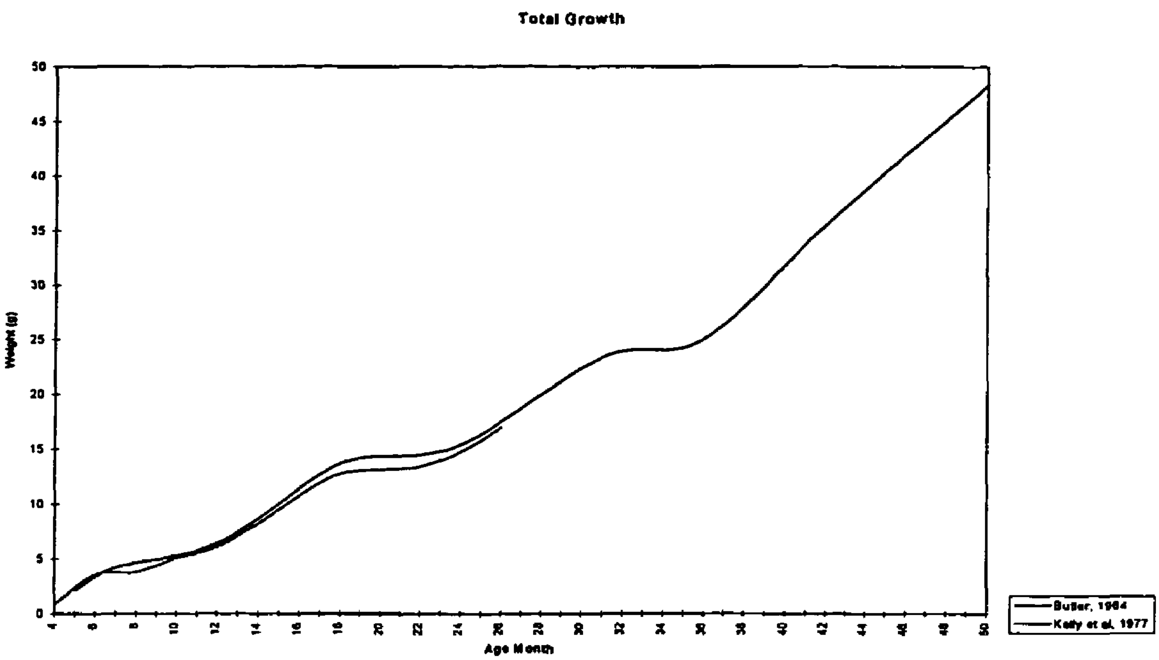

Figure 5-1. Growth Curve for wild Population of Prawns (Butler, 1964).

It was determined that schedule three would be best for growing spot prawns to harvest size (Table 5-4, page 73) if the survival rates did not differ from year to year. This schedule holds the animals for approximately 3.5 years before harvesting and gives a much better financial report. One benefit of both schedules 2 & 3 is that the capital investment can be spread out over more years than with schedule one which would decrease interest payments, spreading them out over time. Although neither of the reported indicators would be particularly attractive to investors given the amount of capital required, the values do show that should *P. platyceros* culture ever become a commercial venture, this schedule would be the most profitable.

Table 5-4: Results of Schedule Analysis and the effect of Decreasing Survival Rate.

	Schedule 1	Schedule 2		Schedule 3		
Survival (%)	70	70	65	70	65	60
Economic Indicators						
NPV	114,975	128,995	-14,268	409,252	246,260	81,881
IRR	2.69%	2.01%	-0.22%	4.66%	2.86%	0.97%
ROI	0.84	1.20	0.91	2.16	1.79	1.43

There are some negative aspects of not harvesting until the fourth year of operation. Revenue would not be realised until year four, so a much higher investment is required to carry the operation until the first harvest. With added time in the water there is also increased risk of the animals developing disease and experiencing mortalities as well as the increased labour and costs to keep them penned longer. The lack of research growing *P. platyceros* for any more than one year would certainly make schedule 2 or 3 much more risky. It is not known if there would be any serious problems over the extended years and as can be seen from Table 5-4 (page 73), any benefit is quickly lost with a slight decrease in survival. Since the ROI is only slightly better with schedule three and the risk of biological problems is potentially much greater, schedule one may be the best method, at least until there is greater knowledge of their survival over an extended period of time. This schedule will therefore be used for all the following tests.

