AN INVESTIGATION INTO THE COMMERCIAL FEASIBILITY OF *JASUS EDWARDSII* AQUACULTURE IN NEW ZEALAND

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IAN HECTOR RURU

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Abstract

In 1996 New Zealand introduced legislation to allow *Jasus edwardsii* pueruli to be collected as "seedstock" and ongrown in a commercial aquaculture trial. The aim of this thesis was to investigate the commercial feasibility of *J. edwardsii* aquaculture in New Zealand by working with an organisation involved in the trial.

The methodology involved a combination of experiments in the field, in laboratories, and within an ongrowing facility. This thesis examined five key areas and found the following:

1. Data obtained in the research indicates that New Zealand will continue to rely on harvesting pueruli from the wild since significant technical obstacles remain in the development of commercial scale pueruli hatcheries. Forecast data, obtained using the delphi technique and information about current research on larval rearing, indicates that commercial scale supply of pueruli from hatcheries may occur between 2017 and 2021.

2. Harvesting trials collected a low number of pueruli with the lowest unit cost for collection being $1.80. A greater collection rate could be achieved with a better understanding of seasonal and local settlement patterns.

3. Survival rates in pueruli transporting experiments were significantly affected by stocking density, time and temperature. The safest transit conditions were achieved with 15 pueruli per litre for less than 6 hours at 14°C.

4. A range of stocking densities, from 3 lobsters per tank to 12 per tank, were tested for their effect on growth of six-month old lobsters. The lobsters were reared in a total recirculation seawater system at a constant 16°C, and fed fresh mussels (*Perna canaliculus*). For the 121 day trial, no statistically significant effect was detected. However, there was a trend for growth rates to be highest at 3 and 6 lobsters per tank and for growth rates at stocking densities of 9 and 12 lobsters per tank to decrease after Day 50. Lobsters showed increased mortality at the highest stocking rate.

5. A bioeconomic model of a hypothetical farm was developed to assess economic benefits and risks and to determine overall profitability. The model showed an annual net cash position of $287,100 and cumulative cash position of $859,200 by the 10th year of operation based on annual sales of 10,837 kg at $65 per kg. The model indicates that the highest cost components in the first 10 years are processing and transport, and labour. Based on the model and the scenarios examined, profitability is very sensitive to factors such as the farm size, processing and transport costs, and sale price. Biological factors such as growth rates, survival, and feed requirements also influence overall profitability. Good returns will depend upon consistent exports of high quality lobsters.

The study concludes that commercial feasibility will be affected by these key areas. The potential of *J. edwardsii* aquaculture in New Zealand will continue to benefit from further research.

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"Ka pū te ruha
Ka hao te rangatahi"

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1 Introduction

1.1 Background

The New Zealand rock lobster fishery is based mainly on the palinurid lobster *Jasus edwardsii* (Hutton, 1875), which accounts for more than 99% of the commercial harvest (Booth & Breen, 1994). Commercial fishers use baited pots to catch lobsters, which are then held in land-based holding facilities to be "conditioned" (temperature-induced hibernation) before being exported. The holding period can be varied according to market demand and price. Ninety percent of the lobster catch is processed and airfreighted live to Asian markets.

Total rock lobster exports in 1998 were worth $NZ101.7 million, which was $NZ9.1 million less than exported in 1997 (NZSIC, 1998). This decrease meant that lobster fell from second to third most valuable fishery.

New Zealand's commercial fishery is managed under the Quota Management System (QMS), which was introduced in 1986 to manage and conserve the major commercial fisheries (Clement & Associates, 1997). Under the QMS, the right to catch is assigned to individual fishers. The sustainability of the fishery is also protected by restricting the catching of fish below a minimum legal size (MLS). All fish caught below the MLS must be returned to the water or else the fisher risks prosecution.

The rock lobster industry "is very much dependent on productive fish stocks and strong export market returns for its economic prosperity" (Sykes, 1996). Increase in rock lobster production from wild fisheries are unlikely as most fisheries are fully exploited, or over exploited and near their long-term equilibrium (Annala, 1993). The only way to expand production is through enhancement and aquaculture (Kittaka & Booth, 1994).

Increasing market demands and diminishing natural populations have generated considerable interest in rock lobster aquaculture (Hooker *et al.*, 1997). The potential benefits of aquaculture are that it is a form of long-term sustainable production, may relieve fishing pressure and can have a relatively low impact on the environment.

In late 1996, New Zealand introduced legislation to allow commercial harvesting and ongrowing of *J. edwardsii* pueruli under a trial trade-off scheme. Before this trial, pueruli had only been harvested from the wild on a much smaller scale, mainly for research purposes. The trial was a world-first and seen as an opportunity for new business and a mechanism to help develop the New Zealand rock lobster aquaculture industry.

Encouraging results from research (Hollings, 1988; Manuel, 1991; Rayns, 1991) had demonstrated that growing juvenile *J. edwardsii* was possible and that reasonable survival rates could be achieved (Hooker *et al.*, 1997). Market research had identified a lucrative niche export market for 'tailor-made' lobsters (Hollings, 1988; Oshikata, 1994). Two organisations - Aqua (Bay of Plenty) Limited (Aqua BoP) and Hawkes Bay Aquaculture Limited (HB Aquaculture) - took up the challenge and invested to pioneer this industry. Developments were assisted by government-funded research completed for the two organisations by the National Institute of Water and Atmospheric Research Limited (NIWA).

1.1.1 Sourcing seedstock

A fundamental issue limiting aquaculture of *J. edwardsii* and other spiny lobster species is obtaining enough pueruli as seedstock. The seed source for *J. edwardsii* pueruli aquaculture can be either harvested from the wild or cultured in hatcheries. Currently, all pueruli supplied to research or commercial organisations are harvested from the wild because cost-effective larval rearing techniques have yet to be perfected.

The ability to produce *J. edwardsii* pueruli economically will have a significant impact on rock lobster aquaculture and the New Zealand rock lobster fishery. According to Peacey (1997), 'closing the life cycle' of species such as rock lobster, by developing the technology to produce juvenile animals from farmed stock, will make the industry less dependent on natural resources of juveniles and increase the industry's ability to undertake selective breeding. Furthermore, developing a process for culturing rock lobster throughout their life cycle would also reveal the potential for enhancement of the wild stock (Sykes, 1996; Schapp, 1997).

1.1.2 Harvesting

The viability of the industry depends on "access to predetermined numbers of pueruli irrespective of natural fluctuations" (Thomas *et al.*, 1998). The most prolific and consistent settlement areas of *J. edwardsii* pueruli are on the East Coast of the North Island, south of East Cape to Castlepoint. New Zealand research programmes have largely relied on a "crevice collector", developed in the 1970s, to collect pueruli. This collector was primarily designed to monitor puerulus settlement patterns along the coastline and has changed little since its invention.

Whilst being suitable for research purposes, it was inevitable that the advent of the aquaculture trial and commercial scale demands for pueruli would require improved and/or new types of harvesting devices. From a commercial perspective, new collectors need to be cost-effective, easy to construct, operate and maintain (Thomas *et al.*, 1998).

The Special Permit regulations that govern the aquaculture trial, stipulate that only *J. edwardsii* pueruli and first instar juveniles can be harvested for ongrowing. For the purpose of this thesis, the term 'pueruli' includes all three puerulus stages and first instar juveniles (Stages; P1, P2, P3 & J1).

1.1.3 Transporting

Aqua BoP harvests over 90% of its pueruli from collectors in the Gisborne Harbour. Once harvested, the pueruli are transported by road to the ongrowing farm in Papamoa 300km away. This journey can take up to nine hours.

For transit the pueruli are packed in plastic bags filled with ambient temperature seawater (between 12~18°C) and placed into insulated containers. Severe deterioration in the transport environment such as increasing ambient temperatures or excessive vibrations can reduce survival rates. Therefore, lobster survival depends on developing safe and reliable handling and transporting protocols.

1.1.4 Ongrowing

Information on growth and mortality is needed to assess the economic feasibility of *J. edwardsii* aquaculture (Sorensen, 1969). Previous studies of the growth of captive *J. edwardsii* (Hollings, 1988; Rayns, 1991; Hooker *et al.*, 1997; James & Tong, 1998) used simple flow-through culture systems. Filtered seawater at ambient temperature was continuously pumped from the adjacent ocean. The seawater flowed once through the ongrowing unit and was then discharged back into the ocean. The captive juveniles had good growth rates and high survival rates.

Aqua BoP uses a prototype recirculating seawater system (Appendix A) to grow the juveniles through to a saleable size. In this system, the seawater is recycled continuously through complex filtration units to remove impurities and waste. Fresh seawater is trucked to the facility periodically to replenish the system.

In comparison to flow-through systems, recirculation systems have the advantage of having greater control over environmental factors such as weather and location. However, with the exception of Manuel (1991), these systems are largely unproven for lobster ongrowing.

1.1.5 Bioeconomic analysis

It is prudent to carry out a bioeconomic analysis of profitability when assessing commercial feasibility of an aquaculture venture. The valuable but dated study by Hollings (1988) concluded that *J. edwardsii* aquaculture could be profitable. There is very little published information on the economic feasibility of culturing

J. edwardsii. However, the economics of aquaculture of other families of lobsters have been assessed (Allen *et al.*, 1984; Nash, 1990; Medley *et al.*, 1994).

Production and market uncertainties significantly affect the viability of an aquaculture facility. Mathematical modelling of production and marketing issues is one way of assessing the economic feasibility of an aquaculture venture (Zucker & Anderson, 1999). The economic climate and uniqueness of each venture means that the analysis must be customised. Such an analysis may also indicate the significance of various parameters such as sensitivities to feed price, survival rate and sale price, on potential profitability. Furthermore, productive research and development areas may be identified from the analysis.

1.2 Statement of the Problem

The Ministry of Fisheries (1996) introduced legislation to allow *J. edwardsii* pueruli to be collected as "seedstock" and ongrown in commercial aquaculture trials.

> "It is the Ministry's intention that any special permits issued pursuant to the approved purpose will be for trials to establish the viability and biological neutrality of a system that allows adult rock lobster to be traded off against taking juveniles that have not yet been recruited into the fishery. There is no guarantee of ongoing approvals and any business decisions should be made with this in mind."

A commercially successful process to harvest and ongrow *J. edwardsii* pueruli has yet to be achieved. The aim of this thesis is to investigate the commercial feasibility of *J. edwardsii* aquaculture in New Zealand.

1.3 Research Approach

The aim was to work symbiotically with a commercial aquaculture company (Aqua BoP) throughout the trial period. In this way the research objectives underpinning the thesis would be guided by first-hand experiences with the commercial realities of the new venture.

1.3.1 The Research Questions

The research wanted to address the following questions:

1. How might *J. edwardsii* pueruli be sourced as a seed stock for aquaculture?
2. Can *J. edwardsii* pueruli be harvested cost-effectively?
3. Once harvested, how can *J. edwardsii* pueruli be transported to the grow-out site safely?
4. How might stocking densities affect growth rates of juvenile *J. edwardsii* cultured in a recirculating system?
5. What are the potential economic benefits and risks of *J. edwardsii* aquaculture?

1.3.2 Structure of the Thesis

The thesis contains the following sections:

Chapter One:	introduces the main issues and concepts and outlining the thesis structure.
Chapter Two:	reviews the literature relevant to *J. edwardsii* aquaculture in New Zealand.
Chapter Three:	describes the materials and methods used and how the problems were investigated.
Chapter Four:	provides and discusses the results of the investigation.
Chapter Five:	provides conclusions and recommends areas for future research.
Appendix A:	seawater recirculation system used for growing juvenile lobster.
Appendix B:	complete transcription of the Delphi '99 forecast.
Appendix C:	raw data and statistical analyses from the transporting trial.
Appendix D:	raw data and statistical analyses from the growth-density trial.
Appendix E:	spreadsheets from the bioeconomic model.

2 Literature Review

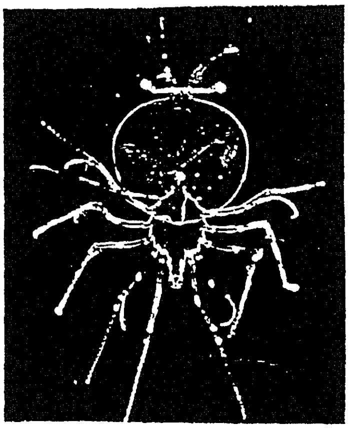
Introduction

This Chapter begins with a brief overview of the life history and ecology of *J. edwardsii*, followed by an assessment of some of the technical difficulties that have hindered complete culture of the species. The current pueruli harvesting techniques are discussed and the potential physiological stressors that pueruli may be exposed to whilst being transported to an ongrowing unit are identified. Next, two types of ongrowing systems are evaluated, with particular attention on factors that influence the growth of spiny lobsters in a captive environment. Finally, literature on *J. edwardsii* farming is reviewed.

2.1 Life history and ecology of *J. edwardsii*

The spiny or rock lobster (Crustacea: Decapoda: Palinuridae: Jasus) *J. edwardsii* is found in the shallow (0 to 50m) coastal waters of New Zealand, South Australia and Tasmania. *J. edwardsii*, like most spiny lobsters, has a long and complex life cycle (Phillips & Sastry, 1980; Booth & Phillips, 1994). Life begins as an externally fertilised egg carried on the ventral surface of the female's tail (MacDiarmid, 1988). The egg is incubated for three to six months depending on the water temperature, and hatches into a small naupliosoma larva. The female moves to an area with strong current action to aid dispersal and releases the larva. The naupliosoma larva soon moults into a leaf-shaped phyllosoma larva (Fig. 2.1). The phyllosoma drift for hundreds of kilometres, moving up and down the water column to feed. They spend between 12-24 months at sea, passing through 11 planktonic larval stages often moulting several times between each stage. Ocean current carries the late-stage phyllosoma closer to the continental shelf where it metamorphoses into a post-larval puerulus (Booth & Breen, 1994).

Figure 2.1: Final-stage phyllosoma larva of *J. edwardsii*, total length 45 mm excluding antennae (top) and legs (Photo A. Blacklock).



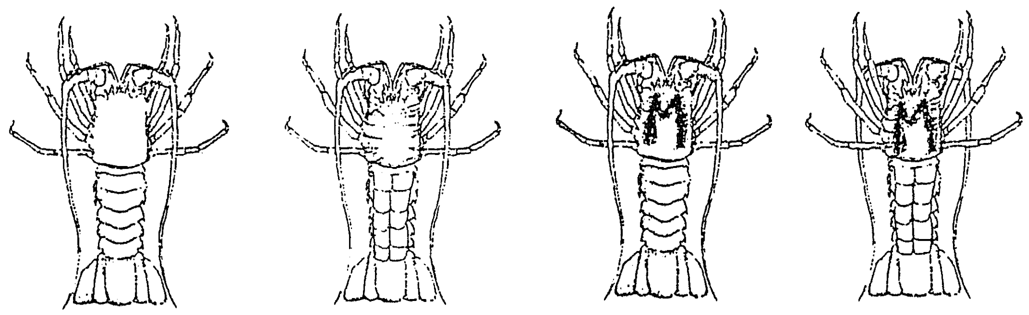
The puerulus resembles the juvenile in shape (9-13 mm CL) but is transparent because the exoskeleton lacks pigment and calcium (Fig. 2.2). It settles in shallow coastal waters often preferring small crevices for shelter. After three stages (P1, P2 and P3) the puerulus moults into the first instar juvenile (J1). The juvenile often remains in shallow inshore nursery areas before moving to deeper water (Cobb & Wang, 1985).

Puerulus Stage One: P1

Body: transparent
Tail: fine swimmerets
Top View *Underside*

Puerulus Stage Two: P2

Body: gut visible
Tail: fine swimmerets
Top View *Underside*



Puerulus Stage Three: P3

Body: well coloured
Tail: fine swimmerets
Top View *Underside*

Juvenile Stage One: J1

Body: totally coloured
Tail: no swimmerets
Top View *Underside*

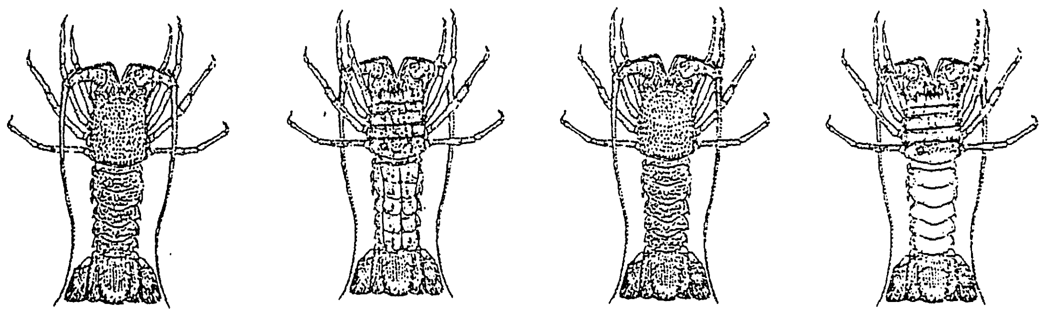


Figure 2.2: Description of puerulus and first instar juvenile stages of *J. edwardsii*.

Remaining growth follows an exponential function and is related to temperature (Saila *et al.*, 1979). The growth of *J. edwardsii* at ambient water temperatures in southern New Zealand (6-17°C) is slow (McKoy, 1985; Rayns, 1991) but increases in warmer ambient water temperatures in north-eastern New Zealand (Hooker *et al.*, 1997). Size and age at maturity is highly dependent on local environmental conditions (Annala *et al.*, 1980). Lobsters in the wild take about of five years to reach the MLS or a weight of approximately 400 g (Tong & James, 1997).

Growth is a discontinuous and stepwise process consisting of a series of moults (ecdyses) separated by moult intervals. The period between successive moults is known as an instar. At each moult the lobster sheds its old shell and emerges in a new soft shell. Like all crustaceans, the lobster depends on a rigid exoskeleton (shell) for structural support and protection (Fig. 2.3). The lobster is very vulnerable to predation until the new shell hardens (Rayns, 1991).

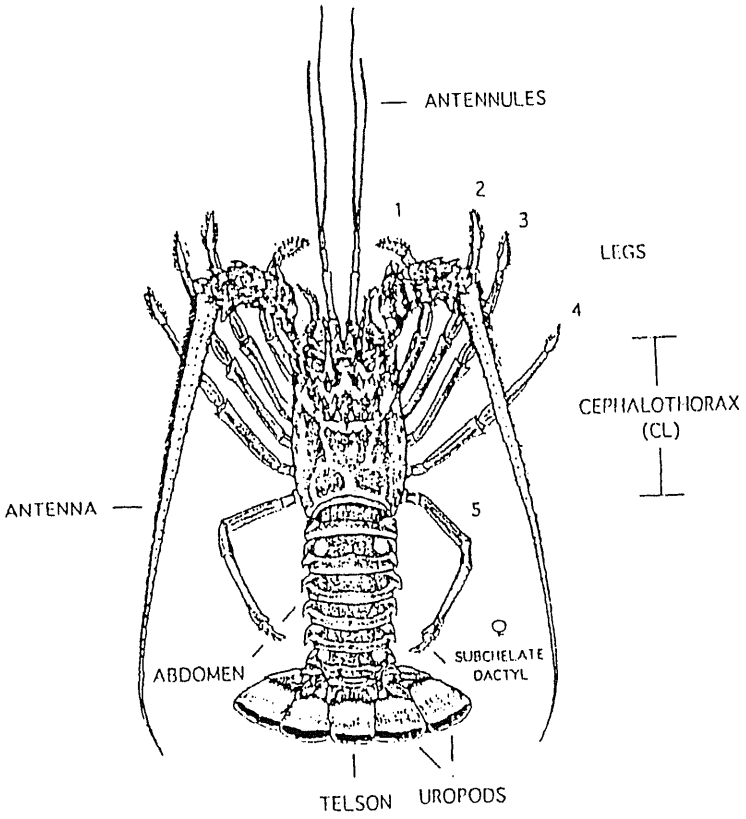


Figure 2.3: Morphology of a palinurid lobster (adapted from Holthuis, 1991).

The body can be divided into two parts; the cephalothorax and the abdomen. The cephalothorax consists of the fused head and thorax. The appendages on the cephalothorax include the eyes, the antennae and antennules, the mouth-parts and five pairs of legs. The abdomen (tail) is a muscular structure also covered with a shell. The abdomen shell is divided into six segments to allow flexing or rapid backward swimming. Female and male lobsters are similar in appearance except the female has a pair of pincers on the hindmost pair of walking legs, genital apertures at the base of the third set of legs rather than the hindmost (for males), and extra pleopods on the underside of the tail. The carapace length, which is the distance from the base of the sub-orbital horns to the posterior of the carapace, is frequently used by researchers to indicate body length (Cobb & Wang, 1985).

2.2 Sourcing seedstock

Culturing phyllosoma in a laboratory has been difficult because of the complex life cycle (Phillips & Evans, 1997). Growing a *J. edwardsii* puerulus from the egg was first achieved in Japan (Kittaka, 1988). New Zealand's first success at complete phyllosoma development occurred in 1995 (Booth, 1996). However, the extremely low survival rates have hindered transferring the laboratory technology to commercial-scale hatcheries that would provide pueruli for lobster farmers. This alternative seed stock would reduce the reliance on harvesting pueruli from the wild. Hatchery-supplied seed stock is common in the aquaculture of other marine and freshwater animals. For example, the New Zealand paua or abalone (*Haliotis iris*) is farmed for the meat and for mabe (half-round) style pearls. The breeding biology and life cycle of an abalone is well understood and so commercial hatchery operations supply most of the seed abalone used for aquaculture (Tong & Moss, 1992).

