CHITIN AND CHITOSAN INDUSTRY AND ITS POTENTIAL IN QUEBEC

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ABSTRACT

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The shrimp processing industry has to deal with the ever-growing costs associated with the disposal of their residuals. However, investigation into the possibility of making high-value biopolymers (chitin and chitosan) from this waste shows significant potential for developing a chitin and chitosan industry in Quebec.

Based on the Gulf of St. Lawrence shrimp landings, it is estimated that more than 12,000 metric tons of shrimp waste is expected to be generated by the shrimp processing industry in Quebec each year. In reality, the quantity of shrimp waste is more than what is estimated since Quebec processors import shrimp from the Atlantic Provinces and from the State of Maine. This waste is abundant enough to provide the raw materials needed for an environmentally friendly technology to make high value-added commercial products such as chitin and chitosan to suit a variety of industrial applications.

The estimation of the production costs at the industrial level (0.65 $/g for chitosan, 0.26 $/g for chitin and 0.07 $/g for carotenoprotein) shows gross margins over 90% for making chitin and its derivative chitosan. This is due to the ease of the proposed process, the low cost of the required equipment and the use of enzymes instead of chemical acids that require stainless steel equipment and high-energy consumption.

The pharmaceutical and medicine industry is the target market for high-grade chitosan. Based on the related data of cellulose derivatives (the closest substitute for chitosan), the Bass model was used to forecast the sales of high-grade chitosan in Quebec. It is estimated that the

potential market for chitosan in Quebec is worth 37 million dollars (in 1999 prices) cumulative for the next 20 year period and 59 million for Canada. In the first year of marketing chitosan, sales in Canada (high-grade) are expected to reach $3.2 million from which $1.55 million is expected to be generated in Quebec.

RÉSUMÉ

Chaque année, l'industrie Quebécoise de la transformation des crevettes génère plusieurs milliers de tonnes de déchêts. Par conséquent, elle doit assumer l'augmentation continue des coûts associés á l'évacuation de ces déchêts. Pourtant, l'investigation de la possibilité de transformer ces résidus en produits biochemiques de haute qualité a montré que l'industrie de la la chitine et de la chitosane a de grandes opportunités au Québec.

Basé sur les quantités des deparquement du fleuve du St Laurent, il est estimé que plus de 12,000t de carcasse de crevettes est genérée chaque année par les transformateurs au Québec. En réalité, la quantité des dechets est superieure a ce qui est estime vue que les transformateurs quebecois imprtent leur matiere premiere des provinces atlantique et de l'etat du Maine. Ces déchêts sont assez abondants pour fournir de la matière première necessaire pour la continuité d'une technologie environementale pour fabriquer des produits commerciaux de haute valeur ajoutée comme la chitine et la chitosane.

L'estimation du coût de production au niveau industriel affiche une marge benificiaire brute superieur á 90% pour la chitine et sa dérivé la chitosane. Cette grosse marge est principalement düe á la facilité du processus d'extraction, au coût bas des equipements requis et aussi aux enzymes utilisés qui ne nessite pas de grandes quantités d'energie contrairement aux vielles methodes d'extraction.

Une chitosane de haute qualité devra être utilisée dans l'industrie pharmaceutique. En se basant sur les données historiques d'un polymer succetible d'être remplacé par la chitosane (derivés de cellulose), le Model de Bass a été appliqué pour faire les previsions des ventes de la chitosane. D'apres les resultats de l'analyse, il est prevu que le marché potentiel de la chitosane de haute qualité serait d'une valeur cumulative de 37 millions de dollar constant (1999) durant les 20 prochaines années. Pour la meme periode, la valeur du marché Canadien est éstimée á 59 millions de dollar. Lors de la première année du lancement, les ventes au Canada vont atteindreplus de 3.2 million don't 1.55 million serait réalisé au Québec.

ACKNOWLEDGEMENTS

I would like to thank my co-advisers Dr. Kisan Gunjal and Dr. Peter Goldsmith for all the help and patience they showed during this research. Their encouragement and constructive comments were key to the accomplishment of this thesis. I am thankful to Dr. B.K. Simpson of the Department of Food Science and Agricultural Chemistry. McGill University. for allowing me to collaborate with him and his laboratory staff as well as for providing financial assistance through Conseil des Recherches en Peche et en Agroalimentaire du Quebec (CORPAQ). I would also like to recognize the professionalism of Dr. Paul Thomassin. Chair of the Department of Agricultural Economics. the advises of Dr. Laurie Baker and Dr. John Henning. I am also very thankful to Mrs. Pat Atkinson. the administrative assistant for her tremendous help and her friendship.

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FOREWORD

The potential of chitin and chitosan industry in Quebec is analyzed and presented under three separate papers. This thesis format conforms with the policies of McGill University relating to theses. The following text is reproduced from the guidelines for thesis preparation provided by McGill's Faculty of Graduate Studies and Research:

"Candidates have the option of including, as part of the thesis, the text of one or more papers submitted or to be submitted for publication, or the clearly-duplicated text of one or more published papers. These texts must be bound as an integral part of the thesis.

If this option is chosen, connecting texts that provide logical bridges between the different papers are mandatory. The thesis must be written in such a way that it is more than a mere collection of manuscripts: in other words, results of a series of papers must be integrated.

The thesis must still conform to all other requirements of the "Guidelines for Thesis Preparation." The thesis must include: A Table of Contents, an abstract in English and French, an introduction which clearly states the rationale and objectives of the study, a final conclusion and summary, and a through bibliography or reference list.

Additional material must be provided where appropriate (e.g. in appendices) and in sufficient detail to allow a clear and precise judgement to be made of the importance and originality of the research reported in the thesis.

In the case of manuscripts co-authored by the candidate and others, the candidate is required to make an explicit statement in the thesis as to who contributed to such work and to what extent. Supervisors must attest to the accuracy of such statements at the doctoral oral defence."

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INTRODUCTION AND ORGANIZATION OF THE THESIS

The importance of seafood in the Canadian diet has been increasing over time. The per capita fish consumption was 7.62 kg in 1988 and reached 8.84 kg in 1996[1]. Many people are choosing fish as an alternative to red meat, in which there are high amounts of saturated fats and cholesterol. The demand for novel and convenience seafood products is also increasing. Therefore, the market response to the demand for ready-to-use seafood products has resulted in increased waste products in the industry. The main forms of this waste are heads and the hard carapace of crustacean species. The seafood industry must dispose of its material waste at a high cost because of stringent environmental standards, or convert it into high-value added products.

At the Macdonald Campus of McGill University, scientists are investigating the possibility of making useful biochemicals, such as chitin and chitosan from shrimp shells. These biochemicals may be recovered in superior quality by inexpensive biotechnological processes undertaken in Quebec making chitin and chitosan available to industries to replace synthetic inputs.

Chitin and its derivative chitosan are relatively new products in Quebec. They have been developed and used elsewhere especially in Japan, the USA and in Finland where they are produced on a mass scale. In Canada, there is only an experimental production plant in Nova Scotia.

For the past 20 years, in Japan chitin and its derivatives have been used for their health benefits. In 1992, Japan's Health Department approved chitin and its derivatives as a functional food. To be considered as a functional food, it should posses the following 5 functions: fortification of immunity, prevention of illness, prevention of aging, recovery of illness, and control of biorhythm. Chitin has all these 5 functions.

[1] Statistics Canada (1996) - Cat. No. 32-230-XPB

The purpose of this study is to investigate the potential of the chitin and chitosan industry in Quebec. The study is presented under three separate papers.

The first paper entitled " Recovery of High Value-Added Products from Shrimp Processing Residuals: Availability of Raw Materials in Quebec", estimates the quantity of waste generated by the shrimp processors in Quebec. The paper investigates the current uses of this waste, showing the potential for making new value-added products such as chitin and chitosan.

After proving that there is abundant amounts of raw material to make chitin and chitosan, the second paper estimates the cost of production. Based on the economic engineering theory, an evaluation of the production costs was performed at a semi-pilot level and then an estimate of the scaled-up process plant was determined by using the cost-capacity factor. The estimates are based on the pilot plant located at Macdonald Campus of McGill University.

In general, the economic viability of any resource recovery operation will depend largely on the revenues expected from the sale of recovered products. Therefore, the success of an establishment recovering chitin and chitosan from shrimp shells depends on the volume and the economic value of the final products. Paper three investigates the potential market for high-grade chitosan in Quebec using the Diffusion of Innovation Theory and using the Bass Model to forecast the sales.

The three papers are logically connected. The conclusions from this research are presented in the final section along with a recommendation for further research.

CHAPTER ONE

Recovery of High Value-Added Products from Shrimp Processing Residuals:

Availability of Raw Material in Quebec

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Abstract

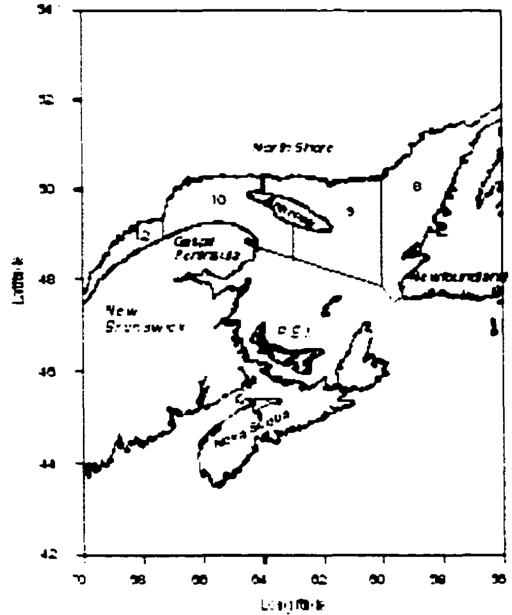
The estimation of the quantity of processed shrimp in Quebec was performed in order to forecast the quantity of waste generated by the shrimp processing industry. Using available time series data, a relationship between total processed shrimp, total allowable catch and total shrimp landings gave better estimates of the quantity of shrimp processed than the naïve forecast, the Moving Average (MA) and the exponential smoothing model. As a result, it is estimated that more than 12, 000 metric tons of shrimp waste is generated by the fish industry in Quebec each year. This volume of waste is adequate to support the production of making high value-added commercial products such as chitin and chitosan using a simple environment-friendly technology.

Introduction:

The shrimp fishery in the Gulf of St. Lawrence began in 1965. Presently, shrimp are exploited from spring to fall in four management units by three provincial fleets (fig.1-1). Fisheries and Oceans Canada (FOC) assess stocks of shrimp every year in order to determine whether to adjust the conservation strategy and management plan.

In 1997, the total allowable catches (TACs) for shrimp increased by 10% over 1996 in three of the four management units. Furthermore, landings in 1997 were the highest ever observed for the fishery and the TACs were reached in all fishing areas. In fact, the shrimp biomass in the Gulf has increased continuously since the early 1980s (Gascon, 1998). The specialists related this increase to the reduction in cod and redfish stocks, which are natural predators of the shrimp.

Figure 1-1. **The Management Units for the Shrimp Fishery of the St. Lawrence Estuary and Gulf: Sept-Îles (Area 10), Anticosti (Area 9), Esquiman (Area 8) and Estuary (Area 12)**



Source: Savard, L. 1997. Shrimp of The Estuary and the Gulf of St Lawrence. DFO Science. Stock Status Report C4-06

The objective of this study is to estimate the quantity of shrimp waste generated by the processors in Quebec, to investigate the current uses of this waste and to show its potential for making new value-added products such as chitin and chitosan. The first section provides some information about the biological characteristics of shrimp. The second section is an overview of the Quebec fisheries industry, the seafood industry and waste disposal issues. Chitin and chitosan are two new value-added products that can be made from the shrimp waste. Therefore, the definition of these products, their general properties, methods for preparation and their potential applications are presented in section three. In the last section, there is a forecast of the quantity of shrimp waste that will be available for making these value-added products.

Biological Characteristics of Shrimp

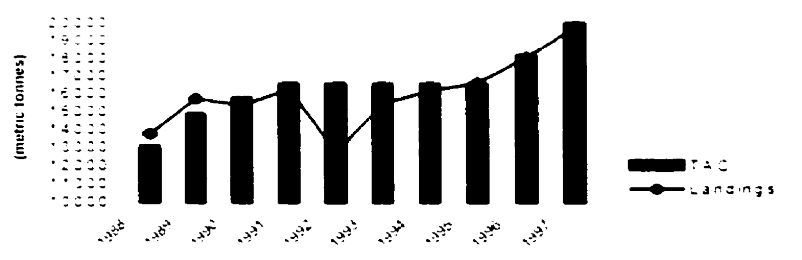
The biology of Northern Shrimp (Pandalus borealis) has had a direct impact on the type of fishing that has developed in the Gulf of St. Lawrence since the 1960s. Shrimp reproduce in fall and the females carry their eggs under their abdomen all winter long, from October to May. In spring, from April to mid May the larvae are released from the eggs. After being released, the pelagic (larvae) reach sexual maturity 30 months later. Shrimp spend the first four years of their lives as males, then change sex and reproduces as a female for at least two years. Therefore, egg-bearing shrimp (females) make up most of the commercial catches. On the other hand, shrimp are distributed differently throughout the area according to their age and size. A large concentration of young male shrimp are found in shallower areas, while a smaller concentration of older shrimp are found in the deeper zones. Therefore, fishermen search for spots where yields are highest to optimize the proportion of large shrimp in their catch.

Since 1994, changes in the geographic distribution of shrimp have been observed. In fact, geostatic analyses were performed on data collected from 1990 to 1996 in order to map the annual distribution of shrimp in the St. Lawrence Gulf and Estuary. The movement of shrimp can be explained as a reaction to the environmental changes affecting either their own geographic distribution, or the distribution of their food (Savard,L. 1997).

The abundance of shrimp increased between the first half of the 1980s and remained high until the early 1990s when they began to decrease in 1992. It remained stable in 1993 and increased again in 1994 and 1995. This increase resulted in higher catches in 1996 and 1997 as well. The TACs, which had remained the same during the period of 1991-1995

(16.600 mt) had increased in the following years. In 1996 and 1997. TACs were reached in all fishing areas (figure 1-2).

Figure 1-2. **Landing and TACs of Northern Shrimp in the Gulf of St. Lawrence (1988-1997)**



Source: Savard, L. 1997. Shrimp of The Estuary and the Gulf of St Lawrence. DFO Science. Stock Status Report C4-06

The Quebec Fisheries Industry: An Outlook

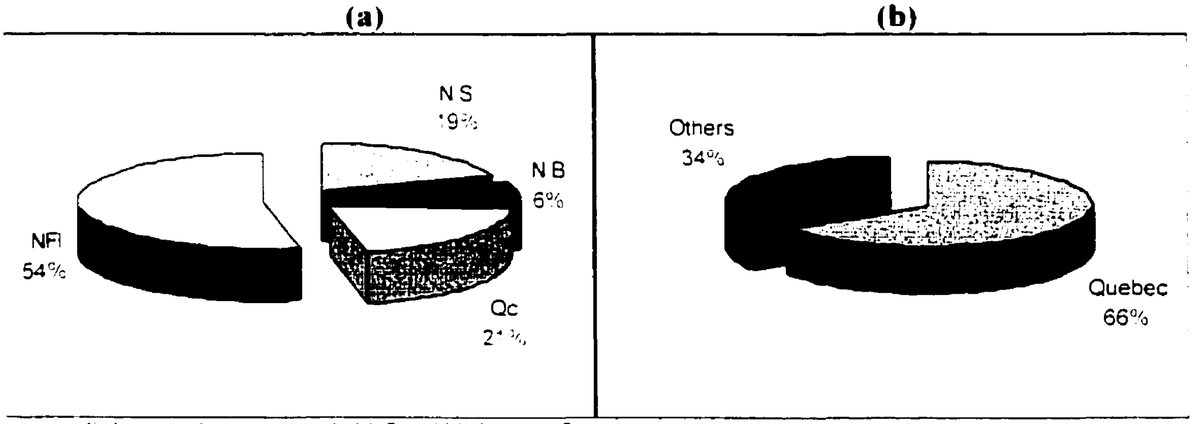
Two important geographical fishing zones characterize Eastern Canada: the Atlantic Ocean and the Gulf of St. Lawrence. Quebec fishermen are allowed to fish only in the Gulf of St. Lawrence[2] (with few exceptions) where they share their quotas with other fishermen from Nova Scotia and Newfoundland. Therefore, when Quebec landings are compared to those of the Atlantic Coast, they are less significant than if they are compared to the landings of the Gulf of St. Lawrence (figure 1-3). For example, in 1996, 7% of all species' landings for the Atlantic coast (657.800 mt) were recorded in Quebec and valued at $135.000 (12% of the total value). Meanwhile the same quantity represents 22% of the St. Lawrence landings (32% of the total value).

