Towards the development of a protocol for rearing juvenile rock lobster, *Jasus lalandii*.

Submitted in Fulfilment of the

Requirements for the Degree of

MASTER OF SCIENCE

Rhodes University

by

J.A. Esterhuizen

November 2004

TABLE OF CONTENTS

CHAPTER 5

Acknowledgements

I would like to thank Professor Pete Britz for providing me with the opportunity of doing an MSc in a field of great personal interest. His help, enthusiasm and encouragement during this study, as well as his valuable criticism of earlier manuscripts are greatly appreciated.

Many people helped with field work, to whom I am extremely grateful. I would like to thank the staff from Elsenburg Research Institute especially Kobus Swart and Jaco Swart who assisted with the collection of pueruli and the Department of Agriculture that provided funding. Without the abalone farmers especially HIK Abalone Farm, which provided research facilities, this project wouldn't have been possible. Roger Krohn, Bertus and Louise, thank you so much your patience. A special thanks to Luderitz Mariculture that provided the pueruli and juvenile lobsters. Prof. P.Court, Mr. Koegelenberg and Roger, again, your input to the development of the business plan proved invaluable.

Thanks must go to my friends at DIFS and in Hermanus;- Mikey, Meaghie Poo, Thompson, Guy, Simon and Hannes, it was great to have you around those times when we were watching "Felicia on e-TV". To my other friends, too many to name, your insight, support and assistance has been greatly appreciated. Faith and Terry, you are not forgotten.

Laastens aan Ma en Pa, daar is nie genoeg woorde om die moontlikhede wat julle vir my geskep te beskryf nie. Julle was altyd daar en ek hoop dat die tesis is n bewys van die vrugte wat julle afgewerk het.

Abstract

The diversification of current aquaculture practise in South Africa is crucial for the future development of the industry. The rock lobster, *Jasus lalandii* has been identified as a possible candidate species for shore based culture in systems similar to those used for abalone farming. Reduced Total Allowable Catch (TAC's) and an increased minimum legal size were implemented as management strategies to relieve fishing pressure on natural stocks of *J. lalandii*, and in turn led to increased market demand and a possible niche for farmed lobsters. High puerulus settlement along the Namibian coast, together with other favourable aquaculture attributes, indicate that the commercial grow out of wild harvested juveniles could be feasible. The aim of study was to investigate the feasibility of growing out rock lobsters in shore based systems in Namibia and South Africa. The experimental objectives of the project were to investigate the nutritional requirements, as well as the effect of stocking density and tank design on growth and survival of *J. lalandii*. The economic viability of shore based rock lobster farming was then evaluated based on the experimental results and typical capital requirements of an abalone farm in South Africa.

Puerulus and early juvenile rock lobsters were collected in Luderitz, Namibia and transported to HIK Abalone Farm in Hermanus, South Africa where they were acclimated in black fibre glass tanks in a flow through system. The pueruli were stocked at 50, 75, 100 and 125/m^2 and early juveniles at 20, 30, 40 and 50/m^2 to test the effect of density on growth and survival. A comparative dietary study with both size classes was conducted using a mussel diet (*Choromytilus meridionalis* and *Mytilus galloprovincialis*), a commercial shrimp feed diet and a rotational diet comprising both mussels and shrimp feed. Tanks provided with “v-shaped” asbestos hides, PVC hides and no hides were compared to test the effect on growth rate and survival of pueruli. All treatments were conducted in triplicate. Temperatures were recorded twice daily while water quality parameters were tested every second week.

The results indicate that density had a significant effect on growth and survival on post-pueruli. An initial stocking density of 75 post-pueruli/m² is regarded as optimal both in terms of the growth rate and biomass production per tank. No differences in growth and survival rates were attained in the early juvenile size class. This indicates that higher densities can be used to rear juvenile *J. lalandii*.

No significant differences were obtained in growth rate when reared under different hide conditions although asbestos hides yielded significantly higher survival rates (93.3 %) compared to the tanks provided with PVC hides (74.04 %) and no hides (77.8 %, $p \leq 0.05$). As a result of the high survival rate observed in tanks provided with “V-shaped” asbestos hides, these tanks also yielded higher biomass production per tank (297.8 grams) compared to the tanks provided with PVC hides and no hides (261.09 and 260.5 grams respectively).

In the diet trials, growth rates of post pueruli and juvenile lobsters fed the mussel and rotational (mussel and shrimp feed) diets did not differ significantly, however, growth rates of lobsters fed the shrimp feed only diet was significantly lower than both the mussel and rotational diets ($p \leq 0.05$). Lobsters fed the mussel diet yielded significantly higher survival rates compared to lobsters fed either the rotational diet or shrimp feed diet only. An imbalance in the fatty acid profile of the shrimp feed could have been a major contributing factor to the poor growth and survival in lobsters fed the shrimp feed only diet as the level of linoleic acid (LOA) was exceptionally high resulting in a high (n -6):(n-3) ratio (1.01) compared to the mussel and rotational diets (0.17 and 0.56 respectively). The low level of arachidonic acid (ARA) in the shrimp feed diet could be a further contributing factor explaning for the poor growth and survival of juvenile rock lobsters.

An economic feasibility study was conducted at the end of the experimental phase by modelling a hypothetical shore based rock lobster farm. A projection of production costs and revenues was based on the typical costs of a shore based abalone farm and the current market prices for wild harvested *J. lalandii*. The economic viability was evaluated using benefit-cost ratios, payback period, internal rate of return and break-even analysis. Sensitivity analyses revealed that the projected lobster growth and survival rates were the main biological factors influencing the economic feasibility of the hypothetical rock lobster farm. An assumed four year grow out period at a low stocking density yielded more lucrative internal rate of return (IRR), benefit-cost ratio, payback period and net present values (NPV) than a five year grow out period at a high density. The four year grow out scenario proved to be more robust to the fluctuating Rand/US$ exchange rate and could accommodate a lower lobster survival rate. Results presented in this study indicate that rock lobster farming is a marginal commercial prospect based on current production performance and costs. Further research to develop effective puerulus collection techniques as well as to make lobster grow out technology more cost effective is required.

Chapter 1: General Introduction

The palinurid lobster, *Jasus lalandii* forms the basis of an important commercial fishery in South Africa and Namibia. Live lobsters caught from natural stocks are exported to the United States, Europe and the Far East and fetch market prices as high as US$ 27.50/kg (G. Koegelenberg, Oceana Fishing Group, *pers. comm*., 2003). Together with other various products such as frozen tails, whole frozen raw and whole frozen cooked, the total revenue was estimated to be approximately R200 million in South Africa in 2000 (Sauer *et al*., 2003). However, the resource is heavily depleted in terms of the harvestable component (~ 6 % of pre-exploitation levels) (Sauer *et al*., 2003). This is due to virtually uncontrolled exploitation during the second half of the 20th century. Total landings declined dramatically during the 1960s from just over 10 000 tons per annum to less than 6 000 tons in 1970/71. The unstable fishery was further affected when a marked decrease in the somatic growth rate of the west coast rock lobster was observed early in the 1990's. It was postulated that the decreased growth rate was due to a reduction in productivity of the Benguela upwelling system caused by the anomalous *El Nino* conditions experienced from 1990 to 1993 (Pollock *et al*., 1997). The minimum legal size for the commercial industry was increased from 75 to 89 mm carapace length and the total allowable catch (TAC) being reduced from 3790 tons in 1990/91 to 2400 in 1992. A further reduction of the TAC to 1500 tons occurred in the 1995/96 season (Pollock *et al*., 1997). In 1997, an operational management procedure (OMP) was developed and implemented to set a basis for current TAC's (Cockcroft and Payne, 1999). The vagaries inherent in the harvesting of the wild lobster resource and the possible negative implications that reduced supply may have on the export markets stimulated interest in the possible culture of this species.

In 2000 a number of abalone farms expressed interest in conducting lobster grow out trials as it was evident that the shore based culture systems used for the abalone, *Haliotis midae*, could be adapted for the culture of *J. lalandii.* The Department of Agriculture in the Western Cape, South Africa established a Rock Lobster Steering Committee representing researchers from the abalone farms, tertiary institutions and Marine and Coastal Management (MCM) to coordinate on farm investigations to determine the viability of rock lobster culture in South Africa. Grow out parameters such as stocking density, nutritional requirements and tank configuration were listed as top priorities. These few pilot studies yielded no published data and their results were often questionable (Rock Lobster Steering Committee, May 2002). Therefore, the present study was funded by the Department of Agriculture during 2001 and 2002 to obtain quantitative data for rock lobster grow out in shore based systems on abalone farms.

Biology and life history

In order to develop culture techniques for rock lobster, an understanding of its biology and life history provides certain insights into its requirements The biology and life history of *J. lalandii* is fairly well documented. The west coast rock lobster, *J lalandii* occurs in shallow water (0-50m) off the south-western coast from about 23° S, just north of Walvis Bay (Namibia) to about 28° S close to East London on the east coast of South Africa (Pollock, 1986). Rock lobsters have an elaborate life cycle consisting of larval (nauplisoma and phyllosoma) and post larval stages (Booth, 1997). The nauplisoma stage is short-lived (several hours) and small (1-2mm) while the phyllosoma larval stage is long-lived (several months) and occur up to several hundred kilometres off-shore. The puerulus stage (post larvae, 3-5 cm) is associated with final settlement in-shore followed by metamorphosis into small juvenile rock lobsters. *Jasus lalandii* have been shown to utilize a wide variety of prey species in the wild which include coralline algae, sponges, barnacles, ribbed mussels (*Aulacomya ater*) and black mussels (*Choromytilus meridionalis*) (Mayfield *et al*., 2000). Field studies conducted along twenty eight sites off the coast of Namibia and South Africa by Barkai *et al*. (1996) revealed that black mussels and ribbed mussels are the most common food items. It is also well documented that *J. lalandii* is well suited to the cool temperate waters of the Beguela current (Hazell et al., 2001). Field work conducted by Hazell *et al*. (2001) indicated that during the study period, optimal growth rates and food conversion indices were achieved at temperatures in the close vicinity of 16ºC.

Female *J. lalandii* have shown to produce and carry large numbers of eggs in captivity (*pers. obs*.). Although *J. lalandii* has a complex and extended larval cycle, this species have been successfully cultured through its entire larval development (Kittaka, 1988), however, current culture techniques must still be refined as the captive conditions required for phyllosomas are not yet fully understood and the long larval developmental period may induce prohibitive inventory costs (Kittaka and Booth, 2000). Due to the immediate difficulties in rearing lobster larvae, attention in South Africa has been focused on the capture of wild pueruli for on growing.

Attempts have been made to identify locations along the west coast of South Africa where sufficient numbers of settled pueruli may occur for commercial on growing purposes. Several collector types including the "crevice collector" and "bottle brush collector" described by Phillips *et* al. (2003) have been deployed on several sites along the west coast of South Africa with limited success (Rock Lobster Steering Committee, May 2002). The limited success was attributed to the high energy nature of the west coast that made servicing of these collectors impractical combined with the often difficult and rough terrains that have to be crossed to reach the sites. In Namibia, large numbers of pueruli are known to settle on oyster rafts in Luderitz Bay (Grobler and Ndjaula, 2001). Settled pueruli on the oyster rafts die as a result of the oyster harvesting process and this has created an opportunity for the collection and on growing of puerulus and juvenile rock lobsters. Advantages of collecting wild juveniles listed by Hair *et al*. (2002) include:

1). A reduction in juvenile propagation costs (no hatchery costs).

2). Socio-economic benefits: The collection and sale of juveniles can create small enterprises for people of different sectors that would have been excluded from the aquaculture venture.

3). Increasing overall productivity: Often juveniles in the wild have a very low survival rate due to extreme and variable environmental conditions. Collection of juveniles can provide refuge against these conditions and juveniles can be grown to larger sizes for restocking or in this case, for sale to foreign markets.

4). Reduced risk of disease outbreak- Juveniles propagated in hatcheries usually have higher incidences of disease outbreak than those collected from the wild.

The principle diseases of cultured lobsters have been identified as bacterial diseases (shell disease, gaffkemia, and vibrioses), fungal infections (systemic and superficial mycoses) and parasitic infections (Evans *et al*., 2001), although palinurid lobsters tend to contract few diseases in captivity (Sindermann, 1977). The farming of other crustaceans such as shrimps and crabs has allowed researchers to study various diseases encountered (Evans *et al*., 2000). Rayns (1991) investigated shell disease in *J. edwardsii* and have suggested that infestation rates of chitin digesting bacteria are dependant on the feed type, stocking density and water quality. Bacterial shell disease was recorded to be responsible for eighty percent of all deaths among *Homarus americanus* fed a formulated diet, while animals reared on an adequate diet (e.g. Brine shrimp) did not become susceptible to this disease (Fisher *et al*., 1978). High lobster densities which negatively affect water quality may result in the prevalence of bacterial shell disease since there is a periphytic association of bacteria on particulate matter (Rayns, 1991). It appears that disease outbreak would not pose an immediate threat to lobster culture, once an adequate diet is formulated and optimal stocking densities have been determined. Management procedures such as isolating infected animals from healthy ones, adequate feeding strategies and proper water treatment are important for preventing disease outbreak.

Transportation techniques of live adult lobsters are not well documented (Taylor *et al*., 1997) although adult *J. lalandii* are currently exported live to foreign markets with great success. Stress in lobsters was identified as the main physiological response of animals during handling and transport, but few studies have been conducted on post-harvest physiology (Paterson and Spanoghe, 1997). Prolonged exposure of rock lobsters to stress factors (high temeperatures, low oxygen levels, excessive physical handling and direct sunlight) can increase mortality (Suigita and Deguchi, 2000). Low temperatures are generally applied during transport which lowers metabolic rates and anaesthetizes lobsters to some extent (Taylor *et al*., 1997). Ammonia secretion, which is primarily related to metabolism, is the main nitrogenous excretory product and is associated with diffusion and ion exchange at the gills. High levels of stress outside the water can result in failure of the excretion of ammonia and can therefore result in elevated blood ammonia which is believed to be toxic. Taylor *et al*. (1997) reported that lobsters can recover within several hours after handling provided long enough recovery period in water. From an aquaculture point of view, rock lobsters (*J. lalandii*) appears to be robust and current transportation techniques of live rock lobsters in the commercial industry can be directly transferred to aquaculture ventures. However, relatively little research on culture techniques for *Jasus* species has been carried out.

Jasus lalandii possesses several biological attributes that could make commercial farming feasible. These include:

1). Propagation in captivity is possible although larval culture techniques still need to be refined for commercial purposes.

2). Pueruli abundance off the coast of Namibia and possibly South Africa could accommodate the collection of large numbers of juveniles for on growing purposes.

3). Palinurid lobsters tend to contract few diseases in captivity.

4). Live rock lobsters appear to be rather resilient to physical stress during transportation to foreign markets.

In terms of the biological attributes described above, *J. lalandii* has potential as an aquaculture candidate in South Africa. At the outset of this study, inadequate quantitative research on the biological aspects determining optimal culture conditions was the main constraint preventing commercialisation of the culture technology.

A central focus of previous local studies has been the nutritional aspects of lobster rearing. Investigations have been conducted to determine the effect of diet on growth and survival of *J. lalandii* fed Abfeed (a commercial abalone diet formulated by Seaplant Products Pty. Ltd., South Africa), trash fish (including pilchards and squid) as well as a combination of these food items occasionally supplemented with black mussels (*Choromytilus meridionalis* and *Mytilus galloprovincialis*). However, in almost all pilot studies conducted on abalone farms in South Africa, poor growth and survival was observed in *J. lalandii* except for lobsters fed mussels only. This indicated that poor growth of lobsters in captivity was related to nutrient deficiencies in Abfeed and trash fish. In New Zealand, similar results have been reported for *J. edwardsii* (Sheppard, 2001; Crear *et al*., 2000). Studies have been conducted to compare growth and survival performance of *J. edwardsii* fed natural food (i.e. fresh mussels) and artificial diets such as commercial shrimp and prawn feeds. Mussel diets fed to *J. edwardsii* have yielded superior growth and survival rates compared to formulated diets (Crear *et al*., 2000; Kington, 1999 and Ward *et al*., 2003). Kington (1999) concluded that reduced growth of *J. edwardsii* fed formulated feeds was a result of essential nutrients leaching in the water and suggested that lower rations fed more frequently could circumvent this problem. However, Thomas *et al*. (2003) tested this hypothesis and concluded that nutrient leaching was not the major contributing factor for reduced growth in formulated feed, but rather the lack of essential nutrients in the diet. The artificial diets fed by Crear *et al.* (2000) and Thomas *et al*, (2003), contained adequate levels of macronutrients such as lipids, proteins and minerals. Therefore, the poor growth was attributed to the lack of an essential nutrient, for example, an essential fatty acid or amino acid. These results highlighted the need to identify the essential nutrients required for satisfactory growth and survival in rock lobsters. The need to formulate a local artificial diet was clear since the use of mussels and trash fish alone was regarded as impractical and too expensive. The varying availability of these food items year round and additional labour costs involved with cleaning tanks on a regular basis once lobster farming commenced on a commercial scale was seen not economically viable (Rock Lobster Steering Committee, May 2002). Therefore, the objective of the present study was to compare growth and survival performance of *J. lalandii* fed fresh mussels and an artificial shrimp feed diet (as well as a daily rotational diet comprising both fresh mussels and shrimp feed). The aim of this study was to identify some of the limiting essential micronutrients such amino acids and fatty acids.

Satisfactory growth and survival rates of a species stocked at high density are prerequisites in achieving acceptable production costs (Webber and Riordan, 1976). It was deemed necessary to investigate density related effects on growth and survival of *J. lalandii* since little work has been done on this aspect in South Africa (Rock Lobster Steering Committee, May July 2002). Spiny lobsters (palinurids), in general, are known to be gregarious which makes them ideal candidates for aquaculture. This contrasts to the aggressive and cannibalistic clawed lobsters (homarids) which have to be raised in separate tank compartments. Palinurid lobsters in captivity seem to tolerate high stocking densities showing minimal aggression to conspecifics (Chittleborough, 1975).

Holding facility costs were identified as the major cost (as much as 45 % of total cost) for a *J. edwardsii* land based culture systems (Jeffs and Hooker, 2000). The cost structure for shore based grow out outlined by Jeffs and Hooker (2000) is likely to reflect similar investment requirements for other spiny lobster species (Booth and Kittaka, 1994; Jeffs, 2001). It has been speculated that seacage culture could reduce infrastructure costs to make lobster farming more feasible (Jeffs and Hooker, 2000; Booth and Kittaka, 1994; Kam *et al.*, 2003). However, the high energy nature of the South African and Namibian coastline as well as the lack of estuaries and bays limits the possibilities of cage culture (Hecht and Britz, 1990). In addition, seacage culture would be subject to high risk as control over feed intake, mortality and theft would be limited. The economic feasibility of future rock lobster farming greatly depends on the initial capital costs for a land based culture facility and length of the grow out period before the sale of marketable animals commences. In addition, economic criteria such as the Rand/US$ exchange rate, seasonality of lobster demand (and supply) must be evaluated before assessing the economic feasibility of such a venture (Webber and Riordan, 1976). This study therefore aimed to gather some preliminary biological information (such as growth, survival and food conversion ratios) needed for assessing the economic feasibility of future rock lobster farming in South Africa.This thesis therefore aimed to determine an “optimal” set of grow out conditions based on current knowledge by investigating (in Chapter 2):

1). Growth and survival of juvenile lobsters under various stocking densities.

2). Growth and survival of juvenile lobsters fed formulated and natural diets with the objective of identifying essential nutrients required for satisfactory growth.

3). Growth and survival of early juveniles provided with and without hides as well as different hide designs.

A further aim of the thesis was to determine the economic feasibility of shore based rock lobster farming in South Africa and in Chapter 3 a financial model of two production scenarios is presented with various sensitivity analyses.

Chapter 2: An Investigation into the Effect of Density, Diet and Hide Design on Production of Juvenile Rock Lobsters, *Jasus lalandii* under Culture Conditions.

Introduction

The captive conditions required for the optimal growth of spiny lobsters have been investigated for several species, however, this information is still fragmentary and results are often contradictory (Kittaka and Booth, 2000). Webber and Riordan (1976) outlined that selection of a species to be farmed on a large scale is dependant on various biological criteria including ease of propagation, resistance to disease and more importantly, rapid growth and a high survival rate. Palinurid lobsters in captivity seem to tolerate high stocking densities and display minimal aggression to conspecifics (Chittleborough, 1975). This is in contrast to the aggressive and cannibalistic clawed lobsters (homarids) which have to be raised in separate tank compartments. Satisfactory growth and survival rates of a species stocked at high density are prerequisites to achieve acceptable production costs (Webber and Riordan, 1976). Therefore, this study focused on defining the basic captive conditions required for optimal growth of *J. lalandii*, including stocking density, tank configuration and dietary requirements. A brief review of the relevant literature on lobster rearing is presented below followed by a definition of the experimental objectives.