The spiny lobster species *Jasus verreauxi* (packhorse lobster) has been successfully cultured through to the puerulus stage. This species is uncommon in New Zealand waters, with an annual commercial harvest of about 10 tonnes compared to about 3,000 tonnes of *J. edwardsii*. *J. edwardsii* aquaculture has received more research attention because it is perceived to be of higher quality than *J. verreauxi*, and therefore deemed more lucrative. However, interest in farming *J. verreauxi* has increased for two reasons. Firstly, it is a warm water species with a fast growth rate; secondly, there has been greater success in rearing the eggs and larvae. This is attributed to this species having a shortened and hardier larval life than *J. edwardsii* (Tong, 1999). Lessons learned from rearing *J. verreauxi* may accelerate the development of commercial-scale hatchery production of *J. edwardsii*.

2.3 Harvesting pueruli

Puerulus settlement around New Zealand has been monitored since the 1970s to better understand larval recruitment processes and therefore assist in management of the fishery. A knowledge of seasonal, interannual, and geographical variation in settlement has been used to predict recruitment, provide early warning of overfishing, and show levels of interannual recruitment variability (Booth & Stewart, 1993). Similar information has been essential to management of the Western Australian rock lobster fishery (Phillips, 1986). Large numbers of *J. edwardsii* pueruli are known to settle on the East Coast of the North Island, south of East Cape to Castlepoint, (Booth & Stewart, 1993). Large pueruli settlements have also been recorded in the Marlborough Sounds and in the seawater intake of the New Plymouth power station (Booth, 1989). Settlement does not take place uniformly with time or between geographic regions (Booth, 1991). Settlement is mainly at night and can occur at any lunar phase. It is usually seasonal and levels of settlement can vary by an order of magnitude or more from year to year (Booth, 1999). The crevice collector was developed to monitor puerulus settlement. It consists of seven crevices, each 25 mm at its opening, created by stacking eight plywood sheets, with spacers, in a metal frame (Fig. 2.4).

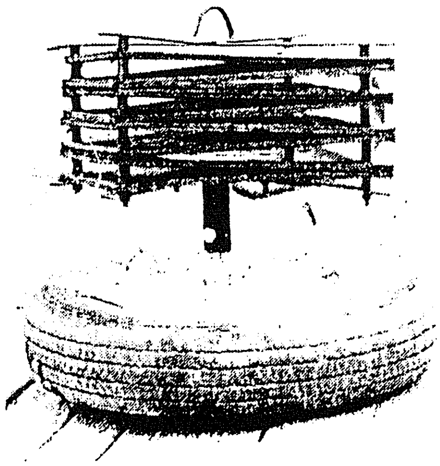


Figure 2.4: Crevice collector attached to base weight (concrete-filled car tyre).

2.4 Transporting

Pueruli are exposed to several potential stressors when captured and transported. The most significant stressors include harvesting and handling, post-harvest transfers, induction of vigorous escape behaviour (tail flicks), physical damage (e.g. limb loss, blood loss), interactions between pueruli, poor water quality in transporting vessels, and exposing the pueruli to air. Stress responses may be evaluated subjectively (behaviour, vigour) or expressed quantitatively by measured changes in physiological variables such as oxygen uptake, heart rate, muscle metabolites, blood gases, pH, hormones and ions (Taylor *et al.*, (1997)). Lobsters are ectothermic (outside heat) which implies that their metabolic rate increases as the temperature increases. Oxygen is essential for respiration; the amount required increases with stress and temperature. Dissolved oxygen concentration is also influenced by temperature; the higher the temperature the lower its oxygen concentration. Lobsters kept at high densities are especially prone to die if there is a build-up of nitrogenous wastes and decrease in dissolved oxygen (Vijayakumaran & Radhakrishnan, 1997).

2.5 Ongrowing

Systems

Flow-through and recirculating systems are used to culture lobster in New Zealand. The flow-through or open system is the simplest type of operation. Seawater is pumped from a nearby harbour or bay and mechanically filtered to remove impurities. For example, NIWA's Mahanga Bay Research Centre uses a triple-unit, multimedia (sand and carbon) filter. The system can remove particles as small as 20 μm and supplies up to 36 m^3 of seawater/hour to the research facility. After the filtration process, the seawater passes through the reticulation system to the ongrowing tanks and is then pumped back to sea (Illingworth & McDermott, 1997). The main limiting factor of a flow-through system is having a reliable source of high quality seawater at ambient temperatures that promote rapid growth. These systems are also subject to pathogens and algal toxins that may appear periodically in the ocean environment and adversely affect the lobsters. To adequately manage these risks, early warning bioassays, complex filtration and sterilisation systems and may be necessary (Chang & Redfearn, 1999).

Recirculating or closed systems are usually more complex than flow-through culture systems. As a result they have higher initial capital costs and relatively high operating costs. The major components of a recirculating system include; ongrowing tanks, mechanical filter, biological filter, heat exchanger, pump and a reservoir. A major concern of a recirculating system is the build-up of metabolites. Mechanical filtration is required to remove solids, uneaten food and faeces. Toxicity of the nitrogenous compounds can also be a serious problem. Sub-lethal ammonia and nitrite levels may reduce growth, damage gills and other organs, and may be a trigger factor for several diseases. The ammonia and nitrite can usually be controlled with a biological filter, which has nitrifying bacteria that metabolise excreted ammonia and convert it to nitrate and nitrite. Lobsters can tolerate higher concentrations of nitrate than ammonia, and the water can be reused almost indefinitely if the nitrification process remains stable (Spotte, 1970). A heat exchanger controls water temperature and a pump and reservoir help control water flow. Two major advantages of a recirculating system are the capability to manage and control optimum culture conditions and the capability to operate in isolation from the external environment. Aqua Bop uses a recirculating system to ongrow pueruli (see Appendix A for a system schematic).

Habitat

The habitat for captive spiny lobsters needs to accommodate their complex social behaviour. Aqua Bop uses shallow (200 mm water depth) rectangular tanks that are stacked three layers high to minimise floor area. Minimising waste material build-up by maintaining good tank hygiene greatly reduces the risk of bacterial contamination. Lobsters are graded so tanks contain similar-sized animals. Large individuals may dominate for shelter and food, reducing growth and increasing cannibalism (Rayns, 1991). Cannibalism is especially common among spiny lobster if there is a shortage of food or shelter. Moulting or just-moulted animals seem to be the most vulnerable, but it is uncertain whether healthy animals are attacked (Booth & Kittaka, 1994; personal observation). Death at moulting has been widely reported among captive spiny lobster, often with symptoms consistent with moult death syndrome (MDS) of homarids or clawed lobsters (Rayns, 1991; Gerring, 1992). Stress and poor nutrition are possible causes of MDS (Conklin *et al.*, 1991).

Temperature

Water temperature affects metabolic rate and thus has a significant effect on respiration, food intake, digestion, assimilation, growth and behaviour (Forteath *et al.*, 1993). Temperature strongly influences the growth of juvenile spiny lobster. The optimum temperature for growth and survival of juveniles is approximately 16-18°C (Hollings, 1988; Forteath *et al.*, 1993). Juvenile lobsters stop growing if the water temperature is below 10°C (Manuel, 1991). Above 23°C mortality increases (Hooker *et al.*, 1997). Accelerated growth decreases production costs because of labour and energy cost savings. However, these gains can be negated by lower food conversion efficiency, higher food consumption, greater activity and increased incidence of disease (Booth & Kittaka, 1994).

Density

The generally communal nature of spiny lobsters make them especially suitable for culture. Tank stocking rates are generally 100/m^2 for puerulus to one-year old animals, 50 m^{-2} for one to two-year old, and 30/m^2 for two to three-year old animals (Hooker *et al.*, 1997). However, at excessively high densities, growth and survival can be adversely affected. Higher densities reduced growth rates of juveniles with physical and chemical cues being held responsible. Mortality was also highest under crowded conditions; large individuals survived better than smaller ones in tanks with a size mix and some cannibalism occurred. Lobsters held in tanks downstream of either similar-sized or larger animals grew slowly. This may be due to a growth inhibitor released by the lobsters upstream (Rayns, 1991).

Ablation and photoperiod

Ablation (surgical removal) of the eyestalks has been used in nutrition research and has the potential for accelerating growth in aquaculture (Rayns, 1991). Eyestalks are the sites for synthesising a moult-inhibiting hormone, and ablated lobsters moult more frequently and grow faster. However, attempts to use this technique on small lobsters usually result in high rates of mortality, especially during moulting. Marketing and ethical concerns also limit widespread use of this practice (Berry, 1997).

Brett (1989) found that growth of juveniles in the laboratory was influenced by photoperiod (rate of dark and light periods) manipulation. Berry (1997) identified maximum growth occurred with LD16:8 (16 hours light : 8 hours darkness) light regimes. The light cycle may be varied to modify behaviour and promote feeding and growth.

Diet

Lobster feed contributes to a large percentage of the production costs. The food must have high nutritional value, be acceptable to the lobsters, available all year round at reasonable cost, and be easy to store and handle. Artificial diets consist of dry or moist pellets made from powdered, mixed feed ingredients. A binding ingredient such as wheat gluten or alginate is included so that the pellet will have high stability in water. Binders also reduce the rate at which water-soluble nutrients such as vitamins leach from the feed. Gerring (1992) reported that juvenile lobsters grew slowly and survived poorly on some artificial diets, including some commercially available for crustacea; moult death syndrome appeared to be a common cause of death. The lack of suitable artificial food ration is a major obstacle to commercial lobster farming.

Captive lobsters prefer foods of a marine rather than terrestrial origin (Fielder, 1965). Daily feeds of fresh rather than frozen *Mytilus galloprovincialis* (blue mussel) and *Perna canaliculus* (Greenshell mussel) have consistently produced the best growth rates. Diet also affects the degree of paling in exoskeletal colour of captive juveniles. *J. edwardsii* retained its natural red colour when fed *M. galloprovincialis* but turned a light pinkish purple when fed *P. canaliculus* (James & Tong, 1997). Kittaka (unpubl.) found food conversion ratios (wet weight of food: gain in wet weight of lobster) for small juveniles fed mussels to be between about 5:1 (at 12°C) and 7:1 (at 20°C). Other ratios of 14:1 for 12-40g lobsters and 22:1 for 58-105g lobsters have been reported (James & Tong, 1998).

Disease

The high risk of disease is a major concern when culturing lobsters in elevated water temperatures (~18°C). Problems can include build-up of external growths, infection of damaged limbs, development of the bacterial disease gaffkemia, carapace erosion, moult death syndrome and fungal diseases. The most important aspect of disease control in lobster culture is to reduce physiological stress. Stressed animals are more susceptible to disease, which can spread rapidly in dense cultures. Lobsters become stressed when subjected to improper culture conditions such as overcrowding, poor water quality, excessive temperature and inadequate diet. To minimise the risk of disease, rearing systems should be kept free of uneaten food, exuvia (cast moult) and dead animals that can harbour the disease agents. Intrusions such as bright lights, unnecessary movement and handling are also stressful. If these improper conditions are minimised, most researchers believe that disease will not be a major problem in lobster culture (Van Olst *et al.*, 1980).

Water Quality

The quality of the water supply is a major concern in all aquaculture ventures. The health of the lobsters depends on many complex and interlinked factors. Large or sudden fluctuations in water quality stress the lobsters, slowing growth and making them more prone to disease or moulting difficulties. Table 2.1 summarises the more commonly considered water quality factors and guideline levels. Each factor is inextricably linked to many others so a holistic approach is necessary to ensure the overall wellbeing of the lobsters. For example, oxygen consumption and the lethal oxygen levels depend on lobster body size, moult state, water temperature and salinity. Furthermore, information on both ammonia excretion rates and safe ammonia tolerance limits is required to optimise the design of the seawater circulation and waste treatment components of an intensive lobster culture system (Forteath, 1993).

Table 2.1: Water quality factors for *J. edwardsii* aquaculture.

Water Quality Factor	**Guideline Level**
Temperature	16-18 °C optimum, 10-20 °C tolerable
Dissolved oxygen (DO)	Above 4.0 mg/L
Total available nitrogen (TAN)	Below 0.5 mg/L
Unionised ammonia (NH_3 or NH_3~N)	Below 0.1 mg/L
Nitrite (NO_2^- or NO_2~N)	Below 1 mg/L
Nitrate (NO_3^- or NO_3~N)	Below 100 mg/L
Dissolved nitrogen gas (N_2)	Below 105% saturation
Water flow rate	Above 0.5 L/min/kg of lobster
pH	7.6-8.2
Salinity	33 ppm optimum, 25-36 ppm tolerable

Market

The Japanese seafood market has some of the highest prices in the world for spiny lobsters, especially for species that look and taste similar to the favoured local species, *Panulirus japonicus*. This market can pay a premium for smaller (200-300 g) fresh whole lobsters, particularly for ceremonial and banquet occasions such as weddings where they have symbolic significance (C. Zame, personal comment). The Japanese demand for smaller lobsters is not met because of New Zealand's MLS restrictions on wild-caught lobsters. The MLS for wild-caught lobsters is measured by tail width. Female *J. edwardsii* must have a tail width greater than 60 mm and males a tail width greater than 54 mm to meet the MLS (Ministry of Fisheries, 1998). These measurements correspond to a weight of about 400g. There is no MLS for cultured lobsters (i.e. ongrown from pueruli) so they can be used for markets that prefer lobsters beneath New Zealand's MLS. Therefore, a cultured product will not compete with wild lobster in the existing commercial market. The smaller target weight will also reduce production costs.

Growth rates

Growth rates of captive juvenile lobsters can vary depending on captive environment, water temperature, stocking density, feed, and water quality. In the wild, *J. edwardsii* can grow to 250 – 350 g in less than three years after settlement (McKoy & Esterman, 1981). The greatest growth rate of *J. edwardsii* in culture was at a constant 18°C water temperature (Table 2.2). Booth & Kittaka (1994) estimate that a weight of 250 – 350 g can be achieved in two years.

Table 2.2: Comparisons of the growth of *Jasus edwardsii* in culture, arranged from highest to lowest growth rate. (Adapted from Hooker *et al.*, 1997). Final weight after one year from settlement. Density is based on the floor area of the tank.

Study	Water temperature (°C)	Density (lobsters m/2)	Food*	Growth rate (g/day)	Final weight (g)
Hollings (unpublished)	18	72	pc, me, a, f	0.098	36
Manuel (1991)	18	59	pc	0.091	33.6
Hooker *et al.*, (1997)	13-23	105	pc	0.085	30.8
Hollings (unpublished)	15	72	pc, me, a, f	0.085	31
Hollings (unpublished)	11-19	72	pc, me, a, f	0.068	26
Rayns (1991)	8-18	74	as	0.039	14.2
Manuel (1991)	10	59	pc	0.027	11.8

*Food: pc, *Perna canaliculus* (mussel); a, *Haliotis* sp. (abalone); me, *Mytilus edulis* (mussel); f, fish (albacore tuna); as, *Austrovenus stutchburyi* (cockle).

2.6 Bioeconomic analysis

The term bioeconomics is used to describe how the biological performance of an aquaculture system is meeting economic and technical constraints (Allen *et al.*, 1984). The goal of most aquaculture ventures is to achieve a level of profitability or return on investment. Achieving profitability involves the following considerations:

1. Estimating production costs under a given technology and local economic environment, and determining the values of certain variables that optimise (usually least-cost) the system.
2. Determining the sensitivity of the output measures (mainly costs) to variation in parameter values.
3. Assessing the market that exists or is projected for the product.
4. Defining areas where research success would have high potential benefits.

The profitability of farming *J. edwardsii* in New Zealand was assessed by Hollings (1988). Findings indicated that lobster farming could be profitable. The assessment incorporated observations of juvenile growth and survival at continuous and elevated temperatures and a study of world lobster markets. It was estimated that each 300g lobster would sell for $14.50 each. Each puerulus would cost $2.00 to harvest, $6.00 to ongrow to 300 g, and $1.50 to process and transport. The cost of mortality would be $2.00 giving a total cost of $11.50. Each lobster would therefore return a profit of $3.00. In addition to the profitability analysis, the study identified the importance of further research into hatchery production of puerulus and cost-effective harvesting of puerulus from the wild. The estimates and assumptions used could be improved with further biological research and a costing study on different ongrowing systems.

3 Materials and Methods

Introduction

This Chapter describes and explains why particular methods and techniques were used and discusses the procedures, sample sizes, method of selection, choice of variables and controls, measurement tests and statistical analyses.

3.1 Sourcing seedstock

Technological Forecasting

Technological forecasting was used determine when larval rearing techniques might be used to supply *J. edwardsii* pueruli as seedstock. Technological forecasting can be defined as the applying scientific methods to predict the future characteristics and timing of technology. To avoid ambiguity a forecast should define four elements (Twiss, 1992):

1. What to forecast (the qualitative element).
2. What measure to forecast (the quantitative element).
3. When the event will occur (the time element).
4. The likelihood of occurrence (the probability element).

Two qualitative delphi studies were applied because they best suited budget and time constraints. Extrapolative forecasting techniques were not used because little useful long-term quantitative data on larval-rearing was available.

The delphi method

Rand Corporation USA developed the delphi forecasting method during the 1970s. It is one of the more popular judgmental approaches to technological forecasting. The key feature of the Delphi method is that it is a group forecast based on anonymity, controlled feedback and iteration (Basu, 1977). A panel of experts make anonymous, subjective judgements about the probable time when a specific technological capability will be available. Results are aggregated and fed back to the group, which then uses the feedback to generate another round of judgements. After several iterations, areas of agreement or disagreement are noted and documented. Unlike many other forecasting methods, the Delphi method may not produce a single answer as its output. Often, a spread of opinions that reflect differing schools of thought are produced, which gives the forecast greater breadth and depth of information. Limitations of the Delphi method of technological forecasting include over-sensitivity of results to ambiguous questions and the difficulty in assessing the degree of expertise of the participants.

The forecast consisted of 2 studies; Delphi '97 conducted in October 1997, and Delphi '99 conducted in March and April 1999. The methodologies used in the studies are summarized in Table 3.1. A full transcription of Delphi '99 is included in Appendix B.

Table 3.1: Summary of methodologies used in Delphi '97 and Delphi '99 to forecast when larval-rearing techniques will be used to supply pueruli as seedstock.

	Delphi '97	**Delphi '99**
Participants	Ten	Eight
Country	New Zealand	Australia (2), New Zealand (6).
Topic	To forecast when, with a 90% probability, technologies will be capable of culturing New Zealand rock lobster, on a commercially feasible scale.	To forecast which year, with a 90% probability, larval-rearing techniques would be used by more than 50% of rock lobster farmers in your country to produce pueruli of the rock lobster, *J. edwardsii*, as seed stock.
Topic timeframe	Asked to choose from 5-year periods.	Asked to choose a single year.
Anonymity	Participants knew each other's identities but not their forecasts.	Participants did not know each other's identities.

3.1.1 Data collection

'Step 1' of each study involved emailing an invitation to people with some level of aquaculture expertise asking them if they would like to participate. Most people had specific rock lobster research interests. Electronic mail was chosen as the communication medium because message transmission was immediate and reliable, thereby decreasing the time between steps. Messages were manipulated easily by word processing software, which saved time when compiling and analysing data. Email is also inexpensive and can be printed when needed.

The initial information package was designed to state clearly and succinctly the purpose and scope of the study. Anonymity and the amount of time and effort required was emphasised. The topic was framed with the aim of clearly defining the task and including the four essential forecasting elements. This inherent process of continually questioning and improving definitions encouraged lateral thinking and exploration of different research possibilities.

3.1.2 Data analysis

Participants submitted their forecast timeframe, along with any assumptions, via email. They also offered opinions on responses from the group. All submissions shared amongst the group were anonymous to minimise possible peer pressure to conform. The responses were collated and all assumptions and opinions were summarised and discussed by the facilitator. The mean, median and mode of each study was calculated and then combined.

3.2 Harvesting pueruli

3.2.1 Collector construction

Nine differently designed collectors were built between May and June 1997 to investigate if pueruli could be harvested cost-effectively (Table 3.2). The eight new designs were a collaborative effort between Aqua BoP and NIWA. The performance of the devices, measured by collecting effectiveness and time taken to check and clear, was compared with the standard crevice collector. Operational issues surrounding the use and maintenance of each design is also discussed.

Table 3.2: Description of the nine collector designs used in the harvesting experiment.

Type	Code	Replicates	Description
Bamboo bunch	BB	3	Variable diameter, 100 mm (approx.) lengths of bamboo held loosely in groups by a short length of cord.
Bamboo sausage	BS	3	Polypropylene mesh bags filled with short lengths of bamboo of various diameters.
Crevice collector (standard)	CC	5	Eight sheets of 9 mm thick plywood and total area 38 cm^2.
Concrete pipe	CP1	3	A rectangular wooden frame containing 80-mm lengths of PVC pipe (diameters: 15, 20, 25 and 32 mm) coated in a cement and sand mix. One end closed off with a PVC sheet.
Concrete pipe	CP2	3	A 300-mm diameter PVC pipe containing 80-mm lengths of PVC pipe (diameters; 15, 20, 25 and 32 mm) coated in a cement and sand mix. One end closed off with a PVC sheet.
Netting	NS	3	A PVC pipe wrapped in heavy polypropylene fish netting.
Plastic Pipe	PP1	3	As for CP1 except without the cement and sand coating.
Plastic Pipe	PP2	3	As for CP2 except without the cement and sand coating.
Wooden Pipe	WP	3	A 200-mm square block of H3 treated pine with a series of holes (diameters; 15, 20, 25 and 32 mm) drilled to a depth of 80-mm.

The collectors were constructed at Aqua BoP's ongrowing facility. After construction, the collectors were placed under the wharf at Gisborne because this area has a high natural settlement of pueruli. The wharf also provides shelter when deploying, checking and maintaining the collectors. The collectors were left to condition for three weeks to allow chemicals to leach out of construction materials, and also allow a natural biofilm to grow on the collector surface (conditioned collectors are more effective than new collectors). Each collector was suspended by rope from the underside of the wharf just above the seafloor. At low tide they were submerged in 3-5 m of water. The collectors were placed randomly to minimise possible bias from any localised effects.