Cod, lobster and redfish have traditionally dominated the fisheries in the Gulf of St. Lawrence. In last twenty years, significant changes have taken place. The crab and shrimp fisheries greatly expanded as the cod and redfish fisheries closed down following the

[2] Anon . 1997

collapse of these resources. This collapse has had significant effects on fishermen, on processing fish plants and their employees. For example, there were 64 fish processing plants in Quebec in 1987, there were only 53 in 1996.

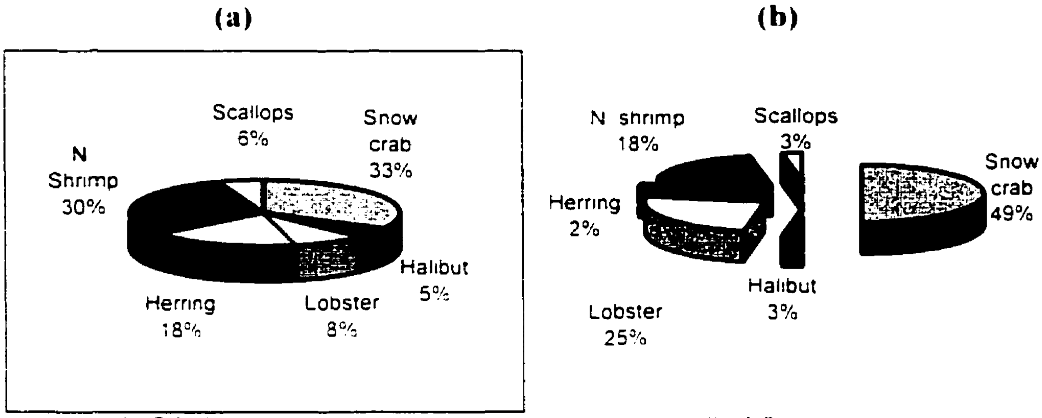
Figure 1-3: **The Quebec Shrimp Landings Compared to those of the Atlantic Provinces' (a), and Quebec's part of the Shrimp Landings from the Gulf of the St. Lawrence (1996) (b)**



Source: Fisheries and Oceans Canada 1997 and MAPAQ 1997

During these past years, there has been a sharp increase, especially in value, of crustaceans' landings in Quebec. In 1987, 58% of the value of Quebec landings was composed of crustaceans, compared to 66% in 1991, and 92% in 1996 (Anon. 1997). The decline of the ground fish catch and the increase in crustaceans' landings has contributed to this change. Figure 1-4 depicts the composition of Quebec landings in 1996 in terms of quantity and value. In 1995, Quebec's harvest reached its maximum value ($177 million) before decreasing by 24% in 1996. This decrease was mostly due to the dramatic drop in the price of crab. However, the volume of these landings increased by 6% in 1996 compared to the 1995 harvest.

Figure 1-4: **The Composition of the Quantities of Quebec Landings (a), and Their Respective Proportion in the Total Value (b), 1996.**



Source: Anon. 1997. Peches et aquaculture commerciales au Quebec en un coup d'oeil. Portrait statistique

The Quebec Seafood Industry:

The seafood industry is an important part of the Quebec food industry, even though it generated only 2% of industry sales in 1997 (MAPAQ, 1998). This importance comes from the value of its exports to other provinces and to other countries as well. In fact, Quebec exported $202 million worth of sea products, of which 70% comprised seafood products. More than 80% of the total exports were sent to the US (59%) and Japan (25%). Both of these countries import Quebec seafood products for different reasons. In the case of the US, the demand for seafood products is growing over time. This increase in demand can be related to different factors such as, lifestyle changes (a shift away from red meats to other forms of protein-rich products), increase in the frequency of out-of-home eating and technology improvements in the preparation and marketing of seafood products. Also, the change in demographics related to the increase in working and single consumers, has increased demand for convenience (ready to use) products for cooking and storage (Lorne, 1995, Kinnucan et al. 1993).

The reasons for Japan's imports are two-fold. Japanese households spend more on seafood products than on chicken, beef and pork combined. Thus, Japan keeps importing more and more seafood products to satisfy its growing population's demand. A decrease in Japan's fish harvest has also contributed to greater import need. Due to the sharp decline in Japan's fish catch that started in 1989 caused by overfishing, as well as increasing water pollution in the inland and coastal waters (Taha, 1996). Japan needs to import more seafood products.

Canadians are also including more fish and shellfish products in their diet, though red meat and poultry remained the most popular choices for many consumers (Statistics Canada, 1996). In 1996, total fish consumption reached almost 9 kg per person, up by more than 2 kg from the 1991 level. This increase was due mainly to improved retail marketing, the on-going demand for other sources of low-fat protein, and to the tastes and preferences of a growing population of Asian origin (Statistics Canada, 1997).

The Waste Disposal Issues

In 1996, the shrimp processing plants in Quebec had produced 5,163.70 mt of processed shrimp, and generated more than $ 54 million (MAPAQ, 1997). But this production resulted in more than 15,000 mt of waste[3]. Figure 1-5 shows the quantity of processed shrimp produced and the waste generated by the shrimp processing plants in Quebec. More than 80% of this waste (12,730 mt) was generated in the Gaspésie region, which represented a serious and costly problem for the processors. The managers of these plants said it cost them between $10,000 to $20,000 a year to get rid of there shrimp waste. Some of them paid the cost of transportation to a composting company, while others had to pay the dumping fees.

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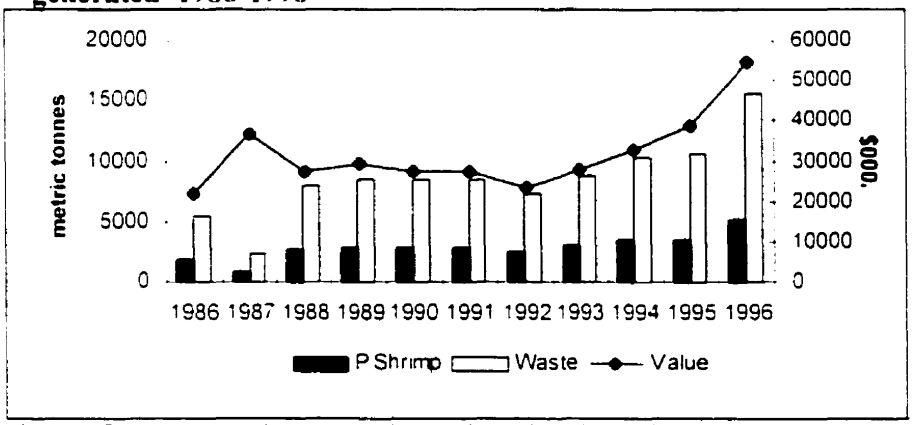
[3] the process of 1 kg of shrimp generates 0.75 kg of waste and 0.25 kg of final product

In addition, the dumping sites in the Gaspésie Peninsula are almost filled to capacity. According to Quebec environmental law[4], processing plants are the ones responsible for discarding the residue of production and the dumping sites are privately owned. According to the "Environnement et Faune Quebec" report, the situation in Gaspésie is problematic because of the critical situation of its landfill sites[5], therefore, the waste has to be managed and minimized. In fact, due to the negative characteristics of the residue such as attracting animals, causing odors, creating migration gases and making recycling more difficult, it is important to minimize the quantity of fish processing residuals being dumped in the landfills.

Figure 1-5: **The Value and the Volume of Shrimp Processed in Quebec & the Waste generated 1986-1996**



Source: MAPAQ 1997. Service des analyses et des politiques. Recueil des donnees historiques sur les peches et l'aquiculture commerciales au Quebec

Another way of disposing of the waste is by sea dumping. However, Environment Canada regulates the disposal of substances at sea through the Canadian Environmental Protection Act (CEPA), and deliver permits for sea dumping. In 1994, 126 permits were issued for fisheries waste for the Atlantic region, compared to only 60 permits in 1995. This drop is due to the continuing cod and capelin moratorium, and the increase in cost of a permit

[4] La loi sur les cites et villes, le Code municipal et la Loi sur l'amenagement et l'urbanisme, la Loi sur la qualite de l'environnement

[5] The region has 5 sites, two will close in 1999, one in 2002, and the other two will be filled in 2003.

fee ($2,500 instead of $50). CEPA is pushing the processors "*either to recycle their waste through fish meal plants or combine their sea disposal operations where no recycling opportunities exist*" (Environment Canada, 1994. Part VI, p3).

In other words, the shrimp processing plants have to deal with the ever-growing costs associated with the disposal of the residuals. With the mandatory closing of municipal landfills (two in Gaspésie) and the environmentally costly practice of ocean disposal, industry has to find a creative way to dispose of the increasing volume of waste.

Composting requires little technology and offers a cost-effective approach to handle fish processing wastes. When it is carried out properly, it can produce a beneficial fertilizer product which is stable, odor free, and easily stored (King, 1996). However, due to the perishable nature of shrimp residuals, composting piles require diligent management to prevent problems with odors and animal attraction. Moreover, composting should not be looked at as a money making venture, as most facilities often end up breaking even, at best (King, 1996).

Food processing residuals in general are rapidly becoming the focus of research as the new recovery products are believed to be a better alternative to the current methods of waste disposal. By being involved in the process of converting its waste into high value-added products, a fish plant can enhance its economic return. Therefore, scientists are investigating the possibility of making useful biochemicals from shrimp waste; one of these value added-products is called chitin.

Definition of Chitin

Chitin is the second most abundant polysaccharide (large molecules consisting of smaller sugar molecules strung together) in nature, after cellulose and before starch. It is found naturally in the shells of crustaceans, such as crab, shrimp and lobster. Insects, such as butterflies and ladybugs, have chitin in their wings. The cell walls of yeast, mushrooms and other fungi also contain this natural substance.

According to Simpson et al. (1994), chitin has a structural resemblance to cellulose. It is associated with protein in the exoskeletons of marine invertebrates, insects and in the cell walls of various fungi and algae. Chitosan is derived from the deacylation of chitin. Research has shown that chitin and chitosan are non-toxic, non-allergenic, and biodegradable. More than a hundred billion tons of chitin is annually produced by animals and microorganisms, but the amount of annually accessible chitin has been estimated at one hundred and fifty thousand tons (Tsugita, 1989).

On the other hand, cellulose and starch are key carbohydrates which plants use as a food source to build cell walls. In addition, they have widespread use in industry. Researchers and entrepreneurs see similar potential for chitin and chitosan. In fact, from 1950 to the present, a substantial amount of work has been published on these biopolymers and their potential use (Skaugrud and Sargent, 1990). The interest in chitin and chitosan was encouraged by the need to better utilize shellfish shells. Scientists worldwide began to chronicle the more distinct properties of chitin and its derivatives and understand the potential use of these natural polymers.

General Properties of Chitin and Chitosan

Many studies on chitin chemistry have shown that it has several properties. The most important are listed below:

- Chitin and chitosan are natural, non-toxic, high molecular weight, water insoluble, biodegradable and have a capacity to form films or coating.

- According to Muzzarelli (1977) and Austin (1988), chitin and chitosan are soluble in strong mineral acids and in anhydrous formic acid but insoluble in alkali.

- Chitin can be cast into films or membranes because of its high degree of crystallinity.

- Knorr (1991), proved that chitin can produce a number of flavor compounds when it is pyrolysed at high temperatures (about 900 °C).

- Chitosan is made from the deacylation of chitin. The characteristic difference between chitin and chitosan is their solubility. They are both insoluble in alkaline solutions and organic solvents, but chitosan is found to be soluble in dilute acid solutions. Therefore, chitosan has more industrial uses than chitin.

- Chitosan is a highly charged positively polyelectrolyte (NH_3^+). As many materials carry negative charges (eg: proteins), their interaction with chitosan produces electric neutrality. Thus chitosan adheres to natural polymers like hair and skin.

Methods for Preparation of Chitin and Chitosan

The most important source of commercial chitin is shellfish processing waste. Simpson (1994, p.158) wrote: "*chitin in shellfish waste is tightly associated with proteins, lipids, pigments and calcium deposits. Therefore, these source materials have to be pretreated to remove these components.*" In order to do so, two major steps are required: the demineralization of the shells, and the deproteinization or protein separation. These operations can be achieved either in a chemical way or in a biological one. The chemical method requires a large amount of alkali and causes a decrease in the molecular size of the product. Meanwhile, the biological method produces chitin with more consistent physiochemical properties.

As described earlier, chitosan is derived from chitin by deacetylation. The chemical deacetylation needs high temperatures and a large volume of concentrated acetic acid. Therefore, this method of extraction involves a high-energy cost and is not environmentally safe. However, the biological operation produces a consistent chitosan for maximum economic use of shellfish waste. Figure 1-6 is a suggested scheme for the production of chitin and chitosan by biological means.

Potential Applications for Chitin and Chitosan

The quantity of work done on chitin and chitosan shows an enormous potential for these natural polymers. Their physical, chemical, and biological properties could be used in industry and in sophisticated medical and biotechnological applications where ultra-pure, well-characterized grades are required (Skaugrud & Sargent, 1990). Nearly 1,000 research papers have been published on chitin and its derivatives and nearly 200 patents have been issued in the U.S., in addition to those issued in several other countries. Scientists from dozens of countries, including the U.S. and Russia gather every three years to present the newest research on chitin and its derivatives. Many believe these natural compounds have a great potential, especially in the biomedical, nutrition and food industries (Anon, 1995).

Chitin extraction and chitosan processing can produce different grades of purity depending on the treatment used. The following is a review of the use of chitin and chitosan with respect to their grade of purity. The review starts from the lowest grade to the highest one.

1- Industrial wastewater treatment: As mentioned earlier, the positive charge of chitosan allows it to form complexes with metal ions. It could then be used to filter out contaminants and pollutants from industrial wastewater. Presently, some companies decolorize their wastewater with ozone or other chemical treatments but these appear to be more toxic than the original chemicals. Therefore, they face a toxicity problem. However, wastewater treatment can be done with chitin chitosan in an environmentally safe way.

2- Protein recovery: At the end of 1970's and during the 1980's, scientists used chitosan for the recovery of proteins from several food processing waste. The results revealed the effectiveness of chitosan compared to various coagulating and flocculating agents.

3- Agriculture: For agricultural purposes, seeds can be coated with chitosan, protecting plants from germinating and resulting in crop yield increases. Recent results prove that a mixture of chitosan and liquid fertilizers sprayed over fruit trees produce beneficial effects by retarding superficial leaves and improving fertilizer retention. Chitosan has also been used in the formulation of a fertilizer called "Florograma" which has given encouraging results when used in cereals.

Fig. 1-6[6]. **Production of Chitin and Chitosan by Biological Means for Maximum Economic Use of Shellfish Waste.**

Shrimp shells

↓

Recovery of carotenoprotein by a trypsin-aided process for use as feed supplement for cultured salmonids

↓

Demineralization
with 1.75 N CH_3COOH for 12h at ambient temperature

↓

Further deproteinization with proteases (e.g. chymotrypsin)

↓

Decoloration with H_2O_2

↓

Washing and drying

↓

Chitin

↓

Deacetylation with chitin deacetylase

↓

Chitosan

---

[6] Source: Simpson (1994) p.164.

According to Hansen and Illanes (1994), the application of chitosan in agriculture is most promising, because it can act as a fungicide, virucide, growth enhancer, nutrient carrier and protective agent for plants and trees.

4- Human food and food processing: During the processing of chitin, crab/shrimp shells are deproteinized, obtaining a high quality protein for human consumption. One kilogram of this protein can be a substitute for 330 eggs (Knorr, 1982). Thus, it is a good substitute for egg white. Chitin and chitosan can also be used as a food additive, being a functional ingredient for texture control in foods. They can also be used in fruit juice production to reduce turbidity and act as a preservative.

5- Diet supplement: Since chitin acts like a fiber, it is largely indigestible and passes through the gut mostly unchanged. These fiber-like properties can be used to replace calories in food. Research has shown that chickens fed with a microcrystalline form of chitin were leaner than chickens fed with regular feed. As an added benefit, the study also found that chitin relieved the lactose intolerance caused by feeds containing whey, a cheese by-product containing 70 percent lactose. Normally, whey had limited use in animal feed, since it can lead to diarrhea. But chickens fed a substantial level of whey with chitin did not develop diarrhea (Austin et al., 1981). It is thought that this same effect may be achieved in humans. According to the results of Kono, the growth rate of all fish fed with 10% chitin supplement recorded the highest value indicating diet superiority (Knorr, 1991).