Density

Several investigations have been conducted to determine optimal stocking densities for palinurid and homarid lobsters (James *et al*, 2001; Jones *et al*, 2001; Kaleemer Rahman *et al*, 1997). Although results vary for different studies and species which there is evidence that stocking density plays an important role in the growth and survival of lobsters reared under culture conditions. Rayns (1991) concluded that stocking density affects growth rate differently in the early and late juvenile stages of *J. edwardsii*. Early juveniles exhibited significantly faster growth at lower densities than late juveniles. James *et al*. (2001) reported similar results for *J. edwardsii*. Satisfactory survival rates (ranging from 89–96 %) were obtained by James *et al*. (2001) who found no differences between density treatments. This was partially attributed to the provision of adequate shelter. Rayns (1991) hypothesised that smaller moult increments at higher densities could be a biological response to diminishing resources such as shelter and individual space in the captive environment. Jones *et al*. (2001) showed that densities of 14, 29 and $43/m^2$ produced no significant differences in the growth of the ornate lobster *Panulirus ornatus*. Survival (which averaged 52.5%) showed no difference between the density treatments. Mortalities were consistent throughout the experimental phase and were almost entirely attributed to cannibalism of postmoult individuals. It was speculated that cannibalism could have been due to the provision of inadequate shelter.

Hide Provision

Field studies on the early benthic stages of several commercially exploited species of spiny lobsters such as *P. cygnus*, *P. argus*, *P. longipes*, *P. japonicus* and *J. edwardsii*, have given scientists and aquaculturists insights into the captive conditions required for enhanced growth and survival (Dennis *et al*., 1997 and Chittleborough, 1975). It is well documented that lobsters avoid predators by inhabiting crevices among rocks and coral rubble (Steele *et al*., 1997). Chittleborough (1970) showed that natural mortality in reef populations of *P.*

longipes was density dependant and it was suggested that increased aggression resulting from shortage of shelter and food could have been a contributing factor. The behaviour of fish under culture conditions has been extensively studied and provides an indication of some of the responses which may be expected in lobsters (Sayer, 1998). In general, agonistic behaviour is a trait associated with survival through competition for food and space, and predator avoidance (Ruzzante, 1994). Under farming conditions, optimal utilization of space (which results in artificially high stocking densities) often results in increased competitive behaviour in animals. This behaviour can lead to slower growth rates as well as decreased survival and a poor aesthetic appearance. A dominance hierarchy was reported to occur in *H. americanus* when in direct physical contact with conspecifics (Cobb *et al*., 1982). Subsequently, subordinate lobsters were deprived of food and exhibited slower growth. It can be expected that with increasing density, the frequency of physical encounters between conspecifics will increase possibly resulting in agonistic behaviour and stress. If food supply is adequate, shelter might therefore become a limiting factor for successful rearing of juvenile *J. lalandii* in a captive environment that may induce physiological stress.

Diet

An adequate artificial diet for rock lobsters is yet to be formulated (Sheppard, 2001; Crear *et al*., 2000). Several studies have been conducted that have compared the growth and survival performance of lobsters fed natural food (fresh mussels) and artificial diets such as commercial shrimp and prawn feed. In almost all studies, mussel diets have yielded superior growth and survival rates compared to formulated diets (Crear *et al*., 2000; Kington, 1999 and Ward *et al*., 2003). Kington (1999) concluded that reduced growth of *J. edwardsii* fed formulated feeds was a result of essential nutrients leaching in the water and suggested that lower rations fed more frequently could circumvent this problem. However, Thomas *et al*. (2003) tested this hypothesis and concluded that nutrient leaching was not the major contributing factor to the reduced growth observed on formulated feed, but rather the lack of essential nutrients in the diet. The artificial diets fed contained adequate levels of macronutrients such as lipids, proteins and minerals. Therefore, the poor growth is partly due to the lack of an essential nutrient, for example, an essential fatty acid or amino acid. This highlights the need to identify the essential nutrients to be included in artificial diets.

Lipids play an important role in animals either as high energy storage molecules or as components of cell membranes (De Silva and Anderson, 1995). Fatty acids rarely occur freely in nature, and are more commonly found in esterified forms called triglycerides (De Silva and Anderson, 1995). Triglycerides are an efficient form to store metabolic energy since they are less oxidised than carbohydrates or proteins and therefore yield more energy on oxidation (DE Silva and Anderson, 1995). It is believed that essential fatty acids (EFA) in diets of penaeids are linoleic acid (18:2 n – 6, LOA), linolenic acid (18:3 n – 3, LNA), arachidonic acid (20:4 n – 6, ARA), eicosapentanoic acid (20:5 n – 3, EPA) and docosahexaenoic acid (22:6 n -3, DHA) (Merican and Shim, 1996; D'Abramo, 1997). The competitive interactions between essential fatty acids have led to difficulties in understanding the optimisation of these nutrients in artificial diets. Sargent *et al*. (1999a) outlined that competitive interactions between fatty acids stem from a) different interactions between fatty acids such as n – 6 and n – 3 polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids, and b) between fatty acids of different chain lengths. Eicosanoids (biologically active paracrine hormones) produced from ARA (the major precursor of eicosanoid formation) in general yields more biological activity than EPA as these compete for the same cell membrane receptors (Sergant *et al*., 1999b). Also, the eicosanoid formation from EPA actively inhibits the formation of eicosanoids formed from ARA. Therefore, addition of ARA (n -6) fatty acid in artificial diet formulation has attracted more interest in recent times. When investigating the requirements of a new species such as rock lobsters, it is therefore important to examine the EPA:ARA ratio instead of examining the levels of EFA's in isolation. Another important aspect is the dietary ratio of the n – 3 and n – 6 fatty acid balance. The importance of this ratio is yet to be clarified (Xu *et al*., 1994 and Glencross *et al*., 2002).

Lobsters require a constant supply of nutrients to ensure satisfactory growth (Bordner and Conklin, 1981). For animals to grow, the rate of protein synthesis must be greater than protein degradation which requires the dietary inclusion of essential amino acids (EAA's) (DE Silva and Anderson, 1995). EAA's are those that a fish cannot synthesise *de novo*, and are obtained entirely from the dietary protein (Cowey *et al*., 1970). Even if the diet has high levels of protein, a deficiency in any of the EAA's will result in decreased food conversion efficiency and poor growth (Piper *et al*., 1982).

In the light of the experience described above, the following objectives were formulated for this study:

1). To examine effects of density on the growth and survival of post-pueruli and juvenile rock lobsters (*Jasus lalandii*).

2). To investigate the effects of a mussel, shrimp feed and a rotational diet comprising both mussels and shrimp feed, on the growth and survival of post-pueruli and juveniles.

3). To analyse the nutrient composition of both the diets and experimental lobsters to possibly identify some of the essential nutrients required for optimum growth and survival of juvenile rock lobsters.

4). Investigate the effect of hide provision (and hide design) on the growth and survival of post-pueruli.

Materials and Methods

A simultaneous, multi-factorial growth trial was performed with post-pueruli and juvenile rock lobsters to test the effects of density, diet and hide design on growth and survival. The study was conducted at HIK Abalone Farm in Hermanus, South Africa from 1 July 2002 till 30 January 2003. Experiments were conducted on lobsters using a set of fibre glass tanks connected in a flow through system.

Experimental System

The experimental system consisted of fibreglass tanks, painted black with epoxy paint (Glatex Eight, Plascon). Before the paint dried, the bottom of each tank was covered with sea sand to provide a rough surface that would aid in the mobility and grip of lobsters, while the sides were kept smooth (Figure 2.1). Twenty four tanks with dimensions of 600 x 600 x 200 mm (surface area of 0.36 m^2) and 18 tanks with dimensions of 1200 x 600 x 200 mm (surface area of 0.72 m^2) were used. The smaller tanks were used for the post-pueruli while the larger tanks were used for the early juveniles. Each tank had separate water inflow and the water was drained by means of a 150 mm stand pipe. The water inflow and the outlet stand pipe were positioned in opposite corners to promote fresh water movement across the tank. Water was provided directly from the sea at ambient temperature and filtered through 100 µm drum filter. The flow rate was set at 1-2 tank volume exchanges per hour. Aeration by means of two airlines (fitted lengthwise along the bottom edge on both sides of each tank) promoted mixing of the water column. Oyster mesh strips (10cm width, 5mm mesh size) were fitted along the top edge of each tank to prevent the lobsters from escaping.

Figure 2.1: The experimental system consisted of fibreglass tanks painted black with epoxy paint. Each tank had separate water inflow and drainage with oyster mesh fitted along the top edge to prevent lobsters from escaping.

Animal collection and transport

Two thousand five hundred pueruli and early juvenile rock lobsters were collected during June 2002 from oyster rafts at Luderitz Mariculture, Luderitz, Namibia. The animals were held in baskets in recirculation raceways at Luderitz Mariculture and were purged for two to three days before being transported to Hermanus, South Africa. This was done to reduce possible water quality degradation and thus overall stress during transit. During transit, the animals were kept in 20 litre plastic bags half filled with sea water and the half filled with oxygen. Black shade cloth strips were placed with the lobsters in the bags to provide a substrate for grip during transportation. Pueruli were stocked at 20/litre while the early juveniles were stocked at 10/litre. The plastic bags were placed in polystyrene boxes with two litres of ice cubes (evenly distributed) to keep temperatures down during transit. On arrival in Hermanus, the plastic bags with the lobsters were placed in 1 m^3 tanks containing seawater (at ambient temperature) for 1 hour to acclimate them for temperature differences before they were slowly released.

The lobsters were held in $1m^3$ tanks supplied with fresh sea water for a period of 1½ months prior to the experimental phase and fed freshly opened, black mussels (*Choromytilus meridionalis* and *Mytilus galloprovincialis*) once every second day. Tanks for different experiments were randomly positioned and lobsters were randomly stocked before the experiments commenced.

Density trial

In the density trial, the post-pueruli were stocked at 50, 75, 100 and 125 animals per square meter in tanks with a surface area of 0.36 m^2, and juveniles at 20, 30, 40, and 50 per square meter in tanks with surface area of 0.72 m^2. All treatments were run in triplicate. For the juvenile size class, four "V-shaped" asbestos hides (described below) were provided in each tank while in the puerulus size class, two asbestos hides were provided in each tank. Lobsters in this experiment were fed opened, live black mussels (with shell) (*Choromytilus meridionalis* and *Mytilus galloprovincialis*) once daily in slight excess.

Diet trial

In the dietary study, growth and survival of pueruli and juveniles using three dietary treatments with 3 replicates per treatment, was investigated. The post-pueruli were stocked at 75/m^2 while the juveniles were stocked at 30/m^2. The diets consisted mussels, formulated shrimp feed (manufactured by Amatikulu Pty. Ltd., South Africa), and a daily rotational diet comprising both mussels and shrimp feed. The shrimp feed diet was fed twice daily to apparent satiation in the morning and afternoon. Lobsters in the mussel only diet were fed opened, live black mussels (with shell) once daily in slight excess. For the rotational diet, mussels and shrimp feed were fed on alternate days following the procedures described above. Before feeding, mussels were weighed with shell, and uneaten mussels (with shell) were weighed again the next morning prior to feeding. To limit any possible dominance hierarchy effect, the feeding regime was adapted in two ways. Firstly, in the trials where shrimp feed was provided, lobsters were fed twice daily to apparent satiation and in trials where mussels were provided, food was given in slight excess so that a small proportion of mussel flesh remained uneaten the next morning. During feeding, the food was distributed evenly across entire tank bottom to prevent monopolisation of feeding by the more dominant lobsters. The tank sizes and shelter were the same as for the density trial.

Shelter trial

A third trial tested the effect of hide provision and design on the growth and survival of post-pueruli. Three treatments were compared which consisted of tanks provided with 1) “V-shaped” asbestos hides, 2) PVC piping and 3) tanks with no hides. The “V-shaped” asbestos hides and PVC piping were chosen as they proved to be durable, easy to clean, and provided an increased surface area for rearing rock lobsters.

The “V-shaped” asbestos hides consisted of two layers of “Victorian shape” asbestos cement plates with dimensions of 150mm x 450mm. These plates were fitted to one another using PVC spacers as illustrated in Figure 2.2 and 2.3. The second hide design (PVC piping) consisted of 25 mm pipes cut to 100 mm lengths

(Figure 2.4). In this trial, twenty seven PVC pipes were provided in each tank. Twenty-five millimeter piping was chosen to ensure that lobsters would not outgrow their hides during the trial period. The feeding protocol was the same as that used in the density trial where the lobsters were fed live, opened black mussels. The post-pueruli were stocked at $75/m^2$ and all treatments were run in triplicate.

Figure 2.2: The "v-shaped" asbestos hides consisted of two Victorian shaped asbestos plates, attached to each other by means of PVC spacers.

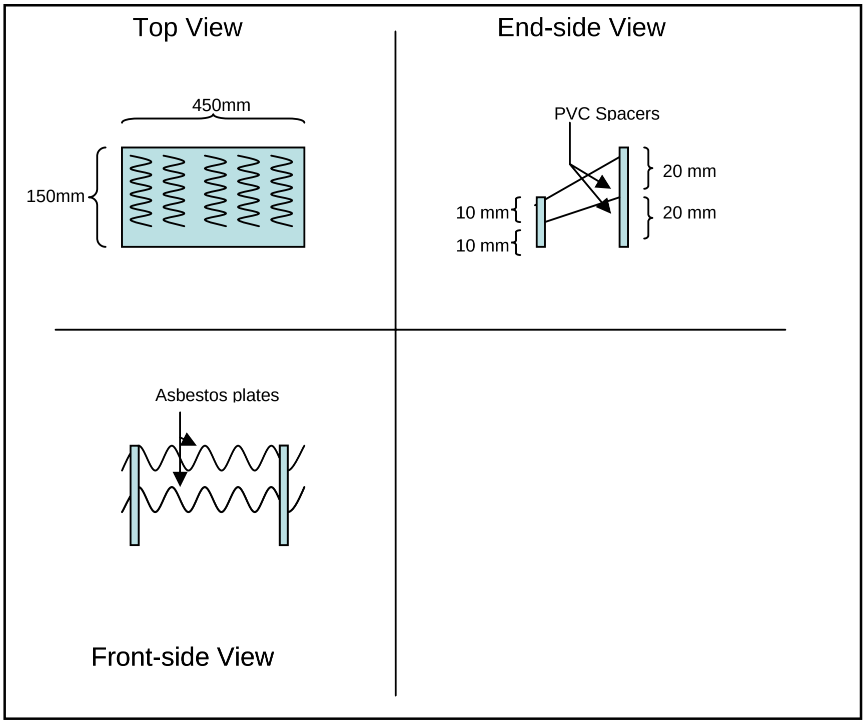

Figure 2.3: Illustration of the 'V-shaped" asbestos hides with dimensions of asbestos plates and PVC spacers used in the study.

Figure 2.4: The PVC hides consisted of 25 mm piping cut to 100 mm lengths. Each tank was provided with 27 pipes.

Experimental procedures

The weights and lengths of the lobsters were measured one week after introduction into the experimental tanks. This was done by blotting them damp-dry on paper towel and then measuring them using a Mettler scale and Vernier callipers. The pueruli were measured to the nearest 0.01 gram while the early juveniles were measured to the nearest 0.1 gram. Carapace length was measured from the anterior tip of carapace to the posterior dorsal edge. Both the pueruli and the early juveniles were measured to the nearest 0.1 millimeter. Lobsters that died during the first week after introducing them to the experimental tanks were removed and were replaced with new ones of similar size. Animals that died after this phase were not replaced. The total duration of the experiments was 162 days. All individual lobsters were weighed and measured after day 49, 105 and 162.

Tagging of animals was not possible as the post-pueruli were too small, and moulting occurred too frequently. As dead animals could not be replaced with new ones of similar size, density throughout the duration of the experiment could not be kept constant.

Water quality

Water temperature was recorded twice daily in the morning and afternoon while other water quality parameters were measured fortnightly. Temperatures were recorded using a "HOBO H8" data logger. Mean temperatures for day 0-49, 49-105 and 105-162 were 15.3°C (±0.6), 16.5°C (±0.7) and 15.6°C (±2.3) respectively. Water quality parameters such as ammonia, nitrite, nitrate and pH were measured using "INTERPET Easy Test Kit". Ammonia, nitrite, and nitrate levels were found to be <0.7 mg/l, <0.01 mg/l and <25 mg/l respectively, while the pH remained consistent between 7.9 and 8.5.

Calculations

The following formulae were used to calculate growth parameters in the density, diet and hide design experiments.

Growth (grams) = $Wt – Wi$

Growth rate (grams/day) = $Wt – Wi/T$

Specific growth rate (% Bw/day) = $((\ln Wt – \ln Wi)/T) \times 100$

Biomass yield (total weight increase) = $S \times (Wt – Wi)$

Where

Wi initial body weight (grams)

Wt final body weight (grams)

T number of days and

S number of survivors per tank.

The food conversion ratio (FCR) and protein efficiency ratio (PER) over the 162 day experimental period were calculated as follows:

FCR = Estimated dry weight feed consumed (grams)* : lobster wet weight gain (grams)

PER = Wet weight increase (grams) / protein intake per day (grams)

* Estimated dry weight of mussel meat without the shells.

Nutritional analyses

Proximate analyses (protein, ash, fat, and moisture) were conducted on the mussels and shrimp feed as well as lobsters from the diet experiment. Fatty Acids and amino acids were analysed from the sampled lobsters and different diets while carotene content was determined from the experimental lobsters and a control group of wild caught lobsters.

From each tank in all the treatments (including both pueruli and juvenile rock lobsters), 10 animals were collected and frozen fresh at -10 ºC. These were freeze dried at the Department of Microbiology, University of Port Elizabeth. The percentage moisture was calculated by placing a sample of known weight in a freeze drier. These samples were weighed periodically until a constant weight was achieved.

Protein

Crude protein was calculated using the Micro-Kjeldahl method (Steyn, 1957). In this method, the percentage nitrogen was calculated from the volume of HCL titrated according to the following formula:

$$N = (\text{mole Cl} \times 14.007 \times 100) / \text{weight of sample (mg)}$$

Percentage crude protein was calculated as N x 6.25 (AOAC, 1984).

Fat

Crude fat content was determined gravimetrically after extraction with methanol and chloroform as described by Knauer *et al*. (1994). Percentage fat was determined using the formula:

$$\% \text{ Fat} = [(\text{mass of fat (g)} \times 1.67)/\text{mass of sample (g)}] \times 100$$

Ash

Ash was determined by burning a powdered sample of known weight in a muffle furnace at 550 °C for 7 hours (Montgomery and Gerking, 1980), from which the final weight was determined. Protein, crude fat, fatty acids and ash were done at the Artemia Reference Centre, University of Gent, Belgium.

Fatty Acids

Fatty acid composition was determined by gas chromatography. Fatty Acid Methyl Ester analysis (FAME) was done by means of a modified procedure of Lepage and Roy (1984). This approach uses direct acid catalyzed trans-esterification, without prior extraction of total fat, on dry sample amounts ranging from 10-150 mg. Ten percent of internal standard 20:2 (n-6) was added prior to the reaction.

Amino Acids

Amino acid content was determined by hydrolysing a sample of protein. From this, the constituent amino acids were isolated by means ion-exchange and purified by partition chromatography (Cowey *et al*., 1970). The analysis was conducted at the Department of Animal and Poultry Science, University of Natal. As the total dry weight sample of post-pueruli in each tank was too small, amino acid analysis could only be performed on lobsters in the juvenile size class.

Fatty Acid and Amino Acid ratio in the rotational diet

The ratio of dry mass of mussel flesh to shrimp feed fed to lobsters in the rotational diet treatment was calculated. A ratio (mussel:shrimp feed) of 1:0.992 and 1:1.05 was obtained for the pueruli and juveniles respectively. Therefore, a ratio of 1:1 was assumed in the analysis of amino and fatty acids.

Carotenoids

Ten lobsters from each tank in all diet treatments were analysed for carotene pigmentation while twelve wild caught lobsters (*J. lalandii*) were used for comparison. The wild caught lobsters were divided in groups of four (three replicates) for pigmentation analysis. Muscle tissue was removed from the abdomens and carapaces. The abdomens and carapaces were then dried in an oven at 30 ºC for 48 hours. The dry lobster shells were ground to a powder form using a pestle and mortar. Approximately 0.2 g of lobster shell was placed in a glass vial filled with 10 ml of acetone. The solution was then allowed to stand for a period of six hours with the solution being mixed every half an hour. After the extraction was completed, the solution was filtered through paper filter and then measured using a spectrophotometer (PowerWave multi-well plate reader) set at 480 nm. A spectral scan was carried out to determine the peak absorbency of pure astaxanthin supplied by Sigma. Using the pure astaxanthin, a standard curve was prepared from which the absorbency of each carotene solution was plotted to determine the concentration of carotene content in the lobster shells.