3.2.2 Data collection and analysis

The pueruli in each collector were counted on 23 July, 7 August, 20 August and 16 September 1997. Each collector was carefully lifted to the surface of the water. A fine meshed net was then placed beneath the collector to catch any pueruli attempting to escape. The collector and the net were then gently lifted into a small boat and each collector was then methodically checked for pueruli. All lobsters in the collectors were removed and assessed for their development stage and for any damage during collection. Lobsters were then placed in a container of fresh seawater held in the boat. After each collector was cleared, it was placed back into the water and shaken to remove any accumulated debris before being lowered back into position. Once the collectors had been cleared, the captive pueruli were packed and transported to the Aqua BoP ongrowing facility in Papamoa.

Each collector was analysed in terms of cost to clear (per puerulus). Estimates of the unit cost for clearing different types of collectors were based on determining the time taken to clear each collector. The unit cost of each puerulus was then calculated using the following formulae:

$$\text{Unit cost of collecting each puerulus} = \left(\frac{4T}{P}\right) \times W$$

where:
T = mean time to clear collector (minutes)
4 = the number of collection times
P = mean number of pueruli caught per replicate
W = wage rate (assuming \$15/hour or \$0.25/min)

The mean for the four collection dates were determined.

3.3 Transporting

Commercially, pueruli are transported from the harvest site to the ongrowing facility in plastic bags three-quarters filled (≈3L) with chilled (12-14°C) oxygenated, oceanic seawater. Immediately before the bags are sealed, oxygen was bubbled through the seawater for approximately ten seconds. Aerating the water is a cheap and easy method to ensure that the lobsters have sufficient available oxygen for the journey. Cooler water temperatures are advantageous because oxygen solubility increases with decreasing temperature. Also, lobsters are less active at low temperatures, making them easier to handle.

The sealed plastic bags were put into poly-bins (polystyrene) for insulation, along with 1.5-L plastic bottles filled with ice. The ice bottles help to minimise large temperature fluctuations that may occur during transportation. The number of ice bottles per poly-bin varies according to environmental conditions. Often, the ambient air temperature can be more than 5°C higher than the seawater temperature, so more ice bottles must be used.

The pueruli are acclimatised when they arrive at the ongrowing facility by removing the sealed plastic bags containing pueruli and seawater from the polybins and submerging them in the ongrowing tanks. The transit seawater temperature gradually adjusts to the temperature of the ongrowing seawater temperature. The acclimatisation period depends on the temperature difference between the transit seawater and the ongrowing seawater. Once the temperatures were equalised, the plastic bags were opened and the lobsters were introduced to their new surroundings.

To ascertain the upper stocking density, maximum travel time, and effect of seawater temperature an experiment was carried out in the laboratory to simulate commercial transport conditions.

3.3.1 Collection and transport of lobsters

One hundred and forty-four stage 3 pueruli (P) and 144 stage 1 juveniles (J) were harvested from collectors in the Gisborne Harbour between 24 May and 28 May 1999 and were transported by road to the NIWA research facility at Greta Point, Wellington. Upon arrival the lobsters were acclimatised to the ambient temperature seawater tanks. There were no observed mortalities from the time of harvest to the beginning of the experiment three days later.

A factored experimental design (Fig 3.1) was used to examine lobster survival, using the following factors:

- Two age groups – stage 3 (P) and stage 1 juveniles (J)
- Two observation times – survival at 6, and 9 hours
- Two temperatures – 14°C and 20°C
- Three stocking densities – 2, 4 or 6 lobsters/container (or 15, 30 and 45/litre)
- Three replicates of each treatment.

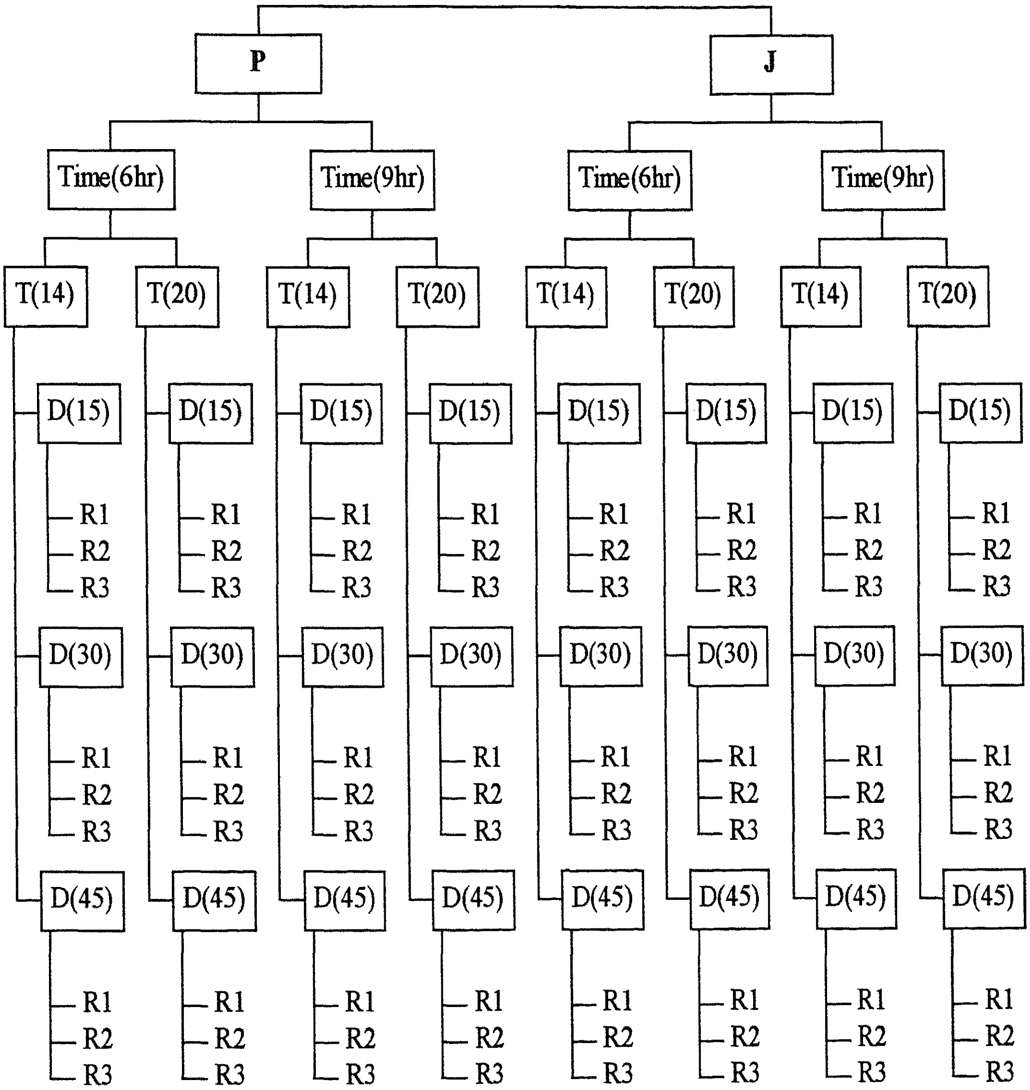


Figure 3.1: Transporting experimental design, where P = puerulus stage 3, J = juvenile stage 1, Time (hr) = survival observation times, T = temperature (°C), D = density (lobsters/litre), R = replicate.

The required number of lobsters were put into 0.14 L lidded plastic containers filled with 0.13 L of seawater. Each container was floated in a constant temperature water bath. The containers were not aerated or agitated significantly. A 'Clayson Refrigerated' water bath was used for 14°C and a 'Grant' water bath was used for 20°C (Fig. 3.2).

Figure 3.2: Photo of 20°C water bath with containers used in the transporting experiment.

3.3.2 Data collection and analysis

Data on class, stocking density, temperature, time and survival were recorded on a Microsoft® Excel 97 Workbook. Lobsters that showed remote signs of life were put into recovery containers filled with fresh seawater and kept within 4°C of the original treatment temperature. There was a second, recovery observation, 8.5 hours after the start of the 6-hour treatment and 20.5 hours after the start of the 9-hour treatment. All lobsters that recovered were included in the survival results. The influence of class, time, temperature, and stocking density on survival rates were determined.

3.4 Ongrowing

To study the influence of four different stocking densities on the growth rate, 120 six-month old lobsters were reared at Aqua BoP's ongrowing facility. Two weeks before the first measurements (i.e., Day 0) were recorded, 120 lobsters were transferred from a large fibreglass tank to 16 white, round, plastic basins (0.275 m diameter x 0.145 m deep; 3.9 L) 593.8 cm^2 x 6.5 cm = 3859.7 cm^3 for conditioning. The flow rate to each white plastic basin was 1 L/min. The two-week 'conditioning' period enabled the removal of any lobsters that may have perished due to stress from handling. There were no deaths in the 2-week conditioning period between transferring the lobsters from the large tank to the small basins for the experiment. Growth was measured between February and June 1999.

Water quality

The recirculated seawater was pumped continuously through mechanical and biological filters to remove animal wastes and disinfected with ozone. Water temperature was measured at least five times per week using a Carel™ in-line temperature probe. Ammonia, nitrite and nitrate levels were measured daily using a FasTest™ saltwater aquarium master test kit. Salinity was measured using a SeaTest™ specific gravity meter. Ammonia and nitrite levels remained below the measurable limits of the test kits. Nitrate levels remained below 100 mg/L and salinity between 33 and 35 parts/thousand. The oxygen content of the seawater on 22 April 1999 was 97% saturation, or 7.7 mg/L at 16°C.

Culture system

The lobsters were reared in 16 lidded utility baskets (0.25 m x 0.34 m x 0.18 m deep) distributed randomly within two larger fibreglass tanks (2.37 m x 1.2 m x 0.18 m deep; 512 L). They were submerged to 0.12 m (volume = 10.2 L) in recirculated (7-8 L min^{-1}) seawater and kept at a constant 16°C (±1°C) by a heat-chill unit. Each basket was provided with shelter in the form of a plastic waste pipe (0.2 m long, 0.1 m diameter) cut longitudinally. As well as the eight baskets, each large fibreglass tank housed approximately 400 non-experimental lobsters that could move freely in the large tank but could not enter the experimental baskets (Fig. 3.3).

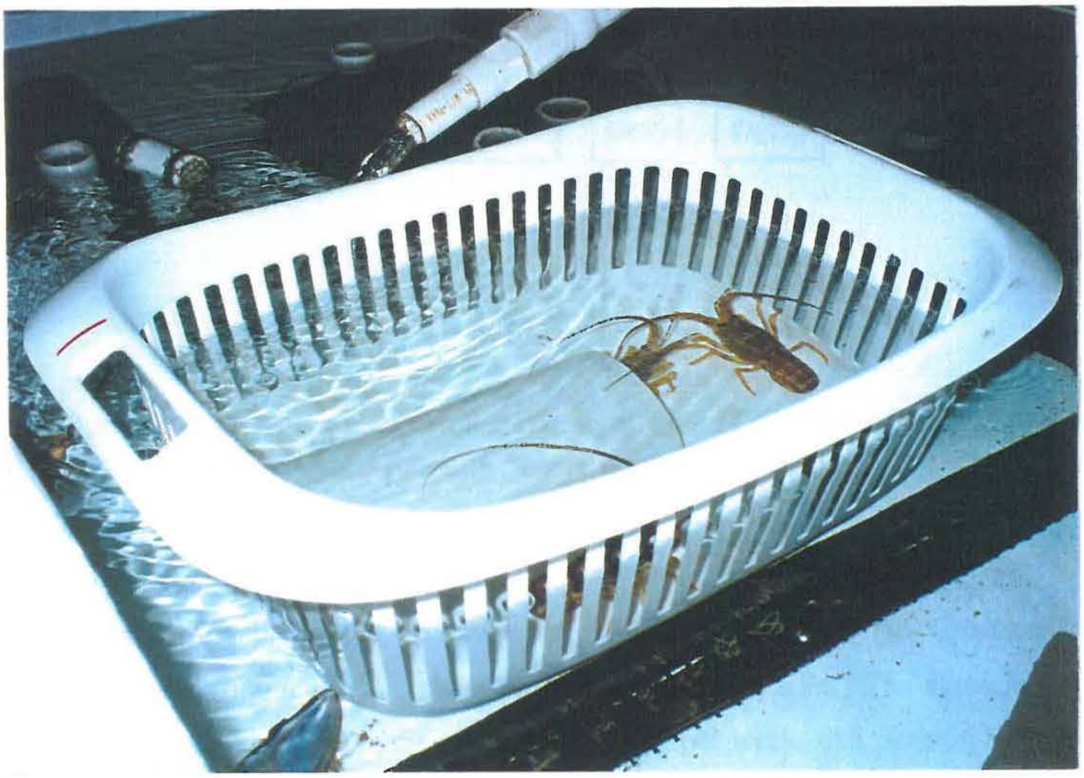


Figure 3.3: Photo of a utility basket (with lobsters and shelter) used in the ongrowing experiment.

The lobsters were exposed to an ambient photoperiod (LD 8:16) during which the light period consisted of a mixture of subdued natural and artificial light. The lobsters were assigned randomly to density regimes shown in Table 3.3 and the replicates in Fig 3.4.

Table 3.3: Equivalent experimental stocking densities for the ongrowing experiment.

Stocking Density Lobsters/tank (D)	Lobsters/m^2 (tank space)	Lobsters/m^3 (water)
3	35	175
6	71	355
9	106	530
12	141	705

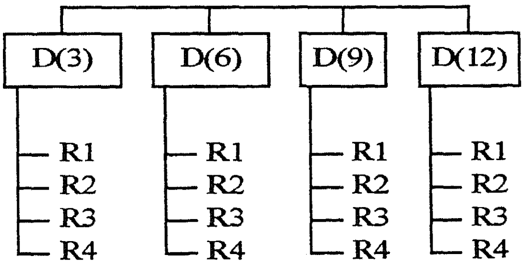


Figure 3.4: Ongrowing experimental design, where D= density (lobsters/tank), E = equivalent density (lobsters/m^2), R = replicate.

Feeding and cleaning

The lobsters were offered an excess of 40-80 mm long cultured Greenshell™ Mussels, (*P. canaliculus*) purchased live from a local retailer. The mussels were presented to the lobsters in the half shell six days per week. All uneaten food and empty shells were removed each feeding time. Weekly cleaning involved lifting the baskets out of the water for ten seconds. This allowed any sediment to drain out freely and minimised any adverse cleaning disturbance to the lobsters..

Lobster measurements

On days 0, 50 and 121, the weight of each lobster was measured to the nearest 0.1 g with an electronic AND-HL200™ balance. The CL was measured to the nearest mm with vernier calipers. Shortly before measurement, each lobster was placed between slightly dampened Chux™ multi-cloths to absorb any residual seawater and provide a temporary cover, which minimised stress and physical damage.

Any lobster that died during the experiment was replaced with a similar sized one to maintain stocking density. However, replacement lobsters were not included in the data analysis because of variability of individual growth rates. Replacement lobsters were identified by uropod clipping, which involved the removal of a diagonal-half of the outer-left uropod. Replacement lobsters had to be re-identified when the uropod regenerated, usually after three moults.

3.4.1 Data analysis

Data on CL, wet weight, mortalities, and moults was recorded on a Microsoft® Excel 97 Workbook. Two general statistical analyses were performed to compare mean growth rates within and between each group of lobsters using Systat® version 5.03.

3.5 Bioeconomic Analysis

A baseline bioeconomic model was developed on a Microsoft® Excel 97 Workbook using assumptions drawn from literature and expert opinion. It consisted of four linked components: biological, economic, physical, and a cash flow analysis. The biological component (Table 3.4a) characterised the performance of lobster growth and survival. The economic component (Table 3.4b) characterised market returns, export costs and the costs involved in harvesting seedstock. The physical component (Table 3.4c) characterised production and capital requirements over the first 10 years of operation. The cash flow analysis (Table 3.4d) predicted the financial performance of the operation over a 10-year planning horizon.

Table 3.4a: Assumptions in the biological component of the baseline model.

Lobster biomass	
Puerulus (number)	Number of pueruli harvested/year. The 1,000kg annual quota traded allows for 40,000 pueruli to be harvested.
1-yr lobster (number)	5% mortality rate; 38,000 pueruli survive.
2-yr lobster (number)	3% mortality rate; 36,860 1-yr olds survive.
3-yr lobster (number)	2% mortality rate: 36,123 2-yr olds survive. Lobsters reach a saleable size (300 g) at the end of their third year.
Total lobster weight in system (kg)	Total weight of lobsters in the farm at any given time.
Feed required (kg)	Weight of feed (kg) to achieve forecasted growth rates. This is calculated by multiplying the difference in total lobster weight in the system between two consecutive years by the FCR.
Sale weight (kg)	The number of lobsters at the end of their third year multiplied by their weight.
Feed conversion ratio (FCR)	Feed required to increase lobster weight. The FCR of 7:1 used indicates that lobsters gain 1 g of body weight for every 7 g of mussel meat supplied.
Lobster growth	
Lobster weight (kg)	Puerulus weigh about 0.00025 kg. In the model, it is assumed that lobsters weigh 0.05 kg after 1 year, 0.15 kg after 2 years and reach a saleable size of 0.3 kg at the end of year 3.
Growth rate (%/yr)	Multiplication factors of yearly growth.
Yearly mortality (%)	Yearly mortality percentages.
Total mortality (%)	Annual deaths, expressed as a percentage.

Stocking density	Number of lobsters stocked per unit volume, which depended on their age and size. Pueruli were stocked at 100/m^2 of tank area, which represented 500 (or 0.125 kg) pueruli/m^3 of water. One-year old lobsters were stocked 50/m^2 of tank area, which represented 250 (or 12.5 kg) 1-yr old lobsters/m^3 of water. Two-year old lobsters were stocked at 30/m^2 of tank area, which represented 150 (or 22.5 kg) 2-yr old lobsters/m^3 of water. Three-year old lobsters were stocked at a density of 20/m^2 of tank area, which represents 100 (or 30 kg) 3-yr old lobsters/m^3 of water.

Table 3.4b: Assumptions in the economic component of the baseline model.

Lobster selling price ($/kg)	The 300 g lobsters have an export price of $65/kg. The target market is Japanese wedding ceremonies, which prefers small (300 g), live lobsters. Farmed New Zealand lobsters have a similar appearance and quality to Japanese domestic lobsters. As there is no minimum legal size requirement for farmed lobster, they could fulfil the specifications. Specific natural diets, such as different mussel species, can enhance lobster appearance and quality.
Quota traded from Year 1 (kg/yr)	The farm trades 1000 kg of CRA3 quota for harvesting 40,000 pueruli from the CRA3 area (East Cape to Wairoa).
Sale weight from Year 4 (kg/yr)	The farm exports 10,837 kg of 300 g lobsters annually from Year 4.
Quota (kg) : sale (kg) increase	Returns the increase of quota traded to lobsters exported. That is, for each 1,000 kgs of lobster quota traded there is 10,837 kgs exported – an increase of 1,084%.
Pueruli : quota traded (/kg)	Under Ministry of Fisheries guidelines, 1 kg of quota can be traded for permission to harvest 40 pueruli.

Quota lease ($/kg/yr)	Annual cost to lease 1 kg of CRA3 quota. CRA quota lease prices depend on demand, but are currently $15/kg/yr.
Quota lease ($/yr)	Annual cost to lease 1,000 kg of CRA3 quota.
Quota cost ($/puerulus)	Quota cost component for each puerulus.
Harvest cost ($/puerulus)	Harvest and transporting cost component for each puerulus.
Total cost ($/puerulus)	Sum of quota and harvest costs, and represents the cost of a puerulus 'delivered' to the ongrowing farm.
Feed price ($/kg)	Cost of lobster feed/kg. Greenshell mussel meat is set at $0.50/kg.
Processing & transport cost ($/kg)	Cost/kg to pack and airfreight live lobsters to Japan, set at $10/kg. Process & transport costs are incurred when lobsters reach saleable size (beginning of Year 4).
Vehicle cost ($)	A single purchase of $10,000.
Fuel (vehicle) ($/yr)	Set at $2,500/year.
Fees and licences ($/yr)	Farm and harvesting fees, licences and permits set at $5,000/year.
Investment amount ($)	An alternative investment scenario used to compare the return that an investor might expect if the funds required to start the venture (approximately $1,000,000 or the cumulative cash position at Year 3) were invested in a bank.
Interest rate (%)	Interest at 10%, compounded annually.
Investment duration (years)	Duration of investment.
Return on investment ($)	At the end of 10 years, an investor could expect $2,573,742, including principal and interest, on the initial $1,000,000 invested.

Table 3.4c: Assumptions in the physical component of the baseline model.

Tank water depth (m)	The ongrowing tanks have a recirculating seawater depth of 0.2 m.
Seawater cost ($\$/m^3$)	Oceanic seawater to recharge the system costs $\$20/m^3$.
Seawater changed (%)	One fifth (20%) of the seawater is changed at a time.
Seawater changed (/year)	The seawater is changed 12 times/year.
Seawater turnover factor (/yr)	Number of times the seawater is changed/year multiplied by the percentage changed each time.
Ongrowing area calculation	
Tank area: age of lobster (m^2)	The total ongrowing tank area required and constructed during start-up (Years 1-4). By Year 4, the maximum tank area has been reached.
New building area (m^2/yr)	During start-up, the area of new buildings required is half the area of the ongrowing tanks. Ongrowing tanks are stacked up to three high to maximise the use of floor space. Building floor space reaches 2,097 m^2.
Tank water volume (m^3)	Volume of seawater in the ongrowing tanks = total tank area multiplied by tank water depth.
Filtration and recirculation water volume (m^3)	Volume of seawater in filters and plumbing (= tank water volume).
Total water in system (m^3)	Total volume of water in system = tank water volume + (filtration water volume + recirculation water volume).
Total water discharged (m^3/yr)	Volume of seawater discharged (and replaced by oceanic seawater) each year, determined by multiplying the total volume of water in the system by the water turnover factor.