6- The application of chitosan in medicine: Over the past decade, researchers in Japan, Europe, and the United States have tested chitin and its derivatives in biomedical applications. Several experiments proved that chitosan facilitates and accelerates wound healing and reduces blood serum cholesterol. Other studies showed that chitosan stimulates the immune system (Knorr, 1991). Furthermore, chitosan can make strong surgical sutures that do not have to be removed as they slowly dissolve in the body. Allergic reactions seem to be almost nonexistent (Anon, 1995).

Chitosan has also been considered for pharmaceutical formulation and drug delivery applications. In these applications, attention is focused on chitin's absorption-enhancing, controlled release and bioadhesive properties. Synthesized from a naturally occurring source, this polymer has been shown to be both biocompatible and biodegradable (Dodane & Vilivalam, 1998).

Of all the applications of chitin and chitosan, health care applications offer the most potential in Quebec and Canada. However, the market will take time to develop them. The key factor is approval from Health Canada. In order to get such approval, an important investment in time and money is required. However, for potential Canadian investors, we believe that they will not have to spend much time and money for approval. Chitin properties will be able to lineage the extensive research and clinical trials already in progress in the US and Europe which study toxicity and optimize chitosan-based formulations for drug delivery (Dodane & Vilivalam, 1998). Furthermore, as a rule of thumb, if the U.S. Food and Drug Administration (FDA) gives its approval, it will not take too much further time for Health Canada to follow.

All commercial production of chitin and chitosan relies on available sources of waste crustacean shells. Even though the waste is plentiful, its availability varies with fluctuations in shellfish population and shellfish disease. In the following section, an estimation of the shrimp waste in Quebec is performed.

Forecasts of Shrimp Waste in Quebec

The quantity of shrimp waste is linearly dependent on the quantity of the processed shrimp (as mentioned earlier, one kilogram of raw shrimp produces 0.25 kg of processed shrimp and 0.75 kg of waste). Therefore, the estimation of the quantity of waste is the same as the estimation of the quantity of the processed shrimp. Ideally, the best way to forecast this quantity is by estimating the production function of the shrimp processing industry.

As defined in the literature, a production function is a mathematical model relating the maximum output that can be produced from given quantities of various inputs (McGuigan and Moyer, 1975). The major inputs are raw material, labor and capital. Therefore, to estimate the production function of shrimp processors in Quebec, data related to quantities of shrimp processed, the number or cost of labor hired by shrimp processors and the capital invested must be gathered. However, the only available data is related to the shrimp processed, the quantity of shrimp caught and the TACs. The data related to other variables was not specific to the shrimp industry. Wessells and Anderson (1992, p 224) said, "*...It is quite challenging to attempt to construct complete yet realistic economic models of seafood markets...It is even more challenging to empirically estimate these models without unduly sacrificing the structure of the model. Lack of data, as well as lack of reliability and accuracy of available data are common problems.*" It is always possible to estimate the portion of what would be the value of these missing variables for the shrimp industry, but the results would likely lack accuracy and reliability.

The objective of this study is to estimate and forecast the quantity of shrimp processed in Quebec. The data related to the Total Allowable Catch and the volume of the shrimp landings in Quebec was provided by Fisheries and Oceans Canada (FOC).

Meanwhile, the data related to the quantity of the shrimp processed in Quebec was provided by MAPAQ*.

According to FOC, the TACs in 1998 are the same as in 1997 and there will be no risk for the sustainability of the resource. On the other hand, the biomass of redfish and cod (the predators of shrimp) is very low in the Gulf. The recovery of cod abundance to average levels will take several years and a significant recovery of the redfish stock can only occur seven or eight years from now (Gascon, 1998). Therefore, we assume that the TACs will remain the same (20,031 mt) for at least five years.

The data related to the quantity of processed shrimp (PROC), the total allowable catch (TACs) and the Quebec landing (CATCH) is from 1985 to 1996. For forecasting purposes, PROC is the dependent variable. The correlation matrix shows that TACs and CATCH are highly correlated (which is obvious because CATCH depends on TACs). The correlation between TACs and CATCH is higher than the correlation between CATCH and PROC (Table 1-1). Therefore, the variable CATCH will not be introduced in the regression.

Table 1-1: **Correlation Matrix for Processed Shrimp, TACs and Shrimp Landings**

	PROC	TACs	CATCH
PROC	1		
TACs	0.729	1	
CATCH	0.725	0.753	1

The linear regression equation is defined as:

PROC = - 2038 + 0.328 TACs. Regression (1)

The regression is statistically significant (F=10.18 and P=0.011). The annual changes in the TACs explain 53.1% of the annual changes in PROC (R^2 = .531).

* MAPAQ: Ministere de l'Agriculture, des Pecheries et de l'Alimentation du Quebec.

Finally, there is a positive autocorrelation between PROC and TACs (Durbin-Watson statistic d^{8}= 0.93). These results are logical because the quantity of shrimp processed depends on many other variables such as the labor, the demand for processed shrimp and so on. However, the regression equation can be used to forecast PROC and compare it with the naïve forecast, the Moving Average forecast or the exponential smoothing forecast. Before this comparison is performed, the variables are verified to see if they are logarithmically related or not.

In fact, the correlation matrix (Table 1-2) shows that LnPROC is highly correlated to LnTACs and LnCATCH. Also, no autocorrelation between the independent variables is suspected.

Table 1-2: **Correlation Matrix for the Logarithm of the Total Processed Shrimp (LnPROC), Total Allowable Catchs (LnTACs) and of the Shrimp Landings (LnCATCH)**

	LnPROC	LnTACs	LnCATCH
LnPROC	1		
LnTACs	0.745	1	
LnCATCH	0.731	0.722	1

The regression equation is:

LnPROC = -5.20 + 0.445 LnCATCH + 0.927 LnTACs Regression (2)

The results show that this relationship is statistically significant, no decision can be made about the autocorrelation ($dL= 0.812<d=1.12< d_U = 1.579$) and 63.6% of the variation in dependent variable is explained by the variation of LnCATCH and LnTACs.

The most critical factor in the selection of a forecasting model is usually the model's ability to forecast accurately (Kress and Snyder, 1994). The methods used most often to measure the accuracy of a forecasting model are: a) the Mean Absolute Difference (MAD)

8 d_L = 0.971 and d_U = 1.33

which is the mean of the absolute values of the errors. b) the Mean Absolute Percentage Error (MAPE) which is used to express errors in percentages. c) the Mean Squared Error (MSE) which is used to select the forecasting model that minimizes large errors. A model with the lowest MAD or MAPE provides consistent accuracy and lowest average error. Meanwhile, a model with the lowest MSE minimizes major forecasting errors.

To forecast the quantity of the processed shrimp, six different models are used and their accuracy is measured by comparing the forecasted production to the actual production of processed shrimp.

The first model is the naïve forecast ($\mathbf{PROC_{t-1} = PROC_t}$, t represents year). The second model is the Moving Average with length 2 (the short moving average is used to smooth the series because the time series were not seasonal). The third and fourth models are the single and double exponential smoothing. The fifth model is the regression (1).

From LnPROC = -5.20 + 0.445 LnCATCH + 0.927 LNTACs

We derived the last model, which is:

$$\mathbf{PROC = e^{-5.20} * CATCH^{0.445} * TACs^{0.927}}.$$

The results of the forecasts using each of the previous models are shown in the appendix1.

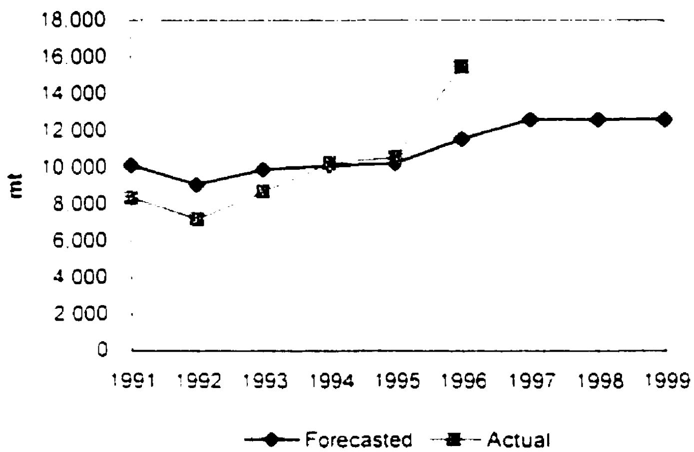
The quantity of the processed shrimp is well forecasted with the regression (2). In fact, the model derived from this regression has the lowest MAD, MAPE and the lowest MSE as well (Table 1-3). This model is then the most accurate and the most conservative. Figure 1-7 shows the predicted and the actual quantities of shrimp waste waiting to be processed.

Regression (2) predicts that 4,208 mt of processed shrimp is to be produced in Quebec in 1999 generating 12, 624 mt of waste.

Table 1-3: **Comparison of Errors of Time Series Models Used to Forecast the Processed Shrimp in Quebec.**

Forecasting Model	MSE	MAD	MAPE
Naïve Forecast	416,199.90	440.06	14.67%
Moving Average (Length 2)	431,276.00	470.00	14.00
Single Exponential Smoothing	408,131.00	441.00	15.00
Double Exponential Smoothing	273,699.00	438.00	15.00
Regression (1)	306,216.43	407.90	13.39
Regression (2)	257,341.71	386.75	12.60

Figure 1-7: **The Actual and the Predicted Quantity of Waste Generated by the Shrimp Processing Plants in Quebec**



Conclusion

The objective of this study is to estimate the quantity of shrimp waste generated by the shrimp processing industry in Quebec. Based on the stock assessments and future prospects of shrimp by the scientists at Fisheries and Oceans Canada, we estimated the total production of processed shrimp considering the total allowable catchs (TACs) and the total shrimp landings in Quebec. This estimation was used to derive the forecasts of the shrimp waste that will be generated in Quebec. Assuming that the stock of shrimp will remain the same for at least five years, we predict that during this period, the Quebec shrimp processors are expected to generate an average amount of 12,640 mt of shrimp waste annually. However, some limitations of the study must be pointed out. The regression chosen explains 63.6% of the variations in the quantities of shrimp processed. Some important variables that can affect the production of shrimp were omitted. Therefore, further research should be undertaken in this area to increase the confidence in the results.

CONNECTING SECTION 1

Two U.S. companies - one on the west coast and one in New Jersey - are already extracting chitin from crab waste: so are companies in Asia and Europe. They mostly produce a low grade chitin and chitosan. This is not the case in Quebec even though it has the largest shrimp landing in the Gulf of St. Lawrence. The Quebec shrimp processors should convert their waste into new value-added products instead of dumping them in landfills causing environmental damage.

There are numerous applications in which chitosan outperforms competitive products. However, the margins of profit appear to be too low, or product costs are not competitive. The production cost for high grade chitosan is twice as much as the synthetics (Lerner, 1998). In fact, the current methods (chemical method) for producing chitin and chitosan result in products with inconsistent physiochemical characteristics (Simpson et al., 1994) and the required equipment and material for the process are expensive and therefore the resulted production cost is high. However, the biological method of making chitin and chitosan using enzymes produces more consistent and highly purified products.

What are the production costs of making high level of purity chitin and chitosan using the biological method? Furthermore, is it even possible to produce chitin and chitosan profitably from shrimp waste when it is only available on a seasonal basis?

The following chapter is thus an attempt to answer these questions. An estimation of the production cost of making chitin and chitosan at the pilot plant level was performed applying the economic engineering concept. The cost-capacity factor was applied to the computed estimates in order to find the production cost at the industrial level.

CHAPTER TWO

Estimation of the Production Costs of Chitin and Chitosan

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Abstract

A cost estimate of a full-scale chitin production facility was prepared based on the results of the estimations at a semi-pilot[9] level. The estimates show that commercial production of chitin, chitosan and pigment would be profitable using a biological process. In fact, the respective production costs for one gram of chitosan, chitin and carotenoprotein is $0.65, $0.26 and $0.07. The respective gross margin of making each product is 90.71%, 96.17% and 98.06%. This is due to the simplicity of the process, the low capital cost and the use of enzymes instead of chemical acids that require stainless steel equipment and high-energy consumption.

Introduction:

The most critical factors that determine whether or not a chemical process plant will be profitable are its design, location and capacity (Desai, 1984). Process design is evaluated on the basis of factors such as an inexpensive and readily available raw material, minimum capital investment, low operating and maintenance costs, salable by-products and minimal pollution. In addition, the geographical location has an important bearing on total costs. As an example, if the plant is located near the market for the products, the firm has the advantages of quick delivery and minimum transportation costs. Finally, the plant capacity (or the plant size) depends on the market projections for the product and the availability of raw material and financing.

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[9] The hourly quantity of input processed in a semi-pilot plant varies between 10 and 100 kg. For the purpose of the study, the quantity processed per hour is 50 kg.

The purpose of this study is to estimate the production cost of value-added products: chitin, chitosan and carotenoprotein (pigment) from shrimp waste. In order to do so, an evaluation of the cost was performed at a semi-pilot level and then an estimate of the scaled-up process plant was determined by using the cost-capacity factor. All the estimates are based on a pilot plant site located at Macdonald Campus of McGill University.

First, a description of the production process and equipment is provided, followed by a cost estimation at a pilot plant level. Then, the production cost of a scaled-up process plant is estimated. The final section discusses the results and limitations of the study.

Production of Chitin, Chitosan and the By-Product Pigment

In general, the quality of an output relates to the quality of the input. Therefore, the quality of chitin and chitosan depend on the quality of the shrimp waste used in the process. During the summer of 1997, we surveyed all shrimp processing plants in the Gaspésie Peninsula. We noticed that the processing was carried out under highly sanitary conditions and generated a good quality shrimp waste. Furthermore, the processors assured us that the waste material could be collected in very good condition at a negligible cost in order to process it into chitin and chitosan. According to Doctor Simpson, his laboratory[10] has been supplied on several occasions with shrimp waste for processing into chitin/chitosan and pigments. The shrimp waste has always been shipped frozen and reached the laboratory in excellent condition. The chemical analysis of chitin/chitosan produced in his laboratory shows that it is of good quality. Thus, the new method of processing shrimp waste allows for

[10] The laboratory of Dr. Simpson at Macdonald Campus, McGill University, where the new method of making value-added products from shrimp waste was innovated.

the pilot plant to operate throughout the entire year instead of the designated shrimp processing season which takes place between the first week of April to the first week of November.

Description of the Production Process and Equipment Selection

The equipment required for the recovery of each of the by proucts is summarized in Table 2-1. This table indicates that some pieces of equipment are common to the processes for making chitin, chitosan and carotenoprotein (for example, the balance and the pH meter). The chemicals required in the recovery processes are few, non-toxic and relatively inexpensive. The following is a description of the process and the equipment used in each step. It must be noted that the duration of each step is based on the findings at the pilot plant level. In this study, it is assumed that each batch contains 50 kg of dried shrimp waste.

The first step is the preparation of the sample to be processed. Dried shrimp shells are blended using the grinder. The grinder used can process 50 kg of dried shrimp per hour. After that, some chemicals and enzymes are added and mixed with the blended shells. Six hours later, a filtrate (Filtrate 1) and a residue (Residue 1) are extracted from the filtration in Step 4. The filter system used is made from cheese cloth and a sieve. "Filtrate 1" is then precipitated and centrifuged in order to obtain "Residue 2" and "Filtrate 2". "Residue 2" is dried at room temperature in order to give a first final product called Carotenoprotein and "Filtrate 2" will be used for the enzyme preparation. Steps 5 and 8 can be executed at the same time (see PERT chart on page 35). In fact, "Residue 2" can be dried while "Filtrate 1" is precipitated. "Residue 2" can either be dried at room temperature or by using the drum dryer. A previous study estimated the production cost assuming that no dryer is used. This assumption resulted in a fewer number of batches that could be processed during a given period (drying one batch at the room temperature requires at least 8 hours versus 1 hour when a drum dryer is used). For the purpose of this study, a drum dryer is used in the process. During Steps 9 to 12, all of the proteins and minerals are removed from "Residue 2" which has been dried using enzymes and a steam kettle. The resulting product "Residue 3" is then decolorized, washed and dried using the drum dryer to obtain chitin. Chitin is then deacylated, washed and dried in a freeze dryer to obtain the final product, chitosan.