5.3 Sensitivity Analysis

With the present model, the economic potential for culturing *P. platyceros* is marginal at best and there is no room for setbacks. This section will look at varying densities, FCRs, survival rates and price for the product on the market. Determining these limits will be essential for evaluating what criteria is necessary and what will potentially inhibit the success of the operation. Table 5-5 (page 74) outlines the initial values for the variables that were altered.

Table 5-5: Starting values for specified variables

Density (#/sq m)	FCR	Survival Rate (%)	Price/kg ($)
30	2.5	70	18.74

5.3.1 Density

Table 5-6 (page 75) displays the effects of varying densities on NPV, IRR and ROI. The economic indicators are very sensitive to changes in density. It is important for researchers to determine the optimal density for the biology of the animal and try to maximise that density for economic purposes. With other factors constant, 30 animals/sq m is approximately the minimum density with a positive return. The sensitivity is equal in both directions. It takes very little increase in density to begin realising a good IRR or decrease to see the return drop dramatically.

Table 5-6: Economic Indicators at Varying Densities

Density	10	15	20	25	30	35	40	45	50
NPV	-1,698,125	-1,166,610	-635,094	-193,463	114,975	394,376	667,925	940,145	1,212,366
IRR	-	-	-	-4.39%	2.69%	8.92%	14.54%	19.79%	24.84%
ROI	-2.96	-1.80	-0.64	0.26	0.84	1.42	2.00	2.59	3.17

5.3.2 Survival

Table 5-7 (page, 75) shows that varying survival rates also strongly affect the return. Starting with a 70% survival rate, which provides a very low but positive IRR, one can see that if the animals were to be affected by a disease returns quickly diminish. It takes only a small change in survival to lose profits and at a two year growout (or longer) it would be hard to recuperate any financial losses.

Table 5-7: Economics Indicators at Varying Survival Rates

Survival	50	55	60	65	70	75	80	85	90
NPV	-559,273	-325,189	-171,145	-24,212	114,975	245,059	375,143	503,578	630,276
IRR	-12.61%	-7.00%	-3.88%	-0.56%	2.69%	5.65%	8.55%	11.32%	13.95%
ROI	-0.46	0.04	0.31	0.58	0.84	1.11	1.38	1.65	1.92

5.3.3 FCR

Table 5-8 (page 75) presents the values for changes in FCR. These are also very sensitive to changes in that the cost of food provided to the animals increases or decreases with variation in FCR. Since *P. platyceros* readily consumes fouling organisms it may be possible that the FCR from supplemented food will be lower than the 2.5 used as the test for this model. Even a slight decrease in FCR combined with another factor such as density or survival could greatly increase the net income of the operation.

Table 5-8: Economics Indicators at Varying FCR

FCR	1	1.5	2	2.5	3	3.5	4
NPV	329,766	258,169	186,572	114,975	40,800	-38,983	-118,767
IRR	8.01%	6.19%	4.42%	2.69%	0.94%	-0.87%	-2.58%
ROI	1.25	1.12	0.98	0.84	0.71	0.57	0.44

5.3.4 Price per Kg

If all of the biological factors can be determined and a stable production of healthy animals be produced, the value of the shrimp can still vary greatly depending on the mood of the marketplace.

The starting point of $18.74/kg is including $1.50/kg increase due to the winter supply and demand ratio. This can vary greatly in either direction and a drop of only $1.00 /kg can result in a negative IRR. Since the product can be sold live, the harvest can be timed to coincide with the highest market demand to obtain the best dollar value. If harvesting is not planned to coincide with the peak market time, then a great loss may occur.