Statistical Analysis

1) Density experiment

Weight and length data were tested for normality with a normal probability plot and the Shapiro-Wilk test, while homoscedacity was checked with a Levene's test. Weight distributions not normally distributed were log transformed. Therefore, all length and weight data in each treatment were standardised so that replicates in each treatment had a starting length and weight of zero, thus retaining information on how the data were distributed (i.e. change in scale average but not variance). This was achieved by dividing the initial and final length/weight measurements of each individual lobster in a replicate by the average starting measurement for that specific replicate. The average length and weight increase over the experimental period were then plotted against average density for each treatment. This was done to account for mortality and consequently density change.

2) Diet and hide design experiments

Weight and length data were tested for normality with a normal probability plot and the Shapiro-Wilk test, while homoscedacity was checked with a Levene's test. Weight distributions not normally distributed were arcsin transformed. Differences in growth between treatments were tested using ANCOVA to compare the slopes of the linear regressions.

Comparisons between dietary essential amino acid profiles and the essential amino acid profile of lobsters fed mussels were calculated as the coefficients of variation between the dietary and lobster EAAs (r^2). The same approach was used for comparisons of fatty acids in the dietary fatty acid profiles and fatty acid profile of lobsters fed mussels.

In all experiments, One-way ANOVA was used to test for differences in percentage mortality between treatments as well as biomass yield between treatments. Replicates were tested for differences within treatments and if no significant differences were evident, replicate data were pooled and then compared between treatments. If a significant difference was evident, Tukey HSD post-hoc test was carried out to determine which treatments differed from one another. For all data tested, significant differences between treatments were assumed at a confidence level of less than or equal to 5 % ($p \leq 0.05$).

Results

Density experiment

The specific growth rate (%body weight/day) of the post-pueruli decreased with increasing density ranging from 1.68 % at 50 pueruli/m² to 1.59 % at 125/m² (Table 2.1). Significant negative correlations between growth rate (weight and length increments) and density were obtained (Figure 2.5 and 2.6). Survival differed significantly between post-pueruli stocked at 75/m² (93.3 %) and 125/m² (80 %), $p<0.05$ (Table 2.1). Total biomass yield per tank was significantly lower for the 50/m² density compared to the 75, 100 and 125/m² treatments which did not differ from each other (Table 2.1).

The specific growth rates of juveniles did not vary between treatments (Table 2.2) and no correlation between growth and density was observed, $p<0.05$ (Figure 2.7 and 2.8). The survival rates differed significantly between the 30/m² (100 %) and the 50/m² (90 %) densities, $p<0.05$ (Table 2.2). Overall, a better survival rate (ranging between 90 and 100 %) was obtained in the juvenile size class than was observed in the puerulus size class (Table 2.2). Tanks stocked at 20/m² yielded the lowest biomass per tank (370.8 grams) while lobsters stocked at 50/m² yielded the highest (741.1 grams). Lobsters stocked at 30 and 40/m² yielded similar biomass per tank (542.9 and 608.4 grams respectively), however, they differed significantly from tanks stocked at 20 and 40/m² (Table 2.2).

In both size classes, lobsters that died were frequently found half-eaten. All dead lobsters were identified as newly post-moulted animals. Since these lobsters all completely shed the old exoskeleton (exoskeletons were intact), it is unlikely that they died as result of "post-moult death syndrome" i.e. death as a result of difficulty in shedding old skeleton. Dead lobsters were removed and examined, and death as a result of disease was not evident. It is therefore likely that these lobsters were most vulnerable to cannibalism during or after the moulting phase.

Table 2.1: Survival, growth and specific growth rates for post-pueruli (*Jasus lalandii*) cultured at four densities over 162 days.

	Treatment	One	Two	Three	Four
Stocking density (#/m²)	**Initial** **Final**	50 45.8	75 70	100 83.9	125 100
Survival (%)		91.7^{ab}	93.3^{a}	83.9^{ab}	80^{bc}
Carapace length (C.L) in mm (mean)	**Initial** **Final**	12.3 ± 1.35 30 ± 2.93	12.07 ± 1.2 28.64 ± 2.81	12.2 ± 1.08 27.8 ± 2.83	11.6 ± 1.96 27.3 ± 2.95
C.L. increment (mm)		17.7 ± 0.67^{a}	16.7 ± 0.66^{ab}	15.6 ± 0.31^{b}	15.7 ± 0.14^{b}
Body Weight in g (mean)	**Initial** **Final**	1.03 ± 0.33 15.55 ± 3.87	0.99 ± 0.37 13.75 ± 3.92	1.03 ± 0.27 12.46 ± 3.32	0.89 ± 0.73 11.62 ± 3.3
Weight gain (grams)		14.5 ± 1.00^{a}	12.81 ± 0.79^{ab}	11.42 ± 0.66^{bc}	10.74 ± 0.57^{c}
Growth rate (g/d)		0.089 ± 0.006^{a}	0.08 ± 0.005^{ab}	0.07 ± 0.004^{bc}	0.066 ± 0.004^{c}
Specific growth rate (%Bw/d)		1.67 ± 0.006^{a}	1.64 ± 0.055^{a}	1.53 ± 0.033^{a}	1.59 ± 0.1^{a}
Biomass yield (total production/tank in g)		217.3 ± 16.2^{a}	297.8 ± 16.6^{b}	277.1 ± 14.7^{b}	290.3 ± 25.9^{b}

Values with different superscripts denote a significant difference of $p < 0.05$

Table 2.2: Survival, growth and specific growth rates for juvenile rock lobster (*Jasus lalandii*) cultured at four densities over 162 days.

	Treatment	**One**	**Two**	**Three**	**Four**
Stocking density (#/m²)	**Initial** **Final**	20 19.68	30 30	40 36.81	50 45.14
Survival (%)		98.4^{ab}	100^{a}	92^{ab}	90^{bc}
Carapace length (C.L) in mm (mean)	**Initial** **Final**	22.6 ± 1.23 38.8 ± 1.31	22.4 ± 1.78 38.5 ± 0.7	23 ± 1.07 38.3 ± 0.42	22.3 ± 0.16 38.1 ± 0.45
C.L. increment (mm)		16.2 ± 0.25^{a}	16.1 ± 1.39^{a}	15.3 ± 0.77^{a}	15.9 ± 0.41^{a}
Body Weight in g (mean)	**Initial** **Final**	7.37 ± 1.34 35.19 ± 2.17	7.26 ± 1.61 32.7 ± 1.42	7.44 ± 0.78 32.76 ± 1.2	6.8 ± 0.41 32.17 ± 1.56
Weight gain (grams)		27.82 ± 1.09^{a}	25.44 ± 0.43^{b}	25.32 ± 0.76^{b}	25.37 ± 1.13^{b}
Growth rate (g/d)		0.172 ± 0.006^{a}	0.157 ± 0.003^{b}	0.156 ± 0.005^{b}	0.16 ± 0.007^{b}
Specific growth rate (%Bw/d)		0.97 ± 0.09^{a}	0.94 ± 0.12^{a}	0.92 ± 0.05^{a}	0.96 ± 0.03^{a}
Biomass yield (total production/tank in g)		370.8 ± 17.1^{a}	542.9 ± 36.4^{b}	608.4 ± 60.3^{b}	741.1 ± 60.9^{c}

Values with different superscripts denote a significant difference of $p < 0.05$

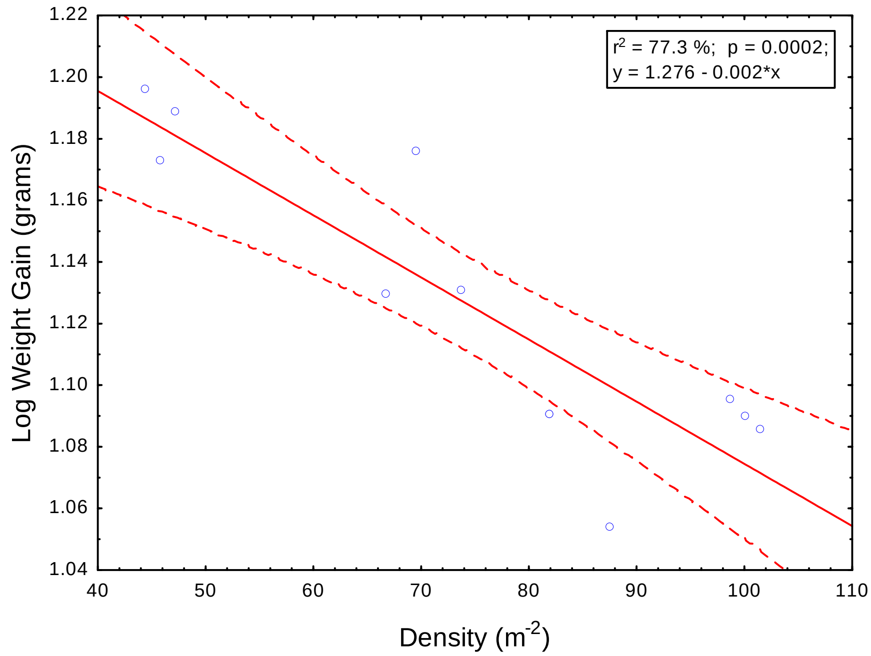

Figure 2.5: Average weight gain of post-pueruli (*Jasus lalandii*) at different densities after 162 days.

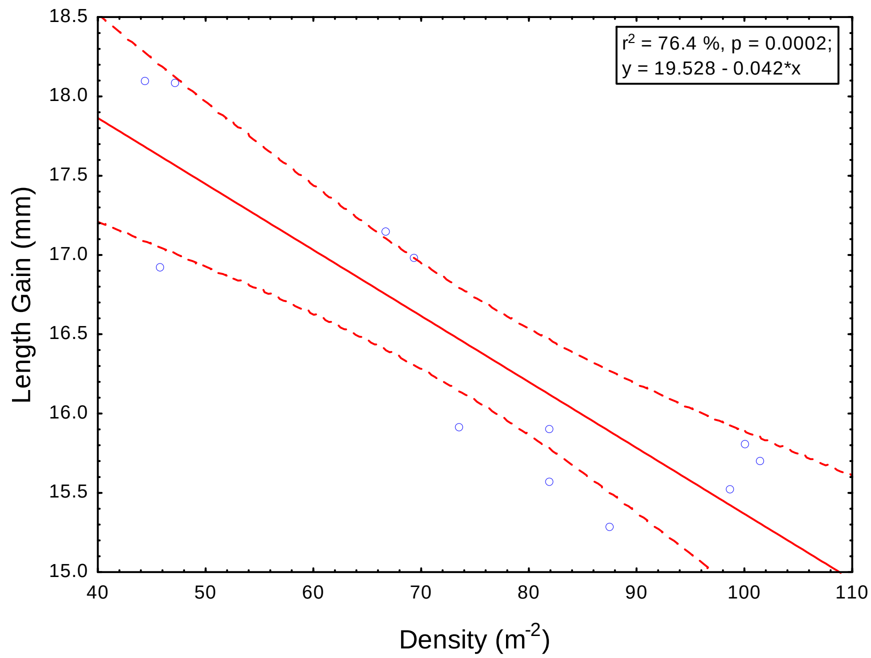

Figure 2.6: Average length gain of post-pueruli (*Jasus lalandii*) at different densities after 162 days.

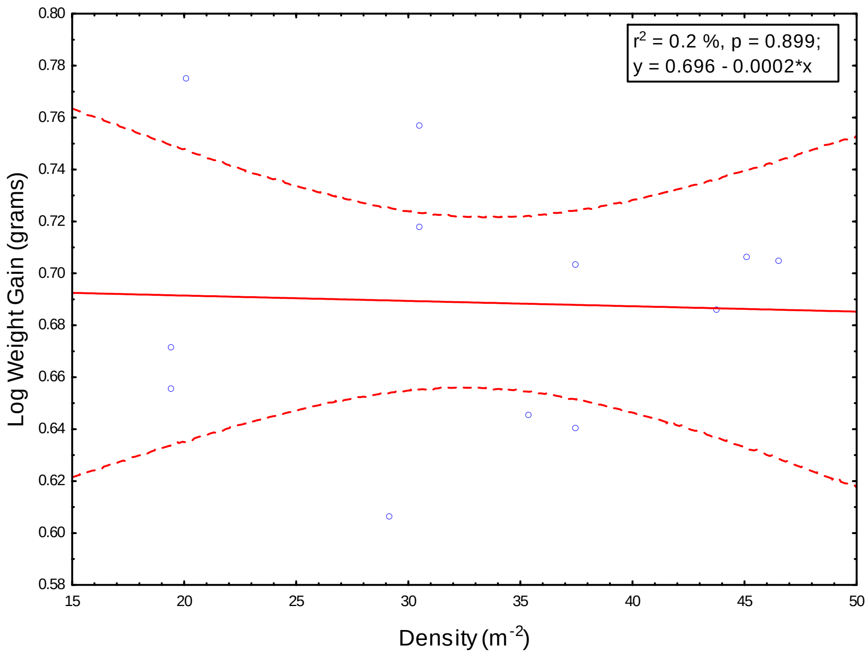

Figure 2.7: Average weight gain of juvenile rock lobsters (*Jasus lalandii*) at different densities after 162 days

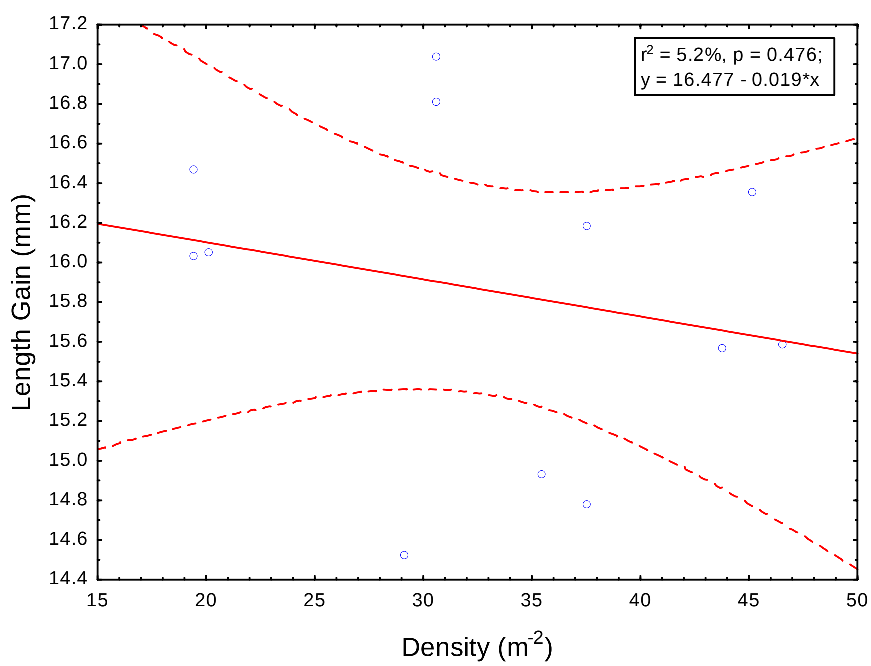

Figure 2.8: Average length gain of juvenile rock lobsters (*Jasus lalandii*) at different densities after 162 days.

Feeding experiment

The proximate composition (protein, fat, ash, carbohydrate and moisture) of post-pueruli and juveniles was similar for all treatments (Table 2.3). The proximate composition of the mussel and shrimp feed diets, however displayed marked differences in the protein and carbohydrate levels. The protein level in the mussel diet was 58.25 % compared to 46.3 % in the shrimp feed diet. The carbohydrate levels on the other hand were substantially higher (34.82 g/100 g dry weight) in the shrimp feed diet in comparison to the mussel diet (15.88 g/100 g).

The size difference and aesthetic appearance of lobsters fed mussels, a rotational diet and shrimp feed is illustrated in Fig. 2.9. Analysis of covariance revealed significant differences in lobster growth rate between the mussel, rotational, and shrimp feed diets for both size classes. Lobster growth on the rotational diet (0.09 and 0.16 g/day for post-pueruli and juveniles respectively) did not differ significantly from growth rates of lobsters fed fresh mussels (0.079 and 0.15 g/day for post-pueruli and juveniles respectively). However, lobsters in both size classes fed shrimp feed exhibited significantly slower growth than lobsters in the mussel and rotational diet treatments, $p<0.05$ (Table 2.4 and 2.5). Post-pueruli lobsters fed shrimp feed displayed a significantly lower survival rate (62.4 %) compared to lobsters fed the mussel and rotational diet (93.3 and 82.7 % respectively, $p < 0.05$). However, this was not the case for the juveniles which displayed no difference in survival between treatments. Again, better survival rates (ranging between 84.5 % and 100) were evident in the juvenile size class. "Post moult death syndrome" was evident in shrimp feed diet treatments as the exoskeletons were still attached to dead lobsters. In both size classes, lobsters fed the mussel diet and rotational diet did not differ significantly in the biomass yield, however, these lobsters yielded significantly higher biomass than lobsters fed the shrimp feed diet (Table 2.4 and 2.5).

Table 2.3: Proximate composition of post-pueruli and juvenile fed mussel, rotational and shrimp feed diets as well as the proximate composition of mussel and shrimp feed diets used in the study. All values are expressed as g/100 g dry weight.

	Pueruli			Juveniles			Diet	
	Mussels	**Rotational diet**	**Shrimp feed**	**Mussels**	**Rotational diet**	**Shrimp feed**	**Mussels**	**Shrimp feed**
Protein	81.13 ± 1.13	81.13 ± 1.13	80.67 ± 1.9	82.23 ± 0.74	82.87 ± 0.76	82.71 ± 0.64	58.25 ± 2.52	41.67 ± 0.54
Ash	13.54 ± 0.06	11.84 ± 1.09	14.02 ± 0.4	10.04 ± 0.36	9.8 ± 0.26	10.27 ± 0.35	14.51 ± 0.31	8.15 ± 0.11
Fat	3.95 ± 0.17	3.74 ± 0.17	3.42 ± 0.34	4.33 ± 0.11	4.05 ± 0.22	3.71 ± 0.04	11.36 ± 0.33	8.85 ± 0.28
Carbohydrates	1.19	3.30	1.89	3.4	3.28	3.31	15.88	31.34
% Moisture	76.21	69.40	70.20	73.90	73.10	70.07	80.10	10

Table 2.4: Survival, growth and specific growth rates of post-pueruli (*Jasus lalandii*) fed mussels, shrimp feed and a rotational diet comprising both mussels and shrimp feed over a period of 162 days.

	Treatment	Mussels	Rotational diet	Shrimp feed
Stocking density (#/m²)	**Initial** **Final**	75 70	75 62.04	75 48.15
Survival (%)		93.3^{a}	82.7^{b}	64.2^{c}
Carapace length (C.L) in mm (mean)	**Initial** **Final**	12.07 ± 1.2 28.64 ± 2.81	11.55 ± 0.95 29.01 ± 3.76	12.06 ± 1.3 19.12 ± 3.03
C.L. increment (mm)		16.7 ± 0.66^{a}	17.51 ± 0.62^{a}	7.07 ± 0.53^{a}
Body Weight in g (mean)	**Initial** **Final**	0.99± 0.37 13.75 ± 3.92	0.84 ± 0.23 14.73 ± 4.71	0.97± 0.34 3.91 ± 1.55
Weight gain (grams)		12.81 ± 0.79^{a}	13.99 ± 0.96^{a}	2.94 ± 0.12^{b}
Growth rate (g/d)		0.079 ± 0.01^{a}	0.09 ± 0.01^{a}	0.02 ± 0.001^{b}
Specific growth rate (%Bw/d)		1.62 ± 0.005^{a}	1.77 ± 0.03^{a}	0.87 ± 0.06^{b}
Biomass yield (total production/tank in g)		297.8 ± 16.63^{a}	240.8 ± 10.76^{a}	44.14 ± 2.8^{b}

Values with different superscripts denote a significant difference of $p < 0.05$

Table 2.5: Survival, growth and specific growth rates of juvenile rock lobster (*Jasus lalandii*) fed mussels, shrimp feed and a rotational diet comprising both mussels and shrimp feed over a period of 162 days.