The pilot plant is assumed to operate 50 weeks a year. From the PERT Chart, we see that the production of one batch of chitin requires 90 hours. The longest step is Step 10 (deproteinization) requiring 72 hours and therefore is the only restriction for a continuous process. Thus, the maximum number of batches that can be processed during the 50 weeks is equal to 117[11] as each batch contains 50 kg of shrimp shells. Therefore, a total amount of 5,850 kg[12] of dried shrimp shells can be transformed into 890.95 kg[13] (15.23 % yield) chitin each year at the pilot plant. This quantity is equivalent to more than nineteen metric tons of shrimp waste produced by the processing plants [14](the shrimp waste contains an average of 70% moisture).

From the same process, a by-product (pigment) called carotenoprotein is produced. The yield for this pigment is 2%. Therefore, 117 kg of carotenoprotein will be produced in the course of chitin production. The complete production of carotenoprotein requires 23 hours. The first 8 hours of the process are shared with the production of chitin.

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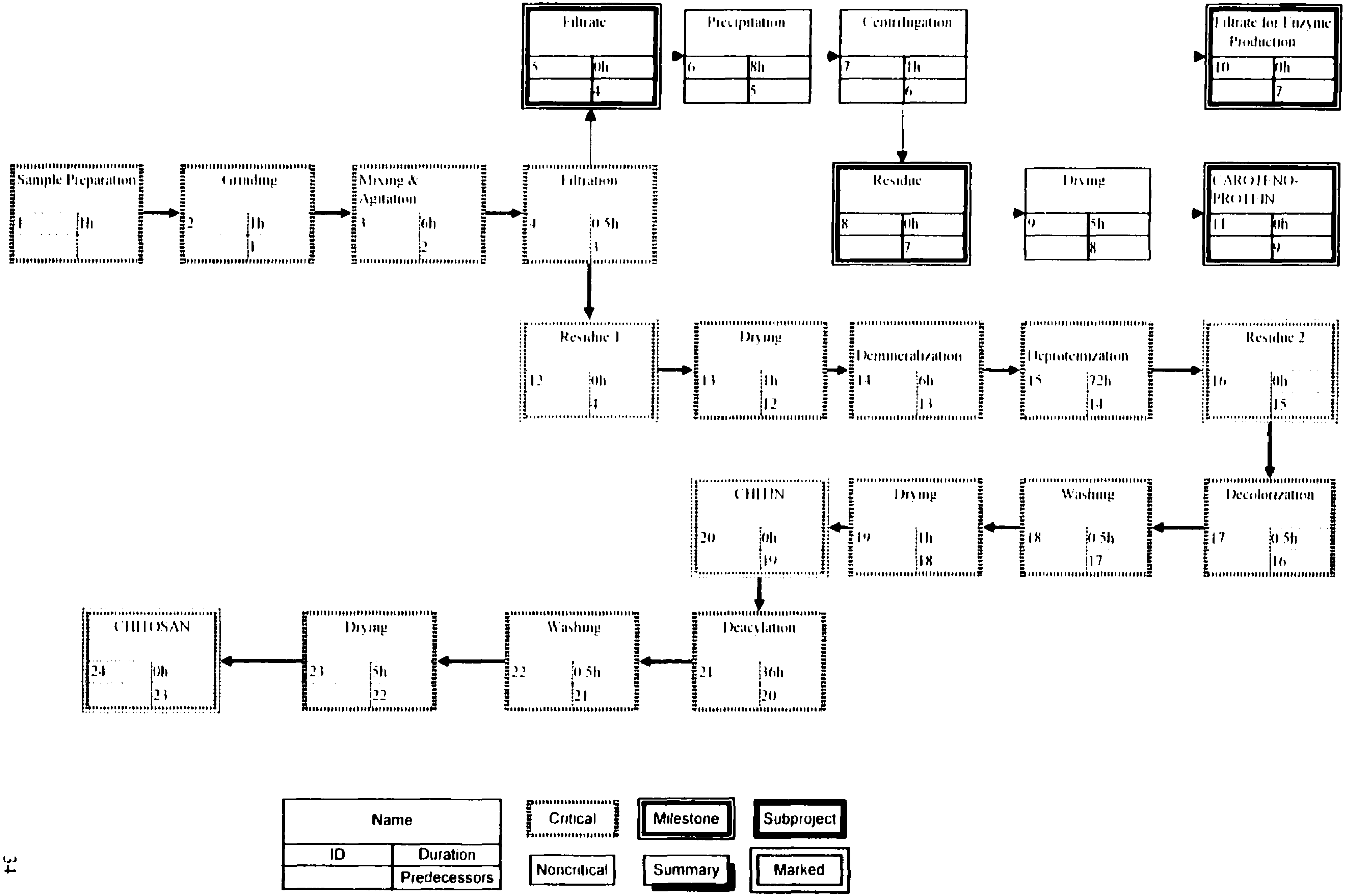
[11] 117=(50 weeks*7 days*24 hours) 72
[12] 5850= 50kg batch * 117 batches
[13] 890.95 kg of chitin = 5850 kg dried shrimp * 15.23% yield
[14] 19500 kg of shrimp waste = 5850 kg of dried shrimp 30%

If all chitin is deacylated to chitosan, the total production of chitosan will be 540 kg (the yield is 60.6% chitin or 9.23% dried shrimp shells). It must be noted that the process of one batch of chitosan requires 41 hours and it can be processed at the same time as chitin. Since chitin is needed to produce chitosan, the same number of batches of both products will be processed. Thus, 117 batches of chitosan will be processed during a year if the objective is to produce chitosan only.

Table 2-1: **Process Steps and Required Equipment for the Production of Chitin, Chitosan and Carotenoprotein from Shrimp Waste**

Step no	Designation	Duration (h)	Previous step	Equipment used	Output at the end of the step
1	Sample Preparation	1	0	Balance	
2	Grinding	1	1	Grindor	
3	Mixing & Agitation	6	2	Balance	
4	Filtration	0.5	3	Filter System	Filtrate 1 & Residue 2
5	Precipitation	8	4	Container	
6	Centrifugation	1	5	Centrifuge	Residue 1 & Filtrate 2
7	Drying (Residue)	5	6	Flat Surface	**CAROTENOPROTEIN**
8	Drying (Residue1)	1	4	Drum Dryer	
9	Demineralization	6	8	Container	
10	Deproteinization	72	9	Container	Residue 3
11	Decolorization	0.5	10	Steam Kettle	
12	Washing	0.5	11	Container	
13	Drying	1	12	Drum Dryer	**CHITIN**
14	Deacylation	36	13	Incubator Shaker	
15	Washing	0.5	14	Container	
16	Drying	5	15	Freeze Dryer	**CHITOSAN**

Pert Chart of the Integrated Approach of Making Chitin, Chitosan and Pigments from Shrimp Waste



Source: Pr B K Simpson, McGill University

Processing Costs Estimation

Production costs (operating costs) are the expenses necessary to maintain a plant, processing line or equipment in production (Zugarramurdi and Parin, 1995). They are vital to microeconomic theory. A profit maximizing firm sets production at a rate where marginal revenue equals marginal cost, with the condition that total revenue covers variable costs. But when the company has little control over prices, it focuses on the rate of production and minimizes costs (Georgianna and Hogan, 1986). The purpose of this study is to analyze the behavior of the production cost of three byproducts, and to find which range of production at which the pilot plant can operate and still make a profit. The most common bases for comparisons used in practice are the daily costs, the cost per unit of production, and the annual cost. In order to even out seasonal variations and to factor for infrequently occurring large expenses, the annualized basis was preferred (Humphreys and Wellman, 1996). Therefore, all the costs presented in different worksheets are annual (Appendix 2).

For a given project, cost estimates are prepared for two basic purposes: to determine the project's economic feasibility and to establish a budget for controlling costs. The degree of accuracy required determines which type of estimates to prepare (Desai, 1984). Also, cost estimating is particularly important to the manufacturer for pricing a product competitively to realize profit (Lovett, 1995).

There are a number of ways to estimate costs once they have been identified.. The most common approaches are price quotes, historical comparison and the industrial engineering method (Horton, 1994). For the purpose of this study, the economic engineering approach is used to estimate the production cost of the value added products. Economic engineering was chosen because it is a specialized field incorporating knowledge of microeconomics. The following are the assumptions made to simplify the calculation (Husack, 1982):

1- Each product is manufactured autonomously in a make-to-stock batch production flow shop.

2- As soon as the processing of a unit is completed on a machine, it is immediately moved to the subsequent machine for the next operation.

3- End product and input item stock out are not permitted.

4- The optimization objective is cost minimization.

5- The pilot plant is assumed to be located in a rented room at Macdonald Campus of McGill University.

6- Good management and practices are assumed at the pilot plant.

All the necessary cost items were identified from the lab experiments conducted by Dr. Simpson at McGill University.

The Equipment Costs:

Estimating the cost of equipment involves allocating the capital cost over the life of the equipment and considering the operating costs directly associated with the use of the equipment. The basic model to compute equipment cost is the annualized cost of capital (investment in the machine). The machines are assumed to last 25 years with no salvage value.

The annual equivalent cost of capital (AECC) is as follows (Lovett, 1995):

$$AECC = P * \frac{i(1+i)^n}{(1+i)^n - 1}$$

Where P is the cost of the equipment, i is the minimum attractive rate of return (i=10%) and n is the equipment's expected lifetime (number of years). The second element of the multiplication is also called the Capital Recovery Factor.

The cost of a piece of equipment is allocated to the production cost of each of the products based on the frequency of use of that equipment in the process. For example, the pH-meter is used in the making of chitin, pigments and chitosan. Therefore, the portion of the pH-meter's cost allocated to the production cost of each product is equal to 33% (1/(1+1+1)) of the AECC of the pH-meter. This portion is based on how many times the equipment was used in the process of getting the output (Table 2-1, p33). In other words, the portion of the fixed cost (FCM) related to each piece of equipment is equal to:

FCM = (Cost Portion Allocated * AECC)

The list of equipment and the cost portion allocated to each process is shown in the respective cost breakdown tables, as is the annual equivalent cost of capital of each machine. The cost breakdown tables are presented in Appendix 2.

Labor:

Two lab operators will conduct the process. The labor cost is as follows: they will each work 40 hours a week during 48 working weeks at $9.00 per hour. The annual cost of labor is $36,000.00 (including 4% for vacation). At the same time, the lab operators will make different value-added products. Since we are making different products at the same time, the net realizable value method was applied to allocate portions of labor costs to the production cost of each product avoiding multiple allocation of these costs

Joint Costs:

The term joint costs applies to two or more kinds of products, which are produced simultaneously and are not identifiable as individual types of products, until a certain stage of production, the split-off point is reached (Humphreys, 1987). Joint costs are combined costs up to the point of separation. To distribute the joint costs amongst chitin, chitosan and pigments, the net realizable value approach is used (also called relative sales value method). It assigns the largest part of the common costs to the product with a highest market value. The allocation is based on net realizable value (Appendix 2, Table A2-4)

Operating Costs Estimation:[15]

Operating costs or manufacturing costs are the expenses incurred during the normal operation of the pilot plant. There are two categories: direct and indirect costs.

Direct Costs:

These costs are related to the factors that contribute directly to the production of the final outputs. From the results of the pilot plant, the quantity of the direct material required to process one batch of 50 kg of dried shrimp waste was calculated. The direct costs are as follows:

1. Inputs: raw materials and the necessary chemicals to produce the final product. The cost of raw materials is the cost of handling and transporting the shrimp shells from Matane to Montreal. The cost of the chemicals is obtained from price catalogues of companies supplying the laboratory of Macdonald Campus.

[15] The estimation of these costs is adapted from Humphreys and Wellman, 1996

2. Power required to run the equipment is the price paid by McGill University per kW-hour per machine when it is in use.
3. Labor: the cost of labor is considered as a shared cost by all the final outputs. The net realizable value method was applied to allocate the cost to each final product.
4. Supervision: the cost of supervision is equal to 15% of the labor cost.
5. Maintenance: the maintenance cost is equal to 4% of the portion of capital cost allocated to each product. The cost itself is 60% for labor to maintain the equipment and 40% for parts.
6. Heat: according to the Facilities Management Department of McGill University, the cost of heating one square foot is $1.25 per year. Thus, the total heating cost is $672.50 per year. This amount is allocated to the different outputs by using the net realizable value method.
7. Payroll charges includes workers' compensation, pensions, group insurance, paid vacation and holidays, social security, unemployment, and so on. Payroll charges represent 32% of total labor cost, supervision cost and 60% of maintenance cost (the equivalent of the labor part).
8. Contingencies (or miscellaneous) costs are added to the estimate to allow for changes that may occur[16]. Cost contingencies range from 1 to 5% of the direct costs. The average rate of 3% was chosen for this analysis.

Indirect Costs:

These costs are not directly assigned to the end product. Many indirect costs are related to the direct costs. Some companies use a range of ratios or factors, which are applied to direct labor and materials to calculate the indirect costs. In this category, the following costs were identified:

1. Depreciation: is the reduction of the market value of a piece of equipment. For this analysis, the cost of capital method was used. All the electrical equipment will last 25 years with no salvation value.
2. Rent: the required space for the pilot plant is about 50 m^2. The average rental cost for one squared meter in an industrial area on Montreal Island is about $7.00 per month[17]. The annual rent is therefore $4,200.00. This amount is allocated to the different output using the net realizable value method.
3. Insurance: According to McGill Risk Management & Insurance Department, the cost of insurance is 1.25% of the value of the equipment. Therefore, insurances costs were allocated to each product based on the proportion of the equipment used in the process.
4. Plant overhead costs: these costs are also called the indirect costs of manufacturing. They are allocated on some base believed to be equitable[18]. They are assumed to be equal to 40% of the cost of labor, supervision and maintenance.

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[16] American Association of Cost Engineers: Standard No. 10S-90, from Humphreys and English (1993)
[17] This is a rough estimate given by some realtors surveyed.
[18] AACE: Standard No. 10S-90, from Humphreys and English, Project and Cost Engineers' Handbook, 1993.

Results and Discussion

Results of the production cost calculation are summarized in Table 2-2. The lowest cost of all value-added products occurs when the pilot plant is functioning at its full capacity. An increase in use of 20% (from 80 to 100), results in the following decreases in the production costs: 8% for pigments, 1.25% for chitin and 1.6% for chitosan. The pilot plant can be efficiently exploited at 80% capacity. In fact, as shown in the figure 2-1, the gross margin of all products increases with capacity use. However, the marginal change of the GM starts slowing down after the capacity has reached 60%, and remains almost unchanged when the plant operates between 80% and 100% of its capacity.

Table 2-2: **The Production Cost of 1g of the Different Value-Added Products with respect to the Capacity Use of the Pilot Plant.** [19]

PLANT CAPACITY USE	20%	40%	60%	80%	100%
Dried Shrimp Shells Processed (kg)	1.170	2.340	3.510	4.680	5.850
Production Cost of 1g Carotenoprotein	0.363	0.232	0.189	0.167	0.154
Production Cost of 1 g Chitin	0.363	0.33	0.323	0.319	0.315
Production Cost of 1 g Chitosan	0.872	0.77	0.744	0.731	0.719

The concept of gross profit margin was used for the analysis because the health of a firm is reflected by its profit margin (Zugarramurdi and Parin, 1995). Also, the performance of any company depends on the amount of sales realized and the production costs of the goods sold. Therefore, management and investors are intensively interested in gross profits and its changes (Horngren, 1993). The gross profit margin must be large enough to cover operating expenses and produce a net income.

[19] See tables A2-6, A2-7 and A2-8 in appendix 2 for detailed calculation.