Table 5-9: Economics Indicators at Varying Prices per Kg

$/kg	17.5	17.75	17	18.25	18.5	18.74	19	19.25	19.5
NPV	-39,945	-7,580	24,784	56,745	87,067	114,975	145,209	174,280	203,351
IRR	-0.92%	-0.18%	0.58%	1.33%	2.04%	2.69%	3.39%	4.06%	4.73%
ROI	0.55	0.61	0.67	0.73	0.79	0.84	0.91	0.96	1.02

5.3.5 Discussion of Analysis

It is evident that using the proposed starting values for these variables would not provide a very secure business environment. An IRR of only 2.69% and a ROI of 0.84 would not be attractive to many investors. Variations in any of these four could lead to major financial failure so only with a successful combination of all variables would this operation become financially appealing. Table 5-10 (page 76) shows the effect of changing all four variables by equal percentages. It is clear that changes of more than one variable can have a profound effect on the economic viability of the operation. This table clearly shows the benefits of positively changing all variables and the economic disaster which would accompany combinations of setbacks in the operation.

Table 5-10: Economic Results Of Varying All Four Variable By Equal Percentages.

	10% Drop of Variables	5% Drop of Variables	Starting point	5% Increase of Variables	10% Increase of Variables
NPV	-587,722	-200,804	114,975	433,862	780,057
IRR	-13%	-4%	2.69%	10%	17%
ROI	-0.51	0.26	0.84	1.50	2.22

Unfortunately the biology of the animal limits the economic success at the present time but with further experimentation the animal may be domesticated enabling higher densities to be used and higher survival rates. The combination of improving these two biological factors will have a very beneficial effect to the economic indicators.

6. Conclusion

It is unlikely that *P. platyceros* will be commercially cultured in the near future. There are many biological and physical impediments which must be overcome before these animals can be profitably raised in captivity. Some of the problems include excessive cannibalism, low density requirements, and inconsistent survival rates all of which are very important variables that affect the financial return of an operation. If further research enables breeding of these animals in captivity and they become domesticated, many of the biological problems may be overcome in which case the possibility of successful culture will increase. One serious drawback of the culture of this animal is the time it takes to grow to a marketable size. This factor is strictly market driven and is not likely to change dramatically in the future. The financial analysis showed that profitability was marginal at best and only in the most optimistic of scenarios were results produced that may attract investors. However, if research is to continue in this area, the next step is set up a pilot project to determine the problems that will be faced with a larger scale culture system. This will focus researchers on the areas that most need studying before fully scaling up to a commercial size operation. *P. platyceros* may never be suitable for culture as a main product but they may be raised by established farm operators who wish to diversify and develop an additional source of income.

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Appendix I

Prawn Trapping areas in British Columbia.