Seawater cost ($/yr)	Total oceanic seawater volume used/year multiplied by the cost/m^3 of water ($/m^3).
Electricity cost ($/yr)	Cost to run the recirculation system set at $65/m^3 of system seawater.
Tank cost ($/yr)	Construction cost of ongrowing tanks set at $10/m^2.
Recirculation system cost ($/yr)	Cost of the recirculation system, which includes purchase of pumps, heat exchangers, plumbing and filtration equipment set at 25/m^2 of new building area.
Monitoring cost ($/yr)	Cost of the alarm and monitoring system used to alert operators of equipment failures and monitor water quality parameters.
Building cost ($/yr)	Building costs set at $100/m^2. Costs include purchase and upgrading of existing buildings (e.g., unused abattoirs or cold stores).

Table 3.4d: Assumptions in the cash flow analysis of the baseline model.

Returns	
Lobster sales	Pueruli harvested in Year 1 are a saleable size (300 g) at the beginning of Year 4. Production and returns remain stable from Year 4. Selling 10,800 kg of lobster at $65/kg returns $704,400.
Total annual returns	
Costs	Costs are divided into capital and annual operating costs.
Capital costs: Land, buildings, monitoring system, recirculation system, tanks, and vehicle	Arranged alphabetically and are incurred during the start-up phase. Increase in lobster biomass dictates farm expansion. Maximum capacity is reached at Year 4 when the farm has 18.2 tonnes of lobster in tanks and exports 10.8 tonnes annually.

Land	Cost of buying 2,500 m^2 is set at $40,000. To minimise cost, the land does not have to be on the coast because the farm uses a recirculation system and oceanic seawater can be trucked. However, it is advantageous to locate the farm near a high puerulus settlement area, such as the east coast of the North Island. Minimising transit time between harvest site and farm reduces pueruli stress.
Total capital costs	
Annual operating costs	
Production costs	
Consumables	Cost of consumables for water quality testing and cleaning equipment, etc., set at $10,000/year.
Electricity	Electricity demand increases as the farm expands. Maintaining water temperature at 18°C requires large amounts of power. Heat exchangers and pumps consume the greatest amount of electricity.
Feed	Feed cost depends on lobster biomass.
Process & transport	Cost to process and airfreight 10,840 kgs of lobster at $10/kg.
Puerulus	Cost of puerulus harvested and transported to the farm. Also includes the cost of quota to harvest.
Water	Cost of oceanic seawater/year.
Labour costs	
Labour	At least two full-time staff ($36,000/yr each) required to run a farm exporting 10,840 kgs of lobster/year.
Indirect operational costs	
Repairs & maintenance ($/yr)	Set at 2% of total buildings, monitoring system, recirculation system, tanks, and vehicle costs.
Fixed costs	
Administration	Set at $10,000/year.

Depreciation	Calculated using a straight-line method, as 10% of total capital costs over 10 years.
Fees and licences	Set at $5,000/year.
Fuel (vehicle)	Set at $2,500/year.
Insurance	Cost to insure stock and plant. Set at $2,400/year.
Total annual operating costs	
Total costs	
Annual cash position	Difference between total annual return and total annual cost.
Cumulative cash position	Present annual cash position plus the previous cumulative cash position. The most negative cumulative cash position of $(994,600) is reached in Year 3 because there have been no returns from lobster sales. This shortfall is usually covered by owner investment or by loan.

3.5.1 Data Analysis

Financial performance of the farm was measured by the annual and cumulative cash positions at Year 10. Components were ranked to determine contribution to costs. Cost components and production values in the model were changed individually to investigate the sensitivity of the cumulative cash position and net annual cash flow at Year 10. The scenarios and values chosen reflect probable improvements or advances through further research and uncertainties through changes in market conditions.

Sale prices of ±$10.00 to the baseline were used to determine profitability in the case of market fluctuations. Trading 2,000 kg of quota is the current maximum allowed per farm; 10,000 kg is the current maximum overall. Processing and transport costs up $3.00 to $13.00 reflect the difficulty in negotiating reduced costs to Asian markets. Improvements in feed conversion and price reflect research into artificial diets and gains from utilising by-products from the mussel industry. Reducing harvest costs from $0.60 to $0.30 reflect improvements in collector technology. Increasing stocking densities without compromising growth could reduce the farm area required. Increasing the growth rates so that lobsters are ready for sale by Year 3 may increase profitability. Mortality rate of 7% reflects improved culture conditions. Mortality rate of 20% reflects greater lobster deaths from system malfunction or disease. The model can then provide information for directing experimental effort towards areas that give the greatest cost benefit ratio (Table 3.5).

Table 3.5: Changes in economic and biological factors used in the sensitivity analysis.

	Sale price ($)	Quota traded (kg)	Feed conversion	Feed price ($)	Harvest ($)	Stocking density (/m^2)				Years to sale	Mortality (%)	Processing & transport ($)
						P	1	2	3			
Baseline model	**65**	**1000**	**7**	**0.5**	**0.6**	**100**	**50**	**30**	**20**	**4**	**10**	**10**
Sale price at $55/kg	**55**	1000	7	0.5	0.6	100	50	30	20	4	10	10
Sale price at $75/kg	**75**	1000	7	0.5	0.6	100	50	30	20	4	10	10
Quota traded 2,000 kg	65	**2000**	7	0.5	0.6	100	50	30	20	4	10	10
Quota traded 10,000 kg	65	**10000**	7	0.5	0.6	100	50	30	20	4	10	10
Processing at $13/kg	65	1000	7	0.5	0.6	100	50	30	20	4	10	**13**
Feed conversion at 3:1	65	1000	**3**	0.5	0.6	100	50	30	20	4	10	10
Feed price at $0.2/kg	65	1000	7	**0.2**	0.6	100	50	30	20	4	10	10
Harvest $0.3/puerulus	65	1000	7	0.5	**0.3**	100	50	30	20	4	10	10
Stock density +25%	65	1000	7	0.5	0.6	**125**	**63**	**38**	**25**	4	10	10
Stock density +50%	65	1000	7	0.5	0.6	**150**	**75**	**45**	**30**	4	10	10
Three years to sale	65	1000	7	0.5	0.6	100*	50*	30*	20*	**3**	10	10
Mortality at 7%	65	1000	7	0.5	0.6	100	50	30	20	4	**7**	10
Mortality at 20%	65	1000	7	0.5	0.6	100	50	30	20	4	**20**	10

* Lobster stocking densities of 100 pueruli/m^2; 50 1 yr-olds/m^2; 30 1.5 yr-olds/m^2; 20 2 yr-olds/m^2.

4 Results and Discussion

4.1 Sourcing seedstock

Some communicative complications between the facilitator and the participants arose because of incompatible software but these were overcome by trial and error. In an effort to keep the topic concise, definition clarity was compromised so some terms were interpreted differently. For example, participants from Delphi '97 had different ideas on what "commercially feasible" meant. In Delphi '99 "commercially feasible" was defined as when larval rearing techniques would be "used by more than 50% of rock lobster farmers". This led to another valid query of whether rock lobster farmers would have their own puerulus hatcheries or purchase seedstock from specialised units, as happens in the New Zealand abalone aquaculture industry.

Delphi '97

Eight of the 10 participants from Delphi '97 forecasted that *J. edwardsii* larvae would be cultured on a commercially feasible scale between 2002 and 2021 (Table 4.1). Three participants in this group thought that *J. edwardsii* larvae would be cultured as early as 2002.

Table 4.1: Participants timeframe responses from Delphi '97 for culturing larvae on a commercially feasible scale.

Timeframe	**Responses**
1997 – 2001	
2002 – 2006	3
2007 – 2011	2
2012 – 2016	1
2017 – 2021	2
2022 – 2026	
2027 – 2031	
2032 – 2036	1
2037 – 2041	
2042 – 2046	
2046 +	1
N	**10**

Participants were given one opportunity to modify their original forecasts after reading the feedback from the first round. There were no changes to the original forecast timeframes. However, some participants elaborated on their original assumptions. The main findings from Delphi '97 identified that the level of government funding and industry support into research has significant implications on developments. Also, increased fishing pressure on the wild fishery may also provide momentum for greater research. Demand and market prices for *J. edwardsii* were likely to rise in the long term. Technically, maintaining clean culture conditions was crucial to increasing the survival rate of the larva. There was also an opinion that *J. verreauxi* was a more viable species for culture than *J. edwardsii* because of its simpler life cycle. However, *J. verreauxi*, was considered to be of poorer quality than *J. edwardsii* and traditionally commands a lower price. Even if *J. verreauxi* were cultured sooner, *J. edwardsii* culture would remain more economically attractive because of its higher value. New Zealand's current legislation, which allows for collecting and ongrowing *J. edwardsii* pueruli, may help to establish the market for farmed product.

Delphi '99

Eight out of 19 participants chose to respond by the deadline. Those that did not reply were deemed to be unwilling or unable to participate. Fifty percent of the responses indicated that between 2009 and 2015, with a 90% probability, larval-rearing techniques would be used by more than 50% of rock lobster farmers to produce *J. edwardsii* pueruli as seed stock. After reading feedback and opinions from the group, four of the eight participants altered their original timeframe by increasing the forecasted years. One participant decided that larval rearing techniques would never be able to supply commercial scale quantities of pueruli to rock lobster farmers (Table 4.2).

Table 4.2: Participants timeframe responses from Delphi '99 for culturing larvae on a commercially feasible scale.

Participant	Response 1	Response 2	Response 3	Δ from original
A	2009	2009	2009	0
B	2010	2010	2015	+5
C	2010	2010	2010	0
D	2014	2014	2014	0
E	2015	2020	2020	+5
F	2015	2020	2020	+5
G	2019	2019	2019	0
H	2020	2020	2050*	>30
Mean	2014	2015	**2020**	
Median	2015	2017	**2017**	
Mode	2010	2020	**2020**	

*The actual forecast from this participant was that the event would *never* happen. For statistical purposes only, this event has been defined as 2050.

Participants of Delphi '99 identified several issues affecting the potential for commercial scale larval culture. The major barrier is the modest funding that research projects are receiving. Increasing the funding, thereby concentrating research resources, will increase the likelihood of breakthroughs. Depleted wild fisheries and strong demand for product tends to drive developments in aquaculture. Technically, the current lack of knowledge on nutrition, disease and the long larval life impedes economic commercial scale culture of *J. edwardsii.* The relatively shorter larval life of warm-temperate or sub-tropical species (e.g., *Panulirus ornatus, P. elephas, P. cygnus,* and *J. verreauxi*) have a better chance of being farmed sooner in a closed life cycle system. Breakthroughs with these species may provide techniques for *J. edwardsii* larval rearing. Once experimental hatcheries succeed, the techniques used would then need to be scaled up to produce commercial numbers. Presently, the wild resource is a more cost-effective seed source because of the greater costs needed to develop larval rearing techniques.

From a global perspective, the technology to produce large numbers of pueruli could be acquired by lobster exporting countries that have greater economies of scale than New Zealand. Chile and other large producers of lobster may then be in a position to dump large quantities of 'cheap' cultured lobsters on the market.

Japan, with its respected larval culture and reproductive specialists, may also succeed in commercial scale larval culture; establishing lobster aquaculture projects in Korea and China alongside other operations. This gives them the ability to compete in supplying *J. edwardsii*. The same process may also occur with other products such as abalone pearls. Over-supply and competition for producing *J. edwardsii* and other species of lobster would drop prices and profitability.

Combined results

Combined forecast frequencies from Delphi '97 and Delphi '99 are heavily grouped between years 2007 and 2021 (Table 4.3).

Table 4.3: Frequency (*f*), relative frequency (rel. *f*) and cumulative frequency (*cf*) data from Delphi '97 and Delphi '99 for culturing larvae on a commercially feasible scale.

	Delphi '97			**Delphi '99**		
Timeframe	***f***	**rel. *f***	***cf***	***F***	**rel. *f***	***cf***
1997 - 2001			0			0
2002 - 2006	3	0.30	3			0
2007 - 2011	2	0.20	5	2	0.25	2
2012 - 2016	1	0.10	6	2	0.25	4
2017 - 2021	2	0.20	8	3	0.38	7
2022 - 2026			8			7
2027 - 2031			8			7
2032 - 2036	1	0.10	9			7
2037 - 2041			9			7
2042 - 2046			9			7
2046 +	1	0.10	10	1	0.13	8
Σ	**10**	**1.00**		**8**	**1.00**	

Forecasts from Delphi ’99 tend to be later than those from Delphi ’97, with the period between 2017 to 2021 having the highest combined relative frequency (Fig. 4.1).

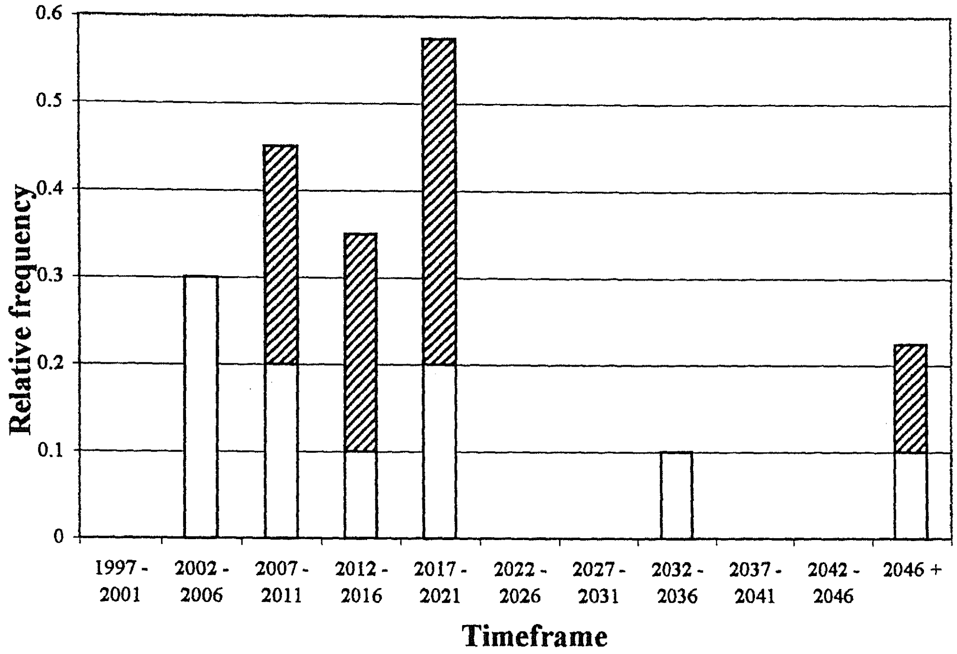


Figure 4.1: Stacked relative frequencies of forecasts from Delphi ’97 (☐) and Delphi ’99 (▨) for culturing larvae on a commercially feasible scale.

Common findings from Delphi ’97 and Delphi ‘99 were that increased funding into research would increase the likelihood of successful developments. Economic demand and the health of the fishery were also key issues that would help drive the level of funding. Technically, nutritional requirements are still an obstacle but breakthroughs may come from lessons learnt from culturing species of lobster with simpler larval cycles. Global implications were raised if the technology was transferred to or from other countries.

Given the limited number of experts used in the Delphi exercise, many benefits and successes were achieved. The Delphi forecasts provided a forum to discuss and debate a common issue and created a new network of expertise. Forming the group and the communication it produced was a valuable outcome. The continual feedback and refinements enabled the groups to explore different ideas and enriched the exercise. It was also evident from participant feedback that reassurances of confidentiality and transparency of the final outcome of the exercise encouraged participation. The results of the exercise identified several key issues that affect the development of a New Zealand rock lobster aquaculture industry.

4.2 Harvesting

A total of 33 pueruli were collected from the experimental collectors during the four observation times. More than half of these were collected on 7 August 1997 (Fig. 4.2). All collector designs were cleared of lobsters in less than 15 minutes and no pueruli were damaged or died whilst being removed from any of the collectors or during the subsequent transport to the ongrowing facility.

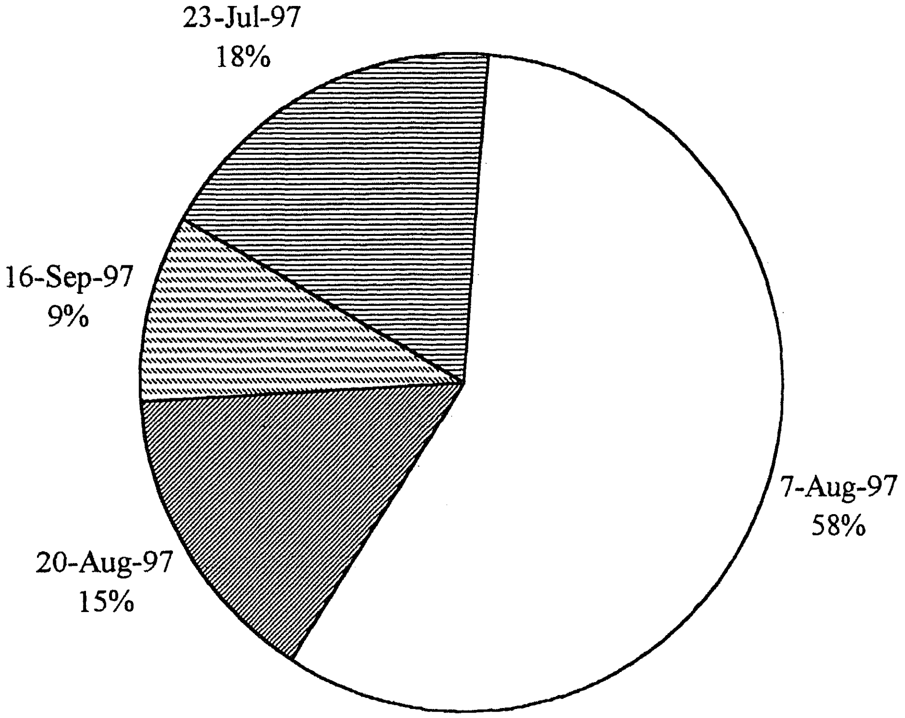


Figure 4.2: Percentage of the 33 pueruli collected at each time.

Concrete pipe collector one (CP1) collected the most (nearly 35%), followed by the crevice collector (CC) with 20%, and the wooden pipe collector (WP) with 17%. Concrete pipe collector one (CP1) caught 1.75 times more pueruli than compared with the crevice collector (CC). Concrete pipe collector two (CP2) collected approximately 10% of the pueruli. The netting design (NS) was the only collector that failed to collect a lobster (Fig. 4.3).

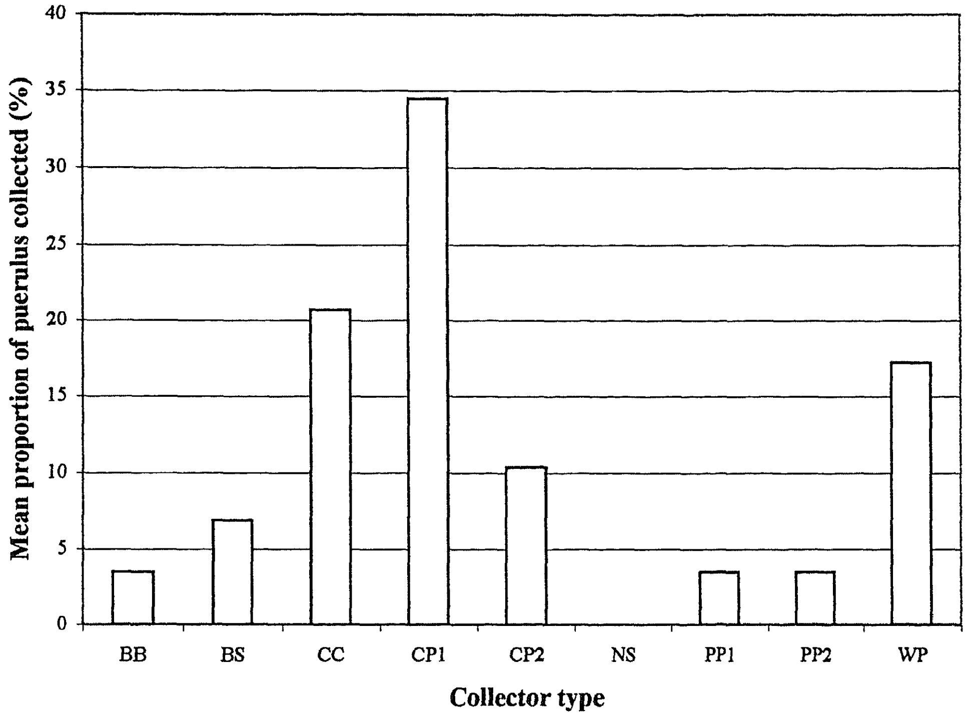


Figure 4.3: Effect of collector design on mean proportion of pueruli caught by collector type (BB = bamboo bunch; BS = bamboo sausage; CC = crevice collector; CP1 = concrete pipe 1; CP2 = concrete pipe 2; NS = netting sausage; PP1 = plastic pipe 1; PP2 = plastic pipe 2; WP = wooden pipe).

Construction costs were not taken into account because the collectors were prototypes. Mass production of an effective collector would normally bring down the cost of manufacture. In terms of unit cost, CP1 was the most effective. Each puerulus cost $1.80 to catch compared with $4.00 for CC and $27.00 for BB. The cost of labour was very high because it took a relatively long time to clear the bamboo bunches. The unit cost for the net sausage (NS) design was infinite because it did not collect any lobsters (Fig. 4.4).