The gross margin of the pilot plant exceeds 90% (Table 2-4) despite using discounted selling prices (the price of chitin, chitosan and carotenoprotein). As we assumed that good management and practices at the pilot plant, the gross profit margin will be in the 60% range. These high margins are mostly due to the price reference used to compute them. They are more expensive than bulk purchases for commercial scale. As an indication, in 1999 the gross margin of major chemical industry (in United States) is as follows:

Table 2-3: **Gross Margin of the Major Chemical Industries in the United States in 1999 and the Average of the Previous Five Years.**

INDUSTRY	GROSS MARGIN	5 YEARS AVERAGE
Synthetic Advanced Polymers	62.2 %	60.1 %
Chemical – Major diversified	33.1 %	36.2 %
Agricultural Chemicals	31.9 %	33.4 %

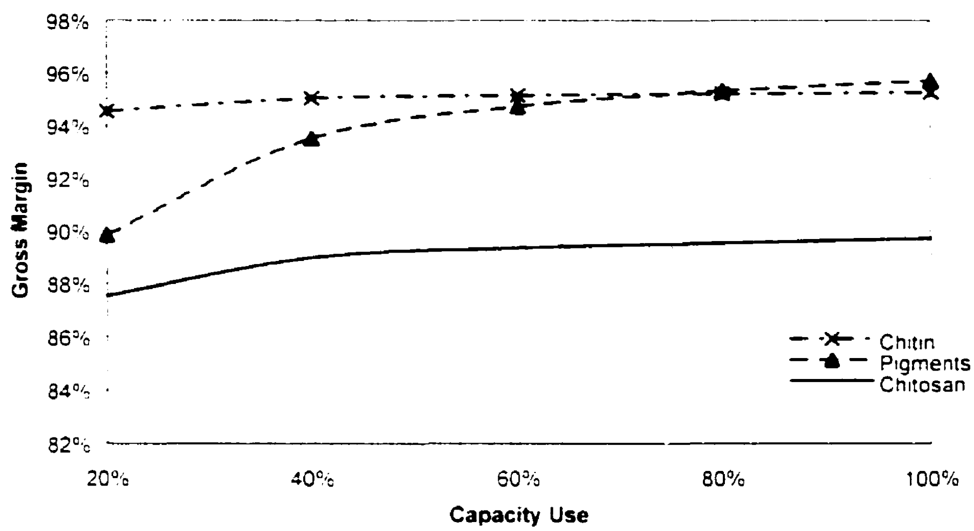
Source: http://www.moneycentral.msn.com

Table 2-4: **The Unit Gross Margin of the Three By-Products at the Pilot Plant Level[20].**

Plant Capacity Use (%)	20%	40%	60%	80%	100%
Production Cost (1g)					
Chitin	$0.36	$0.33	$0.32	$0.32	$0.32
Pigments	$0.36	$0.23	$0.19	$0.17	$0.15
Chitosan	$0.87	$0.77	$0.74	$0.73	$0.72
Reference Price ($/g)					
Chitin	$6.67	$6.67	$6.67	$6.67	$6.67
Pigments	$3.58	$3.58	$3.58	$3.58	$3.58
Chitosan	$7.00	$7.00	$7.00	$7.00	$7.00
Gross Margin (%)					
Chitin	94.56%	95.05%	95.16%	95.21%	95.28%
Pigments	89.85%	93.53%	94.73%	95.33%	95.71%
Chitosan	87.54%	88.99%	89.37%	89.56%	89.73%

[20] See Appendix2, Tables A2-6, A2-7 and A2-8 for more details.

Figure 2-2: **The Gross Margin of Producing the Value-added Products From Shrimp Shells at the Pilot Plant Level.**



Chitin is one of the inputs used to make chitosan, thus explaining its higher gross margin when compared to chitosan. On the other hand, the production cost of chitosan is almost double that of chitin. In fact, the total production cost of chitin is a part of chitosan's cost of production. Also, the reference price of chitosan might be underestimated. In fact, the prices listed in different catalogues[21] vary between 0.99 $/g and 98.4 $/g for chitin. Meanwhile, the prices of low-grade chitosan vary between 0.11 $/g and 16.3 $/g. We based our analysis using a reference price of 6.67 $/g for chitin and 7 $/g for chitosan in order to present a conservative scenario and to compensate for the risk of underestimating the production cost of these value-added products.

[21] Price catalogue of Sigma-Aldrich Canada Ltd, Pronova and other lab suppliers.

Cost Estimates of Scaled-Up Process Plant

A great deal of research has been done on production cost estimates for chemical plants (Guthrie. 1984). Researchers studied:

1). Cost-capacity factor estimates applied to major items of equipment or to complete chemical plants (Pikulik and Diaz. 1977). (Remer and Idrovo. 1990).

2). The relationship between cost capacity to estimate operating costs for plants of different sizes (Black. 1982).

3). Factored operating costs correlation (Parin and Zugarramurdi. 1994).

The concept of cost-capacity factor was introduced for the purpose of investment estimation. This method which is widely used, helps to quickly estimate operating costs. It is based on the concept of economies of scale. Williams (1960) originally stated that the total investment (I_1, I_2) for two plants with different capacities (Q_1, Q_2) but producing the same product are linked by the six-tenths rule. This relation is formulated as follows:

$\mathbf{I_2 = I_1 (Q_2 / Q_1)^x}$ where x is the cost-capacity factor.

"I_i is the cost of the equipment required to produce quantity Q_i"

The average value of x tends to be 0.6. But Remer and Chai (1990a. 1990b) found that the average value of x for 200 chemical processes was equal to 0.7. Therefore, to estimate the production cost (the fixed costs) of these value-added products at the industrial level, we apply the cost-capacity factor to the capacity of raw material that can be processed and assume that:

1. The plant will be used at its full capacity (100%).
2. The cost-capacity factor is equal to 0.7.

3. The pilot plant production cost estimates are based on the quantity of waste processed and the cost of output produced.
4. In general, the total cost of production is the sum of fixed costs, variable costs and semi-variable costs. The semi-variable costs are neither fixed nor variable and they do not affect the gross profit. We assume that there are no semi-variable costs (SVC) for the purpose of this study[22] Therefore, the total cost is the sum of the total fixed and total variable costs.
5. The variable costs are directly proportional to the quantity of shrimp waste processed. They are the costs of processing (raw material, chemicals) and power to run the machines. Labor cost is also considered variable but not linearly dependent on the volume of shells processed. In order to scale-up the labor cost, we assumed the labor requirement would vary by 0.25 power of the capacity ratio when processing plant capacities are scaled up (Jelen and Black, 1983). Other variable costs are those related to supervision, payroll charges and overhead costs. These costs are computed in the same way as the pilot plant level.
6. The fixed costs are scaled up using the cost-capacity factor of 0.7. The fixed costs are for depreciation, rent, insurance and heating. The maintenance costs are also extrapolated using the cost-capacity factor because they are equal to 4% of the investment. For each product, we scaled up the respective portion of the capital computed when the pilot plant is operating at its full capacity.

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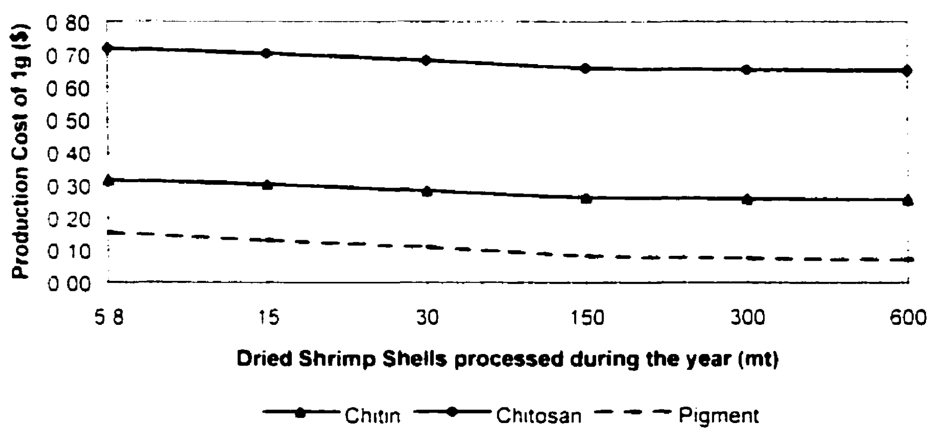
[22] In general, semi-variable costs are the costs of administrative services, management and distribution (Humphreys, 1987).

Figure 2-3 depicts the production cost curve of each byproduct plotted against the quantity of dried shrimp waste processed.

Table 2-5: **The Estimated Production Cost of One Gram of the Value-Added Products at the Industrial Level.** [23]

Dried Shrimp Shells (Kg)	5,850	15,000	30,000	150,000	300,000	600,000
Pigment Total Production Cost ($)	17,982	38,900	65,604	245,352	448,486	832,557
Chitin Total Production Cost ($)	280,765	690,814	1,292,732	5,987,848	11,798,424	23,368,042
Chitosan Total Production Cost ($)	388,010	973,756	1,887,935	9,111,909	18,095,867	36,021,517
Pigment Produced (Kg)	117	300	600	3,000	6,000	12,000
Chitin Produced (Kg)	891	2,285	4,569	22,845	45,690	91,380
Chitosan Produced (Kg)	540	1,385	2,769	13,845	27,690	55,380
Production Cost per gram						
Pigment ($/g)	**0.15**	**0.13**	**0.11**	**0.08**	**0.07**	**0.07**
Chitin ($/g)	**0.32**	**0.30**	**0.28**	**0.26**	**0.26**	**0.26**
Chitosan ($/g)	**0.72**	**0.70**	**0.68**	**0.66**	**0.65**	**0.65**

Figure 2-3: **Estimated Production Costs of the Value-Added Products at the Industrial Level (cost of one gram)**



Results and Limitations:

In general, high production rates allow greater use of facilities. The increased volume of production activities spreads fixed costs over a larger quantity of products produced (Boger and Liao, 1990). That is why the production cost of each of the value added products decreases with the increase of the capacity use of the pilot plant. The cost of producing one gram of chitin, chitosan and carotenoprotein (pigments) is respectively $0.315, $0.719 and $0.154 at the pilot plant level. For a plant processing 2,000 mt of shrimp waste a year, using the biological process to recover the value added products from the waste would result in the production of 91 mt of chitin, 55 mt of chitosan and 12 mt of carotenoprotein. The respective production costs for one gram of each product is $0.26, $0.65 and $0.07. Slight economies of scale exist up to the processing of 500mt shrimp waste. Thus, costs of producing chitosan is almost double that of chitin.

How accurate are these estimates? There are some limitations to this study. These shortcomings relate mainly to data problems. The cost of different pieces of equipment did not include the installation costs. The energy charges were theoretical estimates and may not be the best representation for the selected equipment. The cost of the acquisition of the land to build the plant and the related construction costs were substituted by the cost of the rent. Therefore, a scale up of the cost based on the cost of the rent may not be the best estimate for the liabilities. As a result, the production costs of the value-added products might be underestimated. However, other factors might contribute to an overestimation of these costs such as the method of scaling up the labor costs. It did not take into consideration the eventual automation of some steps of the production process as it may reduce the need for

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[23] See Appendix2, tables A2-10, A2-11 and A2-12 for details.

personnel. The estimate of some costs (electricity, insurance, heat and rent) were based on what would happen if the pilot plant was set up at Macdonald Campus which might change if the plant was in an industrial area. Finally, the cost of material used for the process was based on the price paid by the laboratory to Sigma Chemical Company. These prices were more expensive than bulk purchases of those materials for commercial scale.

Overall, these estimates are preliminary estimates since, their approximate degree of accuracy falls between 25 to 40 percent because of the method used (Desai, 1984). We believe that the biological process of making chitin and chitosan is much cheaper than the chemical process since it does not require high energy consumption, nor a great deal of chemicals. Furthermore, the results of this study encourage further study of a complete plant design and detailed description of every item involved in the process. This would allow for a thorough investment and financing analysis.

CONNECTING SECTION 2

The success of an enterprise in recovering and using bio-ingredients from seafood processing waste depends on: the availability of predictable volumes of waste, processing requirement, ease of the process, volume and economic value of the final products, competing products and potential market. In general, the economic evaluation of any resource recovery operation will depend critically on the revenues expected from the sale of recovered products.

The first paper analyses the possibility of making chitin and chitosan from shrimp processing wastes in Quebec. For the next five years, it is estimated that the shrimp processing industry will generate on average more than 12,000 metric tons of shrimp waste every year. This abundant waste material is largely unused. In addition, this waste can be transformed into high value-added commercial products (chitin and chitosan) instead of converting it into low value by-products like compost, animal feed or simply dumping it in landfills or the ocean. The second paper estimated the production cost of chitin and chitosan and found the gross margin of making these value-added products varies between 90 and 98 percent.

In practice, any industrial development starts with a number of questions: How many tons of a product can be sold? At what price? To whom? What is the current supply? Thus, we ask the same questions about making high-grade chitosan in Quebec. To answer some of these questions, an investigation of the potential market for high-grade chitosan is performed in the third paper.

CHAPTER THREE

The Market Potential for High Grade Chitosan in Quebec

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Abstract

The primary objective of this study is to examine the market potential for high-grade chitosan in Quebec. The target market for this product was the Pharmaceutical & Medicine Industry. Based on related data for cellulose derivatives, the Bass Model was used to forecast the sales of high-grade chitosan in Quebec. It is estimated that the potential market for chitosan is worth 37 million dollars (in 1999 prices) cumulative for a period of 20 years of market penetration. In the first year of marketing chitosan, sales in Canada (high-grade) are expected to reach $ 3.2 million including $ 1.5 million in Quebec.

Introduction

The industrial production and use of chitosan has been steadily increasing since the 1970s (Dunn et. al. 1997). The Japanese production of chitosan increased 37% each year from 1978 to 1983. In 1983, this production was 311 mt and reached 1270 mt by 1986. Major applications were found in food processing and wastewater treatment. In the United States, chitin and chitosan is used in agriculture and cosmetics industries (Anon. 1995). However, the industrial application of chitosan is oriented towards producing high-value products for other uses, such as cosmetics, drug carriers, semi-permeable membranes, and pharmaceuticals. These new applications are fueled by the large difference in value between the products and the low-cost polymer. Biotechnology is undertaking large-scale production of high-value bio-products. Since chitosan membranes and gels have great potential for use in immobilized cell culture systems, the most profitable market segment seems to be within the pharmaceutical sector. It is primarily for this reason this study is focused on the pharmaceutical and medicine industry, especially since chitosan produced through an enzymatic process such as the one used in this study, is of a high-grade quality.

This study estimates sales of high-grade chitosan to the pharmaceutical & medicine industry in Quebec. As chitosan is a new product for the industry (in Quebec), historical sales data is not available. Therefore, we treated it as an innovation and we applied the Diffusion of Innovation Theory to forecast the demand (sales) for high-grade chitosan.

In order to reach the objective of the present study, an overview of the pharmaceutical & medicine industry in Canada and in Quebec is first presented, followed by a review of the Diffusion of Innovation Theory and a description of some diffusion models and diffusion functions. Forecasting methods without a relevant database and a discussion of the Bass model is presented in the second section and the sales forecast for chitosan and the limitations of the study are presented in the final section.

Overview of the Pharmaceutical and Medicine Industry in Canada

The Canadian pharmaceutical industry first developed in Montreal at the turn of the century[24]. Even though this industry has expanded within other provinces (especially Ontario), it remains dynamic in Quebec. The Quebec pharmaceutical industry benefits from a strong research infrastructure and synergies between companies, universities and public and private research centers.

The pharmaceutical industry is an important contributor to the Canadian economy. It accounts for 1 percent of manufacturing employment and 10 percent of all industry research and development (R&D) expenses. This industry recorded high rates of profit during the late 1980s and early 1990s. The gross operating profit margin was in the order of 30 percent in both 1986 and 1992. A comparison with other R&D-intensive sectors showed that the return on capital in the Canadian pharmaceutical industry was higher than in other industries (figure 3-1)

The Canadian pharmaceutical industry is characterized by high competition and a profitability with above-average wage rates. The industry is an integral part of the health care system in Canada.