	Treatment	Mussels	Rotational diet	Shrimp feed
Stocking density (#/m²)	**Initial** **Final**	30 30	30 26.34	30 25.93
Survival (%)		100^{a}	86.36^{b}	84.85^{b}
Carapace length (C.L) in mm (mean)	**Initial** **Final**	22.4 ± 1.78 38.5± 0.7	22.65 ± 3.09 38.49 ± 3.89	22.03 ± 3.21 30.45 ± 3.49
C.L. increment (mm)		16.7 ± 1.39^{a}	15.83 ± 0.58^{a}	8.42 ± 0.47^{b}
Body Weight in g (mean)	**Initial** **Final**	7.26 ± 1.61 32.7 ± 1.4	7.29 ± 2.72 33.86 ± 8.13	6.5 ± 2.74 16.13 ± 5.24
Weight gain (grams)		25.44 ± 0.43^{a}	26.48 ± 0.83^{a}	9.77 ± 1.65^{b}
Growth rate (g/d)		0.16 ± 0.003^{a}	0.16 ± 0.005^{a}	0.06 ± 0.01^{b}
Specific growth rate (%Bw/d)		0.94 ± 0.12^{a}	0.95 ± 0.04^{a}	0.57 ± 0.04^{b}
Biomass yield (total production/tank in g)		542.99 ± 36.4^{a}	503.89 ± 59.6^{a}	180.87 ± 22.5^{b}

Values with different superscripts denote a significant difference of $p < 0.05$

The FCR and PER values were significantly lower for both post-pueruli and juvenile lobsters fed shrimp feed in comparison to lobsters fed mussels and the rotational diet, $p < 0.05$ (Table 2.9). The FCR and PER values for the mussel and rotational diets did not differ significantly.

The astaxanthin concentration of post-pueruli lobsters fed shrimp feed were significantly lower in comparison to lobsters fed the mussel and rotational diets. No significant difference in pigmentation between lobsters fed the mussel and rotational diets was evident (Table 2.6). However, wild caught lobsters exhibited significantly higher levels of astaxanthin in exoskeletons than in post-pueruli lobsters fed a mussel diet (Table 2.6). This was not the case for the experimental juveniles lobsters fed mussels whose astaxanthin concentrations (113.88 µg/g) did not differ significantly from the wild lobsters (133.74µg/g).

Table 2.6: The food conversion ratios, protein efficiency ratios and astaxanthin concentration in exoskeleton (µg astaxanthin/g exoskeleton) of post-pueruli and juvenile rock lobsters, *Jasus lalandii* fed mussels, shrimp feed and a rotational diet comprising both mussels and shrimp feed. The astaxanthin concentration of lobsters fed different diets was compared to that of wild lobsters.

	Pueruli			Wild lobsters	Juvenile			Wild lobsters
	Mussels	**Rotational diet**	**Shrimp feed**	**-**	**Mussels**	**Rotational diet**	**Shrimp feed**	**-**
Consumption*	18.3 ± 1.06	23.99± 0.56	23.3 ± 0.9	-	35.5 ± 1.1	47.3 ± 0.67	54.4 ± 1.03	-
FCR	1.43 ± 0.06[a]	1.73 ± 0.09[a]	7.98 ±1.06[b]	-	1.4 ± 0.06[a]	1.80 ± 0.07[a]	5.95 ± 0.86[b]	-
PER	1.2 ± 0.05[a]	1.16 ± 0.05[a]	0.30 ± 0.04[b]	-	1.23 ± 0.03[a]	1.12 ± 0.05[a]	0.41 ± 0.05[b]	-
Astaxanthin (µg/g)	69.61 ± 11.12[b]	50.56 ± 14.40[b]	32.57 ±11.12[c]	133.74 ± 7.49[a]	113.8 ± 11.7[a]	43.64 ± 11.71[b]	27.25 ± 5.43[b]	133.74 ± 7.49[a]

Values with different superscripts denote a significant difference of $p < 0.05$

* Total dry weight food consumed in grams/162 days

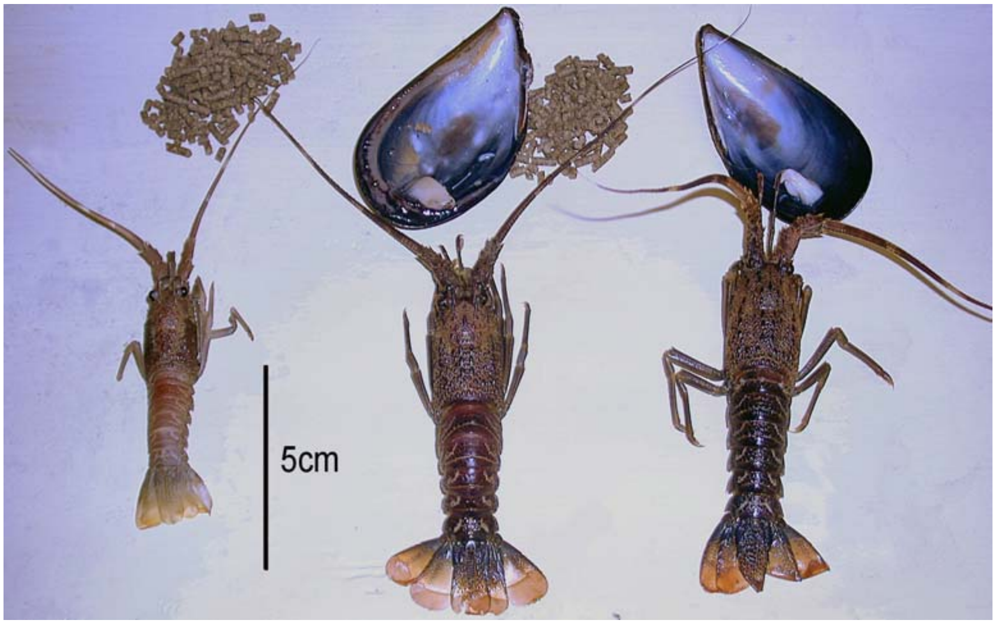

Figure 2.9: Size and aesthetic differences between juvenile lobsters (*Jasus lalandii*) fed shrimp feed, a rotational diet and mussels respectively. Note the lighter pigmentation of the lobster fed the shrimp feed diet.

The dietary essential amino acid (EAA) composition (mussels, shrimp feed and rotational diet) as well as mussel flesh of lobsters fed the different diets is presented in Table 2.7. The amino acid profile of shrimp feed and that of the rotational diet was similar to the amino acid profile of *J. lalandii* flesh (fed mussels) as an $r^2 = 0.75$ was obtained when comparing the profiles of lobster flesh (fed mussels) with that of the shrimp feed and the rotational diet (Table 2.8).

Table 2.7: Essential amino acid composition (g / 100 g dry weight) of *Jasus lalandii* fed different diets and the composition of the diets used in this study.

EAA	Diet			Lobster flesh		
	Mussels	**Rotational diet**	**Shrimp feed**	**Mussels**	**Rotational diet**	**Shrimp feed**
Arginine	2.32	2.25	2.19	6.53	6.51	6.36
Histidine	1.03	1.02	1.02	1.49	1.60	1.65
Isoleucine	2.16	2.05	1.95	3.24	3.34	3.44
Lysine	3.25	2.97	2.69	6.19	6.58	6.40
Phenylalalnine	1.91	1.94	1.98	2.99	3.08	3.20
Leucine	3.50	3.33	3.16	5.52	5.66	5.45
Methionine	1.02	0.88	0.75	2.00	2.06	1.97
Threonine	2.36	1.97	1.58	2.64	2.68	2.52
Tryptophan	0.44	0.35	0.26	0.52	0.41	0.40
Valine	2.34	2.27	2.19	3.31	3.40	3.47

Table 2.8: Essential amino acid (EAA) profile of the whole soft body tissue of juvenile *J. lalandii* (fed mussels), and the calculated essential amino acid profiles of the experimental diets. A comparison between dietary EAA profiles and the EAA profile of lobsters are presented as the degree of similarity (r^2). Amino acid values are presented as percentages of protein (dry weight).

	Arginine	Histidine	Isoleucine	Lysine	Phenylalalnine	Leucine	Methionine	Threonine	Tryptophan	Valine	Degree of similarity (r^2)
Lobsters*	6.53	1.49	3.24	6.19	2.99	5.52	2.00	2.64	0.52	3.31	
Mussels	2.32	1.03	2.16	3.25	1.91	3.50	1.02	2.36	0.44	2.34	**0.73**
Shrimp feed	2.19	1.02	1.95	2.69	1.98	3.16	0.75	1.58	0.26	2.19	**0.75**
Rotational diet	2.25	1.02	2.05	2.97	1.94	3.33	0.88	1.97	0.35	2.27	**0.75**

* Fed mussel diet

The fatty acid (FA) profiles of the diets used in this study are presented in Table 2.9. The (n – 6):(n – 3) ratios were 0.17, 0.56 and 1.01 for the mussel, rotational and shrimp feed diets. The large (n – 6):(n – 3) ratio in the shrimp feed diet can be entirely attributed to the high levels of linoleic acid (LOA) found in the shrimp feed (more than 13 times the level of LOA in mussels) (Table 2.9). The FA profiles of the three diets was compared with the flesh of lobsters fed the mussel diet as these were regarded as a "natural control". The degree of similarity (r^2) of lobster flesh (fed fresh mussels) and the shrimp feed diet yielded low r^2 values of 0.45 and 0.43 for juveniles and post-pueruli respectively (Table 2.10 and 2.11). However, the profile of the rotational diet and lobster flesh (fed mussels) yielded a good fit in both size classes, r^2 = 0.71 and 70 for post-pueruli and juveniles respectively. Inspection of the fatty acid profile of lobsters fed the three diets revealed that certain essential fatty acids in the shrimp feed diet such as LOA, ARA, EPA and DHA were not assimilated into the lobster flesh. This trend was evident in both size classes and FA levels were remarkably similar for the rotational diet (Table 2.10 and 2.11).

Table 2.9: Fatty acid profile of the mussel, rotational and shrimp feed diets used in this study (values expressed as mg/g dry weight unless otherwise stated). Major polyunsaturated Fatty Acids are linoleic acid (LOA), arachidonic acid (ARA), eicosapentanoic acid (EPA) and docosahexaenoic acid (DHA).

Diet composition	**Mussels**	**Rotational diet**	**Shrimp feed**
Total mg FAME/g dry weight	74.3	79.85	85.4
Protein (% dry weight)	58.25	52.28	46.3
Major fatty acids (% of total Fatty acids)			
Saturated			
14:0	2.8	3.5	4.1
16:0	16.3	16.3	16.2
18:0	3.1	3.0	2.8
Monounsaturated			
16:1 (n -7)	4.5	4.8	5.0
18:1 (n -9)	1.7	4.5	7.2
18:1 (n -7)	2.1	2.3	2.5
20:1 (n -9)	1.8	1.5	1.1
Polyunsaturated			
18:2 (n -6) **(LOA)**	1.2	8.8	16.4
20:4 (n -6) **(ARA)**	1.6	1.1	0.5
20:4 (n -3)	0.1	0.2	0.3
20:5 (n -3) **(EPA)**	8.3	8.2	8.1
22:5 (n -3)	0.6	4.4	8.1
22:6 (n -3) **(DHA)**	11.0	9.5	7.9
∑ omega-3 fatty acids	20.4	18.9	17.4
∑ omega-6 fatty acids	3.5	10.6	17.6
EPA:ARA ratio	5.19:1	7.45:1	16.2:1
(n -6):(n-3) ratio	0.17:1	0.56:1	1.01:1

Table 2.10: Fatty acid profile of the whole soft body tissue of juvenile *Jasus lalandii* (fed mussels, shrimp feed and rotational diet), and the fatty acid (FA) profiles of the experimental diets. A comparison between dietary FA profiles and the FA profile of lobsters fed mussels are presented as the degree of similarity between dietary and lobster FAs (r^2). Fatty acid values are presented as mg/g (dry weight).

	Lobster tissue			Diet		
Fatty Acid	**Mussels**	**Shrimp feed**	**Rotational diet**	**Mussels**	**Rotational Diet**	**Shrimp Feed**
14:0	**0.25**	**0.26**	**0.26**	2.77	3.44	4.12
14:1(n-5)	**0.01**	**0.01**	**0.01**	0.10	0.11	0.12
15:0	**0.19**	**0.07**	**0.14**	0.47	0.39	0.30
15:1(n-5)	**0.25**	**0.22**	**0.24**	0.25	0.15	0.04
16:0	**4.71**	**3.78**	**4.52**	16.35	16.26	16.17
16:1(n-7)	**2.23**	**0.72**	**1.43**	4.52	4.74	4.96
17:0	**0.20**	**0.13**	**0.20**	0.71	0.70	0.68
17:1(n-7)	**0.99**	**0.29**	**0.46**	5.87	3.27	0.67
18:0	**1.86**	**1.73**	**1.94**	3.07	2.96	2.84
18:1(n-9)	**3.15**	**2.22**	**2.97**	1.67	4.46	7.24
18:1(n-7)	**1.04**	**0.53**	**0.69**	2.13	2.33	2.53
18:2(n-6) (LOA)	**0.21**	**0.03**	**0.06**	1.18	8.80	16.43
19:0	**0.02**	**2.41**	**1.71**	0.03	0.13	0.24
18:3(n-6)	**0.00**	**0.09**	**0.07**	0.08	0.09	0.10
19:1(n-9)	**0.04**	**0.01**	**0.00**	0.03	0.02	0.02
18:3(n-3)	**0.15**	**0.01**	**0.03**	0.67	1.43	2.19
18:4(n-3)	**0.11**	**0.19**	**0.21**	1.93	1.61	1.28
20:0	**0.08**	**0.04**	**0.09**	0.06	0.20	0.34
20:1(n-9)	**0.46**	**0.13**	**0.11**	1.84	1.48	1.12
20:1(n-7)	**0.20**	**0.24**	**0.33**	2.82	1.45	0.08
I.S.	**0.00**	**0.03**	**0.14**	0.00	0.00	0.00
21:0	**0.08**	**0.00**	**0.00**	0.15	0.08	0.00
20:3(n-6)	**0.01**	**0.02**	**0.02**	0.00	0.01	0.02
20:4(n-6) (ARA)	**1.17**	**0.00**	**0.01**	1.65	1.06	0.48
20:3(n-3)	**0.02**	**0.43**	**0.88**	0.03	0.01	0.00
20:4(n-3)	**0.04**	**0.04**	**0.03**	0.15	0.20	0.26
22:0	**0.00**	**0.03**	**0.04**	0.00	0.00	0.00
20:5(n-3) (EPA)	**4.89**	**0.00**	**0.00**	8.28	8.20	8.12
22:1(n-9)	**0.00**	**3.90**	**4.32**	0.00	0.00	0.00
22:1(n-7)	**0.00**	**0.02**	**0.00**	0.00	0.00	0.00
23:0	**0.04**	**0.01**	**0.01**	0.35	0.18	0.00
21:5(n-3)	**0.08**	**0.02**	**0.03**	0.29	0.30	0.32
23:1(n-9)	**0.00**	**0.05**	**0.09**	0.00	0.00	0.00
22:4(n-6)	**0.04**	**0.00**	**0.00**	0.16	0.08	0.00
22:3(n-3)	**0.00**	**0.00**	**0.03**	0.00	0.00	0.00
22:5(n-6)	**0.05**	**0.00**	**0.00**	0.17	0.15	0.12
22:4(n-3)	**0.00**	**0.03**	**0.04**	0.00	0.00	0.00
24:0	**0.00**	**0.00**	**0.00**	0.03	0.06	0.08
22:5(n-3)	**0.23**	**0.00**	**0.00**	0.60	0.68	0.77
24:1(n-9)	**0.00**	**0.13**	**0.21**	0.00	0.19	0.38
22:6(n-3) (DHA)	**5.10**	**0.01**	**0.01**	11.02	9.48	7.94
r^2				**0.76**	**0.71**	**0.45**

Table 2.11: Fatty acid profiles of the whole soft body tissue of post-pueruli *Jasus lalandii* (fed mussels, shrimp feed and rotational diet), and the fatty acid (FA) profiles of the experimental diets. A comparison between dietary FA profiles and the FA profile of lobsters fed mussels are presented as the degree of similarity between dietary and lobster FAs (r^2). Fatty acid values are presented as mg/g (dry weight).

	Lobster tissue			Diet		
Fatty Acid	**Mussels**	**Shrimp feed**	**Rotational diet**	**Mussels**	**Rotational diet**	**Shrimp feed**
14:0	**0.18**	**0.31**	**0.21**	2.77	3.44	4.12
14:1(n-5)	**0.01**	**0.02**	**0.01**	0.10	0.11	0.12
15:0	**0.16**	**0.10**	**0.14**	0.47	0.39	0.30
15:1(n-5)	**0.24**	**0.25**	**0.21**	0.25	0.15	0.04
16:0	**3.70**	**4.95**	**4.00**	16.35	16.26	16.17
16:1(n-7)	**1.41**	**0.92**	**1.09**	4.52	4.74	4.96
17:0	**0.21**	**0.18**	**0.19**	0.71	0.70	0.68
17:1(n-7)	**0.29**	**0.30**	**0.37**	5.87	3.27	0.67
18:0	**1.58**	**2.10**	**1.65**	3.07	2.96	2.84
18:1(n-9)	**2.11**	**2.92**	**2.21**	1.67	4.46	7.24
18:1(n-7)	**0.59**	**0.65**	**0.56**	2.13	2.33	2.53
18:2(n-6) (LOA)	**0.24**	**0.05**	**0.03**	1.18	8.80	16.43
19:0	**0.00**	**2.88**	**1.37**	0.03	0.13	0.24
18:3(n-6)	**0.01**	**0.09**	**0.07**	0.08	0.09	0.10
19:1(n-9)	**0.05**	**0.02**	**0.02**	0.03	0.02	0.02
18:3(n-3)	**0.13**	**0.01**	**0.00**	0.67	1.43	2.19
18:4(n-3)	**0.09**	**0.23**	**0.19**	1.93	1.61	1.28
20:0	**0.08**	**0.09**	**0.09**	0.06	0.20	0.34
20:1(n-9)	**0.36**	**0.08**	**0.12**	1.84	1.48	1.12
20:1(n-7)	**0.34**	**0.28**	**0.41**	2.82	1.45	0.08
I.S.	**0.00**	**0.05**	**0.25**	0.00	0.00	0.00
21:0	**0.06**	**0.00**	**0.00**	0.15	0.08	0.00
20:3(n-6)	**0.00**	**0.04**	**0.07**	0.00	0.01	0.02
20:4(n-6) (ARA)	**1.03**	**0.00**	**0.00**	1.65	1.06	0.48
20:3(n-3)	**0.00**	**0.56**	**0.91**	0.03	0.01	0.00
20:4(n-3)	**0.00**	**0.03**	**0.03**	0.15	0.20	0.26
22:0	**0.00**	**0.04**	**0.03**	0.00	0.00	0.00
20:5(n-3) (EPA)	**4.03**	**0.00**	**0.00**	8.28	8.20	8.12
22:1(n-9)	**0.00**	**4.92**	**3.95**	0.00	0.00	0.00
22:1(n-7)	**0.01**	**0.03**	**0.00**	0.00	0.00	0.00
23:0	**0.00**	**0.01**	**0.01**	0.35	0.18	0.00
21:5(n-3)	**0.05**	**0.01**	**0.00**	0.29	0.30	0.32
23:1(n-9)	**0.00**	**0.06**	**0.06**	0.00	0.00	0.00
22:4(n-6)	**0.03**	**0.06**	**0.07**	0.16	0.08	0.00
22:3(n-3)	**0.00**	**0.01**	**0.02**	0.00	0.00	0.00
22:5(n-6)	**0.05**	**0.00**	**0.00**	0.17	0.15	0.12
22:4(n-3)	**0.00**	**0.04**	**0.06**	0.00	0.00	0.00
24:0	**0.00**	**0.00**	**0.00**	0.03	0.06	0.08
22:5(n-3)	**0.17**	**0.02**	**0.00**	0.60	0.68	0.77
24:1(n-9)	**0.00**	**0.13**	**0.17**	0.00	0.19	0.38
22:6(n-3) (DHA)	**4.65**	**0.01**	**0.00**	11.02	9.48	7.94
r^2				**0.75**	**0.70**	**0.43**

Hide design experiment

Analysis of covariance did not reveal any differences in growth (length and weight) between tanks provided with asbestos hides, PVC hides or no hides (Table 2.12). Tanks provided with asbestos hides yielded a significantly higher survival rate (93.3 %) than those with PVC hides (74.07 %,) and tanks with no hides (77.8 %) (Table 2.12). The total biomass yield in the asbestos hide's treatment (318 g) was significantly higher in comparison to the PVC and no hide's treatments, $p < 0.05$. Biomass yield did not differ significantly between PVC hides and no hides (Table 2.12).

Table 2.12: Survival, growth and specific growth rates of post-pueruli (*Jasus lalandii*) stocked in tanks provided asbestos hides, PVC hide and no hides over a period of 162 days.