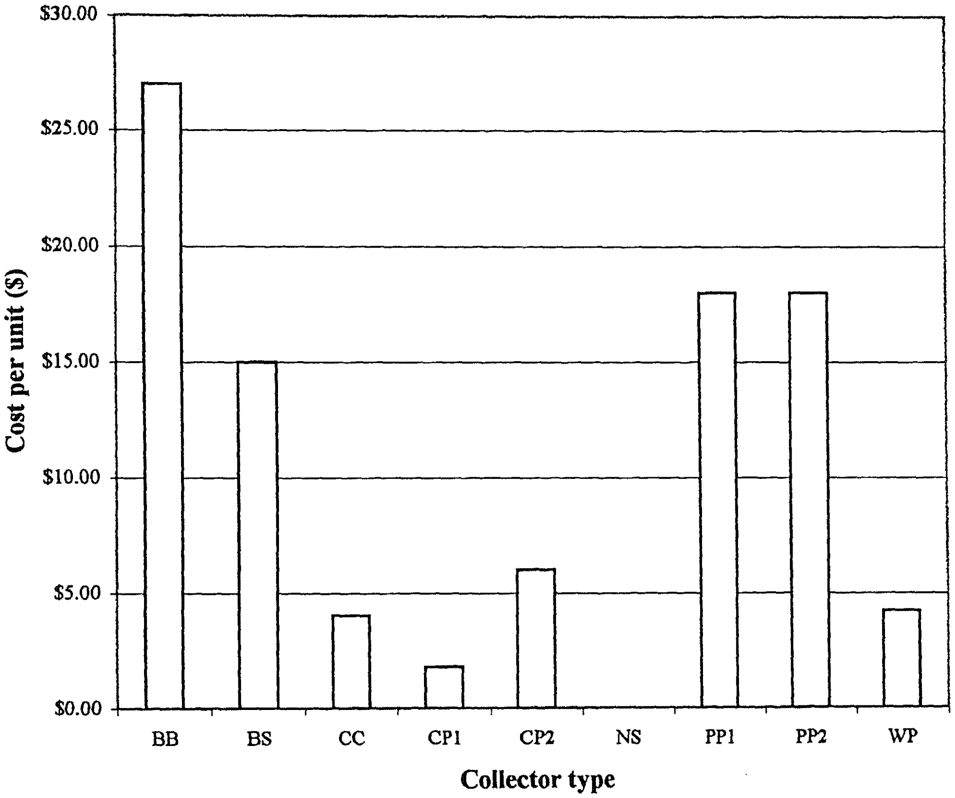


Figure 4.4: Effect of collector design on the cost of catching a puerulus, (see Fig. 4.3 for abbreviations).

It is unclear why CP1 was more effective than CP2, but there are two possibilities:

1. The pipes in CP1 were open at each end. Anecdotal evidence from the behaviour of juvenile and adult lobsters suggests they prefer shelters with more than one escape route and this may be true for pueruli. The open ends also allowed sediment to be flushed away with the current. The lower accumulation of sediment may have encouraged the pueruli to settle.

2. The type of construction material may enhance the ability to collect lobsters. The major differences were using a wooden frame around the collector, using a different type of concrete mix for coating, and using smaller amounts of volatile PVC glue for construction.

The total number of pueruli collected during the experiment was very low. This may have been due to several reasons:

1. Information from NIWA (Booth, personal comment) indicates that the lobster settlement season in Gisborne during the winter of 1997 was relatively poor compared with previous years. Also, the peak of settlement occurred in June rather than July as in previous years.
2. Collectors were not conditioned for as long as was planned. Pueruli collection improves significantly with increasing periods of conditioning. For example, collectors conditioned for over three months tend to catch more lobsters (Booth, personal comment).
3. Fluctuating lobster settlement along the Gisborne wharf. The entrance to the wharf is substantially deeper than the inner-wharf. The collectors for this experiment were in the shallower water of the inner-wharf, which may have been less suitable for pueruli collection than further seaward. The collectors that NIWA had in the deeper water (8 m deep), closer to the entrance caught many more pueruli than these experimental collectors did.
4. Settling lobsters (puerulus stages 1-3 and juvenile stage 1) are known to inhabit collectors for up to a month. During clearances of the commercial collectors the experimental collectors were cleared mistakenly and the numbers of pueruli taken were not recorded. Therefore, the pueruli recorded at each sampling time may have been only a sub-sample of the total numbers of pueruli caught.

There is a large amount of temporal variability in pueruli arrival in Gisborne harbour even within the main winter collection season. Pulses of post-larval lobsters entering the harbour have been observed that may be associated with weather patterns and/or other environmental influences such as lunar or tidal phases.

A few operational issues that should be considered in commercial scale harvests were identified. Collectors should be designed and maintained to minimise fouling and being blocked up by marine debris. Excessive fouling, for example by encrusting organisms, reduces collector effectiveness and increases maintenance cost. Collector materials must be chosen carefully because the marine environment is particularly corrosive. Collectors should also be deployed in areas sheltered from storms so they are not destroyed or lost.

4.3 Transporting

Of the original 288 Js and Ps, 51 survived the 14°C treatments and 8 survived the 20°C treatments (see Appendix C for the raw data and analyses). Percentage survival was calculated from the mean of each set of replicates and are summarised in Table 4.4. The percent survival at 6 and 9 hours included any lobsters that had recovered by the second observation but do not take into account any delayed mortality that may have been caused by the experiment.

Table 4.4: Effect of class, density, temperature, and time on survival over the observation period (J = juvenile stage 1; P = puerulus stages 1-3).

			Survival over time (%)		
Class	Density (lobsters/L)	Temperature (°C)	0 hours	6 hours	9 hours
J	15	14	100	100	50
J	30	14	100	25	0
J	45	14	100	6	17
J	15	20	100	33	0
J	30	20	100	0	0
J	45	20	100	0	0
P	15	14	100	100	67
P	30	14	100	83	17
P	45	14	100	72	0
P	15	20	100	100	0
P	30	20	100	0	0
P	45	20	100	0	0

All Js and Ps survived at the lowest stocking density (15lobsters/L), lowest temperature (14°C), and shortest time (6 hrs), (Fig, 4.5a and 4.5b).

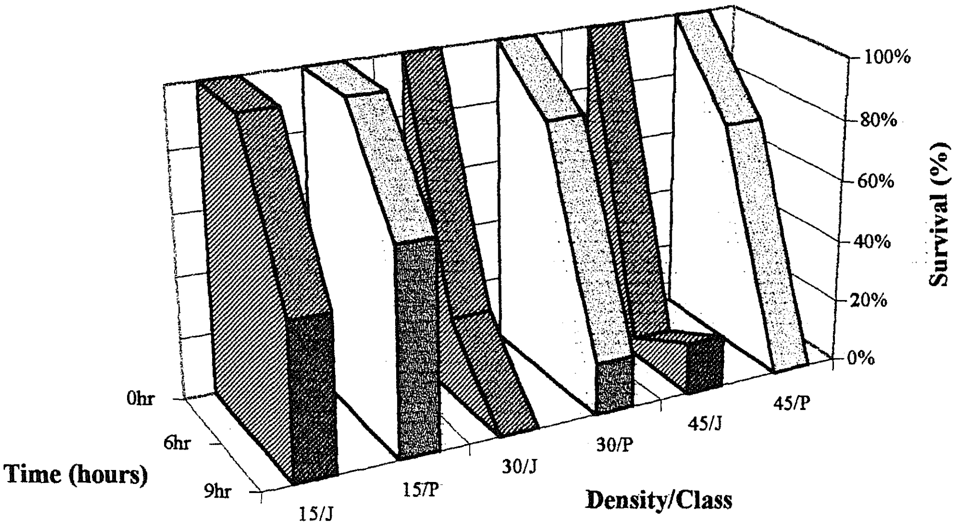


Figure 4.5a: Effect of class, stocking density, and time on survival at 14°C.

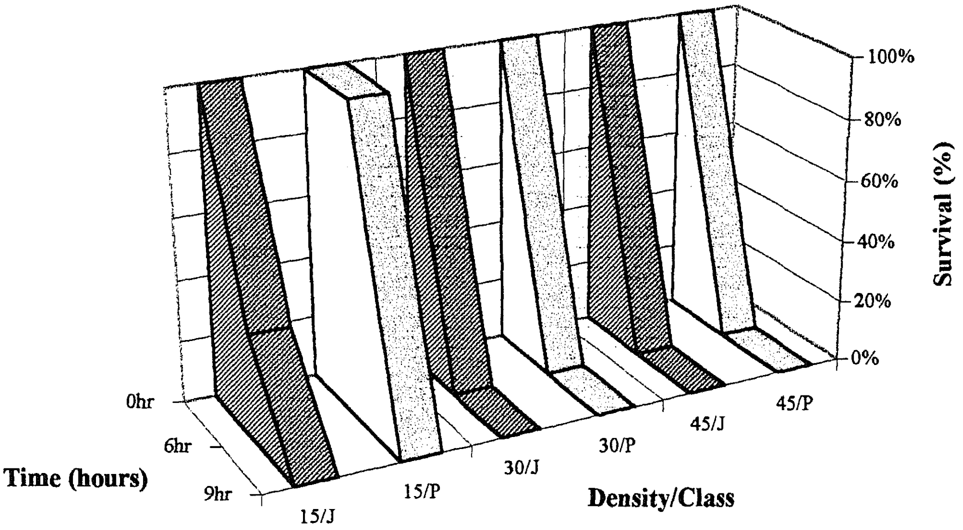


Figure 4.5b: Effect of class, stocking density, and time on survival at 20°C.

At 14°C, survival rates fell significantly only after 6 hours and at densities of 30 and 45 lobsters/litre. Survival rates at 20 °C were poor over all densities and time periods, except for 15 P for 6 hours. For this configuration, all the Ps survived compared with only 33% survival for the Js. For densities of 30 and 45/litre (20°C) all lobsters perished before the 6-hour observation. In general, the Ps had better survival rates than the older Js. The exception was at 45 lobsters/L, 14°C, and 9 hours, where 17% of the Js survived and no Ps survived.

The experimental design and commercial transporting conditions differed in a number of ways. The experimental lobsters were transported from Gisborne to Wellington prior to the experiment. Ideally, the experiment would have been conducted as soon as the lobsters were harvested but it was difficult to get the testing equipment to the harvest site. Another difference was that during the experiment the lobsters were not subjected to the level of vibrations or agitation, as would be expected when transporting by vehicle. Lobsters are also prone to injury when they are harvested in extreme weather conditions. Occasionally, injured lobsters can be transported to the ongrowing facility which may affect the survival rate of the others.

The findings suggest that lobsters at different post-larval stages (P1 – P3, J1 – J3) are more likely to survive. This could have commercial implications if specific post-larval stages are harvested because they are more likely to survive. However, the added time, cost, and stress on the lobsters to sort may negate the benefits of this strategy.

The following factors may decrease mortality when transporting Ps and Js:

1. Minimising stress through careful handling.
2. Using full and fresh oceanic seawater for transport media.
3. Aerating the seawater prior to despatch.
4. Keeping temperatures below 20 °C, ideally at 14 °C. Large and quick changes in temperature should also be avoided.
5. Allowing for lobster recovery at destination.

4.4 Ongrowing

At Day 0, the lobsters weighed between 5.6-18.6 g, had carapaces 20-34 mm long, and had no missing appendages (see Appendix D for raw data). Lobsters with more than two missing appendages are thought to have lower growth rates (Chittleborough 1975; Juanes and Smith 1995; Hooker *et al.*, 1997). The sex of each lobster was not recorded. As there were no significant statistical effects, data for stocking density and temperature were pooled. An overall statistical summary of weight and carapace lengths during the experiment is shown in Table 4.5.

Table 4.5: Effect of conditioning time on average weight (WT, g) and carapace length (CL, mm) of lobsters, irrespective of stocking density and temperature (16°C).

	Day 0		*Day 51*		*Day 121*	
	WT	*CL*	*WT*	*CL*	*WT*	*CL*
Number of lobsters	120	120	105	105	104	104
Largest lobster	18.6	30	21.7	33	28.1	36
Smallest lobster	5.6	20	6.4	21	7.9	23
Sum	1299.3	2919.0	1474.6	2815.0	1841.5	3092.0
Mean	10.8	24	14.0	27	17.7	30
Standard Error	0.24	0.21	0.35	0.24	0.48	0.31
Median	10.8	24	14.0	27	17.7	30
Mode	10.9	24	14.5	27	14.1	28
Standard Deviation	2.61	2.32	3.54	2.47	4.91	3.15
Sample Variance	6.82	5.38	12.56	6.12	24.09	9.91
Kurtosis	-0.04	-0.31	-0.56	-0.33	-0.71	-0.71
Skewness	0.49	0.35	0.09	0.15	0.08	0.06
Range	13.0	10	15.3	12	20.2	13

The effect of density on mean lobster growth (measured by WT and CL) together with relative growth increases, are shown in Table 4.6. There was no statistically significant effect of density on growth (both in WT and CL).

Table 4.6: Effect of density and conditioning time on pooled lobster growth.

	Density (lobsters/tank)			
Carapace length (mm)	*3*	*6*	*9*	*12*
Day 0	25	25	24	24
Day 50	28	27	26	27
Day 121	32	32	29	29
Average increase	7	7	5	5
Relative increase in CL				
Day 0	1.00	1.00	1.00	1.00
Day 50	1.13	1.10	1.09	1.11
Day 121	1.28	1.28	1.20	1.21
Weight (g)				
Day 0	12.0	11.4	10.2	10.7
Day 50	15.9	15.0	13.1	14.0
Day 121	21.2	20.7	16.6	16.6
Average increase	9.2	9.3	6.4	5.9
Relative increase in weight				
Day 0	1.00	1.00	1.00	1.00
Day 50	1.32	1.32	1.28	1.30
Day 121	1.77	1.83	1.62	1.55

Fastest overall growth was observed at the lower stocking densities of 3 and 6 lobsters/tank (Fig. 4.6).

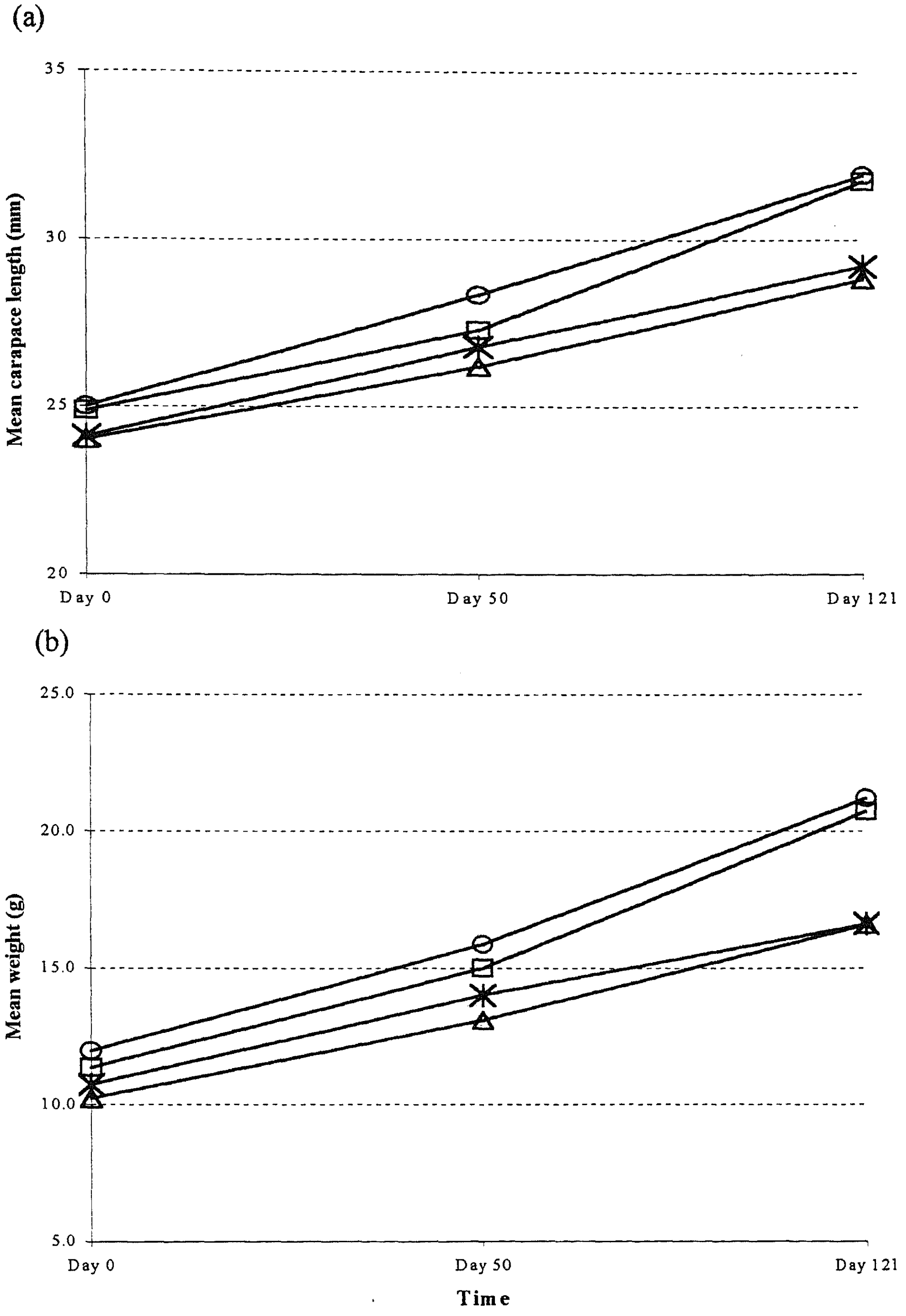
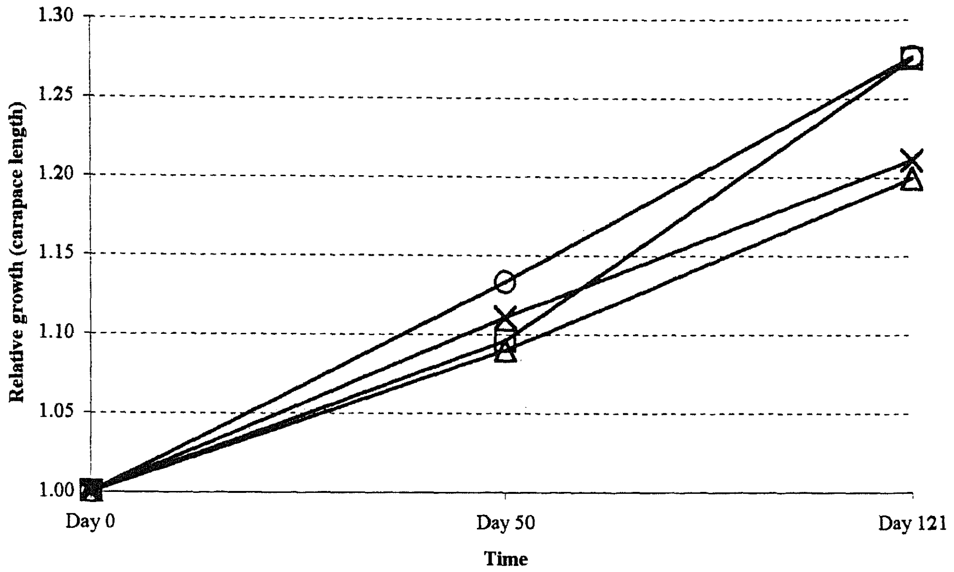


Figure 4.6: Effect of stocking density on (a) mean carapace length and (b) mean weight over 121 days. O = 3 lobsters/tank, □ = 6 lobsters/tank, Δ = 9 lobsters/tank, × = 12 lobsters/tank.

Fastest relative growth (in CL and WT) was also observed at the lower stocking densities of 3 and 6 lobsters/tank (Fig. 4.7).

(a)



(b)

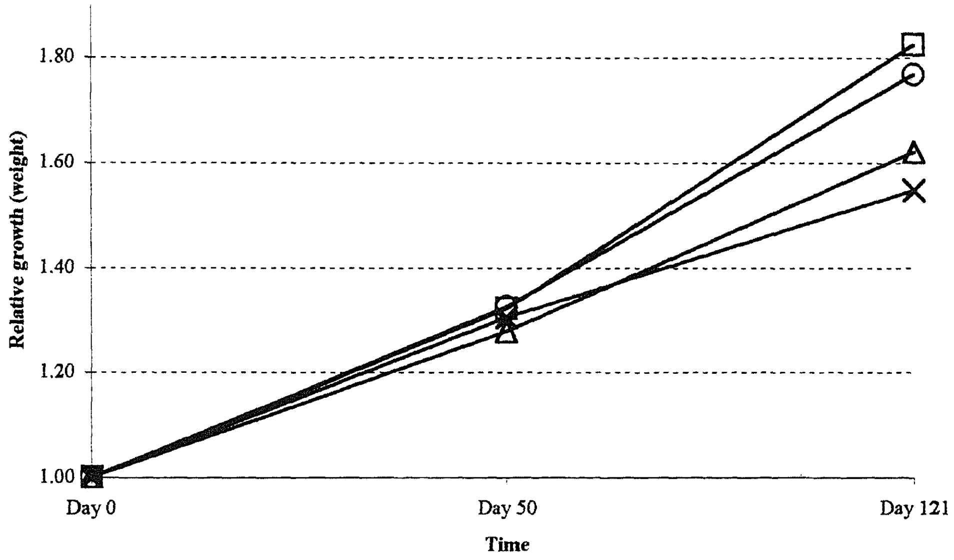


Figure 4.7: Effect of stocking density on (a) relative growth (CL) and (b) relative growth (WT) over 121 days. O = 3 lobsters/tank, □ = 6 lobsters/tank, Δ = 9 lobsters/tank, × = 12 lobsters/tank.