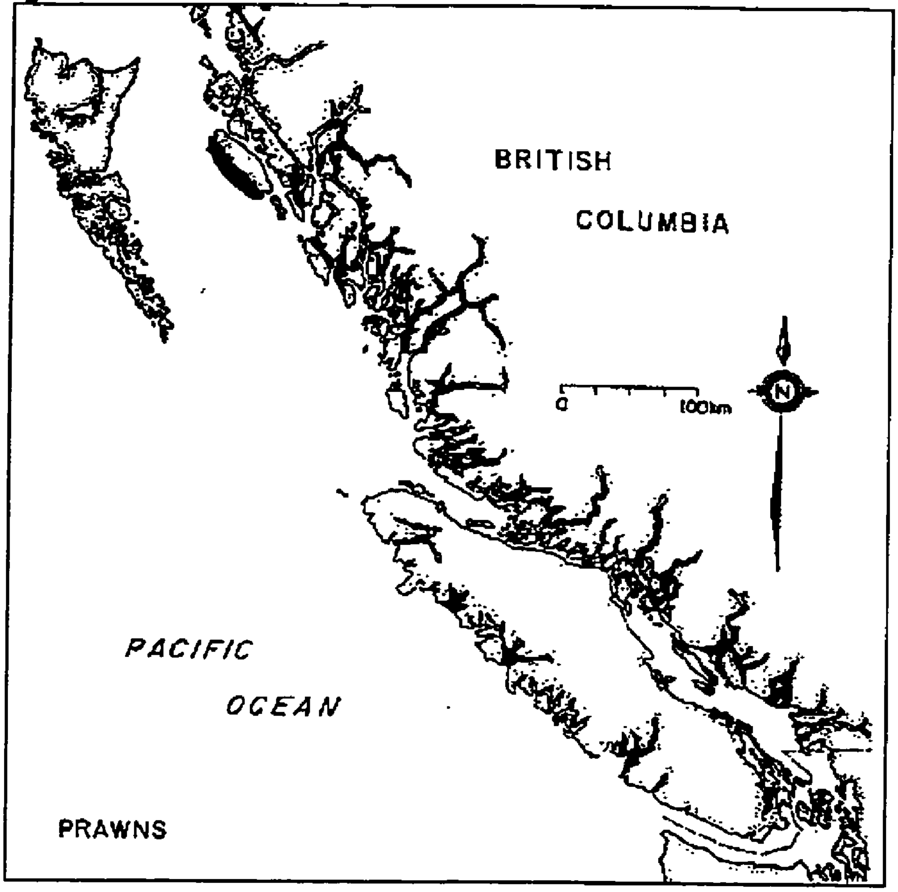

Figure ix: Map showing areas of Prawn Trapping.

(Modified from Jamieson and Francis, 1986)

Appendix II

Economic Calculations for Final Assumptions

Calculation for cost of a single Nursery Netpen

Area of netting for each pen.

Surface Area of netting = 554.33 sq m = 5964.59 sq ft

Net type: Green knotless nylon 1/4" mesh sold in 20 ft wide strips at $4.25/ft (pers. comm. Chad Ayukawa)

Cost per net

(5964.59 ft^2 / 20 ft)*$4.25/ft = $1268

PVC tubing: 200ft/net * 34¢/ft (50% of local retail prices) = $68/pen

Total cost per nursery net = $1336

Calculation for cost of a single Growout Netpen

Same size pen but the netting is Green knotless nylon 1/3" mesh sold in 20 ft wide strips at $3.80/ft (pers. comm. Chad Ayukawa).

Total cost per growout net = $1134 + cost of extra inserts at $475/insert

Calculation Of Harvested Weight And Value

Survival and densities varied with the experiments performed as reported in Table 3-5 (page 43). As a starting point, a density of 10 animals /m^2 is assumed and a survival rate of 80% will be used which is approximately the average of the 5 reported rates in that Table. An FCR of 5.5 will be used to start with as this is the best report in the literature (Kelly, Haseltine and Ebert, 1977). The value of the harvests are calculated based on the extra dollar value of the animals throughout October - April when the wild supply is at its lowest value. The top 0.3 m of the net pen is unusable by the prawns thereby decreasing the productive area of the net to 506 sq m.

Number of animals harvested per net.

506 sq m surface area *10 prawns/m^2 * 80% survival = 4048 animals/net. The initial stocking density would be at least 20,240 animals for a section of four nets. Ten animals/m^2 was used at first because this was the densities used by Rensel & Prentice (1979) that had a survival of 93 %

(Table 3-5 page 43). The density was then varied up to 30 animals/m^2 as was also used by Rensel & Prentice (1979).

CALCULATION OF COST PER 1000 POST LARVAE

The average fecundity is about 3000 eggs/female and larvae survival varies but was assumed to be 80% as seen by Wickens (1972). The density of larvae rearing was taken to be 125 animals/l. This is higher than any density reported in the literature for *P. platyceros* but is well within the 50 - 200 larvae/l culture methods for penaeids as reported by Lee & Wickens (1992). It is assumed that larvae rearing of *P. platyceros* would have to be better understood before culture operations would commence. There would need to be a minimum of 20,240 animals required to stock a section of four netpens.