	Treatment	Asbestos Hides	PVC Hides	No hides
Stocking density ($\#/m^2$)	**Initial** **Final**	75 70	75 55.25	75 58.21
Survival (%)		93.3^{a}	74.07^{b}	77.8^{b}
Carapace length (C.L) in mm (mean)	**Initial** **Final**	12.07 ± 1.2 28.64 ± 2.81	12.21 ± 1.48 29.42 ± 3.28	12.61 ± 1.26 28.72 ± 2.26
C.L. increment (mm)		16.7 ± 0.66^{a}	16.83 ± 0.79^{a}	15.79 ± 0.8^{a}
Body Weight in g (mean)	**Initial** **Final**	0.99 ± 0.37 13.75 ± 3.92	1.05 ± 0.42 14.33 ± 4.58	1.41± 0.35 13.23 ± 2.94
Weight gain (grams)		12.81 ± 0.79^{a}	12.8 ± 0.88^{a}	11.83 ± 1.2^{a}
Growth rate (g/d)		0.079 ± 0.01^{a}	0.079 ± 0.01^{a}	0.073 ± 0.001^{a}
Specific growth rate (%Bw/d)		1.64 ± 0.06^{a}	1.59 ± 0.05^{a}	1.52 ± 0.05^{a}
Biomass yield (total production/tank in g)		297.8 ± 16.63^{a}	261.09 ± 32.1^{b}	260.5 ± 33.52^{b}

Values with different superscripts denote a significant difference of $p < 0.05$

Discussion

Density experiment

The present study showed that increasing lobster density from 50 to 125/m² had a negative effect on growth and survival of post-pueruli. A similar trend was reported for *J. edwardsii* by James *et al*. (2001) who tested densities ranging from 50 to 200 post-pueruli/m². Rayns (1991) showed that optimum growth of *J. edwardsii* (11.5 - 13.5 mm carapace length) was attained at a density of 22/m² which was lower than those tested by James *et al*. (2001). Lower densities, however, are not considered economically viable as increasing infrastructure costs marginalize profits (Jeffs and Hooker, 2000). As density had no significant effect on growth of juvenile *J. lalandii* in the present study, higher stocking densities might be feasible over the size range studied, but this will require further investigation.

Our results for *Jasus lalandii* revealed similar growth rate to those recorded in experiments with *J. edwardsii* in captivity. Thomas *et al*. (2000) investigated the growth performance of *J. edwardsii* (mean weight 1.02 ± 0.02) kept at 18°C for 92 days and fed either fresh cultured mussels (*Mytilus edulis planulatus*) or dry pellets for penaeids (*Penaeus japonicus*). The reported specific growth rate for *J. edwardsii* was 1.92 (% Bw/day) whereas that computed for *J. lalandii* after 105 days in the present study, revealed an average rate of 1.89 % Bw/day. Dubber *et al*. (2004) reported very similar growth increments for *J. lalandii* (11.5 ± 0.2 mm CL) when kept at 18ºC. However, caution should be taken when comparisons between specific growth rates are made as tank the environment (temperature, hide configuration and density) and feed type play an important role in growth rates under culture conditions.

Aggressive behaviour between conspecifics was not evident over the duration of this study. When lobsters were first introduced in the tanks, the post-pueruli clustered together in corners of the tanks, but after several days they became more dispersed within the tank and started to utilise the shelters provided. The survival rate for *J. lalandii* in this study was excellent (mean survival ranged from 80 to 93.3 % for all densities tested) compared to other studied lobster species. For example, Jones *et al*. (2001) obtained a mean survival rate of 58.3 % at a low density ($14/m^2$) and 44.6 % at a high density ($43/m^2$) for the ornate lobster *P. ornatus* (mean weight ranged between 3.15 and 3.32 g). This was attributed to possibly inadequate shelter as adequate shelter and regular food supply may have limited possible agonistic behaviour. Almost all dead lobsters observed in the present study were found to be half eaten post moult individuals. In most cases, the abdomens were consumed with some appendages missing. It is unclear whether these lobsters were scavenged upon after they died or were killed during the moulting phase. If the latter was the case, it is a difficult behaviour to address as food was provided in slight excess daily. This observation was most common in the tanks stocked at higher densities. Rayns (1991) speculated that mortality of spiny lobsters under mass rearing could be a mechanism by which a group of lobsters can control the biomass in a tank when subjected to limited space and shelter. As space becomes limiting with the increase in biomass per tank, physical encounters are expected to become more frequent. This will leave moulting subordinate lobsters with less space and shelter to isolate themselves from their conspecifics and thus increase the possibility of cannibalism.

Although mortality increased with increasing density, the biomass yield indicates that an initial stocking density of 75 post-pueruli/m^2 was optimal for the first phase of the grow-out period. Lobsters stocked at $50/m^2$ displayed faster growth, but there were fewer individuals per tank, thus overall biomass yield was lower. Stocking densities above 75/m² produced increased lobster mortalities as well as a decrease in total biomass per tank. Jones *at al*. (2001) reported similar results for *Panulirus ornates* where lobsters stocked at an initial density of 43/m² yielded a biomass of 4.05 kg/m² (survival 44.6 %) while lobsters stocked at 14/m², produced a total biomass of 1.85 kg/m² (survival 58.3 %). From a commercial point of view, it is clear that there is a trade off between survival rates and density in terms of optimal biomass yield.

Feeding experiment

The development of an effective formulated diet for rock lobsters, *J. lalandii* depends on a better understanding of the nutrient requirements of this species. The present study showed that the mussel and rotational diet were superior in terms of lobster growth and survival performance compared to the lobsters fed shrimp feed only.

The artificial diet (shrimp feed) used in this study was readily accepted by the lobsters despite the poor FCR and PER observed. Even in treatments where lobsters were fed on a rotational basis, the shrimp feed was consumed and feeding commenced immediately after placing the food in tanks. The shrimp feed therefore proved to be attractive to the lobsters in terms of pellet size and palatability. This rapid detection and utilization of the shrimp feed indicates that food wastage and leaching probably does not account for the exceptionally high food conversion ratio (FCR) (7.98 and 5.95 for pueruli and juveniles respectively) and low protein efficiency ratio (PER) (0.0.30 and 0.41 for pueruli and juveniles respectively) observed in lobsters fed shrimp feed only. We can deduce that FCR and PER values for the shrimp feed portion of the rotational diet were much better than for the shrimp feed diet alone, if it is assumed that the FCR and PER of the mussel portion of the rotational diet was the same as observed for the mussel only diet treatment (Table 2.13).

Table 2.13: Food conversion ratios (FCR) and protein efficiency ratios (PER) of the shrimp feed only diet compared to the estimated FCR and PER values of the shrimp feed portion in the rotational diet.

	Pueruli		**Juveniles**	
	Shrimp feed (actual values)	**Rotational diet Shrimp feed portion (estimated values)**	**Shrimp feed (actual values)**	**Rotational diet Shrimp feed portion (estimated values)**
FCR	7.98	2.03	5.95	2.18
PER	0.30	1.12	0.41	1.01

The ratio of dry mass of mussel meat to shrimp feed consumed for the rotational diet (0.992 and 1.05 for pueruli and juveniles respectively) is a further indication that overfeeding of shrimp feed was unlikely. It can therefore be concluded that something inhibited nutrient assimilation in the shrimp feed only diet and that mussels provide an essential nutrient which enables the lobsters to utilize the shrimp feed nutrients. Possible limiting nutrients in the shrimp feed only diet are discussed below based on the nutritional analyses performed on the diets and the lobster carcasses.

Proximate analysis of mussels and shrimp feed used in the study revealed that the protein level in mussels (58.25 %) was more than 10 % higher than in shrimp feed (46.3 %) while the carbohydrate levels in the mussels (15.88 %) was almost 20 % lower than in the shrimp feed diet (34.82 %). The low crude protein level in the shrimp feed is, however, not considered as contributing factor to the exceptional low FCR and PER levels observed for lobsters fed shrimp feed diet only. Ackefors *et al*., (1992) investigated optimum protein, carbohydrates and lipid levels in juvenile crayfish (*Astacus astacus*) and suggested that optimum protein levels should be in the range of 30-35 %, carbohydrates between 20-25 % and lipids should not exceed 10 %. Various protein levels tested above 40 % did not affect growth differently, however, it is known that freshwater and warmwater fish species utilize carbohydrates more efficiently than marine and temperate species (Wilson, 1994). Ward *et al*. (2003) investigated the optimal dietary protein levels for juvenile rock lobster, *J. edwardsii* at two different lipid levels. The author indicated that optimal crude protein levels were 29 % and 31 % when lobsters were fed diets containing 5 % and 9 % lipids respectively. Shrimp feed used in the present study contained more than 46 % protein which is considered sufficient. The very poor PER values obtained from the shrimp feed only diet, indicate that the protein ingested was very poorly assimilated. Furthermore, comparison of the degree of similarity (linear regressions) of the amino acid profiles of the shrimp feed and lobsters flesh (fed mussels), revealed an r^2 of 75 % (compared to 73 and 75 % for mussels and rotational diet respectively) which suggests that the essential amino acids (EAA) present in shrimp feed was sufficient. Cuzon *et al*., (2004) outlined that amino acid requirements should be based on their biological availability to the animal which can be affected by three main factors: 1) incomplete digestion, 2) presence of inhibitors and 3) damage to protein. The present result points to some form of inhibition occurring in the shrimp feed only diet.

There is limited information available on the ability of crustaceans to utilize carbohydrates as an energy source (Shiau, 1997). Cuzon *et al*. (1994) have written a comprehensive summary on protein and energy ratios for crustacean nutrition. Digestible carbohydrates and lipids are the prime source from which energy is derived; however, lipid levels are restricted in crustacean diets which results in a narrow range of protein and energy ratios that can be formulated. Therefore, the only energy source that can be altered significantly for different experimental diets is carbohydrate. Protein retention in crustaceans is known to be affected by the carbohydrate/lipid balance in the food (Ackefors, 1992; Kanazawa and Koshio, 1994). Johnston *et al*. (2003) investigated the carbohydrate/lipid balance required for optimal growth in *J. edwardsii*. Various diets containing carbohydrate/lipid ratios of 17.4:1, 4.8:1, 2:1 and 0.8:1 were tested. Although no significant differences in growth were observed between treatments, a carbohydrate/lipid ratio of 2:1 yielded the best growth numerically and significantly increased the lipid levels in the digestive glands while a ratio of 17.4:1 yielded the slowest growth. High lipid content in the digestive gland is thought to play an important role in the moulting process of crustaceans (Chang, 1995). Although total lipid levels were not validated for the various diets tested in the present study, a possible imbalance between carbohydrates and lipids could have been a contributing factor for poor growth observed in lobsters fed the shrimp feed only diet.

A highly significant correlation between lipid content in the hepatopancreas and rock lobster (*Jasus lalandii*) growth in the wild (Cockcroft, 1997) demonstrates the importance of essential lipid identification and inclusion in artificial diets. In the present study, major differences in the fatty acid (FA) profile of lobsters fed the three diets were detected suggesting that poor assimilation of FA was a likely contributing factor to the poor growth and survival observed in lobsters fed the shrimp feed only diet. Although all the diets appeared to possess adequate levels of essential fatty acids (EFA), the flesh of lobsters fed the shrimp feed or rotational diet was deficient in several EFA's such as LOA, ARA, EPA and DHA. This indicates that assimilation of certain FA in the shrimp feed was inhibited and that an unknown factor present in the mussels facilitated FA uptake or the FA requirements of the lobsters was mostly supplied from the mussels. It is evident that in the shrimp feed diet only; there was little or no assimilation of EFA. The good growth observed in lobsters fed the rotational diet could be explained by the possible assimilation of EFA present in the mussel portion and that EFA from the shrimp feed portion was not deposited in the lobster tissue. Thus, further investigation is required to identify factors that could potentially inhibit the assimilation of FA from formulated diets. Other factors such as fatty acids ratios could also explain the poor growth and survival in lobsters fed the shrimp feed only diet. Of particular importance was the low degree of similarity of the fatty acid profile between the shrimp feed diet and the flesh of lobsters fed mussels (r^2 = 43 % and 45 % for post-pueruli and juveniles respectively) compared to the rotational diet (r^2 = 70 % and 71% for post-pueruli and juveniles respectively) and mussel diet (r^2 = 75 % and 76% for post-pueruli and juveniles respectively). This indicates that the fatty acid composition of the shrimp feed was possibly inappropriate to the needs of the lobsters. The major contribution to the imbalance between the n – 6 and n -3 fatty acids was the exceptionally high levels of linoleic acid (LOA) in the shrimp feed. D` Abramo (1997) reported that the greatest essential fatty acid (EFA) value in homothermic animals is derived from LOA while marine species derive more EFA value from linolenic acid (LNA). Glencross *et al*. (2002) found that the addition of high levels of n – 6 fatty acids relative to n – 3 fatty acids, had a negative effect on the growth of *Penaeus monodon*. Xu *et al*. (1993) reported that although the n – 6 fatty acid series (18:2 n – 6, LOA; 20:4 n -6, ARA) may have beneficial effects on growth and survival, n – 3 fatty acids (especially 22:6 n – 3, DHA) prove more beneficial to growth and survival in the Chinese prawn (*P. chinensis*). Results in this study have shown that LOA levels in shrimp feed were exceptionally high and docosahexanoic acid (DHA) relatively lower compared to the mussel diet. It therefore appears that the high levels and/or low concentrations of DHA in the shrimp feed only diet negatively affected the growth of *J. lalandii*. The concentrations of DHA across the different diets (mussel, rotational and shrimp feed diet) had a very narrow range (11.0, 9.5 and 7.9 mg/g dry weight respectively) compared to the wider range of LOA (1.2, 8.8 and 16.4 mg/g dry weight respectively). Arachidonic acid (ARA) concentrations in shrimp feed were less than a third of the levels found in the mussel diet. Although the eicosapentanoic acid (EPA) concentration in shrimp feed was similar to that found in the mussels, the EPA:ARA ratio was much higher in shrimp feed suggesting that slow growth observed in this study may partly be due to competitive interactions between EPA and ARA (Sargent, 1999). Bell and Sargent (2003) reviewed the effect on growth, survival and stress resistance in juvenile turbot, *Scopthalmus maxima* with increased addition of ARA in artificial diets. The results indicated that juvenile turbot fed ARA as the only highly unsaturated fatty acid (HUFA) in the diet resulted in better growth and survival compared to any of the DHA/ARA mixtures or DHA only diets. Also, fish fed DHA alone yielded the lowest growth performance. This illustrates that the level of ARA is an important consideration in formulation of artificial diets. The mechanism by which increased levels of ARA can improve growth is not yet fully understood (Bell and Sargent, 2003); however, results of the present study suggests that ARA in the shrimp feed diet possibly did not satisfy the lobster dietary requirements as it was the only fatty acid that was substantially lower as compared to with the mussel diet.

A further explanation for the poor growth observed in lobsters fed shrimp feed could have been due to a lack (or imbalance) of other nutrients such as cholesterol and phospholipids, but it was beyond the scope of this study to evaluate this. It could well be that the ratio of shrimp feed fed to mussels in a rotational diet can be further increased with satisfactory growth and survival. Future research should therefore focus on the quantification of the dietary requirements of other micronutrients not validated in this study. In particular, focus should be placed on the phospholipid inclusion in artificial diets as they play an important role for satisfactory growth and survival in crustaceans. Gonzáles-Félix *et al*. (2002) found that different diets containing coconut, soybean, linseed, peanut and menhaden oils with a commercial lecithin (97.6 % phospholipid) yielded significantly higher final weights and lower FCR's in *Litopenaeus vannamei* than those fed diets containing the same oil without lecithin. It is has been suggested that the beneficial effect of phospholipid inclusion in the diet can be attributed to: 1) the limited ability of crustaceans to biosynthesize phospholipids from fatty acids, 2) dietary phospholipids may take part in the emulsification of dietary lipids such as triglycerides and cholesterol and 3) certain types of phospholipids are necessary as constituents of lipoproteins which play an important role in the transport of lipids (Kanazawa *et al*., 1985). Furthermore, cholesterol inclusion and quantification should also be investigated. As crustaceans are unable to synthesize sterols *de novo*, they should be included in artificial diets as cholesterol (in particular) plays an important role as a cell constituent and as a metabolic precursor of steroid hormones and moulting hormones (Teshima, 1997).

In the present study, astaxanthin levels in lobster carapaces were primarily used as a relative indicator to the aesthetic appearance of lobsters fed a mussel dietin comparison to those fed an artificial diet. However, astaxanthin levels in the diet affect some other biological processes in crustaceans (described below). The astaxanthin concentrations in lobster shells varied across the different treatments. In both size classes, lobsters fed mussels had higher concentrations of astaxanthin in their exoskeletons than in lobsters fed shrimp feed. However, astaxanthin concentrations in early juvenile lobsters fed mussels did not show marked differences to wild caught lobsters whereas post-pueruli fed mussels did. It can be assumed that astaxanthin accumulation commences immediately after the first moult from pueruli to early juveniles as it is well known that newly settled pueruli lack pigmentation (Kittaka, 1988; Kittaka *et al*., 1997). Similar results have been reported for *Penaeus japonicus* (Petit *et al*., 1998), where one month old postlarvae can absorb dietary pigments easier than at younger postlarval stages. Further investigation into the rate of astaxanthin accumulation and the effect of dietary astaxanthin on survival is therefore required. This would be of particular interest to commercial production where carotene supplements in the diet can add to the cost of feed formulation. To date, little is known about the carotene requirements for post-pueruli or early juvenile rock lobsters and the biological significance of carotenoids in survival and growth. Apart from the aesthetic appearance, carotenoids may play an important role in the survival and growth of post-pueruli in the wild. It is well documented that carotenoids play an important role as vitamins, anti-oxidants, pigments and protectants against photosensitive damage (Snodderly, 1995). Torrissen (1984) speculated that xanthophylls (which can include cantaxanthin and astaxanthin) might increase the ability of salmonid larvae to tolerate variable environmental conditions such as the effect of light. Also, astaxanthin supplements in the diet have been showed to play an important role in stress resistance. In juvenile *P. monodon*, astaxanthin have been shown to increase resistance against salinity stress (Merchie *et al*., 1998 and Chien *et al*., 2003), oxygen depletion stress (Chien *et al*., 1999), thermal stress (Chien *et al*., 2003) and ammonia stress (Pan *et al*., 2003). Astaxanthin supplemented diets have been shown to reduce the moulting cycle in the postlarval stages of *P. japonicus* (Petit *et al*., 1997). The rather low concentrations of astaxanthin in the exoskeletons of lobsters fed shrimp feed only could be a further contributing factor behind the slow growth and low survival rate of these lobsters.

Hide design experiment

Results shown in this study revealed that provision of hides or different hide designs had no significant effect on the growth post-pueruli, *J. lalandii*; however, mortality between treatments was significantly different. Tanks provided with "V-shaped" asbestos hides yielded the highest survival rate compared to tanks provided with PVC hides or no hides. Interestingly, post-pueruli provided with no hides had a similar survival rate than lobsters provided PVC hides (77.8 % and 74.07 % for no hides and PVC hides respectively) compared to a survival rate of 93.3 % for lobsters provided with asbestos hides. Survival of lobsters in tanks with asbestos hides was superior to tanks provided with PVC hides, indicating that this form of shelter was adequate. In almost all cases (in all treatments), dead lobsters were found to be newly moulted and half eaten. This is a further indication that the PVC hides provided inadequate protection when moulting lobsters were most vulnerable to cannibalism. Alternatively, the smooth PVC piping as hide structures did not provide the necessary substrate to aid in moulting. The biomass yield in the various treatments showed that asbestos hides yielded a significantly higher biomass compared to tanks with no hides and PVC hides. This is of particular interest from a commercial and economic point of view. This design was, however, more costly than the PVC piping and future research should therefore focus on cheaper materials that can be used in a similar way asbestos plates were used.

Conclusions

Density experiment

The present study showed that increased stocking density negatively influenced the growth and survival post-pueruli. Optimal density for post-pueruli in terms of growth rate and biomass yield was attained at an initial stocking density of 75/m². The juvenile lobsters did not yield any significant differences in growth. Although a stocking density of 50/m² yielded the lowest survival rate, the biomass production per tank yielded significantly higher final weights. This is an indication that the stocking densities applied in this experiment were below the optimal and higher stocking densities could be used. In both size classes, death as a result of disease and "post-moult death syndrome" was not evident. Dead animals were frequently found half eaten and it is not clear whether these animals were cannibalised during the moulting period or scavenged upon. Further investigation is therefore required.