Mortality

Sixteen lobsters died during the 121 days (Table 4.7). Most of the deaths (15 lobsters; 94%) occurred before Day 50 (Fig. 4.8). Eight of these mortalities were the direct result of a pump failure on Day 9. The other 8 lobsters that died were cannibalised either while moulting or immediately after. A large proportion (44%) of the total mortality occurred at the highest stocking rate (12 lobsters/tank).

Table 4.7: Effect of stocking density on lobster mortalities over 121 days.

	Density (lobsters/tank)				
	3	*6*	*9*	*12*	Σ
Day 0	0	0	0	0	**0**
Day 50	2	2	4	7	**15**
Day 121	0	1	0	0	**1**
Σ	**2**	**3**	**4**	**7**	**16**

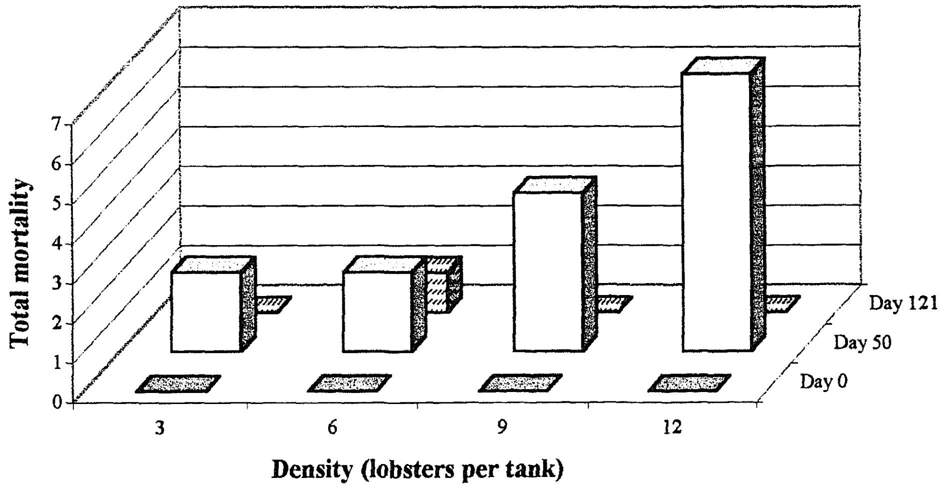


Figure 4.8: Effect of stocking density on cumulative ongrowing mortality over 121 days.

Lobster growth at the higher stocking densities (9 and 12 lobsters/tank) was slower than those at the lower stocking densities (3 and 6 lobsters/tank). There was no statistically significant effect of stocking density on growth but there was a trend for growth rate to be increasing at densities of 3 and 6 lobsters/tank and growth rate to be decreasing at densities of 9 and 12 lobsters/tank. For the 9 and 12 densities growth appears to be slowing. The pattern may have become more significant if the experiment had continued. Continuing the experiment may have also indicated where growth rate slows due to the increasing biomass in each tank. Lobster mortality was highest at the highest density (12 lobsters/tank).

4.5 Bioeconomic Analysis

The values generated from the biological, economic, and physical assumptions are shown in Table 4.8. Maximum production is reached from Year 4 where 18,276 kg of lobster are in the system at any one time. At a feed conversion ratio of 7:1, this requires 75,858 kg of mussel feed per year to achieve the necessary growth rate (300 g in 4 years). The farm requires 903 m^2 of buildings and runs with 722 m^3 of seawater, replacing 1,734 m^3/year at a cost of $34,678. The electricity cost to run heat exchangers, pumps and other equipment is $46,960/year. Every year 40,000 pueruli are harvested for every 1,000 kg of quota traded. This equates to 10,837 kg of lobsters exported 4 years later (an increase of 1,084%).

The baseline cash flow analysis shows an annual net cash position of 287,100 and cumulative cash position of 859,200 at Year 10 (Table 4.9). The main points are that total capital costs of $410,500 are spread over the first four years (start-up phase). After all major capital purchases, the total annual operating costs reach $417,300. Annual lobster sales begin in the fourth year, where 10,837 kg (36,123 lobsters) are sold for $704,400 ($65/kg).

Table 4.8: Values generated from the baseline assumptions for a hypothetical rock lobster farm.

Biological component

Lobster biomass	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Puerulus (number)	40000	40000	40000	40000
1-yr old lobster (number)		38000	38000	38000
2-yr old lobster (number)			36860	36860
3-yr old lobster (number)				36123
Total lobster weight (kg)	10	1910	7439	18276
Feed required (kg)	13300	38703	75858	75858
Sale weight (kg)	0	0	0	10837
Feed conversion ratio (kg feed : kg lobster)			7:1	

Lobster growth	**Puerulus**	**1-yr old**	**2-yr old**	**3-yr old**
Lobster weight (kg)	0.00025	0.05	0.15	0.3
Growth rate (%/yr)		200	3	2
Yearly mortality (%)		5%	3%	2%
Total mortality (%)				10%

Stocking density	(/m² tank)	(/m³ seawater)	(kg/m³ seawater)
Puerulus	100	500	0.125
1-yr old	50	250	12.5
2-yr old	30	150	22.5
3-yr old	20	100	30

Economic component

Lobster selling price ($/kg)	65
Quota traded from Year 1 (kg/yr)	1000
Sale weight from Year 4 (kg/yr)	10837
Quota (kg) : sale (kg) increase	1084%
Pueruli : quota traded (/kg)	40
Quota lease ($/kg/yr)	15
Quota lease ($/yr)	15000
Quota cost ($/puerulus)	0.375
Harvest cost ($/puerulus)	0.6
Total cost ($/puerulus)	0.975
Feed price ($/kg)	0.5
Processing & transport cost ($/kg)	10
Vehicle cost ($)	10000
Fuel (vehicle) ($/yr)	2500
Fees and licences ($/yr)	5000
Investment amount ($)	1000000
Interest rate (%)	10
Investment duration (Years)	10
Return on investment ($)	2593742

Physical component

Tank water depth (m)	0.2
Seawater cost ($/m³)	20.00
Seawater changed (%)	20%
Seawater changed (/year)	12
Seawater turnover factor (/yr)	2.4

Ongrowing area calculation	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Tank area: puerulus (m²)	400	400	400	400
Tank area: 1-yr lobster (m²)	0	760	760	760
Tank area: 2-yr lobster (m²)	0	0	1229	1229
Tank area: 3-yr lobster (m²)	0	0	0	1806
Total tank area (m²)	400	1160	2389	4195
New building area (m²/yr)	200	380	614	903
Tank water volume (m³)	80	152	246	361
Filtr+Recirc. water vol. (m³)	80	152	246	361
Total water in system (m³)	160	304	491	722
Total water discharged (m³/yr)	384	730	1180	1734
Water cost ($/yr)	7680	14592	23590	34678
Electricity cost ($/yr)	10400	19760	31945	46960
Tank cost ($/yr)	4000	7600	12287	18061
Recirc. system cost ($/yr)	9600	18240	29488	43347
Monitoring cost ($/yr)	400	1160	2389	4195
Building cost ($/yr)	20000	38000	61433	90307

Table 4.9: Cash flow analysis of a baseline model of a hypothetical rock lobster farm over the 10-year period.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Returns										
Lobster sales				704,400	704,400	704,400	704,400	704,400	704,400	704,400
Total annual returns	0	0	0	704,400	704,400	704,400	704,400	704,400	704,400	704,400
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	61,400	90,300						
Monitoring system	400	1,200	2,400	4,200						
Recirculation system	9,600	18,200	29,500	43,300						
Tanks	4,000	7,600	12,300	18,100						
Vehicle	10,000									
Total capital costs	84,000	65,000	105,600	155,900						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,800	31,900	47,000	47,000	47,000	47,000	47,000	47,000	47,000
Feed	6,700	19,400	37,900	37,900	37,900	37,900	37,900	37,900	37,900	37,900
Process & transport	0	0	0	108,400	108,400	108,400	108,400	108,400	108,400	108,400
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,700	14,600	23,600	34,700	34,700	34,700	34,700	34,700	34,700	34,700
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,400	7,400	7,400	7,400	7,400	7,400	7,400	7,400	7,400	7,400
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,100	41,100	41,100	41,100	41,100	41,100	41,100	41,100	41,100	41,100
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total annual operating costs	214,100	243,100	282,800	417,300	417,300	417,300	417,300	417,300	417,300	417,300
Total costs	298,100	308,100	388,400	573,200	417,300	417,300	417,300	417,300	417,300	417,300
Annual cash position	(298,100)	(308,100)	(388,400)	131,200	287,100	287,100	287,100	287,100	287,100	287,100
Cumulative cash position	(298,100)	(606,200)	(994,600)	(863,400)	(576,300)	(289,200)	(2,100)	285,000	572,100	859,200

The model predicts that over the 10-year period, 252,860 lobsters are exported at $19.50 each, returning $4,930,800. The predicted profit on each lobster (return minus cost) is $5.02. Ranking the cost components (over the ten-year period) of the baseline model shows that processing and transport (20.7%) and labour (19.7%) contribute to 40% of the total cost (Table 4.10). Other significant cost components are electricity (10.7%), puerulus (10.7%), feed (9.0%), and water (7.0%).

Table 4.10: Summary of the value and contribution to cost (total and per lobster basis) over 10 years of the components in a pueruli ongrowing venture. Depreciation at 10%/year is not included.

Component	*Cost over the 10-years ($)*	*Total cost (%)*	*Cost per lobster ($)**
Processing & transport	758,600	20.7	3.00
Labour	720,000	19.7	2.85
Electricity	390,800	10.7	1.55
Puerulus (quota + harvest)	390,000	10.7	1.54
Feed	329,400	9.0	1.30
Water	288,600	7.9	1.14
Buildings	209,700	5.7	0.83
Recirculation system	100,700	2.8	0.40
Consumables	100,000	2.7	0.40
Administration	100,000	2.7	0.40
Repairs and maintenance	74,100	2.0	0.29
Fees and licences	50,000	1.4	0.20
Tanks	41,900	1.0	0.17
Land	40,000	1.1	0.16
Fuel (vehicle)	25,000	0.7	0.10
Insurance	24,000	0.7	0.09
Vehicle	10,000	0.3	0.04
Monitoring system	8,100	0.2	0.03
Total cost over 10 years ($)	**3,660,900**	**100**	**14.48**
*Calculated by dividing the component cost by the 'total number of lobsters sold'.			

Some of these components can be influenced by negotiating with the appropriate organisations; others are outside the immediate influence of the operation. It has been difficult for exporters of wild caught adult lobsters to negotiate economical processing and transport costs because of the distance between New Zealand and the Asian markets. However, there is potential to negotiate reduced costs with exports on a sufficient scale. Labour costs consist of two full-time personnel and would be a minimum for a farm of this magnitude. More automated equipment could be included but would increase the capital costs. Electricity costs could be reduced by negotiating high-use industrial rates or utilising alternative energy streams. Waste heat generated from geothermal activity or from large refrigeration cool stores could be utilised. Puerulus cost is made up of quota and harvest costs. Long-term quota costs could be reduced by purchasing rather than leasing annually. This would also 'secure' availability but require a large initial capital purchase. Harvesting costs could be reduced through the development of more cost-effective collecting technology. Locating the farm close to large natural settlements of pueruli would reduce transporting costs and minimise stress on the lobsters. In the near future, pueruli hatcheries would have the potential to reduce the cost per puerulus and provide a consistent supply. Feed costs could be reduced through an alliance with a Greenshell mussel farm. The cost of 'seconds' and blue mussels are much less than the export grade mussels. The development of suitable artificial diets would also have a large impact upon feed costs. The cost of fresh oceanic seawater could be reduced by locating the farm close to a shoreline and pumping the seawater directly from the ocean.

The results of a sensitivity analysis are shown in Table 4.11.

Table 4.11: Sensitivity of the baseline models' cumulative cash position and net annual cash flow (at Year 10) to changes in variables.

	Net annual cash flow at Year 10	Cumulative cash position at Year 10
Quota traded 10,000 kg	2,949,300	9,465,000
Quota traded 2,000 kg	582,900	1,815,400
Sale price at $75/kg	395,500	1,617,800
3 years to sale	287,100	1,436,700
Stock density +50%	328,700	1,350,100
Stock density +25%	312,300	1,157,900
Feed price at $0.2/kg	309,900	1,056,900
Feed conversion at 3:1	308,800	1,047,500
Harvest at $0.3/puerulus	299,100	979,200
Mortality at 7%	301,100	943,600
Baseline model	**287,100**	**859,200**
Processing at $13/kg	254,600	631,600
Mortality at 20%	238,200	568,500
Sale price at $55/kg	178,700	100,600

Ranking each scenario by cumulative cash position at Year 10 shows that increasing the amount of quota traded has the largest positive effect. Other scenarios that have significant positive effects are an increase of sale price to $75/kg, increased growth rates, improved stocking densities and improved efficiencies in feed. The '3 years to sale' scenario shows an identical net annual cash flow but a higher cumulative cash position than the baseline because returns from lobster sales occur 1 year earlier. Halving the cost to harvest a puerulus to $0.3 each (giving a total cost of $0.675/puerulus) corresponds to only a small improvement in cash position and cash flow.

A drop in sale price to $55/kg has the largest negative effect, followed by increased mortality and increased processing and transporting costs. Increasing the cost to process and transport the lobsters by $3/kg to $13/kg corresponds to a relatively large drop in cash position and cash flow.

The cumulative cash position at Year 3 is -$994,600, and represents investment into the farm before any returns are realised. As a comparison for potential investors the model predicts that investing $1,000,000 in a bank, instead of the farm, at an interest rate of 10%/yr for 10 years will yield a return on investment of $2,593,742 (including principal). Compared to the baseline model this scenario has a substantially higher cumulative cash position, has a similar annual cash position, and is a lower risk investment. However, the baseline shows more assets, stock on hand, employment opportunities and potential for expansion. It also predicts the first returns from lobster sales of $704,400 in Year 4. This could be offset by alternative income streams such as research grants and tourism which would provide earlier returns than the sale of lobsters at Year 4. Polyculture (multi-species aquaculture) could also be explored as a means of product diversification.

The results of this analysis suggests that ongrowing of *J. edwardsii* in a land-based recirculation system is commercially feasible if the underlying assumptions remain static. Production costs have the potential to be reduced through improving efficiencies in system design. For example, ongrowing tanks that require less time to clean will reduce labour costs. The sensitivity analysis suggests that the baseline models profitability is very sensitive to relatively small changes in sale price and processing and transport costs. Increasing productivity through faster growth rates has a significant effect on profitability. The scale of production, whilst increasing capital costs, will also have a major impact on the scale of profitability. Other factors such as stocking density, feed, harvesting, and mortality should be taken into account as they have a notable effect on profitability.

5 Conclusions and Recommendations

Sourcing seedstock

Seedstock (or pueruli) for *J. edwardsii* aquaculture could be sourced from either the wild or from hatcheries. The data obtained in the research undertaken indicates that, in the short term, New Zealand should continue to rely on harvesting pueruli from the wild. Hatcheries that can supply commercial quantities of pueruli have been hindered by the long and complex phyllosoma larval cycle. A significant technical obstacle to rearing pueruli is gaining an understanding of larval nutritional requirements so suitable artificial diets can be developed. It is more likely that faster growing warm-temperate or sub-tropical lobster species will be farmed sooner in a closed life cycle system. This is because these species have simpler life cycles compared with *J. edwardsii.* Forecast data, obtained using the delphi technique and information about the current knowledge and research being done on larval rearing, indicate that commercial scale supply of pueruli from hatcheries may occur between 2017 and 2021.

Harvesting

Only a low number of pueruli were collected from the wild during the trials. A greater collection rate could be achieved if the seasonal settlement patterns and settlement patterns within the Gisborne harbour were understood better. This information would help optimise checking frequency and target collection for the highest settlement times. The lowest unit cost for collection was $1.80.

Transporting

Temperature, transit time and stocking density significantly affect lobster survival rate. The safest transit conditions in the study were achieved with 15 pueruli/L for 6 hours at 14°C. At 20°C, few pueruli will survive at any density and for only very short lengths of time. Other factors affecting survival rates are careful handling, transporting injured pueruli, and the quality of transit seawater.

Ongrowing

For the 121 day trial, stocking density did not have a statistically significant effect on growth rate and mortality rate. There was a trend for growth rates to be highest at 3 and 6 lobsters/tank and for growth rates at stocking densities of 9 and 12 lobsters/tank to decrease after Day 50. The highest mortality occurred at the highest stocking rate (12 lobsters/tank). Mechanical failure of the equipment contributed the most to mortality, underlining the importance of having a risk management strategy.

Bioeconomic Analysis

The baseline bioeconomic model for a hypothetical farm assumed harvesting 40,000 pueruli annually and growing them to a saleable size (300 g) by Year 4 with an overall mortality of 10%. The required working capital would be $1,000,000. The model showed an annual net cash position of $287,100 and cumulative cash position of $859,200 by the 10th year of operation based on annual sales of 10,837 kg at $65/kg. A farmer could expect a return of $19.50 per lobster less costs of $14.48. Good returns will depend upon consistent exports of high quality lobsters. The model indicates that the highest cost components in the first 10 years are processing/transport, and labour. Electricity, pueruli, and feed also contribute significantly. Profitability is very sensitive to factors such as the farm size, processing and transport costs, and sale price. Biological factors such as growth rates, survival, and feed requirements also influence overall profitability.

Recommendations

A commercially successful process to harvest and ongrow *J. edwardsii* pueruli is still under trial. Experiments carried out in this thesis suggest that *J. edwardsii* aquaculture has good potential to be commercially feasible. However, there are several limiting factors that should be further investigated.

Future research into *J. edwardsii* aquaculture should include:

1. Gaining a better understanding of larval nutritional requirements so that laboratory scale larval rearing techniques can be developed into commercial scale hatcheries.

2. Quantifying puerulus settlement and identifying environmental factors that affect puerulus settlement within the Gisborne harbour.
3. An analysis of collector effectiveness that includes overall costs of construction, operation and maintenance. This should include research incorporating material selection and design.
4. A more detailed feasibility study that includes; site selection, building and equipment design as well as addressing marketing issues such as product specification and demand, competition, and developing alternative markets.

The potential benefits of rock lobster aquaculture are that it is a form of long-term sustainable production, it will relieve fishing pressure, it will have a relatively low impact on the environment, and improved efficiencies will generate greater returns. It is hoped that this research will contribute towards developing this potential.

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Glossary of terms

ablation	removal of a particular structure
Aqua BoP	Aqua (Bay of Plenty) Ltd. A company involved in the trade-off scheme
bioeconomics	describes the interactions between biological, economic, and technical components
biological filter	primarily removes waste nitrogenous compounds with a substrate supporting colonies of nitrifying bacteria
CL	carapace length, distance between the base of the sub-orbital horns to the posterior of the carapace
closed or recirculating system	seawater is 'recycled' continuously within an ongrowing system
ecdysis	moult
FCR	food conversion ratio
instar	the duration between successive moults
LD	annotation for a light:dark ratio
MDS	moult death syndrome
mechanical filter	reduces turbidity of water
MLS	minimum legal size
open or flow-through system	oceanic seawater is pumped through an ongrowing system and then discharged back to the ocean
pueruli	plural for puerulus. For the purpose of this thesis includes all three puerulus stages and first instar juveniles (stages; P1, P2, P3 & J1), unless otherwise stated
PVC	poly vinyl chloride
QMS	the quota management system was introduced in 1986 to manage New Zealand's commercial fisheries
stress	a physiological response to an internal or external change
trade-off scheme	a trial allowing the trade of rock lobster quota for permission to harvest pueruli. Designed to be 'biologically neutral'
WT	wet weight

Appendix A: Schematic diagram of Aqua (BoP)s ongrowing facility.

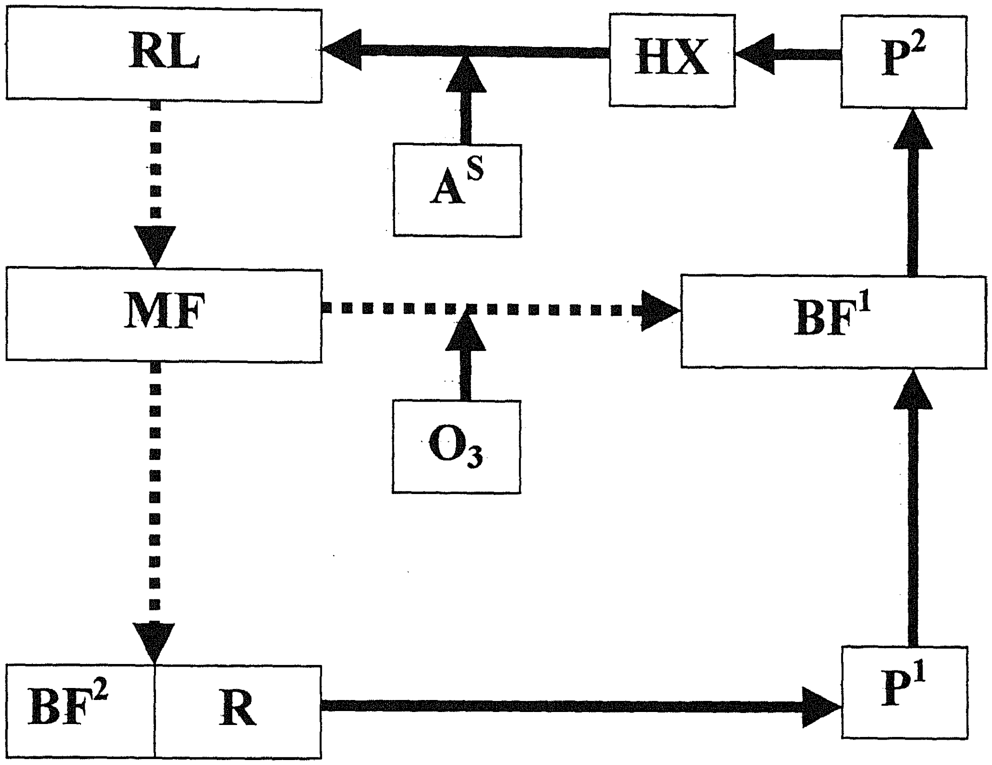

Figure A.1: Schematic diagram of Aqua BoPs ongrowing facility.