20,240 animals = 80% * 25,300 animals. If the required number of larvae prior to any mortality is 25,300 then at least 9 gravid females would be required.

Calculation for feed costs in the Hatchery

Palaemon serratus has been seen to consume from 20 *Artemia*/larvae on day two, to 150 *Artemia*/larvae on day 24 (Wickens, 1972). If we assume that *P. platyceros* will consume 150 *Artemia*/larvae daily, then throughout the 35 (maximum) days spent as larvae, $1.33 * 10^8$ *Artemia* will be required at a cost of approximately $22 (pers. comm. Kimberly Payne). This is based on 300,000 *Artemia* cysts/g that are sold at $44(US)/kilogram (premium grade) with a 90% hatch rate. Since many of the *Artemia* will be lost during water replacement, the amount was quadrupled ($176) in attempt to be conservative. After day 35, all of the animals should be at the post larvae stage and weaned onto the artificial diets. Table 3-3 (page 41) shows that growth throughout the next 60 days will be approximately 2.2 grams. At a FCR of 5.5:1 at a cost of $1.25/kg of feed there will be a total cost of approximately $383.

Cost of Post Larvae from the Hatchery

In attempt to determine the cost to raise the required amount of PL for the growout site a cash flow table was used similar to the one at the end of appendix II. Since no commercial culture of *P. platyceros* is presently being carried out, it was not possible to recuperate the large capital cost of building a hatchery. It would be necessary to utilise a shellfish hatchery already in operation that would require little or no conversion. This minimises cost and with the assistance of public money available for research it may be possible to produce affordable PL. Using this basis a simple cash flow was created based on a shellfish hatchery which would produce *P. platyceros* on a small scale. Only 2.5% of the estimated capital expenses was used to determine the cost to produce PL. This would only be enough money to perform minor modifications to the facility. Since minimal time would be spent on the production of shrimp PL only a small portion of items such as salary and overhead was included in these calculations. An IRR of 6% was set and the required revenue was then determined to achieve this rate. This is a low IRR for any investor, but it is assumed that low income from shrimp larvae would initially be offset by profits from shellfish larvae. It was determined that an absolute minimum of $35/1,000 PL was required for 6% IRR. This figure also ignores opportunity costs and other factors which may be experienced by the hatchery. The estimated cost to produce 1000 PL (penaeid shrimp) in the U.S. is $10.35 (at 1.38 exchange rate) so this figure was used as the cost of PL to the growout facility. The calculated cost of PL makes the cost of seed to the grower much too high to make a profit.

Sample Cash Flow

Table xx: Sample cash flow used to determine Financial Feasibility of the Operation.