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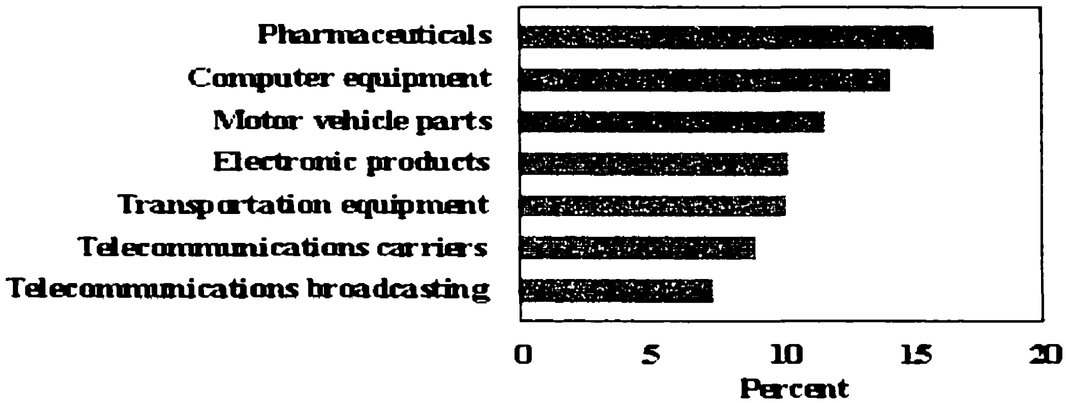
[24] Gouvernement du Quebec. MICT 1993. *Focus on the Pharmaceutical industry*. P.5

Figure 3-1: **Return On Capital Employed**[25]



Source: Statistics Canada, *Financial Performance Indicators for Canadian Business*, Catalogue No. 61F0058XPE, 1996

Demand for Pharmaceuticals

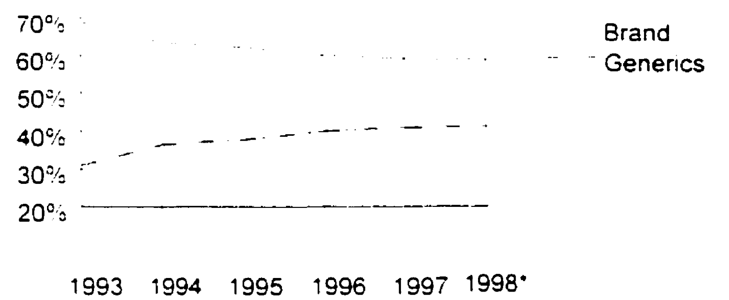
Prescription drug sales in 1998 amounted to over $7 billion in Canada. The Canadian market is relatively small (≅ 2% of global pharmaceutical sales) compared to the US market (40% of the global market). However, Canada ranks eighth in the world in terms of consumption of pharmaceutical products. Canadians are the world's biggest users of medicine, due to the social programs available to them, which includes free access to the health care system.

Over the past ten years, generic drugs acquired a large market share of the number of prescriptions written in Canada. The reason behind this increase was mostly the result of the provinces' efforts to encourage substitution toward lower-priced drugs, usually generics. For example, in 1998 the generic sector represented 41.2 percent of the total number of prescriptions filled in Canada. This represents an increase of 39.8 % of the volume, and 17.4 % of the value in 1996 (Coull, 1998). As a result, many multinationals

[25] Pulled from http://strategis.ic.gc.ca/SSG/ph01429e.html

have generic divisions or close ties with generic companies. Figure 3-2 depicts the evolution of the prescription market share of the both generic and brand name drugs.

Figure 3-2: **Prescriptions' Market Share in Canada from 1993 to 1998**

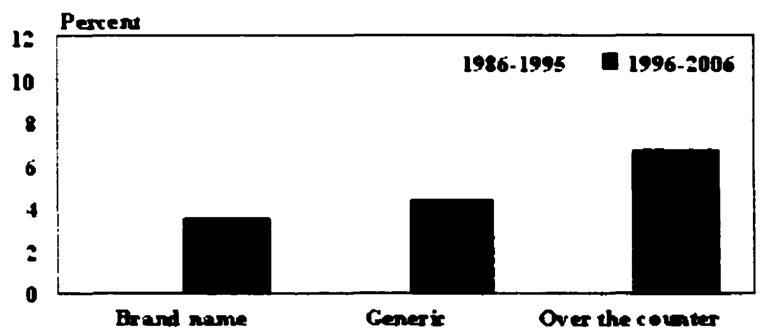


*12 months ended August, 1998
Source: Douglas Coull The Globe and Mail. Tuesday October 20, 1998. Page C6.

According to the Health Industries Branch of Industry Canada, the total real growth of prescription brand-name drug sales from 1996 to 2006 is expected to reach approximately 3.5 percent a year, compared to the 4.1 percent growth seen during 1986-1995 period (Industry Canada-Health Industries Branch, 1998).

This slower projected growth is tied to the unwillingness of both public and private drug plans to freely reimburse rising drug expenditures. It must be noted that in the long run, the growth rate of the market will inevitably rise given the growing aging population. Over-the-counter (OTC) products are anticipated to increase in sales. OTC sales are expected to grow at 6.8 percent a year over the next decade, compared to the 5.1% increase from 1986 to 1995[26]. The personal income growth and a turning away from prescription drugs will cause this change. In addition, some important prescription drugs will soon be available over the counter in Canada[27]. An increase of drug consumption will result on an increase of drug production. This results in more demand for the raw materials to make the drugs. Among these raw materials are polymers, that can be replaced by chitin and chitosan. Figure 3-3[28] summarizes the growth of Canadians' expenditure in pharmaceuticals (1986-2006).

Figure 3-3: **Annual Consumer Expenditure Growth in Pharmaceuticals (cst 1986 $)**



Source: W.N. Palmer & Associates, "Demand Outlook for Pharmaceuticals in Canada," Ottawa, 1996.

The Major Actors in the Canadian Market:

The Canadian-owned generic companies use a highly efficient manufacturing process to produce and sell lower-priced copies of drugs that have come off-patent, or over the counter products (non-prescription). Table 3-1 shows the ranking of pharmaceutical companies (sales) in the Canadian market, for the first half of 1998. Six of the top ten pharmaceutical companies listed bellow operate within Quebec. Therefore, Quebec represents an ideal place for the pharmaceutical industry investments.

[26] Industry Canada-Health Industries Branch. Business Information by Sector. Pharmaceuticals: Growth Prospects for the industry.
[27] http: strategis.ic.gc.ca SSG ph01430e.html
[28] Pulled from http: strategis.ic.gc.ca SSG ph01430e.html

In general, pharmaceutical companies tend to establish in large metropolitan areas possessing the required distribution networks and scientific infrastructure. It is not surprising to see the strong presence of this industry in Ontario and Quebec (Table3-2) and concentrated in the areas of Toronto and Montreal.

Table 3-1: **Top Pharmaceutical Companies in Canada in 1998'**

Company	**Sales ($million)**	**Market Share %**	**1-Year change %**
Merck Frosst*	542.2	7.6	6.2
Johnson & Johnson*	404.1	5.7	13.3
Glaxo Wellcome	389.9	5.5	10.5
Astra Pharma	354.9	5	18.4
Novartis*	346.1	4.9	8.4
Apotex	325.8	4.6	29.3
Bristol-Myers*	317.4	4.5	16.3
American Home Product	277.8	3.9	11.6
Abbott*	272.8	3.8	12.8
Pfizer*	291.5	4.1	34.7
Total Canadian Market	**7124.1**	**100.0 %**	**13.7 %**

' Data covers August, 1997 to July, 1998.
*Established in Quebec
Source: Douglas Coull The Globe and Mail, Tuesday October 20, 1998, Page C6.

Table 3-2: **Provincial Distribution of the Pharmaceutical Companies, 1994**

Province/ Region	**Number of Establishments**
Atlantic	3
Quebec	42
Ontario	54
Prairies	3
British Columbia	4

Source: Statistics Canada, Manufacturing industries of Canada: National and Provincial Areas, Catalogue No. 31-203-XPB, annual.

In 1995, the largest production region within the pharmaceutical and medicine industry was Ontario with $2.7 billion in sales (48.9% of total Canadian sales). The second largest producing province was Quebec with $2.6 billion (47.8% of total Canadian sales). It is clear that almost all of the Canadian production comes from Ontario and Quebec.

The main manufacturing inputs used by the Canadian pharmaceutical industry are fine chemicals, which represented 17.5 percent of the value of gross output in 1992 ($1,294.50 million[29]). Unfortunately, the production of these chemicals is extremely limited in Canada, as up to 80 percent of these products are imported (Industry Canada-Health Industries Branch, 1998).

Grouped within these fine chemicals are polysaccharides and their derivatives. Polysaccharides are used as carriers for the Hydrophilic Matrix (HM):

"*... HM systems based on polysaccharide carriers remain a highly popular design of sustained-release (SR) dosage form. In its simplest form, an HM device is a compressed powder mix of drug with a water-swelling viscous polymer. A variety of other excipients may optionally be included to aid tableting properties. On contact with water or body fluids, an HM dosage does not disintegrate, but rapidly develops a relatively impervious mucilaginous surface barrier which retards further ingress of water and acts as a rate-controlling barrier to drug release...The great majority of HM dose forms are tablets or capsules for oral administration. However, HM devices have also been utilized for drug delivery via other routes, e.g., to the buccal mucosa, periodontal cavity, eye, rectum, and cervical canal.*" (Melia, 1991 p396)

There is a wide range of polysaccharides that form successful HM devices. The most widely used and certainly the most intensely studied HM carriers is cellulose ether, in particular hydroxypropymethylcellulose (Melia, 1991). Research for alternatives to existing cellulose ether continues, chitosan is one of these examples:

[29] Statistics Canada. Catalogue no. 46-250-XPB

"Outstanding scientific progress has been made, demonstrating the application of chitosan in drug delivery systems. The properties of chitosan make it a versatile excipient, not only for controlled release applications but also as a bioadhesive polymer, depending on the route of delivery. In addition, it appears to have potential as an absorption enhancer promoting drug uptake across the mucosal barrier... Extensive research has been devoted to the demonstration of the safety of chitosan by performing toxicity studies and elucidating its mechanisms of action. Clinical trials are currently in progress to optimize chitosan-based formulations for drug delivery systems with a broad range of therapeutic applications." (Dodane et al., 1998 p251)

Therefore, it can be surmised that the production of chitosan (once the regulatory barriers are surpassed) will find an adequate market within the local industry. For example, if it is feasible to make high-grade chitosan in Quebec, a potential market already exists with significant potential demand. In fact, chitosan can be sold at a lower price given its relatively low production cost than the currently used polysaccharides. Chitosan is also proven to be a versatile excipient. Furthermore, the Canadian trade deficit for cellulose ether keeps increasing, from a deficit of $24 million in 1994 to a deficit of more than $37 million in 1998 (Industry Canada, Trade Data on line, www.strategis.ic.gc.ca). Thus, it is anticipated that the pharmaceutical industry will switch over to chitosan.

The development of a new drug takes approximately 12 years and is protected for 20 years. This would imply that it would take longer for brand-name drugs to contain chitosan. In addition, the approval procedures for generic products are simplified (Aronsson et al., 1997) and the effort of provinces and insurance companies to encourage the use of generic drugs due to their lower price contributes to the increase of the generic drug market share in the prescriptions market. Therefore, the generic drug market would be the first segment to be targeted by the eventual producers of high-grade chitosan.

In order to forecast the demand for high-grade chitosan in Quebec, we used the Bass model. The assumptions of this model are similar to the theoretical concepts in the literature on new product adoption and diffusion (Bass, 1969). The following is then a review of Diffusion of Innovation Theory.

Diffusion of Innovation Theory

According to Rogers (1983), diffusion is the process by which an innovation is communicated through certain channels over time and among the members of a social system. From a marketing point of view, Onkvisit and Shaw (1989) defined the diffusion process of innovations as the use of new products or services over time. This process is carried out by adopting units within a social system in a given culture as stimulated by marketing activities. By examining this definition, we can have a better idea about the diffusion process.

According to the Federal Trade Commission (Onkvisit and Shaw, 1989), a new product is also identified as an existing product that has been changed in a functionally significant and substantial manner.

Diffusion must take place within a social structure. However, the diffusion process varies within cultures and across industries. The diffusion of a new product does not go on by itself but it is catalyzed by marketing activities. These activities consist of the four Ps of marketing: product, price, place (distribution) and promotion.

Characteristics of Innovations

Many technologists think that advantageous innovations will sell themselves and seem to suggest that the obvious benefits of a novel idea will quickly be recognized by potential adopters allowing for these innovations to diffuse rapidly. Unfortunately, this is not the case. Most innovations diffuse at a surprisingly slow rate. However, it should not be assumed that all innovations could be analyzed similarly. In repeated studies describing how product characteristics affect the rate of diffusion, five product variables have been identified and have gained widespread acceptance (Rogers, 1983). These five product variables are 1) relative advantage, 2) compatibility, 3) observability, 4) triability and 5) complexity.

1- Relative advantage is the benefit derived from a new product relative to the benefits offered by the existing products. In order to gain rapid acceptance, a new product must be more attractive than the other substitutes (existing products). Thus, the greater the perceived advantage, the more likely it is that the product will be adopted (Onkvisit and Shaw, 1989).

2- A new product should be compatible with the experiences, values and attitudes of consumers as well as with other products in their possession (Onkvisit and Shaw, 1989). An idea that is not compatible with the prevalent values and norms of a social system will not be adopted as rapidly as an innovation that is compatible. The diffusion process is therefore slowed down as soon as the new product necessitates changes in the attitudes of eventual adopters.

3- When an innovation is found to be difficult to understand and not used by most members of a social system, it represents a certain degree of complexity and as a result will also be adopted more slowly. This means that individuals will generally hesitate in adopting a product they do not understand how to use.

4- If a new idea can be tried on an installment plan, it will generally be adopted more quickly than innovations that are not divisible. Consumers are more likely to try a new product if they do not have to wait too long to use it. In other words, the more divisible and triable a new product, the more likely it will gain acceptance (Onkvisit & Shaw,1989).

5- The most important characteristic that determines whether or not a new idea will be adopted is its observability. The easier it is for individuals to see the results of an innovation, the more likely they are to adopt it. Observability relates to whether the use of a new product is publicly visible or not. The public use of a product increases its visibility and identification. Therefore, a new product will be successfully used if its features can easily be communicated into a social system.

In general, innovations perceived by receivers (or adopters) as having greater relative advantage, compatibility, triability, observability and less complexity will be adopted more rapidly than other innovations (Rogers 1983). There are other characteristics that affect the adoption of a new product. According to Onkvisit and Shaw (1989), there are two other variables that are important:

6- Perceived Risk (physical, functional, or financial). In this case, innovators (early adopters) can be considered to be risk takers as they either do not visualize risk or may not be concerned about the risk related to the use of the new product.

7- The Price: when a new product is launched, prices are usually high because of the lack of economies of scale. Thus, the adoption of a new product is low when the relative price is high. Given the product life cycle, mass production makes it possible for prices to decline later on.

In conclusion, it must be noted that these seven characteristics (relative advantage, compatibility, observability, triability, complexity, perceived risk and price) associated with product adoption are based on the consumer's perception. Therefore, they are not necessarily objective.

In order to illustrate what was mentioned earlier, Ryan and Gross (1943) studied the diffusion of hybrid corn seed in Iowa. Their study is one of the most influential efforts in diffusion theory.

The Diffusion of Hybrid Corn in Iowa

The hybrid corn investigation includes each of the four main elements of the diffusion process: innovation, communication channels, time and the social system.

Agricultural scientists at Iowa State University and other land-grant universities had developed hybrid corn seed. It was one of the newest farm technologies when it was presented to Iowa farmers in 1928 and was widespread in the 1930s through to the 1950s. The diffusion of this innovation was communicated (promoted) by the Iowa Agricultural Extension Service and by salesmen from seed companies (Rogers 1983).

Hybrid corn was innovative because it yielded 20% more per acre than the open pollinated varieties that it replaced. It was also more drought resistant and better suited harvesting with mechanical corn pickers. On the other hand, the seed lost its hybrid vigor after the first generation, which meant that farmers had to purchase hybrid seeds each year. Therefore, the adoption of hybrid corn caused significant changes in farmers' behavior. All but 2 of the 259 Iowa farmers had adopted hybrid corn between 1928 and 1941. When plotted cumulatively on a year-by-year basis, the adoption rate formed an S-shaped curve over time. The innovation-decision period from first knowledge to the adoption decision averaged about nine years for all respondents. It took the average respondent three to four years after planting his first hybrid seed, before deciding to plant 100 percent of his corn acreage in hybrid varieties (Rogers, 1983).

On the other hand, the diffusion of innovation inside a social system is represented by a normal curve (Lilien and Kotler, 1983). Even though it is unnatural to assume that all the innovations' curves have the same shape, most of the innovations follow the same distribution.

Diffusion Models

Forecasting market penetration is essential in the development and commercialization stages of new products. There are different methods to forecast the market penetration of a new product such as subjective estimation, market surveys, historical analogy, time series models, econometric models, diffusion models, economic costs models and discrete choice models. For the purpose of this research, diffusion models were chosen to forecast the demand for chitin and chitosan[20].

The diffusion process is concerned with the propagation of a new product in the market place (Teotia and Raju, 1986). Behavioral Theory underlines that new product acceptance is an adoption-imitation process. A new product is first adopted by a few people (or organizations) who, according to the Diffusion Theory are called *innovators*. Innovators influence other actors of the social system to use the new product in question.