Feeding experiment

This study indicated that protein present in the shrimp feed was adequate, but the very poor FCR and PER values in lobsters fed the shrimp feed only diet, indicate that protein ingested was not was not assimilated and converted into body tissue. This could be due to some form of inhibition. A major contribution to the very poor FCR and PER values obtained for lobsters fed the shrimp feed diet only could possibly be due to an imbalance in the fatty acid profile of the shrimp feed diet. Exceptional high levels of linoleic acid (LOA) and a deficiency in arachidonic acid (ARA) in the shrimp feed appears to be responsible factors. Astaxanthin concentrations in the exoskeletons of lobsters fed the shrimp feed diet only was very low compared to the lobsters fed mussels. It is not clear yet whether astaxanthin deficiency in the diet could negatively affect the growth and survival performances of early juvenile lobsters and therefore requires further investigation. Also, other essential micronutrients not validated in this study require further investigations, particularly phospholipids and cholesterol.

Hide design experiment

Although no significant differences were obtained in growth rate of the lobsters, this experiment showed that the "V-shaped" asbestos hides were superior in terms of the survival rate compared to tanks with PVC hides and no hides. This could be attributed to the fact that tanks provided with PVC hides (and tanks with no hides) did not provide the necessary substrate to aid the lobsters during the difficult moulting process or alternatively, did not provide adequate shelter for newly moulted lobsters to protect them from their conspecifics.

Chapter 3: Spiny Lobster (*Jasus lalandii*) Aquaculture; an Economic Feasibility Assessment

Introduction

An economic appraisal of the viability of culturing juvenile lobsters is a prerequisite for further investment in research of pilot commercial operations (Kittaka and Booth, 2000). Although the present and other studies provide some information on the grow out performance for various species of spiny lobsters (Hooker *et al*, 1997; Rayns, 1991; Thomas *et al*, 2003), little work has been done on the economic viability of spiny lobster farming. Jeffs and Hooker (2000) addressed the economic feasibility of farming the spiny lobster, *J. edwardsii* in a land-based system and concluded that the lobster farm was marginally profitable. It was concluded that the shore based holding facility costs significantly marginalised the profitability of the commercial farm, and that increased production by means of better growth and reduced mortality had a relative minor effect on profitability. Potential lobster farming has attracted the attention of abalone farms in South Africa as lobster culture techniques are seen as an extension of current abalone farming techniques. Therefore, this study focused on the economic feasibility of a potential *J. lalandii* farm using a land-based culture system similar to that employed in the growth trials (Chapter 2). A 50 metric tonne *J. lalandii* farm was modelled based on a typical 50 metric tonne, land based abalone farm in South Africa. The cost structure of the lobster farm therefore also reflects that of a 50 metric tonne abalone culture system.

Evaluating the economic feasibility of an aquaculture venture requires a budget for capital outlay, operating expenses and revenues generated for a period of more than five years (Jolly and Clonts, 1993). The present study focused on the economic viability of rock lobster farming over a period of ten years. A ten year financial projection is standard practise in the local aquaculture industry since it usually takes 4-6 years to get to full production, and the economic life of most of machinery, vehicles and other equipment is regarded as "written off" after 10 years and would need replacement. The budget for capital outlay can then be used by the decision maker to apply financial criteria that aid in the evaluation of whether the proposed project will prove viable or not. The most common criteria are payback period, internal rate of return (IRR), net present value (NPV) and profitability index or benefit-cost ratio (Jolly and Clonts, 1993) and these were selected for our model (see Materials and Methods). A minimum IRR value is decided upon before assessing the economic viability. This IRR value is subject to the level of economic and environmental risk involved. Economically induced risks may include competition for premium markets, the Rand/US$ exchange rate, fluctuation in demand and product price. For instance, given that a stable market exists year round and that a minimum market price of US$ 27.50 is assumed in the present study, a certain level of economic risk may be applied. The lobster market in the Far East, in many ways, is associated with cultural events and occasions. For instance, the Japanese spiny lobster, *Panulirus japonicus* has become a symbolic decoration on New Year's Day (Tsuruta and Kittaka, 2000). During other periods of the year, a decrease in market demand and/or a drop in market price may occur. Environmentally induced risks may include threats of disease outbreak, predation and natural disasters (Webber and Riordan, 1976), and most importantly, the availability of pueruli year round. Market trends must be monitored closely while ensuring high standards in hygiene and management practices (preventing disease outbreak) to limit economic and environmental induced risks.

When evaluating the economic viability of a candidate species, it is important that a relevant set of economically sensitive criteria are defined before assessing the economic viability of the aquaculture venture (Webber and Riordan, 1976). Market demand, seasonality of market, current exchange rates and current supply are considered to be important economic criteria. Currently, live *J. lalandii* is primarily exported to the Far East and contributes less than 2 % to the world's lobster market demand (Sauer *et al*., 2003). Marketing of *J. lalandii* depends primarily on seasonal overseas market trends and competition from other lobster producing countries (Sauer *et al.*, 2003). From an economic point of view, lobster farming is attractive since farmed lobsters can be supplied in the off season at higher market prices when competition with the fishing industry in South Africa is the lowest. In 2003, live lobsters ranging in size from 210-265 g sold at a maximum price of US$ 27.50 per kilogram (G. Koegelenberg, Oceana Fishing Group, *pers. comm*., 2003). In our model, a constant market price was therefore assumed at US$ 27.50 where lobsters could be marketed year round. The Rand/US$ exchange rate is subject to trade on the open market and recent times has shown to fluctuate widely. In order to demonstrate the effect of Rand/US$ exchange rate on the economic viability of a potential rock lobster farm, this model determined IRR, NPV, payback period and benefit-cost ratio under various Rand/US$ exchange rates (see Materials and Methods).

The effect of economically sensitive biological criteria such as grow out period, stocking density and survival rate on cash flow rate determine the amount of capital required during the 4-5 year start-up phases when no lobsters are marketed. The experimental lobsters used in Chapter 2, were maintained in the same tanks by the abalone farm staff at Aquafarm after the experimental phase was over until they reached a size of 170 to 190 grams and provide an indication of the expected grow-out period. From the preliminary results, it was evident that *J. lalandii* can reach a market size of 210 to 220 grams after four to five years (F. Endemann, Aquafarm, *pers. comm.*, 2004). Several other studies investigated the growth rates of *J. edwardsii* in captivity. Manuel (1991) compared the growth rates of lobsters kept at 10, 14, 18 and 22°C and concluded that optimum growth is attained at 18°C and market size (200 – 250 g (Tong and James, 1997)) can be achieved in a relative short period of 3 to 3.5 years. Although optimum temperature for *J. lalandii* growth is considered to be 18°C (Dubber *et al*., 2004), it is not considered economically feasible to maintain this temperature on a commercial scale. Hooker *et al*. (1997) measured growth rates of *J. edwardsii* kept at ambient temperature (17.2 ° C ± 2.8) and estimated that lobsters can reach 200 g after three years and market size (250 g) would require a grow out period of up to 4.5 years. In our model, two grow out scenarios were used to evaluate the sensitivity analysis. Firstly, lobsters were stocked at a high initial density and a five year grow out period was assumed while in the second scenario, lower initial stocking densities were applied and a four year grow out period was assumed. The five year grow out period in the present study is considered a conservative measure while the four year grow out period for *J. lalandii* is the more optimistic scenario.

It is important to incorporate realistic survival rates when pueruli are raised to market size. An underestimation of survival rates in the business plan will reflect as an overestimate for return on investment. In Chapter two, it was shown that pueruli can achieve a survival rate as high as 93.3 % (after 162 days stocked at 75/m²) while a survival rate of up 100 % was achieved for juveniles when stocked at 30/m². In the present model, a fairly conservative overall survival rate of 80 % was assumed from when pueruli are first stocked till they reach market size after 4 or five years. As unforeseen factors such as disease or system failure etc. may affect survival rate, a sensitivity analysis on survival rate was performed incorporating survival rates ranging from 50 to 95 %.

In conclusion, the aim of this study was to build a financial model for a hypothetical rock lobster farm which incorporated budget estimates for capital outlay and revenue based on abalone farm costs and existing data on rock lobster production in shore based systems. Financial sensitivity analyses including the IRR, NPV, payback period and benefit-cost ratio were applied to the model to evaluate the economic viability under various scenarios. Other sensitivity analyses included grow out periods, the Rand/US$ exchange rates and survival rate

Materials and Methods

Farm structure and profitability analysis

A hypothetical, shore-based rock lobster farm was modelled based on the capital and operational costs of shore-based abalone farms in South Africa. The farm was based on a flow-through system and designed to produce 50 metric tonnes of lobster per year after year five. A cash flow statement was prepared from which indicators of profitability were calculated. These included the internal rate of return (IRR), a benefit-cost analysis, net present value (NPV) and payback period. These analyses required input data for the size of investment, cash flow (production cost and revenue) and the time frame of the project cycle. Market information was obtained from a lobster fishing and export company (G. Koegelenberg, SA Sea Products Pty (Ltd.), *pers. comm*., 2003) while abalone farm investment requirements and operation costs were obtained from an established commercial abalone farm (R. Krohn, HIK Abalone Farm Pty (Ltd.), Hermanus, *pers. comm*., 2003). The IRR, NPV, benefit-cost analysis and payback period were calculated with the formulae using Microsoft Excel spreadsheets:

Long term cash flows are discounted to reflect the changing value of money, or NPV, over time. The discount rate reflects the country's inflation rate or cost of financing. The discount rate was calculated using the following formula:

$$\acute{R}_e = R_f + \beta(R_m - R_f)$$

Where

$\acute{R}_e$ Discount rate

R_f Risk free rate (0.0981)

β Beta value of the Oceana Group Ltd. (0.9857)*

R_m Market rate (0.13)

The Risk-free rate is the rate of return on a riskless investment. The Market rate is the average rate charged by lenders for conventional, fixed rate loans which is determined by current market conditions. These values were obtained from the Bureau of Financial Analysis at Pretoria University, South Africa. The discount rate ($\acute{R}_e$) was computed and set at 14% (0.14).

The NPV can be defined as the stream of net benefits (*bt*), discounted at the rate of interest, $\acute{R}_e$, and summed over the life of the investment in number of years, *n*.

That is:

$$NPV = \sum_{t=0}^{n} \frac{bt}{((1+\acute{R}_e)^n)}$$

Where

bt cash flow (annual revenue less annual operating cost)

$\acute{R}_e$ discount rate and

n number of years in operation

* The Oceana Group Ltd. is a lobster fishing and marketing company in South Africa.

In this model, the initial capital expenditure (investment requirements) was incorporated in the annual operation costs of year one. The aquaculture venture was considered viable if the NPV proved positive, given that the input parameters were realistic.

The internal rate of return (IRR) expresses the time value of the net annual savings of the business investment in a rate that is comparable to the rate one might earn by investing in a bank account. The IRR is a discounted NPV rate that makes the value of future cash flows equal to the cost of the investment. In this study, the IRR was computed using the "IRR function" in Microsoft Excel. The following equation can be used to determine the IRR (*r*) that equals future cash flows to the cost of investment:

$$-I + \frac{bt^1}{(1 + r)} + \frac{bt^2}{(1 + r)} + \ldots\ldots\ldots + \frac{bt^n}{(1 + r)} = 0$$

Where

I	Initial cost of investment
$bt^{1,2}$	discounted cash flow (annual revenue less annual operating cost) in year 1 & 2
bt^n	discounted cash flow in the n^{th} year
r	internal rate of return

The rate (*r*) that satisfies the above equation is sought as the Internal Rate of Return. Lobster farming in this case is regarded as a high risk venture because of the extended grow out period that leads to a slow return on investment. Therefore, the minimum

IRR was set at 20 % to attract investors as a lower IRR would be regarded as too great a risk. This rather high IRR can be justified due to economically and environmentally determined risks.

The benefit-cost analysis is a ratio between annual revenues (T) discounted by $\acute{R}_e$ and discounted operation costs (O). This analysis allows the investor to compare benefit-cost ratios between several project opportunities. However, when comparing different projects, the investments must be projected over equal time spans which may cause some difficulties (Allen *et al*., 1984). This ratio must be equal to or larger than one, since a value less than one indicates a negative cash flow or a loss. For the purpose of this model, all values larger than one were considered economically viable as a figure equal to one shows zero profit. In this case, it indicates that the investor should search for other opportunities that provide better returns. The following equations were used to calculate the benefit-cost ratio:

$$NPV_{revenues} = \Sigma \{ T \ / \ (1 + \acute{R}_e)^n \}$$

$$NPV_{costs} = \sum \{ O \ / \ (1 + \acute{R}_e)^n \}$$

Thus

$$\textit{Benefit-cost ratio} = \frac{NPV_{revenues}}{NPV_{costs}}$$

Where

T Revenue per year

O Operating cost per year and

$\acute{R}_e$ Discount rate

n number of years in operation

The payback period is the number of years required for a project's after-tax cash inflows to accumulate to an amount that covers the initial investment. In this model, the payback period was considered as number of years it took the project to accumulate a positive net cash flow.

Critical assumptions of the lobster farm model are illustrated in Table 3.1, while investment requirements are illustrated in Table 3.2.

Chapter 2 showed that optimal growth was achieved when pueruli were initially stocked at 75/m², while there were no significant differences between the biomass yields at densities higher than 75/m². Given that initial infrastructure cost (tanks, piping etc.) will increase as the stocking densities are decreased (shorter grow out period), it was deemed necessary to test the effect that a longer grow out period will have on the economic feasibility of lobster culture as a longer period on investment returns is evident when lobsters are stocked at higher densities. Hence, the farm operation analyses were conducted based on two production scenarios. Firstly, pueruli were initially stocked at 200/m² (high density scenario) and a grow out period of five years was assumed while in the second scenario, pueruli were stocked at 100/m² (low density scenario) with a grow out period of four years (see Table 3.1). From these scenarios, the sensitivity analysis outcome was calculated under various tonnages produced and different exchange rates.

The hypothetical stocking densities used in the present study (Table 3.3) are higher than the hypothetical stocking densities used by Jeffs and Hooker (2000), however, Chapter 2 revealed that not only did the provision of "V-shaped" asbestos hides increased the survival rate, but also provided increased surface area that allows better utilization of the water column. The stocking densities were adjusted every half a year as the lobsters grew bigger (Table 3.3). To account for possible lower survival rates due to unforeseen reasons, the sensitivity analysis were conducted at various survival rates including 50, 55, 65, 70, 80, 90 and 95 % and hence annual production of 30, 35, 40, 45, 50, 55 and 60 metric tonnes respectively. The annual production costs were assumed to remain the same as that found for an annul production of 50 metric tonnes (80 % survival rate).

Table 3.1: Critical model parameters for profitability analyses of a *Jasus lalandii* culture project.

Model Parameters	Scenario one Density (200/m^2)	Scenario two Density (100/m^2)
Production (metric tonnes)	50	50
Nr. of tanks required	1527	2085
Grow out period	5 years	4 years
Size at harvest	210 grams	210 grams
Survival rate	80 %	80 %
Market price per kilogram	US$ 27-50	US$ 27-50
Rand/US$ exchange rate	R 7-00	R 7-00
Rand per kilogram	R 192-50	R 192-50
Internal rate of return (IRR)	20 %	20%

Table 3.2: Capital investment requirements for a *Jasus lalandii* shore-based culture facility.

Capital Assets	Cost (Rand)	Economic life (years)
Land	1250000.00	
Buildings (Office, storeroom & house)	1500000.00	
Tanks	2290535.80	10
Piping and fittings	100000.00	10
Pumps	450000.00	10
Vehicles	250000.00	10
Air compressors	240000.00	10
Generator	350000.00	10
Shade Cloth	500000.00	10
Office equipment	30000.00	10
Lab equipment	50000.00	10
Piping from sump	150000.00	10
Perimeter Wall and Security	200000.00	
Earthworks	150000.00	
Electricity Supply	200000.00	
Header Tank and Drum Filter	2000000.00	10
Outflow Drain	200000.00	
Total investment required	**9375535.80**	

Table 3.3: The assumed hypothetical stocking densities for lobsters at age.

Age (years)	High Stocking Density (nr/m²)	Low Stocking Density (nr/m²)
0 - 0.5	200	100
0.5 - 1.0	180	95
1.0 - 1.5	160	85
1.5 - 2.0	140	75
2.0 - 2.5	120	65
2.5 - 3.0	100	55
3.0 - 3.5	80	45
3.5 - 4.0	70	40
4.0 - 4.5	55	-
4.5 - 5.0	40	-

Pueruli Supply and Harvesting

Keulder (2004) has estimated that the rate of pueruli settlement, although sporadic, can be as much as 400000/year at Luderitz Oyster Farm in Namibia. This is sufficient for the hypothetical farm producing 50 metric tonnes (including 20% mortality) of 210 gram lobsters which requires about 300,000 pueruli annually. Collection cost of pueruli would involve a minimum of four workers deployed with the oyster farm workers to service the oyster bags. A minimum of R 50 000.00 was therefore added to the annual production cost for pueruli collection and transport.

Selling Price and Exchange Rate

The selling price of *J. lalandii* in the Far East is dependant on various factors. These include the type of product sold (live, cooked frozen or frozen fresh), demand and quality. Live lobsters generally have a larger demand and sell at a higher price than frozen or cooked frozen. Smaller lobsters ranging in sizes from 210-265 grams sell at a higher market price than larger ones and quality attributes such as a deep red exoskeleton and no missing appendages are an added advantage. Given that a high quality product can be supplied, lobsters can be sold at a minimum of US$ 27.50 per kilogram (G. Koegelenberg, SA Sea Products, *pers. comm*., 2003). The exchange rate of the Rand to the US$ has fluctuated wildly in recent years. Between 1998 and 2001, the Rand declined from R5.05 to R12.11 to the US$. Over the last few years it has appreciated to present levels of around R6.90 to the US$ (April 2004) and an estimated market price of R189.75/kilogram would be attainable for farmed rock lobsters. For the purpose of this study, profitability was calculated at various exchange rates including six, seven, eight, nine and ten Rand to the US$.

Export and Marketing

In this model, the cost of export, transport and packaging was set at 10% of the selling price while marketing cost was set at 3% of selling price. This reflects the standard practise in the abalone industry.

Personnel

The hypothetical farm employed 10 farm workers in year one and then an additional 10 every year until year 4 which totalled 40 farm workers. They would take responsibility of feeding, size grading and cleaning of tanks. Four farm managers were employed for every day supervision and general administration on the farm.

Results

High Density, slow growth scenario (200/m²)

The cash flow analysis showed a negative net cash flow during the first four years which turned positive from year five onwards when sales of lobsters began (Table 3.4). This long period of negative cash flow has serious implications for the profitability analyses, the IRR, benefit-cost ratios, payback period and net present values which illustrate that lobster farming under this scenario is only viable in terms of the IRR for a 50 metric ton p.a. production farm only if a minimum exchange rate of R9.00 to the US$ is achieved or if production is maintained at 60 metric tonnes at R 7.00 to the US$ (Table 3.6). However, increased production due to better survival rates and/or faster growth would accommodate a stronger Rand (Table 3.6). Below 45 metric tonnes of lobster production p.a., the farm does not prove viable even at an exchange rate of above R10.00 to the US$.

Low Density, fast growth scenario (100/m²)

A negative cash flow is evident during the first three years of operation (Table 3.5). The assumption of a four year grow out period and hence a faster positive cash flow yield a more lucrative IRR, benefit-cost ratio, payback period and net present value (Table 3.6). In comparison to a 50 metric ton farm and an exchange rate of R 7.00 to the US$ the hypothetical farm is robust enough to lower production to 40 metric tonnes at a minimum exchange rate of R9.00 to the US$ or 35 metric tonnes at a minimum exchange of R 10.00 to the US$ (Table 3.7).

Table 3.4: Projected cash flow statement (Rands * 1000) of 50 metric tonne *Jasus lalandii* farm with a grow out period of five years. Revenues are calculated at an exchange rate of R 7.00 to the US$.