RL	Juvenile rock lobster ongrowing tanks; rectangular fibreglass and plastic tanks (0.2 m seawater depth) with shelters.
MF	Mechanical filtration; a series of polypropylene bags that remove particles down to 1,000 µm.
BF^1	Biological filter 1; consisting of activated carbon, coral and oyster shell.
BF^2	Biological filter 2.
P^1	Primary pump.
P^2	Secondary pump.
R	Reservoir.
O_3	Ozonator; ozone is added as a disinfecting agent.
HX	Titanium shell/tube heat exchanger.
A^S	Air blower and air stones.
Arrows	Indicate direction of water and air flow. Dotted arrows represent water flow driven by gravity. Solid arrows represent flow by pump.

Appendix B: Delphi transcription

Initial Contact with Potential participants

Hi everyone

Who

I am Ian Ruru- a Master of Science student at Waikato University and based with Aqua BoP Ltd. Aqua is one of two companies in New Zealand that have Special Permits to commercially catch and on-grow *J. edwardsii* pueruli.

I have obtained your email addresses through contacts in the rock lobster industry and relevant research providers. I am sending identical emails to people with backgrounds in rock lobster science in New Zealand, Australia and Japan.

I have attached this message as a Microsoft Word document (in two different versions) for your convenience.

What

I would be grateful if you could participate in a Delphi forecast that I would like to include in my thesis entitled "An investigation into the commercial feasibility of *J. edwardsii* aquaculture in NZ."

Personal commitment

To participate, the forecasting process will require of you:

A maximum of five minutes per week, for three consecutive weeks. In other words, a total of fifteen minutes (maximum) over the entire three-week period. If this hasn't scared you off – read on.

The aim of this experiment is to forecast the following:

By what year, with a 90% probability, will larval-rearing techniques be used by more than 50% of rock lobster farmers in your country to produce pueruli of the rock lobster, *J. edwardsii*, as seed stock.

What is a Delphi Forecast?

The key feature of Delphi is that it is a group consensus forecast based on anonymity, controlled feedback and iteration.

1. A group of experts are asked to forecast an event by a co-ordinator (me).

2. Individual forecasts and assumptions are compiled and fed back to the group for consideration. The feedback information consists only of the forecasts and assumptions and not who submitted them.
3. The group is then asked to reflect on the different forecasts, rethink their own forecast, modify if necessary and re-submit their forecast (with any further assumptions or justifications).
4. Steps 2 and 3 are repeated.
5. The final step requires the co-ordinator to analyse the forecasts and present the results back to the group.

Ethics

The forecasting process and its results will be given back to all that participate.

By participating in the forecast, I assume that you will allow me to include the forecast in my thesis.

Your name, individual forecasts and opinions will remain known only to myself.

Step 1 is to identify:

By what year, with a 90% probability, will larval-rearing techniques be used by more than 50% of rock lobster farmers in your country to produce pueruli of the rock lobster, *J. edwardsii*, as seed stock.

Email me the year and include any assumptions or opinions as to why.

Deadline for first forecast (Step 2)

Please do not feel obligated to participate, as I understand everyone is very busy. If I do not have a reply from you **by March 16**, I will assume you are not participating. You will receive no further emails. Thank you for your time.

For those who are willing to be forecasters I thank you for your valued input and hope that we all learn and benefit from the experience.

Cheers

Ian

Method & Timeline

START OF DELPHI		
Step 1	When	Who
Contact potential forecasters and present proposal.	March 10, 1999	Ian
Step 2		
Submit forecast with assumption(s).	By March 16, 1999	Group members
Step 3		
Collate and send forecasts and assumptions to the Group. Forecast ownership remains anonymous.	By March 17, 1999	Ian
Step 4		
Examine the group's forecasts and modify your personal forecast if necessary. Re-send forecast with any assumptions.	By March 23, 1999	Group members
Step 5		
Collate and send forecasts to the Group. Forecast ownership remains anonymous.	By March 24, 1999	Ian
Step 6		
Last opportunity to examine the group's forecasts and to make any modifications. Re-send with assumptions	By March 30, 1999	Group members
Step 7		
Collate, analyse and report results to Group members	By April 9, 1999	Ian
END OF DELPHI		

First Response

Howdy Forecasters,

Thanks for your most learned responses. This is step 3, where I collate (cut & paste) forecasts and assumptions/opinions and fire them back to the group to digest. I have taken the liberty to edit some responses for the odd spelling mistake etc.

The forecasts are in chronological order.

Step 4 (or Round 2) is for you to read over the forecasts and if you deem necessary, change your forecast or modify your reasoning. You may find other members of the group have forecasts that are aligned with your thinking or are in direct contradiction.

Again any reasoning or opinion is encouraged and appreciated.

Hear from you by March 23.

Cheers

Ian

Step 3	When	
Collate and send forecasts and assumptions to the Group. Forecast ownership remains anonymous.	*In progress*	Ian
Step 4		
Examine the group's forecasts and modify your personal forecast **if** necessary. Re-send forecast with any assumptions.	By March 23, 1999	Group members

2009	I understand the accepted formula in New Zealand is to retire one tonne of wild catch quota for every 40,000 puerulus taken, but US researchers have estimated 75% of puerulus die in their first year. I don't know how recent this information is, but it seems getting beyond puerulus stage is difficult for lobster, whether bred in the wild or in captivity. I understand NZ researchers have achieved a 70-80% survival rate from larvae, but mortality rate is too high with few metamorphosing to the puerulus. Interest has declined in Rock Lobster Aquaculture in Western Australia

	because of fall off in demand in Asia. Wild fishers still have plenty of quota and (possibly) because wild fishery is pre-eminent there may not be the interest to push on with aquaculture. A major part of my work is answering the question, "Why are new Aquaculture species developed?" There does need to be a trigger or driver and now in Australia there appears to be enough resource to satisfy demand. Scientists like yourself would love to commercialise Rock Lobster, but the businessmen are looking for commercial outcomes. However large scale rearing will be essential to any commercial development. Aquaculture of Rock Lobster will happen but my answer to Step 1 is **10 years.**
2010	The assumption is that NZ and world funding for the research is kept at present levels or increased. Another assumption is that rock lobster farming is commercially feasible in the long term.
2010	I think this is a long way off. I suspect technology development will take another 5 years, then development of commercially viable technology another 5 years after that. Key to this will be suitable artificial diets for phyllosomes. Long way off yet.
2014	Best guess based on the very slow progress made to date and the paucity of funds available to do the research, which will ensure even slower progress. Essential that research concentrates on nutritional requirements especially for stage VIII onwards and, until they are understood and solved, no commercial operation will be able to guarantee supply.
2015	I would say that 50% may be using larval rearing techniques by 2010 but with 90% certainty I would have to say 2015. I see it as very costly to gain the techniques whereas I view the wild resource as a better seed-source.
2015	I'm assuming that the current level of research continues to expand at the current rate and that there are no biological fundamental difficulties encountered along the way. I.e. it is just a process of incremental development of technique.
2019	My best guess, and it is merely a guess, is that we are at least 20 years (and possibly 30) away from having an industry where 50% of the farmers are producing their own pueruli. The current techniques used (which would need to be scaled up for production of commercial numbers), the lack of knowledge on nutrition and disease, and the long larval life mitigate against economic commercial scale culture of *J. edwardsii* (at least at this time). However it is possible that some of the faster warm-temperate or sub-tropical species (e.g. *P. cygnus*, *P. ornata*, or *J. verreauxi*) will be farmed sooner in a closed life cycle system.

2020	After a search through 'aquatic, marine and fisheries CD-ROM' I found 73 abstracts referring to J. edwardsii. Of these 2 covered reproduction, 11 puerulus, 5 wild larval life, and 10 culture of larvae. I estimate that within five years the science community would have developed successful larvae culture methods for J edwardsii. However, I estimate that the general use of these methods for aquaculture of *J edwardsii* will not occur before 2020 because puerulus capture from the wild will be far more cost effective.

Second Response

Howdy Forecasters,

Down the home stretch now.

Step 5 means that I am sending you responses made from the last round for you to peruse. This is the last opportunity for you to modify or justify your forecast and/or to make comment.

Again any reasoning or opinion is encouraged and appreciated.

Hear from you by March 30.

Cheers

Ian

Step 5		
Collate and send forecasts to the Group. Forecast ownership remains anonymous.	*In progress*	Ian
Step 6		
Last opportunity to examine the group's forecasts and to make any modifications. Re-send with assumptions	By March 30, 1999	Group members

Round 2	Round 3	Comment
2009	2009	A project exists for the product development, strategic marketing and supply chain management of Moreton Bay Bugs *(Thenus orientalis)*. Dr Satoshi Mikami made a recent scientific breakthrough enabling breeding and growing of Bay Lobster in captivity. Dr Mikami's breakthrough is in adapting a Japanese technique used on spiny lobsters. The technique is to collect the 4000 to 60,000 eggs produced by each lobster and nurture groups of them through several metamorphoses over a four-week growth period to the juvenile stage. His nutrition programme is based on a natural diet of shellfish. The research was timely as the Moreton Bay Bug fishery was seriously depleted. Successful culture of larvae and juveniles offered opportunities both for releasing juveniles into coastal waters to reactivate the fishery, or for continued culture of juveniles through to marketable size.

		Ongoing success of this programme is yet to be seen and it may not be relevant to your work, but the driver of this technological break through was a depleted fishery in Queensland and strong demand for the product in Asia. I am sure forward thinkers in Rock Lobster fisheries will be examining their options for the future. My personal view is that commerce will be a greater driver of change than science.
2010	2010	
2010	2010	I will stick by my estimate but tend towards a longer time interval after reading the arguments from others in the group. The real issue is the low funding that larval rearing of crayfish is receiving. This is a major barrier to the development of this technology.
2014	2014	
2015	2020	I had forecasted, 2015 and stand by it as an earliest date but would increase my 90% certainty for 50% of industry to year 2020. Another concern with NZ hatchery techniques, developed by scientists, is that the techniques would leak out and we would soon find cheap countries e.g. Chile or Mexico, farming our Lobster cheaper than we ever could. Wild puerulus harvest does not face such a problem.
2015	2020	Modify mine - I'll go for 2020 - there's a lot of work to be done, and when you look at the progress over the last 10 years it has been almost minimal on a grand scale.
2019	2019	
2020	2020	Still happy with 2020. In fact, after reading the rational behind the other estimates I am (95%) sure that 2020 is not too early.

Last Response from Group

	Response 3
2009	I will stick with ten years, 2009. I am convinced that science will be pushed in coming years to achieve a break through. The fishery is too valuable not to have every factor in shoring up it's future examined. I am convinced that R&D funding must increase and some of this cost must be borne by those exploiting the fishery.
2015	The work on the Moreton Bay Bugs (*Thenus orientalis*) by Dr Satoshi Mikami has little relevance to spiny lobster larval rearing. It has been known for a long time that they have a much simpler life cycle. After going over the others responses I will modify it up to 2015. The lack of funding is still my main reason that this will take so long.
2010	No change (n/c)
2014	It is going to be slow progress. By concentrating on species with a relatively shorter larval life (eg. *P.ornatus*, *P. elephas*, *P. cygnus* and *P. ornatus*, *J. verreauxi*) we should get answers re nutritional requirements. No one yet working on *P. elephas* but it would be the temperate species to look at with such a short larval life
2020	n/c
2020	n/c
2019	I have no change to my prediction of 20 years. I do however have a suggestion that the question you asked is incorrect, however most have interpreted it as meaning 50% of farmers growing puerulus from a "hatchery". I would suggest that the likelihood that 50% of farmers will be using larval rearing techniques is low. However it is much higher that 50% may be growing puerulus from a larval rearing system. The cost of setting up such an operation to rear phyllosomas will be high and I suspect that there will be only one or two "hatcheries" doing larval rearing and producing puerulus for on-sale to farmers.
Never	I would like to review my prediction that 50% of the cultured crayfish IN NEW ZEALAND will be the result of successful larval culture by 2020 to NEVER. After further consideration of the issues, I agree that it is very likely that this type of technology will be used overseas e.g. Chile and result in large quantities of 'cheap' cultured crays on the market. I would suggest that larval culture and reproductive specialists in Japan will finally succeed and already having secured live stocks of our crayfish will establish crayfish aquaculture projects in Korea and China alongside their other operations. The same process is likely to occur with other products such as abalone pearls. NZ cray aquaculture operators may benefit from puerulus capture in that they start with a beastie already a centimetre or so long, and markedly reduced mortality.

Appendix C: Transporting raw data

Table C.1: Transporting experiment raw data.

Class	Density	Temp	Hours	Replicate	Observation	Survival	Replicate Average
J	2	14	6	1	2	100%	
J	2	14	6	2	2	100%	
J	2	14	6	3	2	100%	100%
J	4	14	6	1	0	0%	
J	4	14	6	2	1	25%	
J	4	14	6	3	2	50%	25%
J	6	14	6	1	1	17%	
J	6	14	6	2	0	0%	
J	6	14	6	3	0	0%	6%
P	2	14	6	1	2	100%	
P	2	14	6	2	2	100%	
P	2	14	6	3	2	100%	100%
P	4	14	6	1	2	50%	
P	4	14	6	2	4	100%	
P	4	14	6	3	4	100%	83%
P	6	14	6	1	6	100%	
P	6	14	6	2	3	50%	
P	6	14	6	3	4	67%	72%
J	2	20	6	1	1	50%	
J	2	20	6	2	0	0%	
J	2	20	6	3	1	50%	33%
J	4	20	6	1	0	0%	
J	4	20	6	2	0	0%	
J	4	20	6	3	0	0%	0%
J	6	20	6	1	0	0%	
J	6	20	6	2	0	0%	
J	6	20	6	3	0	0%	0%
P	2	20	6	1	2	100%	
P	2	20	6	2	2	100%	
P	2	20	6	3	2	100%	100%
P	4	20	6	1	0	0%	
P	4	20	6	2	0	0%	
P	4	20	6	3	0	0%	0%
P	6	20	6	1	0	0%	
P	6	20	6	2	0	0%	
P	6	20	6	3	0	0%	0%

Table C.1: Transporting experiment raw data (continued).

Class	Density	Temp	Hours	Replicate	Observation	% Survival	Replicate Average
J	2	14	9	1	1	50%	
J	2	14	9	2	1	50%	
J	2	14	9	3	1	50%	50%
J	4	14	9	1	0	0%	
J	4	14	9	2	0	0%	
J	4	14	9	3	0	0%	0%
J	6	14	9	1	1	17%	
J	6	14	9	2	2	33%	
J	6	14	9	3	0	0%	17%
P	2	14	9	1	2	100%	
P	2	14	9	2	2	100%	
P	2	14	9	3	0	0%	67%
P	4	14	9	1	0	0%	
P	4	14	9	2	0	0%	
P	4	14	9	3	2	50%	17%
P	6	14	9	1	0	0%	
P	6	14	9	2	0	0%	
P	6	14	9	3	0	0%	0%
J	2	20	9	1	0	0%	
J	2	20	9	2	0	0%	
J	2	20	9	3	0	0%	0%
J	4	20	9	1	0	0%	
J	4	20	9	2	0	0%	
J	4	20	9	3	0	0%	0%
J	6	20	9	1	0	0%	
J	6	20	9	2	0	0%	
J	6	20	9	3	0	0%	0%
P	2	20	9	1	0	0%	
P	2	20	9	2	0	0%	
P	2	20	9	3	0	0%	0%
P	4	20	9	1	0	0%	
P	4	20	9	2	0	0%	
P	4	20	9	3	0	0%	0%
P	6	20	9	1	0	0%	
P	6	20	9	2	0	0%	
P	6	20	9	3	0	0%	0%

Appendix D: Ongrowing raw data

Table D.1: Ongrowing experiment raw data.

Tank	Density	Day 0		Day 50		Day 121	
	(Lobsters/tank)	WT	CL	WT	CL	WT	CL
1	3	15.3	28	20	32	25.7	35
1	3	14.1	28	20.2	30	24.1	32
1	3	10.9	24	15.2	27	18.6	31
2	3	14.8	28	13.8	26	20.6	31
2	3	9.9	23	14.5	28	19.3	31
2	3	9.3	23	Mortality		Mortality	
3	3	12.3	25	17.5	29	23.6	35
3	3	12.2	24	14.8	29	20.2	31
3	3	10.9	23	Mortality		Mortality	
4	3	13.6	27	12.8	27	22.6	33
4	3	9.7	22	18.4	29	19.5	30
4	3	10.7	25	12.9	27	18.2	30
5	6	12.7	27	16.3	27	27.5	35
5	6	13.9	27	21.2	33	24.2	34
5	6	11.9	27	19.2	30	28.1	36
5	6	15.1	29	21.7	32	23.2	35
5	6	13.7	27	19.1	30	Mortality	
5	6	17.2	30	Mortality		Mortality	
6	6	7.6	21	13.5	26	12.1	27
6	6	13.5	26	16	27	22	33
6	6	16.4	29	15.7	28	25.6	35
6	6	10.3	24	12.3	25	14.1	27
6	6	11.6	24	9.9	24	19.9	31
6	6	11.2	24	Mortality		Mortality	
7	6	10.1	23	18.8	30	26.6	35
7	6	9.9	23	15.6	28	18.9	30
7	6	10.9	24	13.6	25	21.6	31
7	6	10.4	24	7.4	21	28	35
7	6	7.1	22	20.8	31	23	33
7	6	7.4	20	15.5	28	16.9	29

Table D.1: Ongrowing experiment raw data (continued).

Tank	Density	Day 0		Day 50		Day 121	
	(Lobsters/tank)	WT	CL	WT	CL	WT	CL
8	6	8.3	22	16.3	28	14.5	29
8	6	12.1	26	14.1	26	14.5	27
8	6	9.8	25	10.2	26	12	27
8	6	9.8	24	11.5	25	24.1	34
8	6	10.1	24	7.3	23	14.3	29
8	6	11.5	25	11	25	16	29
9	9	9.9	25	12.4	25	21.7	32
9	9	11.4	24	16.6	28	24.6	34
9	9	11.2	24	10.9	24	23.3	32
9	9	11.2	25	14.5	27	15.9	30
9	9	7.6	24	14.9	27	22	31
9	9	10.4	24	14.9	27	15.1	27
9	9	8.1	23	11.9	26	10.6	27
9	9	10.1	26	10.6	25	19.2	28
9	9	8.8	22	Mortality		Mortality	
10	9	11.8	24	15.5	28	20.5	32
10	9	8.5	24	10.4	24	17.8	30
10	9	10.8	24	12.7	25	12.4	26
10	9	12.3	26	9	24	9.5	24
10	9	11.5	24	14.4	26	15.4	28
10	9	6.2	21	6.4	22	15.1	28
10	9	9.4	25	10.2	26	14.8	27
10	9	8.1	23	15.8	30	15.2	28
10	9	8	23	Mortality		Mortality	
11	9	12.7	24	17	28	23.9	34
11	9	7.9	21	17.3	28	22.9	32
11	9	12.4	24	15.4	27	20.4	32
11	9	7.5	22	15.8	28	15.1	28
11	9	12.7	25	15.3	28	20.9	33
11	9	11.5	24	10.9	25	15.7	29
11	9	10.5	24	10.9	25	19.8	31
11	9	10.7	26	Mortality		Mortality	
11	9	12.1	26	Mortality		Mortality	

Table D.1: Ongrowing experiment raw data (continued).

Tank	Density (Lobsters/tank)	Day 0		Day 50		Day 121	
		WT	CL	WT	CL	WT	CL
12	9	7.2	20	16.6	28	16.9	29
12	9	13.4	28	15.1	30	12.9	28
12	9	10.9	24	10.5	24	10.7	25
12	9	8.8	25	8.9	24	16.9	27
12	9	7.6	23	12.1	25	9.5	23
12	9	8.1	22	9.5	24	8.3	24
12	9	12.3	24	8.2	22	9	24
12	9	16	29	21	32	12.1	26
12	9	10.7	23	10.8	25	15.2	28
13	12	10.6	23	13.6	27	23.6	34
13	12	8.7	21	11.9	26	10.4	26
13	12	8.8	24	18.6	27	10.1	25
13	12	16.4	27	13.8	27	23.7	34
13	12	7	20	9.2	25	26	36
13	12	10.8	24	14.5	28	18.8	31
13	12	7.4	22	11	24	19.4	31
13	12	10.8	25	13.6	26	17.7	30
13	12	9.7	25	19.2	30	14.7	28
13	12	16.1	27	9.2	23	23.3	34
13	12	7.9	22	Mortality		Mortality	
13	12	10.2	24	Mortality		Mortality	
14	12	12.9	26	15.7	29	18	30
14	12	10.9	24	13.5	26	17.7	30
14	12	8	22	15.6	28	17.8	32
14	12	11.4	25	15.8	28	14.7	28
14	12	9.4	22	14.5	27	14	28
14	12	13.6	28	17	30	16.2	29
14	12	10.8	24	13.1	26	16.8	30
14	12	10.2	24	19.8	30	17.1	29
14	12	11	26	14.8	28	16.7	29
14	12	14.2	27	Mortality		Mortality	
14	12	9.2	24	Mortality		Mortality	
14	12	12.4	26	Mortality		Mortality	

Table D.1: Ongrowing experiment raw data (continued).