Diffusion models can be defined as models that describe the process of the diffusion of an innovation in a society over time (Rogers, 1983). During the last two decades, mathematical diffusion models have been an active area of research and have been used in numerous applications. As is true for all models, diffusion models are a simplification of reality. They serve as descriptive tools and help in describing a range of phenomena in reality by a simple representation (Kalish and Sen, 1986).

Models can also be used for forecasting, but the parameters of the problem must not change over time. In other words, a model must provide a good description of past cases and have parameters that do not change over time.

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[20] The reason behind this is given in the next section of this chapter

According to Kalish and Sen (1986), diffusion models predict the adoption rate and sales of new products, focusing on the adoption process. They model the number of adopters over time, which is the number of units sold of durable goods. Although there have been some applications for non-durable goods, in this case, each adopter represents a flow of sales. Essentially, diffusion models are concerned with the diffusion of new products from the factory to the end users. They also focus on the development of the product life-cycle curve. According to Mahajan and Wind (1986), all new products show a first-purchase sales volume curve regardless of whether they are bought once, occasionally or frequently. In general, diffusion models focus on this curve to forecast the sales of the new product.

Diffusion Functions

Lekvall and Wahlbin (1973) in their study of some assumptions underlying diffusion functions reviewed historical evolution of diffusion functions. According to the authors, mathematical growth functions have been widely used in modeling innovation diffusion processes since F. Stuart Chapin (1928) used the logistic function to analyze the spread of certain ideas of public administration among American cities. He defined this function as the solution of a differential equation of the form:

$$\frac{dy}{dt} = f(y,t)$$

where (y) denotes some measure of the diffusion level and (t) represents time. Furthermore, the solution (y) is a function of time (t). The function (f) determines the shape of the resulting diffusion curve, which is called the **logistic curve** in this case, figure 3-4.

The shape of this curve is depicted in the figure below:

Figure 3-4: **The Logistic Diffusion Function**

The logistic function is the most widely used diffusion function. The basic assumption of the model is that the diffusion rate at a given point in time is proportional to the remaining distance to some predetermined saturation point.

Mathematically:

$$\frac{dy}{dt} = ay(N - y)$$

Where (N) is the saturation level (or asymptote of the curve), (t) the time and (a) the proportionality constant. The diffusion function, as mentioned previously, is the solution of the differential equation with respect to (y). Therefore, the function is defined as follows:

$$y(t) = \frac{N}{\left(1 + be^{-aNt}\right)}$$

Where b is a constant depending on the initial conditions.

The curve (S-shaped diffusion curve) is symmetric around the inflexion point at 0.5 N.

This curve is supported by several empirical diffusion research studies over many years. Griliches (1957) was one of the first researchers to use the logistic function in his study of the diffusion of hybrid seed corn among farmers.

The logistic function is not the only well known diffusion function. The *modified exponential* function is also used to meet the same objective. This function is based on the assumption that the instantaneous diffusion rate depends solely on the remaining distance to the saturation level (Lekvall and Wahlbin, 1973). Mathematically, the modified exponential function is the solution of the following differential equation with respect to (y), providing the process starts at the origin:

$$\frac{dy}{dt} = a(N - y)$$

Therefore, the function is defined as:

$$y(t) = N(1 - e^{-at})$$

and its shape is depicted by the figure 3-5.

This model has been tested and has received concrete empirical support. Fourt and Woodlock (1960) used it to predict the market penetration of new grocery products and Dodd (1955) also used the model for testing laws of interaction. Similarly, Kelly (1967) had used the modified exponential function to predict the growth in patronage of a new retail outlet. All these studies and many others have given encouraging results by producing forecasts closer to what happened later.

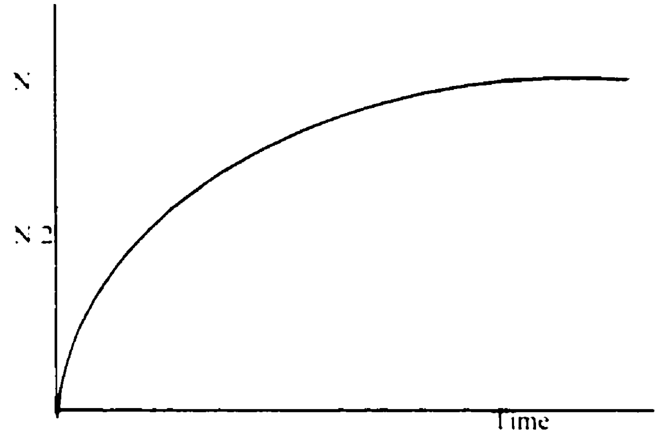


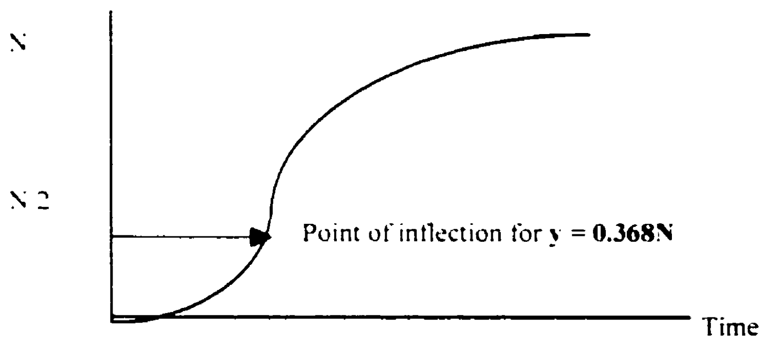
Figure 3-5: **The Modified Exponential Function**

In the real world, the diffusion curves show a more or less asymmetric S-shape, usually with the upper shank of the "S" being more extended (Lekvall and Wahlbin 1973). The function that produces such characteristics is depicted by the Compertz's Curve (figure 3-6). This function's mathematical notation is:

$y(t) = Na^{b^t}$, **0<a<1, 0<b<1**

The difference between the Compertz' curve and the Logistic curve is the position of the inflection point. In the case of Compertz', it is below half of the saturation level. This explains the origin of the right-hand skewness of the curve.

Figure 3-6: **The Compertz' Curve**



New Product Sales Forecasting

Thousands of new products are offered to consumers every year but only a few of them gain acceptance in the marketplace. In 1980, Hopkins reported that as many as two thirds of industrial firms considered their success rate "disappointing" or "unacceptable" (Hopkins, 1980). Cooper (1982) reported a mean failure of 41% for fully developed new products. There is a high variance in these failure rates, as it varies between 50% and 90% (Choffray et al., 1988). This has been the case in the past as well (Twiss, 1984).

In general, the introduction of new products is associated with uncertainty on all sides: the firm, the consumers and the competitors. This uncertainty is mainly due to changes in many factors occurring during the introduction period. It is a known fact that the introductory period of a new product is risky as many new products that are commercialized result in failures. The reasons behind these are varied and can include: poor marketing, poor product design or simply bad launch timing. Another reason, which cannot be overlooked, is the overestimation of sales forecasting. This overestimation is generally caused by the overoptimistic behavior of technologists during the early stages of new product development (Twiss, 1984).

According to Twiss (1984), technology forecasting suffers from a lack of credibility after being popular in the early 1970s. In his paper, Twiss (1984, p20) writes,

"During the two decades prior to 1970 we witnessed an unprecedented rate of economic growth, which was relatively steady. The forecasters fell into the trap of extrapolation. If a parameter could be plotted from past data as a straight line on semilog paper for 15-20 years, they felt confident in projecting it forward into the 1970s and 1980s. But the past ten years have been different. There have been discontinuities... forecasting has been a disappointment".

Forecasting, which may overestimate sales can lead to serious losses for a company through overproduction. The equally tragic experience of underestimation prevents a potentially profitable product from being fully marketed (Geurts and Reinmuth, 1980).

Given a new product, the following is a review of various types of approaches to build forecasting models that can be used to estimate sales prior to its introduction. In the case of chitin and chitosan, one of the following models will be used to forecast their sales, as it is a new product in the market.

By definition, sales forecast is the amount of sales (in units or dollars) a firm expects to achieve during some future period under expected market conditions (Kress and Snyder, 1994). The common approach of forecasting sales is to use past sales of similar products to estimate sales for the new product. But the change of circumstances and the product differences cause inaccuracies in the sales estimation process. Forecasters must also take into consideration the eventual competitors' actions (as their marketing efforts can reduce the sales of the new product). Another major factor that must be considered during the process of forecasting new product sales is the effect of the marketing mix variables of the product (price, promotion and distribution). Finally, the quantity of sales expected depends also on the characteristics of the product according to the Diffusion of Innovation Theory (relative advantage, compatibility, complexity, triability and observability).

Forecasting Without a Relevant Database

Historical data is not available when either a new product is introduced into the market, an old product is introduced into a new market or if the market environment has suddenly changed. In this later case, not only does the historical data not exist but it is useless even if it did. Therefore, given the volatility of the economy, forecasting models based on historical data must be constantly reevaluated (Geurts and Reinmuth, 1980). In general, forecasting models need periodic examination in order to determine their relevance. Four forecasting schemes are used to forecast sales when there is no available past sales data. The following is a brief description of each one along with its limitations.

1- The Panel Consensus Method:

We assume that the company has experts or has access to them in each domain (economy, marketing, production and human resource management). Everyone has specific knowledge in his or her field. In addition, these experts are assumed to recognize each other's specialized area of expertise and they arrive at a consensus, which constitute the company's forecast.

The difficulty with this method remains in complex personality factors, which may not lead to a consensus agreement. Furthermore, a hierarchical bias may exist within the group so that a lower level expert may not try to contradict a higher level expert. This method has generally shown poor results in long term forecasting, and in general, its short-term predictions are not reliable (Geurts and Reinmuth., 1980).

2- The Delphi Method:

The Delphi Method is a refinement of the consensus panel method. It uses a group of experts who make individual forecasts. A mediator who sends out the results of the first attempted forecast conducts the pooling of the forecasts. The forecasters are asked to make a revised forecast and to explain the reasons for their forecasted values. The process continues until forecasters reach a consensus. This research method is limited in its accuracy because forecasters may be pressured to reach the consensus (Geurts and Reinmuth, 1980).

3- Historical Analogy:

This approach assumes that the firm can use the historical sales data of similar products in order to forecast sales of a new but similar one. The assumption that such data must satisfy before using this approach is to verify if the earlier product has had a similar economic and market environment during its introductory stage as the new product being tested. Historical analogies are risky but tend to produce good results in medium and long-term forecasts. Unfortunately, they perform poorly in short run forecasts (Geurts and Reinmuth, 1980).

4- Models Used for Forecasting New Products:

Many models have been created to deal with the large number of variables, which must be considered when forecasting new products. However, most models are specific to individual products or situations. In other words, new product forecasting models vary considerably with respect to their objectives. Some forecast total market demand, others forecast first purchase, still others forecast repeat purchases (Wind 1981). The well-known article by Bass (1969) was primarily responsible for introducing mathematical diffusion models in the marketing literature. Many of the models that have appeared since then are either direct extensions of the Bass model, or relate to it in some way (Kalish and Sen, 1986). However, Fourt and Woodlock (1960) were the first to make an empirical use of a forecasting model. The following is a description of the chronological evolution of the models used to forecast sales for new products.

a- Fourt and Woodlock:

Fourt and Woodlock (1960) were the first to set up a forecasting model and use it empirically. They developed it to forecast the sales of grocery products. The object of this forecast was to predict the increase in penetration Q_t. The model is:

$$\underline{Q}_t = r\underline{Q}(1-r)^{t-1}$$

where $\underline{Q}_t$ (the forecast of incremental sales) is a function of two variables r and $\underline{Q}$:

> r is the penetration rate for potential sales and it is constant. It is the estimated percentage of the non-triers who would try the product:
>
> $\underline{Q}$ is the potential sales expressed as a proportion of all buyers who are expected to buy:
>
> $t-1$ is the previous time period and t is the current period.
>
> After a number of periods. $\underline{Q}_t$ approaches 0. ($\lim \underline{Q}_t = 0$ when t goes to infinity).

The difficulty in using this model is to estimate $\underline{Q}$ and r. Initially, they are subjectively estimated, and only after sales have occurred can they be derived. Theoretically, $\underline{Q}$ represents the total population. But in reality, the value of $\underline{Q}$ is always less.

The limitation of the Fourt and Woodlock approach is that they assume sales are only a function of time (Geurts and Lawrence, 1994).

b- The Bass Model

Bass (1969) pioneered the introduction of diffusion models in the marketing literature. He suggested that the adoption process of a new good (in his case a durable good) is similar to the spread of an epidemic. In this process, those who have not yet adopted (the product) are induced into the adoption process by word of mouth from current adopters, as well as by independent sources such as advertising. This model was estimated given several data sets, and proved to be a good descriptor of diffusion behavior.

This model focuses on measuring the proportion of people who are innovators (early adopters) versus the proportion of people who are imitators (late adopters). The basic assumption of the model is that the timing of a consumer's initial purchase is related to the number of previous buyers. As stated by Bass (p.216), the probability P(t) that an initial purchase will be made at time **t** given that no purchase has been made is a linear function of the number of previous buyers:

$$P(t) = p + \left(\frac{q}{m}\right) Y_t \qquad (1)$$

where p, is the fraction of all adopters who are innovators. It is constant:

$\frac{q}{m} * Y_t$ reflects the proportion of the population who are imitators. q/m is the rate of imitation :

m is the quantity of product expected to be purchased (initial purchases only) during the time period under consideration (the life of the product)

Y_t is the number of previous buyers at time t:

$Y_0 = 0$ therefore, p is the probability of an initial purchase at $t = 0$

p is referred to as the coefficient of innovation and q as the coefficient of imitation.

The magnitude of p reflects the importance of innovators in the social system.

It should be emphasized that all of the parameters depend on the scale used to measure time. In this way, it is possible to select a unit of measure for time such that p reflects the fraction of all adopters who are innovators as defined by Rogers (Bass, 1969).

In order to formulate a continuous model and a density function of time to initial purchase, Bass referred to the linear probability element (P) as likelihood. He assumed the following:

1- Over the life period of the product, there will be m initial purchases of the product. The sales unit of the product coincides with the number of initial purchases during that period of time for which replacement sales are excluded.

2- The likelihood of a purchase at t, denoted $f(t)$ given that no purchase has yet been made:

$$\frac{f(t)}{1-F(t)} = P(t) \qquad (2)$$

$$\Rightarrow f(t) = P(t)(1-F(t))$$

where $\quad F(t) = \frac{Y_t}{m}$

from equations (1) and (2), Bass arrives at:

$$f(t) = \left[p - qF(t)\right] * \left[1 - F(t)\right] = \frac{dF(t)}{dt} \qquad (3)$$

Since $f(t)$ is the likelihood and m is the total number of purchases for the time interval [0, t] and F(0) = 0, we can write:

$$Y_t = \int_0^t S(\tau)d\tau = m\int_0^t f(\tau)d\tau = mF(t) \qquad (4)$$

Total number of purchases in the [0, t] interval (sales at t) is:

$$S(t) = mf(t) = P(t)\left[m - Y_t\right] = \left[p + \frac{q}{m}Y_t\right]\left[m - Y_t\right] \qquad (5)$$

By expanding (5) further Bass found:

$$S(t) = pm + (q-p)Y_t - \frac{q}{m}\left[Y_t\right]^2 \qquad (6)$$

The basic model is formulated by equation (6)[31]. In order to estimate the parameters p, q and m, Bass has used the following analogy:

$$S_t = a + bY_{t-1} + cY_{t-1}^2 \qquad (7)$$

where S_t = sales at t. and $Y_{t-1} = \sum_{i=1}^{t-1} S_i$ cumulative sales.

Using the stochastic error term. ε_t. the regression equation now becomes:

$$S_t = a + bY_{t-1} + cY_{t-1}^2 + \varepsilon_t \tag{7a}$$

where $a = pm$

$b = q - p$

$c = -\dfrac{q}{m}$. and ε_t is the error with p. q. m >0 and q>p.

Given regression coefficients a . b and c . the estimates of the parameters p. q and m can be easily obtained as follows:

$$p = \frac{a}{m} \tag{8a}$$

$$q = -mc \tag{8b}$$

$$m = \frac{-b \pm \sqrt{b^2 - 4ac}}{2c} \tag{8c}$$

The Bass model has been able to provide reasonably accurate forecasts. Its sales forecasts for color TV were very accurate for the years 1968-1970: however. in later years. color TV sales rose and then fell demonstrating a continued cyclical pattern forecasts (Geurts. Lawrence and Guerard. 1994).