		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Revenue		0.00	0.00	0.00	0.00	0.00	9625.00	10587.50	11646.25	12810.88	14091.96	15501.16
	Capital outlay	9960.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs	Operating cost											
	Electricity		34.07	110.42	230.56	394.18	600.00	642.00	686.94	735.03	786.48	841.53
	Insurance		540.00	577.80	618.25	661.52	707.83	757.38	810.39	867.12	927.82	992.77
	Security		120.00	128.40	137.39	147.01	157.30	168.31	180.09	192.69	206.18	220.62
	Telephone		30.00	32.10	34.35	36.75	39.32	42.08	45.02	48.17	51.55	55.15
	Stationary		36.00	38.52	41.22	44.10	47.19	50.49	54.03	57.81	61.85	66.18
	Salaries Farm workers		168.00	359.52	577.03	823.23	880.85	942.51	1008.49	1079.09	1154.62	1235.44
	Managers		504.00	539.28	577.03	617.42	660.64	706.89	756.37	809.31	865.97	926.58
	Legal and Professional fees		600.00	642.00	686.94	735.03	786.48	841.53	900.44	963.47	1030.91	1103.08
	Permit fees		120.00	128.40	137.39	147.01	157.30	168.31	180.09	192.69	206.18	220.62
	Feed		128.50	445.58	995.55	1821.16	2966.14	3173.77	3395.93	3633.64	3888.00	4160.16
	Marketing (3% of sales)		0.00	0.00	0.00	0.00	288.75	317.63	349.39	384.33	422.76	465.03
	Exports, transport and packaging (10% of sales)		0.00	0.00	0.00	0.00	962.50	1058.75	1164.63	1281.09	1409.20	1550.12
	Maintenance		36.00	38.52	41.22	44.10	47.19	50.49	54.03	57.81	61.85	66.18
	Testing and research		60.00	64.20	68.69	73.50	78.65	84.15	90.04	96.35	103.09	110.31
	Sundries		120.00	128.40	137.39	147.01	157.30	168.31	180.09	192.69	206.18	220.62
	Collection cost of pueruli		50.00	53.50	57.25	61.25	65.54	70.13	75.04	80.29	85.91	91.92
	Sales tax (1% of sales)		0.00	0.00	0.00	0.00	96.25	105.88	116.46	128.11	140.92	155.01
	Sub-total		2546.57	2724.83	2915.57	3119.66	3338.03	3571.69	3821.71	4089.23	4375.48	4681.76
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total cost	9960.74	2546.57	2724.83	2915.57	3119.66	3338.03	3571.69	3821.71	4089.23	4375.48	4681.76
Net cash flow		-9960.74	-2546.57	-2724.83	-2915.57	-3119.66	6286.97	7015.81	7824.54	8721.64	9716.48	10819.40
Accumulative Cash flow		-	-12507.31	-15232.13	-18147.7	-21267.36	-14980.39	-7964.58	-140.05	8581.6	18298.08	29117.48

Table 3.5: Projected cash flow statement (Rands * 1000) of 50 metric tonne *Jasus lalandii* farm with a grow out period of four years. Revenues are calculated at an exchange rate of R 7.00 to the US$.

		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Revenue		0.00	0.00	0.00	0.00	9625.00	10587.50	11646.25	12810.88	14091.96	15501.16	17051.27
	Capital outlay	10747.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs	*Operating cost*											
	Electricity		40.89	132.50	276.68	473.01	720.00	770.40	824.33	882.03	943.77	1009.84
	Insurance		540.00	577.80	618.25	661.52	707.83	757.38	810.39	867.12	927.82	992.77
	Security		120.00	128.40	137.39	147.01	157.30	168.31	180.09	192.69	206.18	220.62
	Telephone		30.00	32.10	34.35	36.75	39.32	42.08	45.02	48.17	51.55	55.15
	Stationary		36.00	38.52	41.22	44.10	47.19	50.49	54.03	57.81	61.85	66.18
	Salaries Farm workers		168.00	359.52	577.03	823.23	880.85	942.51	1008.49	1079.09	1154.62	1235.44
	Managers		504.00	539.28	577.03	617.42	660.64	706.89	756.37	809.31	865.97	926.58
	Legal and Professional fees		600.00	642.00	686.94	735.03	786.48	841.53	900.44	963.47	1030.91	1103.08
	Permit fees		120.00	128.40	137.39	147.01	157.30	168.31	180.09	192.69	206.18	220.62
	Feed		147.19	510.39	1140.36	2086.06	3397.57	3635.40	3889.88	4162.17	4453.53	4765.27
	Marketing (3% of sales)		0.00	0.00	0.00	288.75	317.63	349.39	384.33	422.76	465.03	511.54
	Exports, transport and packaging (10% of sales)		0.00	0.00	0.00	962.50	1058.75	1164.63	1281.09	1409.20	1550.12	1705.13
	Maintenance		36.00	38.52	41.22	44.10	47.19	50.49	54.03	57.81	61.85	66.18
	Testing and research		60.00	64.20	68.69	73.50	78.65	84.15	90.04	96.35	103.09	110.31
	Sundries		120.00	128.40	137.39	147.01	157.30	168.31	180.09	192.69	206.18	220.62
	Collection cost of pueruli		50.00	53.50	57.25	61.25	65.54	70.13	75.04	80.29	85.91	91.92
	Sales tax (1% of sales)		0.00	0.00	0.00	96.25	105.88	116.46	128.11	140.92	155.01	170.51
	Sub-total		2572.07	2752.12	2944.77	3150.90	3371.46	3607.47	3859.99	4130.19	4419.30	4728.65
	Total cost	10747.65	2572.07	2752.12	2944.77	3150.90	3371.46	3607.47	3859.99	4130.19	4419.30	4728.65
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net cash flow		10747.65	-2572.07	-2752.12	-2944.77	6474.10	7216.04	8038.78	8950.89	9961.77	11081.86	12322.62
Accumulative Cash flow		-	-13319.72	-16071.8	-19016.6	-12542.5	-5326.47	2712.32	11663.2	21624.98	32706.83	45029.46

Table 3.6: Comparison of sensitivity analyses for a lobster farm after ten year production with a five year grow out period under various production volumes and Rand/US$ exchange rates. Highlighted values indicate economic viability of the hypothetical rock lobster farm. Production cost remained the same for all annual production figures.

Internal Rate of Return

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	-0.05	0.00	0.04	0.08	0.11	0.13	0.15
R192-50 (R7/US$)	0.00	0.05	0.09	0.12	0.15	0.17	**0.20**
R220-00 (R8/US$)	0.04	0.09	0.13	0.16	0.18	**0.21**	**0.23**
R247-50 (R9/US$)	0.08	0.12	0.16	0.19	**0.21**	**0.24**	**0.26**
R275-00 (R10/US$)	0.11	0.15	0.18	**0.21**	**0.24**	**0.26**	**0.29**

Benefit-Cost Ratio

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	0.56	0.65	0.74	0.83	0.93	**1.02**	**1.11**
R192-50 (R7/US$)	0.65	0.76	0.87	0.97	**1.08**	**1.19**	**1.29**
R220-00 (R8/US$)	0.74	0.87	0.99	**1.11**	**1.23**	**1.36**	**1.48**
R247-50 (R9/US$)	0.84	0.97	**1.11**	**1.25**	**1.39**	**1.53**	**1.66**
R275-00 (R10/US$)	0.93	**1.08**	**1.24**	**1.39**	**1.54**	**1.69**	**1.85**

Payback Period in years

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	>10	9	9	9	8	8	**7**
R192-50 (R7/US$)	10	9	8	8	**7**	**7**	**7**
R220-00 (R8/US$)	9	8	8	**7**	**7**	**7**	**6**
R247-50 (R9/US$)	9	8	**7**	**7**	**7**	**6**	**6**
R275-00 (R10/US$)	8	**7**	**7**	**7**	**6**	**6**	**6**

Net present values

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	-10362831.42	-8909667.64	-6575031.85	-4240396.05	-1905760.26	**428875.54**	**2763511.33**
R192-50 (R7/US$)	-8886815.2	-6159264.70	-3431714.20	-704163.70	**2023386.81**	**4750937.31**	**7478487.81**
R220-00 (R8/US$)	-6529326.96	-3408861.75	-288396.55	**2832068.66**	**5952533.87**	**9072999.08**	**12193464.28**
R247-50 (R9/US$)	-4171838.72	-658458.81	**2854921.10**	**6368301.02**	**9881680.93**	**13395060.84**	**16908440.76**
R275-00 (R10/US$)	-1814350.49	**2091944.13**	**5998238.75**	**9904533.37**	**13810827.99**	**17717122.61**	**21623417.23**

Table 3.7: Comparison of sensitivity analyses for a lobster farm after 10 year production with four year grow out period under various production volumes and Rand/US$ exchange rates. Highlighted values indicate economic viability of the hypothetical rock lobster farm. Production cost remained the same for all annual production figures.

Internal Rate of Return

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	0.01	0.06	0.10	0.14	0.17	**0.20**	**0.22**
R192-50 (R7/US$)	0.06	0.11	0.15	0.19	**0.22**	**0.24**	**0.27**
R220-00 (R8/US$)	0.10	0.15	0.19	**0.22**	**0.26**	**0.28**	**0.31**
R247-50 (R9/US$)	0.14	0.19	**0.22**	**0.26**	**0.29**	**0.32**	**0.34**
R275-00 (R10/US$)	0.17	**0.22**	**0.26**	**0.29**	**0.32**	**0.35**	**0.37**

Benefit-Cost Ratio

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	0.70	0.82	0.94	**1.05**	**1.17**	**1.29**	**1.40**
R192-50 (R7/US$)	0.82	0.96	**1.09**	**1.23**	**1.36**	**1.50**	**1.64**
R220-00 (R8/US$)	0.94	**1.09**	**1.25**	**1.40**	**1.56**	**1.72**	**1.87**
R247-50 (R9/US$)	**1.05**	**1.23**	**1.40**	**1.58**	**1.75**	**1.93**	**2.11**
R275-00 (R10/US$)	**1.17**	**1.36**	**1.56**	**1.75**	**1.95**	**2.14**	**2.34**

(Payback Period in years

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	10	9	8	**7**	**7**	**6**	**6**
R192-50 (R7/US$)	9	8	**7**	**7**	**6**	**6**	**6**
R220-00 (R8/US$)	8	**7**	**6**	**6**	**6**	**5**	**5**
R247-50 (R9/US$)	**7**	**7**	**6**	**6**	**5**	**5**	**5**
R275-00 (R10/US$)	**7**	**6**	**6**	**5**	**5**	**5**	**5**

Net present values

	Annual Production in kilograms (% average survival rate)						
Price (Rand/kg)	**30000 (~ 50%)**	**35000 (~55%)**	**40000 (~65%)**	**45000 (~70%)**	**50000 (~80%)**	**55000 (~90%)**	**60000 (~95%)**
R165-00 (R6/US$)	-7852005.5	-4770368.4	-1688731.41	**1862100.65**	**4474542.71**	**7556179.77**	**10637816.83**
R192-50 (R7/US$)	-4770368.4	-1175125.2	**2420118.00**	**6015361.24**	**9610604.48**	**13205847.72**	**16801090.95**
R220-00 (R8/US$)	-1688731.4	**2420118.00**	**6528967.42**	**10637816.83**	**14746666.25**	**18855515.66**	**22964365.08**
R247-50 (R9/US$)	**1392905.65**	**6015361.24**	**10637816.83**	**15260272.42**	**19882728.02**	**24505183.61**	**29127639.20**
R275-00 (R10/US$)	**4474542.71**	**9610604.48**	**14746666.25**	**19882728.02**	**25018789.78**	**30154851.55**	**35290913.32**

Discussion

The present study has shown that the economic viability of future rock lobster farming is greatly dependant on the projected lobster growth rate and Rand/US$ exchange rate. The sensitivity analyses showed that a five year grow out period is not considered viable in terms of investor requirements. The return on investment was too slow as the cost of maintaining slower growing lobsters at high densities became a prohibitive inventory cost. Despite the increase in initial capital outlay associated with reduced lobster density in the four year scenario, the internal rate of return (IRR), benefit-cost ratio, payback period and net present values (NPV) were more lucrative and robust due to the shortened period of sales revenue (Table 3.8).

Table 3.8: Comparisons of the sensitivity analyses between the five year grow out period (high stocking density) and four year grow out period (low stocking density) at an annual production of 50 metric tonnes and an exchange rate of R7-00 to the US$ (R192-50/kg live lobsters).

	High stocking Density/ Slow growth rate	Low stocking density/ Fast growth rate
IRR	0.15	0.22
Benefit-Cost Ratio	1.08	1.36
Payback Period in Years	7	6
Net Present Values (Rand)	2023386	9610604

Apart from the prohibitive inventory cost effect in the five year scenario (high density), the increase risk of disease outbreak at higher densities cannot be disregarded. In both scenarios, the sensitivity analyses showed that increasing productivity (either as a result of faster growth or reduced mortality) enhanced the economic feasibility lobster farming. It must, however, be borne in mind that the assumed growth and survival rates are based on very few experimental data and that pilot scale grow out studies under commercial conditions will be required to obtain more robust inputs for the model. Future research should focus on factors which produce faster lobster growth rates.

Due to the high capital requirement and long grow out period with high fixed overhead costs; the minimum viable operation is a 50 metric ton p.a. farm. Lobster farming is thus not viable as a potential "small-scale" stand alone enterprise. Infrastructure costs are the main concern for the economic feasibility of future rock lobster farming. To attract investors, alternatives measures must be investigated. One such alternative is the diversification of existing aquaculture ventures such as abalone farms in South Africa and Namibia. Infrastructure and operation costs can be reduced significantly as the capital assets, administration, research and other overheads (see Materials and Methods, Table 3.2) of abalone farms can to an extent be shared with lobster farming, particularly during the pilot commercial phase during which the production technology is established on farm. Not only will diversification reduce infrastructure and operation costs, but will also 1) sustain the growth of aquaculture in South Africa and Namibia, 2) spread the risk of disease outbreak and market failure and 3) ensure customer satisfaction (Quéméner *et al*., 2002). Other measures to increase profitability could be achieved by increased revenues through better quality products, and more cost-effective ways of rearing juvenile rock lobsters. This, however, requires further research into ways of reducing the grow out period while ensuring product quality.

Chapter 4: General Discussion

At the outset of this study, inadequate quantitative research on the biological aspects determining optimal culture conditions was the main constraint preventing commercialisation of the culture technology for *Jasus lalandii*. Based on the experience described in Chapter 1, it was deemed necessary to investigate the biological aspects such as density, shelter provision and diet on the growth and survival of juvenile rock lobsters and the economical aspects that would determine the economic feasibility of future rock lobster farming.

Biological Aspects

In Chapter 2, the effect of different densities on growth and survival was investigated using post-pueruli and juvenile rock lobsters. It was evident that higher stocking densities negatively influenced the growth and survival of post-pueruli. It was concluded that from a commercial point of view, both in terms of biomass production and growth, a stocking density of $75/m^2$ was optimal. The juvenile lobsters, however, did not show marked differences in growth and survival when stocked at various densities. This is an indication that juvenile lobsters could be stocked at even higher densities than was tested in the present study (ranging from $20\text{-}50/m^2$). From a commercial point of view, the high survival rate of the juvenile lobsters at these densities is encouraging and therefore further studies investigating growth and survival responses in rock lobsters stocked at higher densities are required. It was evident in Chapter 2 that there is trade off between survival rates and density in terms of optimal biomass yield. For potential rock lobster farming to become reality, a sound understanding of the factors determining the growth response and survival rate from the onset of stocking pueruli till they reach market size is required. Commercial pilot scale studies on existing abalone farms could accommodate such a long study period and could simultaneously accommodate further investigations into density effects and dietary requirements.

The hide structures used in the present study indicated that hide design is an important aspect for the successful rearing of juvenile lobsters. Although the tanks provided with “V-shaped” asbestos hides, PVC hides and no hides yielded any significant differences in growth, it showed that the asbestos hides used, were adequate both in terms of protecting vulnerable, newly moulted lobsters from conspecifics and providing the necessary substrate that aid in the difficult moulting process. This experiment, however, was conducted on the puerulus size class only and could not be experimented upon larger animals due to logistical constraints. Further investigation is therefore required to determine the tank structure required for animals larger than was tested in this experiment. From a commercial point of view, the “V-shaped” asbestos hides can be seen as a realistic commercial prototype. The simple design proved to be easy to construct, durable, easy to clean and most importantly, provided extra surface area that optimises tank space. Asbestos itself, however, appears to be a costly product and which under certain circumstances poses a health risk to humans. A cheaper alternative product therefore needs to be identified that would provide the same benefits as asbestos plates.

The dietary study conducted in Chapter 2, provide an indication for the poor growth and survival observed in lobsters fed the shrimp feed only diet and could also explain the poor growth in *J. edwardsii* observed by Crear *et al*. (2000), Kington (1999) and

Sheppard (2001). The results suggest that an imbalance in the fatty acid profile of the shrimp feed and/or an inability of the lobsters to assimilate the fatty acids in the shrimp feed could have been a major contributing factor to the poor growth and survival observed in lobsters fed the shrimp feed only diet. The imbalance was entirely attributed to the exceptional high levels of linoleic acid (LOA) resulting in a large (n -6):(n-3) ratio (1.01) compared to the mussel and rotational diet (0.17 and 0.56 respectively). An arachidonic acid (ARA) deficiency in the shrimp feed diet could have been a further explanation for the poor growth and survival of juvenile rock lobsters. Although few studies have been conducted on carotenoid requirements of rock lobsters and its influence on growth and survival, evidence from other studied species such *Penaeus monodon* and *P. japonicus*, suggests that carotene (astaxanthin in particular) is an essential nutrient that definitely requires further investigation. The same approach to identify limiting essential nutrients in Chapter 2 could be used to identify other essential micronutrients not discussed in this study. In particular, essential phospholipids and sterols need to be identified as both these micronutrients play an essential role in metabolic processes (Kanazawa *et al*., 1985; Teshima, 1997).

Economic Aspects

The projected growth rates and survival rates have been identified as the main biological factors influencing the economic feasibility of the hypothetical rock lobster farm. An assumed four year grow out period yielded a much more lucrative internal rate of return (IRR), benefit-cost ratio, payback period and net present values (NPV) than a five year grow out period. The four year grow out scenario proved to be more robust to fluctuating Rand/US$ exchange rates and could also accommodate a lower survival rate than a five year grow out period would. Although the four year grow out period seems more economically viable than a five year grow out period, it must be kept in mind that the modelled rock lobster farm was based on very few experimental data and that pilot scale grow out studies under commercial conditions are required. It was concluded that infrastructure, operation and administration costs could be significantly reduced if these costs could be shared to an extend with existing abalone farm operation costs. This emphasises the need to invest in technology development to reduce the grow out period and the associated costs.

Bottlenecks for Potential Rock Lobster farming

The potential for rock lobster farming in South Africa is still dependant on the harvest of pueruli from the wild. Although harvesting from the wild may have beneficial socioeconomic effects, the direct effects it may have on the fishery are not yet fully understood and a possible conflict between fishers and aquaculturalists cannot be disregarded. Luderitz Mariculture in Luderitz Bay (Namibia) has experienced sufficient numbers of pueruli settlement on the oyster bags for on growing purposes (Grobler and Ndjaula, 2001) and these pueruli perish anyway as a result of the oyster harvesting process (*pers. obs.*). Although Luderitz Bay (Namibia) was identified as a so-called “hot-spot” for pueruli settlement, to date, no other similarly productive location has been identified in South Africa or Namibia for puerulus collection, nor has any progress been made on the development of pueruli collectors for *J. lalandii*. If suitable locations are identified in the future, the reseeding of juveniles would need to be considered to compensate for the loss of recruitment into the fishery. It has been suggested that the loss of pueruli collected for culture to the commercial industry can be fully compensated for by releasing the equivalent number of juveniles that would have survived in natural conditions after a year of culture (Gardner *et al.*, 2000). The economic impact on the feasibility of the rock lobster farm when reseeding juveniles to the wild would therefore require further investigation.

The assumption of pueruli collection from the wild cannot be relied upon entirely, since changing environmental conditions (such as the *El Nino* experienced in the early 1990's) can have dramatic effects on the rate of pueruli settlement. Although *J. lalandii* have been successfully cultured through its entire larval development (Kittaka, 1988), this species has a complex and extended larval cycle. Current culture techniques must still be refined as the captive conditions required for phyllosomas are not yet fully understood and the long larval developmental period may induce prohibitive inventory costs (Kittaka and Booth, 2000).

An artificial diet for rock lobsters is yet to be formulated while mussels have been regarded as an alternative to an artificial diet. There are several practical shortcomings to their use on a commercial scale:

1). Large quantities of additional tanks will be required to keep mussels alive. A comparative study conducted by James and Tong (1997) showed that post-pueruli, *J. edwardsii* fed frozen mussels grew significantly slower than those fed fresh mussels.

2). Additional labour will be required to clean tanks on a regular basis. Empty mussel shells in the tank allow the accumulation of organic debris that can decrease the water quality. Removal of these shells will allow better water circulation in the tank and hence, maintain the water quality.

3). Gaining legal rights for the harvesting of wild mussels may prove problematic.

4). Cultured mussels may solve this problem partially; however, ensuring good quality mussels year-round from the supplier may prove difficult. Also, the cost of cultured mussels has to be compared to that of an artificial diet. Second grade mussels produced in South Africa currently reach a farm gate price between R4.50 and R5.50/kg. The dry weight mussel flesh is less than 10 % of total body weight which shows that on average, one kilogram of dry mussel flesh will cost more than R45/kg. The artificial diet used in this study can be supplied on a regular basis at round about R10/kg.