Tank	Density (Lobsters/tank)	Day 0		Day 50		Day 121	
		WT	CL	WT	CL	WT	CL
15	12	10.3	22	11.4	26	8.5	25
15	12	9.5	23	8	23	12	25
15	12	9.8	22	13.6	26	14.9	28
15	12	11	25	8	22	20.4	30
15	12	7.7	21	11.5	24	7.9	24
15	12	13.2	25	13.4	25	12.2	27
15	12	6.2	20	12.3	25	11	25
15	12	7.2	21	13.9	27	14.1	28
15	12	5.6	20	8	23	20.5	32
15	12	8.4	22	10.2	25	14.1	28
15	12	7.5	23	11	24	13.6	27
15	12	7.6	22	Mortality		Mortality	
16	12	18.6	30	14.6	26	20.9	31
16	12	10.8	23	13.8	27	19.4	31
16	12	8.1	22	20	30	24.3	34
16	12	9.5	23	12.1	25	18.4	30
16	12	13.8	28	19.6	31	12.5	26
16	12	14.7	28	14	27	18.7	29
16	12	14.9	28	16.8	30	12.4	27
16	12	8.4	21	16.9	29	16.2	28
16	12	15.9	29	19.1	30	18.3	31
16	12	11.1	24	11.5	26	17.4	30
16	12	13.7	27	17	30	14.3	25
16	12	12.9	26	Mortality		Mortality	

Appendix E: Bioeconomic cash flow spreadsheets

Table E.1: Cash flow analysis of the 'Sale price at $55/kg' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster				596,026	596,026	596,026	596,026	596,026	596,026	596,026
Total annual returns	0	0	0	596,026	596,026	596,026	596,026	596,026	596,026	596,026
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	61,433	90,307						
Monitoring system	400	1,160	2,389	4,195						
Recirculation system	9,600	18,240	29,488	43,347						
Tanks	4,000	7,600	12,287	18,061						
Vehicle	10,000									
Total capital costs	84,000	65,000	105,597	155,911						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,760	31,945	46,960	46,960	46,960	46,960	46,960	46,960	46,960
Feed	6,650	19,352	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929
Process & transport	0	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	14,592	23,590	34,678	34,678	34,678	34,678	34,678	34,678	34,678
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	214,091	243,064	282,826	417,296	417,296	417,296	417,296	417,296	417,296	417,296
Total annual costs	298,091	308,064	388,422	573,206	417,296	417,296	417,296	417,296	417,296	417,296
Annual cash position	(298,091)	(308,064)	(388,422)	22,820	178,730	178,730	178,730	178,730	178,730	178,730
Cumulative cash position	(298,091)	(606,155)	(994,577)	(971,758)	(793,027)	(614,297)	(435,566)	(256,836)	(78,105)	100,625

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.2: Cash flow analysis of the 'Sale price at $75/kg' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster				812,763	812,763	812,763	812,763	812,763	812,763	812,763
Total annual returns	0	0	0	812,763	812,763	812,763	812,763	812,763	812,763	812,763
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	61,433	90,307						
Monitoring system	400	1,160	2,389	4,195						
Recirculation system	9,600	18,240	29,488	43,347						
Tanks	4,000	7,600	12,287	18,061						
Vehicle	10,000									
Total capital costs	84,000	65,000	105,597	155,911						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,760	31,945	46,960	46,960	46,960	46,960	46,960	46,960	46,960
Feed	6,650	19,352	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929
Process & transport	0	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	14,592	23,590	34,678	34,678	34,678	34,678	34,678	34,678	34,678
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	214,091	243,064	282,826	417,296	417,296	417,296	417,296	417,296	417,296	417,296
Total annual costs	298,091	308,064	388,422	573,206	417,296	417,296	417,296	417,296	417,296	417,296
Annual cash position	(298,091)	(308,064)	(388,422)	239,557	395,467	395,467	395,467	395,467	395,467	395,467
Cumulative cash position	(298,091)	(606,155)	(994,577)	(755,021)	(359,553)	35,914	431,381	826,848	1,222,316	1,617,783

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.3: Cash flow analysis of the 'Quota traded 2,000 kg' model over the 10-year period.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Returns										
Sale of lobster				1,408,789	1,408,789	1,408,789	1,408,789	1,408,789	1,408,789	1,408,789
Total annual returns	0	0	0	1,408,789	1,408,789	1,408,789	1,408,789	1,408,789	1,408,789	1,408,789
Costs										
Capital costs										
Land	80,000									
Buildings	40,000	76,000	122,867	180,614						
Monitoring system	800	2,320	4,777	8,390						
Recirculation system	19,200	36,480	58,976	86,695						
Tanks	8,000	15,200	24,573	36,123						
Vehicle	10,000									
Total capital costs	158,000	130,000	211,193	311,821						
Annual operating costs										
Production costs										
Consumables	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Electricity	20,800	39,520	63,891	93,919	93,919	93,919	93,919	93,919	93,919	93,919
Feed	13,300	38,703	75,858	75,858	75,858	75,858	75,858	75,858	75,858	75,858
Process & transport	0	0	0	216,737	216,737	216,737	216,737	216,737	216,737	216,737
Puerulus	78,000	78,000	78,000	78,000	78,000	78,000	78,000	78,000	78,000	78,000
Water	15,360	29,184	47,181	69,356	69,356	69,356	69,356	69,356	69,356	69,356
Labour costs										
Labour	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000
Indirect operational costs										
Repairs & maintenance	14,620	14,620	14,620	14,620	14,620	14,620	14,620	14,620	14,620	14,620
Fixed costs										
Administration	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Depreciation	81,101	81,101	81,101	81,101	81,101	81,101	81,101	81,101	81,101	81,101
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	4,800	4,800	4,800	4,800	4,800	4,800	4,800	4,800	4,800	4,800
Total current costs	419,482	477,429	556,951	825,891	825,891	825,891	825,891	825,891	825,891	825,891
Total annual costs	577,482	607,429	768,144	1,137,713	825,891	825,891	825,891	825,891	825,891	825,891
Annual cash position	(577,482)	(607,429)	(768,144)	271,077	582,898	582,898	582,898	582,898	582,898	582,898
Cumulative cash position	(577,482)	(1,184,910)	(1,953,055)	(1,681,978)	(1,099,081)	(516,183)	66,715	649,613	1,232,510	1,815,408

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.4: Cash flow analysis of the 'Quota traded 10,000 kg' model over the 10-year period.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Returns										
Sale of lobster				7,043,946	7,043,946	7,043,946	7,043,946	7,043,946	7,043,946	7,043,946
Total annual returns	0	0	0	7,043,946	7,043,946	7,043,946	7,043,946	7,043,946	7,043,946	7,043,946
Costs										
Capital costs										
Land	400,000									
Buildings	200,000	380,000	614,333	903,070						
Monitoring system	4,000	11,600	23,887	41,948						
Recirculation system	96,000	182,400	294,880	433,474						
Tanks	40,000	76,000	122,867	180,614						
Vehicle	10,000									
Total capital costs	750,000	650,000	1,055,967	1,559,106						
Annual operating costs										
Production costs										
Consumables	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Electricity	104,000	197,600	319,453	469,596	469,596	469,596	469,596	469,596	469,596	469,596
Feed	66,500	193,515	379,289	379,289	379,289	379,289	379,289	379,289	379,289	379,289
Process & transport	0	0	0	1,083,684	1,083,684	1,083,684	1,083,684	1,083,684	1,083,684	1,083,684
Puerulus	390,000	390,000	390,000	390,000	390,000	390,000	390,000	390,000	390,000	390,000
Water	76,800	145,920	235,904	346,779	346,779	346,779	346,779	346,779	346,779	346,779
Labour costs										
Labour	720,000	720,000	720,000	720,000	720,000	720,000	720,000	720,000	720,000	720,000
Indirect operational costs										
Repairs & maintenance	72,301	72,301	72,301	72,301	72,301	72,301	72,301	72,301	72,301	72,301
Fixed costs										
Administration	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Depreciation	401,507	401,507	401,507	401,507	401,507	401,507	401,507	401,507	401,507	401,507
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000
Total current costs	2,062,609	2,352,344	2,749,955	4,094,657	4,094,657	4,094,657	4,094,657	4,094,657	4,094,657	4,094,657
Total annual costs	2,812,609	3,002,344	3,805,922	5,653,763	4,094,657	4,094,657	4,094,657	4,094,657	4,094,657	4,094,657
Annual cash position	(2,812,609)	(3,002,344)	(3,805,922)	1,390,183	2,949,289	2,949,289	2,949,289	2,949,289	2,949,289	2,949,289
Cumulative cash position	(2,812,609)	(5,814,952)	(9,620,874)	(8,230,691)	(5,281,403)	(2,332,114)	617,174	3,566,463	6,515,752	9,465,040

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.5: Cash flow analysis of the 'Processing at $13/kg' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster				704,395	704,395	704,395	704,395	704,395	704,395	704,395
Total annual returns	0	0	0	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	61,433	90,307						
Monitoring system	400	1,160	2,389	4,195						
Recirculation system	9,600	18,240	29,488	43,347						
Tanks	4,000	7,600	12,287	18,061						
Vehicle	10,000									
Total capital costs	84,000	65,000	105,597	155,911						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,760	31,945	46,960	46,960	46,960	46,960	46,960	46,960	46,960
Feed	6,650	19,352	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929
Process & transport	0	0	0	140,879	140,879	140,879	140,879	140,879	140,879	140,879
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	14,592	23,590	34,678	34,678	34,678	34,678	34,678	34,678	34,678
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	214,091	243,064	282,826	449,806	449,806	449,806	449,806	449,806	449,806	449,806
Total annual costs	298,091	308,064	388,422	605,717	449,806	449,806	449,806	449,806	449,806	449,806
Annual cash position	(298,091)	(308,064)	(388,422)	98,678	254,588	254,588	254,588	254,588	254,588	254,588
Cumulative cash position	(298,091)	(606,155)	(994,577)	(895,900)	(641,311)	(386,723)	(132,135)	122,454	377,042	631,630

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.6: Cash flow analysis of the 'Feed conversion at 3:1' model over the 10-year period.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Returns										
Sale of lobster				704,395	704,395	704,395	704,395	704,395	704,395	704,395
Total annual returns	0	0	0	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	61,433	90,307						
Monitoring system	400	1,160	2,389	4,195						
Recirculation system	9,600	18,240	29,488	43,347						
Tanks	4,000	7,600	12,287	18,061						
Vehicle	10,000									
Total capital costs	84,000	65,000	105,597	155,911						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,760	31,945	46,960	46,960	46,960	46,960	46,960	46,960	46,960
Feed	2,850	8,294	16,255	16,255	16,255	16,255	16,255	16,255	16,255	16,255
Process & transport	0	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	14,592	23,590	34,678	34,678	34,678	34,678	34,678	34,678	34,678
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	210,291	232,006	261,152	395,622	395,622	395,622	395,622	395,622	395,622	395,622
Total annual costs	294,291	297,006	366,749	551,533	395,622	395,622	395,622	395,622	395,622	395,622
Annual cash position	(294,291)	(297,006)	(366,749)	152,862	308,773	308,773	308,773	308,773	308,773	308,773
Cumulative cash position	(294,291)	(591,297)	(958,046)	(805,184)	(496,411)	(187,639)	121,134	429,906	738,679	1,047,451

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.7: Cash flow analysis of the 'Feed price at $0.2/kg' model over the 10-year period.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Returns										
Sale of lobster				704,395	704,395	704,395	704,395	704,395	704,395	704,395
Total annual returns	0	0	0	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	61,433	90,307						
Monitoring system	400	1,160	2,389	4,195						
Recirculation system	9,600	18,240	29,488	43,347						
Tanks	4,000	7,600	12,287	18,061						
Vehicle	10,000									
Total capital costs	84,000	65,000	105,597	155,911						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,760	31,945	46,960	46,960	46,960	46,960	46,960	46,960	46,960
Feed	2,660	7,741	15,172	15,172	15,172	15,172	15,172	15,172	15,172	15,172
Process & transport	0	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	14,592	23,590	34,678	34,678	34,678	34,678	34,678	34,678	34,678
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	210,101	231,453	260,068	394,538	394,538	394,538	394,538	394,538	394,538	394,538
Total annual costs	294,101	296,453	365,665	550,449	394,538	394,538	394,538	394,538	394,538	394,538
Annual cash position	(294,101)	(296,453)	(365,665)	153,946	309,856	309,856	309,856	309,856	309,856	309,856
Cumulative cash position	(294,101)	(590,554)	(956,219)	(802,274)	(492,417)	(182,561)	127,295	437,151	747,008	1,056,864

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.8: Cash flow analysis of the 'Harvest at $0.3/puerulus' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster				704,395	704,395	704,395	704,395	704,395	704,395	704,395
Total annual returns	0	0	0	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	61,433	90,307						
Monitoring system	400	1,160	2,389	4,195						
Recirculation system	9,600	18,240	29,488	43,347						
Tanks	4,000	7,600	12,287	18,061						
Vehicle	10,000									
Total capital costs	84,000	65,000	105,597	155,911						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,760	31,945	46,960	46,960	46,960	46,960	46,960	46,960	46,960
Feed	6,650	19,352	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929
Process & transport	0	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000
Water	7,680	14,592	23,590	34,678	34,678	34,678	34,678	34,678	34,678	34,678
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	202,091	231,064	270,826	405,296	405,296	405,296	405,296	405,296	405,296	405,296
Total annual costs	286,091	296,064	376,422	561,206	405,296	405,296	405,296	405,296	405,296	405,296
Annual cash position	(286,091)	(296,064)	(376,422)	143,188	299,099	299,099	299,099	299,099	299,099	299,099
Cumulative cash position	(286,091)	(582,155)	(958,577)	(815,389)	(516,290)	(217,191)	81,907	381,006	680,105	979,204

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.9: Cash flow analysis of the 'Stock density +25%' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster				704,395	704,395	704,395	704,395	704,395	704,395	704,395
Total annual returns	0	0	0	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Costs										
Capital costs										
Land	40,000									
Buildings	16,000	30,159	48,500	72,246						
Monitoring system	320	923	1,893	3,338						
Recirculation system	7,680	14,476	23,280	34,678						
Tanks	3,200	6,032	9,700	14,449						
Vehicle	10,000									
Total capital costs	77,200	51,590	83,373	124,711						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	8,320	15,683	25,220	37,568	37,568	37,568	37,568	37,568	37,568	37,568
Feed	6,650	19,352	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929
Process & transport	0	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	6,144	11,581	18,624	27,742	27,742	27,742	27,742	27,742	27,742	27,742
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	5,937	5,937	5,937	5,937	5,937	5,937	5,937	5,937	5,937	5,937
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	33,687	33,687	33,687	33,687	33,687	33,687	33,687	33,687	33,687	33,687
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	201,639	227,140	262,298	392,132	392,132	392,132	392,132	392,132	392,132	392,132
Total annual costs	278,839	278,730	345,671	516,843	392,132	392,132	392,132	392,132	392,132	392,132
Annual cash position	(278,839)	(278,730)	(345,671)	187,552	312,262	312,262	312,262	312,262	312,262	312,262
Cumulative cash position	(278,839)	(557,569)	(903,239)	(715,688)	(403,425)	(91,163)	221,099	533,362	845,624	1,157,887

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.10: Cash flow analysis of the 'Stock density +50%' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster				704,395	704,395	704,395	704,395	704,395	704,395	704,395
Total annual returns	0	0	0	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Costs										
Capital costs										
Land	40,000									
Buildings	13,333	25,333	40,956	60,205						
Monitoring system	267	773	1,592	2,797						
Recirculation system	6,400	12,160	19,659	28,898						
Tanks	2,667	5,067	8,191	12,041						
Vehicle	10,000									
Total capital costs	72,667	43,333	70,398	103,940						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	6,933	13,173	21,297	31,306	31,306	31,306	31,306	31,306	31,306	31,306
Feed	6,650	19,352	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929
Process & transport	0	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	5,120	9,728	15,727	23,119	23,119	23,119	23,119	23,119	23,119	23,119
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	5,007	5,007	5,007	5,007	5,007	5,007	5,007	5,007	5,007	5,007
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	29,034	29,034	29,034	29,034	29,034	29,034	29,034	29,034	29,034	29,034
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	193,644	217,193	249,893	375,663	375,663	375,663	375,663	375,663	375,663	375,663
Total annual costs	266,311	260,527	320,291	479,603	375,663	375,663	375,663	375,663	375,663	375,663
Annual cash position	(266,311)	(260,527)	(320,291)	224,791	328,732	328,732	328,732	328,732	328,732	328,732
Cumulative cash position	(266,311)	(526,837)	(847,128)	(622,337)	(293,605)	35,126	363,858	692,589	1,021,321	1,350,053

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.11: Cash flow analysis of the '3 years to sale' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster			704,395	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Total annual returns	0	0	704,395	704,395	704,395	704,395	704,395	704,395	704,395	704,395
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,000	151,740	0						
Monitoring system	400	1,160	6,583	0						
Recirculation system	9,600	18,240	72,835	0						
Tanks	4,000	7,600	30,348	0						
Vehicle	10,000									
Total capital costs	84,000	65,000	261,507	0						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,760	31,945	46,960	46,960	46,960	46,960	46,960	46,960	46,960
Feed	6,650	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929	37,929
Process & transport	0	0	108,368	108,368	108,368	108,368	108,368	108,368	108,368	108,368
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	14,592	23,590	34,678	34,678	34,678	34,678	34,678	34,678	34,678
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051	41,051
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	214,091	261,642	391,194	417,296	417,296	417,296	417,296	417,296	417,296	417,296
Total annual costs	298,091	326,642	652,701	417,296	417,296	417,296	417,296	417,296	417,296	417,296
Annual cash position	(298,091)	(326,642)	51,693	287,099	287,099	287,099	287,099	287,099	287,099	287,099
Cumulative cash position	(298,091)	(624,733)	(573,039)	(285,940)	1,158	288,257	575,356	862,455	1,149,554	1,436,653

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.12: Cash flow analysis of the 'Mortality at 7%' model over the 10-year period.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Returns										
Sale of lobster				726,486	726,486	726,486	726,486	726,486	726,486	726,486
Total annual returns	0	0	0	726,486	726,486	726,486	726,486	726,486	726,486	726,486
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	38,400	62,720	93,139						
Monitoring system	400	1,168	2,422	4,285						
Recirculation system	9,600	18,432	30,106	44,707						
Tanks	4,000	7,680	12,544	18,628						
Vehicle	10,000									
Total capital costs	84,000	65,680	107,792	160,759						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	19,968	32,614	48,432	48,432	48,432	48,432	48,432	48,432	48,432
Feed	6,720	19,757	39,118	39,118	39,118	39,118	39,118	39,118	39,118	39,118
Process & transport	0	0	0	111,767	111,767	111,767	111,767	111,767	111,767	111,767
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	14,746	24,084	35,765	35,765	35,765	35,765	35,765	35,765	35,765
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	7,565	7,565	7,565	7,565	7,565	7,565	7,565	7,565	7,565	7,565
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	41,823	41,823	41,823	41,823	41,823	41,823	41,823	41,823	41,823	41,823
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	215,088	244,758	286,105	425,371	425,371	425,371	425,371	425,371	425,371	425,371
Total annual costs	299,088	310,438	393,897	586,130	425,371	425,371	425,371	425,371	425,371	425,371
Annual cash position	(299,088)	(310,438)	(393,897)	140,356	301,115	301,115	301,115	301,115	301,115	301,115
Cumulative cash position	(299,088)	(609,526)	(1,003,423)	(863,067)	(561,953)	(260,838)	40,277	341,392	642,506	943,621

Appendix E: Bioeconomic cash flow spreadsheets (continued).

Table E.13: Cash flow analysis of the 'Mortality at 20%' model over the 10-year period.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Returns										
Sale of lobster				626,886	626,886	626,886	626,886	626,886	626,886	626,886
Total annual returns	0	0	0	626,886	626,886	626,886	626,886	626,886	626,886	626,886
Costs										
Capital costs										
Land	40,000									
Buildings	20,000	36,000	56,400	80,370						
Monitoring system	400	1,120	2,248	3,855						
Recirculation system	9,600	17,280	27,072	38,578						
Tanks	4,000	7,200	11,280	16,074						
Vehicle	10,000									
Total capital costs	84,000	61,600	97,000	138,877						
Annual operating costs										
Production costs										
Consumables	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Electricity	10,400	18,720	29,328	41,792	41,792	41,792	41,792	41,792	41,792	41,792
Feed	6,300	17,766	33,755	33,755	33,755	33,755	33,755	33,755	33,755	33,755
Process & transport	0	0	0	96,444	96,444	96,444	96,444	96,444	96,444	96,444
Puerulus	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000	39,000
Water	7,680	13,824	21,658	30,862	30,862	30,862	30,862	30,862	30,862	30,862
Labour costs										
Labour	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Indirect operational costs										
Repairs & maintenance	6,830	6,830	6,830	6,830	6,830	6,830	6,830	6,830	6,830	6,830
Fixed costs										
Administration	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Depreciation	38,148	38,148	38,148	38,148	38,148	38,148	38,148	38,148	38,148	38,148
Fees and licences	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Fuel (vehicle)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Insurance	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total current costs	210,257	236,187	270,618	388,731	388,731	388,731	388,731	388,731	388,731	388,731
Total annual costs	294,257	297,787	367,618	527,608	388,731	388,731	388,731	388,731	388,731	388,731
Annual cash position	(294,257)	(297,787)	(367,618)	99,278	238,155	238,155	238,155	238,155	238,155	238,155
Cumulative cash position	(294,257)	(592,044)	(959,663)	(860,385)	(622,230)	(384,075)	(145,920)	92,235	330,390	568,544