Year	0	1	2	3	4	5	6	7	8	9
Sources Of Funds										
Production (Kg)	0	35137	35137	35137	35137	35137	35137	35137	35137	35137
Revenue($)	0	658,465	658,465	658,465	658,465	658,465	658,465	658,465	658,465	658,465
Paid in Capital	1,319,690	0	0	0	0	0	0	0	0	0
Investor Support	0									
Loans	0									
Total	1,319,690	658,465	658,465	658,465	658,465	658,465	658,465	658,465	658,465	658,465
Fixed Costs ($)										
Floating Structure	25,000	0	0	0	0	0	0	0	0	0
Walkways	300,000	0	0	0	0	0	0	0	0	0
Netting	281,256	245,664	0	0	0	281,256	245,664	0	0	0
Pen Covers	17,148	17,148	0	0	0	17,148	17,148	0	0	0
Boat and Engine	17,000	0	0	0	0	0	0	0	0	0
Truck	5,000	0	0	0	0	5,000	0	0	0	0
Generator	1,000	0	0	0	0	1,000	0	0	0	0
Miscellaneous Equip.	16,160	0	0	0	0	0	0	0	0	0
Salaries	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
Overhead (5% of FC)	35,128	15,141	2,000	2,000	2,000	17,220	15,141	2,000	2,000	2,000
Interest and Loan Payment	0	0	0	0	0	0	0	0	0	0
Total Fixed Costs	737,692	317,953	42,000	42,000	42,000	361,624	317,953	42,000	42,000	42,000
Variable Costs ($)										
Seed[1]	35,829	35,829	35,829	35,829	35,829	35,829	35,829	35,829	35,829	35,829
Feed[1]	88,599	88,599	88,599	88,599	88,599	88,599	88,599	88,599	88,599	88,599
Salaries[1]	4,374	4,374	4,374	4,374	4,374	4,374	4,374	4,374	4,374	4,374
Overhead (2.5% of VC)	3,220	3,220	3,220	3,220	3,220	3,220	3,220	3,220	3,220	3,220
Total Variable Costs	132,023	132,023	132,023	132,023	132,023	132,023	132,023	132,023	132,023	132,023
Contribution Margin	-132,023	526,442	526,442	526,442	526,442	526,442	526,442	526,442	526,442	526,442
Income Tax Payable	0	0	0	0	22,902	7,779	29,615	167,591	167,591	167,591
Total Costs	869,715	449,975	174,023	174,023	174,023	493,647	449,975	174,023	174,023	174,023
Net Cash Flow	449,975	208,490	484,442	484,442	484,442	164,818	208,490	484,442	484,442	484,442
Net Income Before Taxes	-1,018,974	59,230	335,183	335,183	335,183	15,559	59,230	335,183	335,183	335,183
Income Tax (50%)	0	0	0	0	22,902	7,779	29,615	167,591	167,591	167,591
Net Income	-1,018,974	59,230	335,183	335,183	312,280	7,779	29,615	167,591	167,591	167,591
Present Value (8%)	-1,018,974	54,843	287,365	266,079	229,535	5,295	18,663	97,788	90,544	83,837
Net Present Value	114,975									
IRR (@8% Discount Rate)	3%									
Return On Investment	0.84									
Roi Capital	0.43									

Appendix III

Picture of Net Pen Set-Up

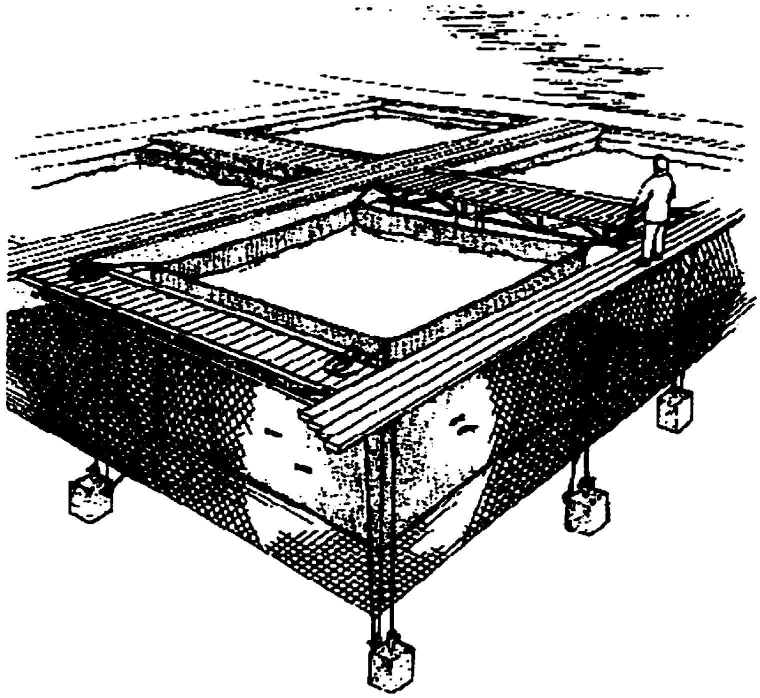

Figure x: Picture of Net Pen Set-Up. (Anonymous, 1987).

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989