Conclusion

The present study investigated factors affecting the growth and survival of juvenile rock lobster, *J. lalandii* under shore based culture conditions. Results presented in this study suggest that rock lobster farming is marginal commercial prospect with the current culture techniques available and the uncertainty of puerulus supply. Rock lobster farming could become viable if further investments are made to develop reliable puerulus collection techniques and make grow out technology more cost efficient. In particular, more detailed investigations on the effects of stocking density on larger lobsters are required and longer study periods must be implemented so that more realistic experimental data can be used when determining the economic feasibility of potential rock lobster farming. This thesis identified some of the possible essential nutrient deficiencies in formulated diets. Until an effective formulated feed id developed for *J. lalandii* commercial aquaculture will probably not be feasible as feeding mussels is expensive and impractical. Future research should therefore focus on developing a better understanding of lobster nutritional requirements.

Chapter 5: References

Ackefors, H., .D. Castell, L.D. Boston, P. Räty and M. Svensson. 1992. Standard experimental diets for crustacean nutrition research. Growth and survival of juvenile crayfish *Astacus astacus* (Linné) fed diets containing various amounts of protein, carbohydrate and lipid. *Aquacult*. **104**: 341-356.

Allen, P.G., L.W. Botsford, A.M. Schuur and W.E. Johnston. 1984. Bioeconomics of aquaculture. Elsevier, Oxford, UK: 351 pp.

Association of Official Analytical Chemists (AOAC). 1984. Official methods of analysis, 14th ed. AOAC, Washington, DC.

Barkai, A., C.L. Davis and S. Tugwell. 1996. Prey selection by the South African Cape rock lobster *Jasus lalandii*: ecological and physiological approaches. *Bull. Mar. Sci*. **58**: 1-8.

Bell, J.G. and J.R. Sargent. 2003. Arachidonic acid in aquaculture feeds: current status and future opportunities. *Aquacult*. **218**: 491-499.

Bordner, C.E. and D.E. Conklin. 1981. Food consumption and growth of juvenile lobsters. *Aquacult.* **24**: 285-300.

Booth, J.D. 1997. Long-distance movements in *Jasus* spp. and their role in larval recruitment. *B. Mar. Sci*. **61(1)**: 111-128.

Booth, J.D. and J. Kittaka. 1994. Growout of juvenile spiny lobsters. In: *Spiny Lobster Management.* (Phillips, B.F., Cobb, J.S. and Kittaka, J. eds.). Blackwell Scientific, Oxford, UK: 550pp.

Chang, E.S. 1995. Physiological and biochemical changes during the moult cycle in decapod crustaceans: an overview. *J. Exp. Mar. Biol. Ecol*. **193**: 1-12.

Chien, Y.H., I.M. Chen, C.H. Pan and K. Kurmaly. 1999. Oxygen depletion stress on mortality and lethal course of juvenile tiger prawn *Penaeus monodon* fed high levels of dietary astaxanthin. *J. Fish. Soc. Taiwan.* **26**: 85-93

Chien, Y., C. Pan and B. Hunter. 2003. The resistance to physical stresses by *Penaeus monodon* juveniles fed diets supplemented with astaxanthin. *Aquacult*. **216**: 177-191.

Chittleborough, R.G. 1970. Studies on recruitment in the western rock lobster *Panulirus longipes cygnus* George: density and natural mortality of juveniles. *Aust. J. Mar. Fresh. Res*. **21**: 131-148.

Chittleborough, R.G. 1975. Environmental factors affecting growth and survival of juvenile western rock lobsters *Panulirus* longipes* (Milne-Edwards). *Aust. J. Mar. Freshwat. Res*. **26**: 177-196.

Cobb, J.S., G.R. Tamm and D. Wang. 1982. Behavioural mechanisms influencing moult frequency in the American lobster, *Homarus americanus* Milne-Edwards. *J. Exp. Mar. Biol. Ecol*. **62**: 185-200.

Cockcroft, A.C. 1997. Biochemical composition as a growth predictor in male west-coast rock lobster *(Jasus lalandii)*. *Mar. Freshwater Res*. **48**: 845-856.

Cockcroft, A. C. and A.I.L. Payne. 1999. A cautious fisheries management policy in South Africa: the fisheries for rock lobster. *Marine Policy*. **23**: 587-600.

Cowey, C.B., J. Adron and A. Blair. 1970. Studies on the nutrition of marine flatfish. *J. Mar. Biol. Ass. U.K.* **50**: 87 – 95.

Crear, B.J., C.W. Thomas, P.R. Hart and C.G. Carter. 2000. Growth of juvenile southern rock lobsters, *Jasus edwardsii*, is influenced by diet and temperature, whilst survival is influenced by diet and tank environment. *Aquacult*. **190**: 169-182.

Cuzon, G., J. Guillaume and C. Cahu. 1994. Composition, preparation and utilization of feeds for Crustacea. *Aquacult*. **124**: 253-267.

Cuzon, G., A. Lawrence, G. Gaxiola, C. Rosas and J. Guillaume. 2004. Nutrition of *Liptopenaeus vannamei* reared in tanks or in ponds. *Aquacult*. **235**: 513-551.

D' Abramo, L.R. 1997. Triacylglycerols and fatty acids. In: *Advances in World Aquaculture- Crustacean Nutrition* (D' Abramo, L.R., Conklin, D.E. and Akiyama, D.M. eds.). World Aquaculture Society, Baton Rouge. LA, USA: 587 pp.

Dennis, D.M., T.D. Skewes and C.R. Pitcher. 1997. Habitat use and growth of juvenile ornate rock lobsters, *Panulirus ornatus* (Fabricius, 1978), in Torres Strait, Australia. *Mar. Freshwater Res*. **48**: 663-670.

De Silva, S.S. and T.A. Anderson. 1995. *Fish nutrition in aquaculture.* Chapman and Hall, London: 319 pp.

Evans, L.H., J.B. Jones and J.A Brock. 2000. Diseases of Spiny Lobsters. In: *Spiny lobsters: Fisheries and Culture* (Phillips, B., and Kittaka, J. eds.) 2nd edition. Blackwell Science, London, UK: 679 pp.

Fisher, W.S., E.H. Nilson, J.F. Steenbergen and D.V. Lightner. 1978. Microbial diseases of cultured lobsters: a review. *Aquacult*. **14**: 115-140.

Gardner, C., D. Mills, S. Ibbott, S. Wilcox and B. Crear. 2000. Preliminary investigation towards ongrowing puerulus to enhance rock lobster stocks while providing animals for commercial culture- FRDC Final Report (project no. 1999/314). Marine Research Laboratories- Tasmanian Aquaculture and Fisheries Institute, University of Tasmania: 67 pp.

Glencross, B., M. Smith, J. Curnow, D. Smith and K. Williams. 2001. The dietary protein and lipid requirements of post-puerulus western rock lobster, *Panulirus cygnus*. *Aquacult*. **199**: 119-129.

Glencross, B.D., D.M. Smith, M.R. Thomas and K.C. Williams. 2002. The effects of dietary lipid amount and the fatty-acid composition on the digestibility of lipids by the prawn *Penaeus monodon*. *Aquacult*. **205**: 157-169.

Gonzáles-Félix, M.L., A.L. Lawrence, D.M. Gatlin lll and M. Perez-Velazquez. 2002. Growth, survival and fatty acid composition of juvenile *Litopenaeus vannamei* fed different oils in the presence and absence of phospholipids. *Aquacult*. **205**: 325-343.

Grobler, C.A.F. and H.O.N. Ndjaula. 2001. Namibian *Jasus lalandii* recruitment: size, weight and growth of pueruli and early juveniles. *Mar. Freshwater Res*. **52**: 1277-1281.

Hair, C., J. Bell and P. Doherty. 2002. The use of wild-caught juveniles in coastal aquaculture and its application to coral reef fishes. In: *Responsible Marine Aquaculture* (Stickney, R.R. and McVey, J.P. eds.). CABI Publishing, Oxon, UK: 391 pp.

Hazell, R.W. A., A.C. Cockcroft, S. Mayfield and S. Nofke. 2000. Factors influencing the growth of juvenile rock lobsters *Jasus lalandii*. *Mar. Freshwater Res. 52*: 1367- 1373.

Hecht, T. and P.J. Britz. 1990. Aquaculture in South Africa; history, status and prospects. *Aquacult. Assoc. S. Afr*.

Hooker, S.H., A.J. Jeffs, R.G. Creeze and K. Sivaguru. 1997. Growth of captive *Jasus edwardsii* (Hutton) (Crustacea: Palinuridae) in north-eastern New Zealand. *Mar. Freshwater Res*. **48**: 903-909.

James, P.J. and L.J. Tong, 1997. Differences in growth and moult frequency among post-puerulus *Jasus edwardsii* fed fresh, aged and frozen mussels. *Mar. Freshwater Res*. **48**: 931-934.

James, P.J., L.J. Tong and M.P. Paewai. 2001. Effect of stocking density and shelter on growth and mortality of early juvenile *Jasus edwardsii* held in captivity. *Mar. Freshwater Res*. **52**: 1413-1417.

Jeffs, A. 2001. The potential for the development of cage culture of rock lobsters in New Zealand. NIWA Client Report (AK01141). National Institute of Water & Atmospheric Research Ltd., Auckland: 24 pp.

Jeffs, A. and S. Hooker. 2000. Economic feasibility of aquaculture of spiny lobsters *Jasus edwardsii* in temperate waters. *World Aquacult. Soc*. **31**: 30-41.

Johnston, D.J., K.A. Calvert, B.J. Crear and C.G. Carter. 2003. Dietary carbohydrate/lipid ratios and nutritional condition in juvenile southern rock lobster, *Jasus edwardsii*. *Aquacult*. **220**: 667-682.

Jolly, C.M. and H.A. Clonts. 1993. *Economics of Aquaculture*. The Haworth Press, Binghamton, New York: 319 pp.

Jones, C.M., L. Linton, D. Horton and W. Bowman. 2001. Effect of density and survival of ornate lobster, *Panulirus ornatus* (Fabricius, 1798), in a flow-through raceway system. *Mar. Freshwater Res*. **52**: 1425-1429.

Kaleemer Rahman, M.D., M.T. L. Joseph and B. Srikrishnadhas. 1997. Growth performance of spiny lobster *Panulirus homarus* (Linnaeus) under mass rearing. *J. Aqua. Trop*. **12**: 243-253.

Kam, L.E., P. Leung and A.C. Ostrowski. 2003. Economics of offshore aquaculture of Pacific threadfin (*Polydactilus sexfilis*) in Hawaii. *Aquacult*. **223**: 63-87.

Kanazawa, A. and S. Koshio. 1994. Lipid nutrition of the spiny lobster *Panulirus japonicus* (Decapoda, Palinuridae): a review. *Crustaceana* **67**: 227-232.

Kanazawa, A., S. Teshima and M. Sakamoto. 1985. Effects of dietary lipids, fatty acids, and phospholipids on growth and survival of prawn (*Penaeus japonicus*) larvae. *Aquacult*. **50**: 39-49.

Keulder, F.J. 2004. Monitoring puerulus settlement in Jasus lalandii at Luderitz Bay, Namibia. M.Sc. thesis. Rhodes University.

Kington, S.W. 1999. Factors influencing the on-growing and restocking of *Jasus edwardsii*. MSc thesis, University of Auckland.

Kittaka, J. 1988. Culture of the palinurid *Jasus lalandii* from egg stage to puerulus. *Nippon Suisan Gakkaishi* **54**: 87-93.

Kittaka, J. and J.D. Booth. 2000. Prospectus for Aqauculture. In: *Spiny lobsters: Fisheries and Culture* (Phillips, B., and Kittaka, J. eds.) 2nd edition. Blackwell Science, London, UK: 679 pp.

Kittaka, J., K. Onu and J.D. Booth. 1997, Complete development of the green rock lobster, *Jasus verreauxi* from egg to juvenile. *Bull. Mar. Sci*. **61**: 57-71.

Knauer, J., T. Hecht and J.R. Duncan. 1994. Proximate composition of the South African abalone, *Haliotis midae* (Haliotidae: Gastropoda). *Aquacult. Fish. Mar*. **25**: 351 – 354.

Lepage, G. and C.C. Roy. 1984. Improved recovery of fatty acid through direct transesterification without prior extraction or purification. *J. Lipid Res*. **25**: 1391-1396.

Manuel, S.A. 1991. Factors affecting the growth rate of juvenile Jasus edwardsii reared in captivity. M.Sc. thesis. University of Otago.

Mayfield, S., L.J. Atkinson, G.M. Branch and A.C. Cockcroft. 2000. Diet of the west coast rock lobster *Jasus lalandii*: Influence of lobster size, sex, capture depth, latitude and moult stage. *S. Afr. J. mar. Sci*. **22**: 57-69.

Merchie, G., E. Kontara, P. Lavens, R. Robles, K. Kurmaly and P. Sorgeloos. 1998. Effect of vitamin C and astaxanthin on stress and disease resistance of postlarval tiger shrimp *Penaeus monodon* (Fabricius), *Aquacult. Res*. **29**: 579-585.

Merican, Z.O. and K.F. Shim. 1996. Qualitative requirements of essential fatty acids for juvenile *Penaeus monodon. Aquacult*. **147**: 275-291.

Montgomery, W.L. and S.D. Gerking. 1980. Marine macroalgae as foods for fishes: an evaluation of potential food quality. *Environ. Biol. Fishes*. **5**: 143 – 153.

Pan, C., Y. Chien and B. Hunter. 2003. The resistance to ammonia stress of *Penaeus monodon* Fabricius juvenile fed diets supplemented with astaxanthin. *J. Exp. Mar. Biol. Ecol*. **297**: 107-118.

Paterson, B.D. and P.T. Spanoghe. 1997. Stress indicators in marine decapod crustaceans, with particular reference to the grading of western rock lobsters (*Panulirus cygnus*) during commercial handling. *Mar and Freshwater Res*. **48**: 829-834.

Petit, H., G. Nègre-Sadargues, R. Castillo and J. Trilles. 1997. The effects of dietary astaxanthin on growth and moulting cycle of postlarval stages of the prawn, *Penaeus japonicus* (Crustacea, Decapoda). *Comp. Biochem. Physiol.* **117 (A)**: 539-544.

Petit, H., G. Nègre-Sadargues, R. Castillo, S. Valin and J. Trilles. 1998. The effects of dietary astaxanthin on the carotenoid pattern of the prawn *Penaeus japonicus* during postlarval development. *Comp. Biochem. Physiol.* **119 (A)**: 523-527.

Phillips, B.F., R. Melville-Smith, M. Rossbach, Y.W. Cheng, N. Caputi, A.W. Thompson, D. Mills and B. Crear. 2003. Towards establishing techniques for large scale harvesting of pueruli and obtaining a better understanding of mortality rates. *Fish. Res. Rep.- FRDC Project 1998/302*. **144**: 138 pp.

Piper, G., I.B. McElwain, L.E. Orme, J.P. McRaren, L.G. Fowler and J.R. Leonard. 1982. *Fish Hatchery Management*. United States Dept. of Interior Fish and Wildlife Service, Washington.

Pollock, D.E. 1986. Review of the fishery for and biology of the Cape rock lobster *Jasus lalandii* with notes on larval recruitment. *Can. J. Fish. Aquat. Sci*. **43** (11): 2107 – 2117.

Pollock, D.E., A.C. Cockcroft, and P.C. Goosen. 1997. A note on reduced rock lobster growth rates and related environmental anomalies in the southern Benguela, 1988-1995. *S. Afr. J. mar. Sci.* **18**: 287-293.

Quéméner, L., M. Suquet, D. Mero and J. Gaignon. 2002. Selection method of new candidate species for finfish aquaculture: the case of the French Atlantic, the Channel and the North Sea coasts. *Aquat. Living Resour*. **15**: 293-302.

Rayns, N.D. 1991. The growth and survival of juvenile rock lobster *Jasus edwardsii* held in captivity. Ph.D. thesis, University of Otago.

Ruzzante, D.E. 1994. Domestication effects on aggressive and schooling behaviour in fish. *Aquacult*. **120**: 1-24.

Sargent, J., L. McEvoy, A. Estevez, G. Bell, M. Bell, J. Henderson and D. Tocher. 1999a. Lipid nutrition of marine fish during early development: current status and future directions. *Aquacult*. **179**: 217-299.

Sargent, J., G. Bell, L. McEvoy, D. Tocher and A. Estevez. 1999b. Recent developments in the essential fatty acid nutrition of fish. *Aquacult*. **177**: 191-199.

Sauer, W.H.H., T. Hecht, P.J. Britz and D. Mather. 2003. An Economic and Sectoral Study of the South African Fishing Industry. Volume 2: Fisheries Profiles. Report prepared for Marine and Coastal Management by Rhodes University.

Sayer, M.D.J. 1998. Manipulating fish behaviour. In: *Biology of farmed fish* (Black, K.D. and Pickering, A.D. eds.) Sheffield Academic press, England: 415 pp.

Sheppard, J.K. 2001. Development of an artificial diet for New Zealand spiny lobster, *Jasus edwardsii* aquaculture. M.Sc. thesis, University of Auckland.

Shiau, S. 1997. Carbohydrates and fibre. In: *Advances in World Aquaculture-Crustacean Nutrition* (D' Abramo, L.R., Conklin, D.E. and Akiyama, D.M. eds.), World Aquaculture Society, Baton Rouge. LA, USA: 587 pp.

Sindermann, C.J. (ed.) 1977. Disease diagnosis and control in North American marine aquaculture. Developments in Aquaculture and Fisheries Science. Elsevier Scientific, Amsterdam, The Netherlands: 329 pp.

Snodderly, D.M. 1995. Evidence for protection against age related macular degeneration by carotenoids and antioxidant vitamins. *Am. J. Clin. Nutr*. **62**: 1448- 1461.

Steele, C., C. Skinner, P. Alberstadt and J. Antonelli. 1997. Importance of adequate shelters for crayfishes maintained in aquaria. *Aquarium Sci. Conserv*. **1**: 189-192.

Steyn, W.J.A. 1957. A statistical study of the errors involved in the sampling and chemical analysis of soils and plants with particular reference to citrus and pineapples. Ph.D. thesis, Rhodes University.

Sugita, H. and Y. Deguchi. 2000. Shipping. In: *Spiny lobsters: Fisheries and Culture* (Phillips, B., and Kittaka, J. eds.) 2nd edition. Blackwell Science, London, UK: 679 pp.

Taylor, H.H., B.D. Paterson, R.J. Wong and R.M.G. Wells. 1997. Physiology and live transport of lobsters: report from a workshop. *Mar. Freshwater Res*. **48**: 817-822.

Teshima, S. 1997. Phospholipids and Sterols. In: *Advances in World Aquaculture- Crustacean Nutrition* (D' Abramo, L.R., Conklin, D.E. and Akiyama, D.M. eds.), World Aquaculture Society, Baton Rouge. LA, USA: 587 pp.

Thomas, C.W., B.J. Crear and P.R. Hart. 2000. The effect of temperature on survival, growth, feeding and metabolic activity of the southern rock lobster, *Jasus edwardsii*. *Aquacult*. **185**: 73-84.

Thomas, C.W., C.G. Carter and B.J. Crear. 2003. Feed availability and its relationship to survival, growth, dominance and agonistic behaviour of the southern rock lobster, *Jasus edwardsii* in captivity. *Aquacult*. **215**: 54-65.

Tong, L. and P. James. 1997. Rock lobster farming. *Aquacult. Update*. **Autumn**: 5-6.

Torrissen, O.J. 1984. Pigmentation of salmonids- Effect of carotenoids in eggs and start-feeding diet on survival and growth rate. *Aquacult*. **43**: 185-193.

Tsuruta, M. and J. Kittaka. 2002. Marketing and Distribution. In: *Spiny lobsters: Fisheries and Culture* (Phillips, B., and Kittaka, J. eds.) 2nd edition. Blackwell Science, London, UK: 679 pp.

Ward, L.R., C.G. Carter, B.J. Crear and D.M. Smith. 2003. Optimal dietary protein level for juvenile southern rock lobster, *Jasus edwardsii*, at two lipid levels. *Aquacult*. **217**: 483-500.

Webber, H.H. and P.F. Riordan. 1976. Criteria for candidate species for Aquaculture. *Aquacult*. **7**: 107-203.

Wilson, R.P. 1994. Utilization of dietary carbohydrates by fish. *Aquacult*. **124**: 67-80.

Xu, X., W. Ji, J.D. Castell and R. O'Dor. 1993. The nutritional value of dietary *n*-3 and *n*-6 fatty acids for the Chinese prawn (*Penaeus chinensis*). *Aquacult*. **118**: 277-285.

Xu, X.L., W.J. Ji, J.D. Castell and R. K. O'Dor. 1994. Essential fatty acid requirements of the Chinese prawn, *Penaeus chinensis*. *Aquacult*. **127**: 29-40.