On the other hand. a number of estimation procedures have been suggested to estimate the parameters p. q and m of the Bass model. The main question is which of the several estimation procedures should be used for this research in particular and why. As mentioned above. Bass suggested estimating the parameters by Ordinary Least Squares (OLS) method. By doing so. a time-interval bias in the parameter estimates may occur because of the use of the time discrete data to estimate a continuous-time model. As is

[31] Further details and intermediate steps in calculation are presented in Bass (1969) publication.

clear from equation (7a), if there are only a few data points and a likely multicollinearity between variables (Y_{t-1}) and (Y^2_{t-1}), parameter estimates may be unstable or possess a wrong sign (Mahajan et al., 1986). The error term contains the net effect of all sources of error such as marketing efforts, economic conditions and consumer attitudes.

Schmittlein and Mahajan (1982) had proposed Maximum Likelihood Estimation (MLE) in order to overcome some of the shortcomings of OLS estimation procedures. The authors used appropriate aggregation of the continuous time model (over the time intervals represented by the data) in order to eliminate the time-interval bias. However, the development of prediction with the MLE requires knowledge of the sample size and considers only sampling error while ignoring all other sources of error.

Srinivasan and Mason (1986) proposed Nonlinear Least Squares Estimation (NLS) to overcome some of the shortcomings of the MLE. However, the estimates are sensitive to the starting values assumed for p, q and m.

Mahajan and Sharma (1985) developed a simple procedure that does not require a sophisticated computer package. This procedure does not provide any standard errors for the parameter estimates. The method is called Algebraic Estimation (AE). It can generate rough estimates of the parameters from knowledge (based on actual data or data relating to analogous products or management judgment) relevant to the point of inflection of the original equation. It creates a time-interval bias, and is not applicable if the sales have not yet peaked. Mahajan et al. (1986) empirically evaluated these four estimation procedures. Based on data from seven innovations, they found that:

- among the four estimation procedures (OLS, MLE, NLS & AE), the MLE and the NLS provide better predictions;

- the NLS procedure provide relatively better predictions and more valid estimates of the standard errors for the parameter estimates;
- in the NLS, *ex ante* formulation, provides better and more reliable predictions than the *ex post* formulation;
- the AE procedure generates better starting values;
- the OLS procedure is the easiest to implement.

c- The Massy Model:

Massy (1969), built a model to forecast sales for new products known as consumer convenience goods (products to be purchased every few weeks or months). Sales for period t can be estimated as follows:

$$S_t = S_{0t} N_{0t} + S_{1t} N_{1t} + S_{2t} N_{2t} + \ldots + S_{it} N_{it}$$

Where S_{it} is the average purchase volume of buyers in the ith repeat purchase class at time t and N_{it} is the number of repeat buyers in the ith repeat purchase class at time t. The model is based on measuring the degree of product loyalty that is developed after the first purchase. Panel data is used to establish the S and N.

The major limitation of the Massy model is that it ignores marketing and economic activities. A basic premise is that the past pattern of sales is sufficient to predict the future. Unfortunately, such techniques, which ignore potential detracting forces, produce inaccurate sales forecasts (Geurts et al., 1994).

d- Market Research for Forecasting a New Product Sales:

Market research for new product forecasting requires asking potential buyers if they would be willing to buy the new product, then evaluating the proportion who would buy and the variance associated with the estimate.

There are two types of research designs, which can be used to estimate the demand for a new product from market research: exploratory research and conclusive research. Conclusive research can be descriptive or causal. Descriptive research is conducted to describe the consumer's perception of the product's characteristics, the behavior of the market, or the characteristics of the samples. Meanwhile, causal research is conducted to determine the cause and effect relationship between different variables (Aneja, 1997). To obtain accurate new product sales forecast, the surveyed sample must be from the population that represents future buyers. But the task becomes difficult when the eventual users are widely dispersed.

In order to be more precise in quantifying the expected purchase intention, Juster (1966) found that the respondent uncertainty about purchase intention is probabilistic and not deterministic resulting in this information to be measured. He defined the probability associated with each descriptive word concerning the purchase intention. For example, he assigned the probability of 0.99 to the descriptive word "certain", and 0.30 to "some possibility" and so on. Therefore, the forecasted sales are:

Forecast = Np*

where p* is the average affirmative action probability .

In general, results in short and medium term forecasting applications concluded by way of market research has faired from good to excellent. Long-term forecasts have been at best fair using these methods (Geurts and Reinmuth, 1980).

Forecasting the Demand for Chitosan in Quebec

In the case of a new product, the best way to forecast its demand is by using market research. From a practical point of view, it is preferable to use subjective managerial judgment and/or experience with analogous products in order to estimate parameters prior to the launch of a new product (Lawrence and Lawton 1986). In fact, the first survey sent to all the pharmaceutical companies in Quebec in order to estimate the demand for chitosan and at the same time, to determine the price elasticity of this product, was not successful for lack of response from such companies.

In general, demand estimation for a new product is difficult and entails a complex set of problems. These problems include difficulties in modeling the growth of a new product when market response data is not practically obtainable prior to launch. (Thomas, 1985a). While the problem of estimating future demand will always remain difficult, the concept of analogy offers one opportunity to manage the problem. Analogy is the observation of similarities between two or more things (Thomas, 1985b). If a model of the demand growth can be developed, and that model is based in part on existing products similar to chitin and chitosan, then this analogical model may provide reasonable estimates of sales growth for chitin and chitosan in Quebec.

Cellulose ether was identified as the most widely used polymer in drug delivery. Chitosan and cellulose have the chemical similarities and the only difference between the two is that chitosan is natural while cellulose ether is artificial. Thus, cellulose ether has been chosen as an analogous product for this study since it is a close substitute for chitosan.

The Data:

The time series data related to cellulose was given by the "Bureau de la statistique du Quebec". the publication is titled "Les Produits Utilises par les Manufacturiers Quebecois" (Material and Supplies Used by the Quebec Manufacturing Industry). Statistics Canada produces these statistics for the Quebec Ministry of Industry and Technology.

The concern was with regards to the quantity or the value of these products used by the pharmaceutical industry in Quebec. Unfortunately. these values were kept confidential because of the problems mentioned vis-a-vis market competition. Therefore. the values of cellulose derivatives given are the values of the quantities used by the entire manufacturing industry in Quebec from 1978 to 1993 (Appendix3). As we are dealing with the value of sales. we first adjusted for inflation using the industrial product price index (1986 = 1.00). The highest sales ($ 3.145 M) were reported in 1982. Meanwhile. sales of cellulose derivatives in 1988 were valued at $ 660.000. This discrepancy can be related to the rate of response of the companies surveyed and the situation of the market (or the economy) in these years.

The principal objective of this research is to forecast sales for high-grade chitosan in Quebec but the available data are not specific to the pharmaceutical and medicine industry. However. a study done by Technical Insights (Anon. 1995) on the potential of chitosan in the United States gave the market proportions of each grade of chitosan. Researchers. based on interviews with people involved in the industry. produced an estimate of the potential market for chitosan in the US. The following table is a summary of their predictions.

Table 3-3: **Segmentation of the Potential Market for Chitosan in the US.**

Use	Percentage
Health Care (High grade)	76.54%
Food and Beverage	1.60%
Agriculture	9.26%
Cosmetic	4.07%
Waste Water Treatment	3.09%
Product Separation Recovery	3.21%
Miscellaneous	2.22%
TOTAL	100.00%

Source: Anon 1995 *Chitin: Key to Low-cost Plentiful Biopolymers*, p37

Believing that the American market is similar to the Canadian market, these proportions will be used for the purpose of this study. Therefore, the Bass model will be applied to the data related to cellulose derivatives so as to forecast sales of all grades of chitosan. The estimation of the market for high-grade chitosan in Quebec will then be derived from these forecasts assuming that they represent 76.54 percent of the total sales (Table 3-3). On the other hand, in order to estimate the potential of high-grade chitosan in Canada, it is assumed that the Quebec market is proportional to its share in the pharmaceutical and medicine market. Thus, the potential market for high-grade chitosan in Quebec is assumed to be equal to 48% of the Canadian market.

The Model

In the absence of historical data on the purchasing habit of the intervening in the pharmaceutical and medicine industry, it is virtually impossible to apply the repeat purchase models. Therefore, we decided to apply the Bass model with the following assumptions:

- the companies buy chitosan products once a year;
- the production cost of these companies will decrease if they switch to chitosan from cellulose derivatives;
- chitosan is assumed to be a perfect substitute for cellulose derivatives;
- initial purchases of the product are made by both "innovators" and "imitators";
- sales include first purchases and replacement ones as well.

From equation (6), sales are formulated as follows:

$S_t = pm + (q-p)Y_{t-1} - (q/m)Y_{t-1}^2$

The next table shows the definition of the different variables and their analogue definition in the original Bass model:

Table 3.4: **Definitions of the Model's Variables and their Analogues in Bass Model.**

Variable	Definition in the Bass Model	Definition in the Model for Chitosan
Y_{t-1}	The cumulative number of adopters at time t-1.	The value of the cumulative sales at time t-1.
M	The total number purchasing during the period for which the density function was constructed i.e. the maximum number of potential adopters	The maximum purchases that can be made by the potential buyers. ≈ The potential sales during the life cycle of the product
p	The coefficient of innovation	Percentage of sales that can be made by innovative firms (i.e. early buyers).
q	The rate of imitation	Percentage of sales made by the follower firms.

Model Estimation and Performance:

Since the Bass model contains three parameters (p, q, and m), theoretically it is necessary to utilize only three data points to estimate these parameters. However, according to Srinivasan and Mason (1986), the parameter estimates and the predictions are very unreliable when only a few data points are used to calibrate the Bass model. Heeler and Hustad (1980) found that their predictions were improved if the data used included the peak[22].

According to the results of Mahajan et al. (1986), the best estimation procedure to use would be the Nonlinear Least Squares estimation procedure. Therefore, we used this procedure to estimate the parameters of the Bass model, which were applied to data related to cellulose derivatives used in Quebec from 1978 to 1993. The convergence was achieved after 3 iterations given the 16 observations. The results were as follows:

Table 3-5: **Regression Results**

Variable	Coefficient	Std. Error	t-Stat	P-Value
a = pm	1562.559007	344.6609	4.533612	0.001
b = q-p	0.119752	0.071950	1.664373	0.043
c = q m	0.000006	0.000003	2.337184	0.036
$R^2 = 0.4800$				

ANOVA

Source	DF	SS	MS	F	P-Value
Regression	2	3014431	1507215	4.86	0.027
Error	13	4034956	310381		
Total	15	704938			

Parameters are statistically significant and have the correct sign.

[22] Mahajan et al., 1986, p214

Solving for p. q and m leads to the following results:

m = $29 million (constant 1986). Approximately $ 37 million in 1999 dollar

p = 5.4% and q = 17.37%.

Thus. according to the results. the potential market for chitosan (all grades) in Quebec is estimated to be equal to $37 million (cumulative for 20 years). The innovative firms will realize 5.4% of this value ($ 2.03 M) in the first year of marketing the product. Table 3-6 is a summary of the potential sales of high-grade chitosan in Quebec and Canada.

Table 3-6: **Chitosan Sales Forecasts (1999$K): New Sales and Total Sales Each Year.**

Period	All Grades Quebec' (First time Purchase)	All Grades Quebec' (New & Repeat P.)	High Grade Quebec'' (New & Repeat P.)	High Grade Canada* (New & Repeat P.)
1	2027	2027	1551	3232
2	2250	4277	3273	6819
3	2454	6731	5151	10731
4	2622	9353	7163	14922
5	2742	12095	9254	19280
6	2799	14894	11393	23735
7	2783	17677	13536	28199
8	2697	20374	15600	32499
9	2546	22900	17540	36553
10	2341	25261	19337	40285
11	2100	27361	20938	43620
12	1839	29230	22020	45876
13	1578	30800	23604	49175
14	1329	32137	24617	51285
15	1102	33239	25457	53036
16	901	34140	26145	54469
17	848	34988	26806	55847
18	773	35761	27393	57068
19	653	36414	27889	58102
20	556	36970	28312	58984

' These sales are derived from cellulose derivatives sales by applying the Bass model. The model estimates sales in 1986 dollars. which are then converted to 1999 dollar value.

'' According to Technical Insight Study. 76.54% of Chistosan sales are expected to be of High Grade.

*It is assumed that the Quebec market for high-grade chitosan is equal to 48% of the Canadian market (the same proportion as for the Pharmaceutical & Medicine Market)

The value in 1999 dollars was derived using the Industrial Product Price Indexes 111.7% "1986=1" (CANSIM. Matrix 5680) and 116.1% "1992=1" (CANSIM. MATRIX 1878)

CONCLUSION

A sales forecast can be a firm's most critical piece of information because it has major short and long-term implications. In general, forecasting sales for a new product is always difficult and complex. The most well-known diffusion model used to forecast sales for new products is the Bass model. It has been adopted, extended and employed by marketing researchers and used by many companies for forecasting purposes (Bass, 1980). Originally, the Bass model was used to forecast sales for durable goods. In this study we used it to estimate the potential market for a non-durable good. When we used it to forecast sales for a new anti-ulcer drug (a non-durable good) and compared these results with the actual sales, the results were accurate and encouraged us to use the Bass model for chitosan. However, there are some limitations to this research. The Bass model ignores variables, such as marketing effort, economic conditions and consumer (firm) attitudes. Finally, the data was the best that could be gathered by Statistics Canada[33]: there are limitations to its reliability.

The most important conclusion of this research shows that there is good potential for chitosan sales in Quebec and Canada. The production cost of these biopolymers is low compared to other substitutes. Sales forecasts for the introduction period are encouraging. Therefore, we recommend to a potential producer to test the market by distributing free samples to the pharmaceutical companies. In doing so, they will be able to measure the willingness of these firms to buy the product and test all the variables that can affect the purchase decision.

THESIS SUMMARY AND CONCLUSIONS

This thesis is an investigation of the potential for a chitin and chitosan industry in Quebec. It comprises three separate papers logically linked. The first paper estimates the quantity of shrimp waste generated by the processors in Quebec, investigates the actual uses of this waste and shows its potential for making new value-added products such as chitin and chitosan. Based on the stock assessments and future prospects of shrimp by the scientists at Fisheries and Oceans Canada (FOC), we estimated the total production of processed shrimp with respect to the total allowable catch (defined by FOC) and the total shrimp landings in Quebec. We used this estimation in order to derive the quantity of waste generated in Quebec. We believe that these estimates are conservative because the shrimp processors import some of their raw materials from Maine and some Asian countries (Thailand, Vietnam). Due to the scarcity of shrimp predators such as cod and redfish, we assume that the stock of shrimp in the St. Lawrence will remain the same for the next five years. Therefore, we predict that during this period, the Quebec shrimp processors are expecting to generate an average annual amount of at least 12,640 metric tons of shrimp waste. This amount is adequate to support an economically viable enterprise making high-grade chitin and chitosan. Furthermore, few companies in Quebec are currently transforming the available shrimp waste into low-value commercial products. More than 50% of this abundant waste is thrown into the sea or into landfills.

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[22] Some factors can affect the accuracy of the data such as sampling errors, response rate and the respondent errors.

However, a more elaborate study of the shrimp processing industry would be necessary to estimate the quantity of waste generated by this industry more precisely.

The second paper estimates the production costs of chitin, chitosan and the by-product carotenoprotein using a biological process involving enzymes. First, an evaluation of the production costs was performed at a semi-pilot plant level and then an estimate of the scaled-up process plant was determined using the cost-capacity factor. For a plant processing 40 metric tons of shrimp waste a week during a fifty week period, recovering the three value-added products from the waste would result in the production of 91 mt of chitin, 12 mt of carotenoprotein and 55 mt of chitosan. The respective production cost for one gram of each product is $0.26, $0.07 and $0.65. The gross margins are expected to be 90% for making chitosan, 96% for chitin and 98% for carotenoprotein.

These results of cost estimation ensure that the biological way of making chitin and chitosan is much cheaper than the chemical way. In fact, the materials required for the recovery processes are few, non-toxic and relatively inexpensive. Similarly, equipment required are few, simple and several are common to the different processes for making the different products. However, some limitations of the study can be mentioned. These shortcomings relate mainly to data problems. For example, the cost of different pieces of equipment did not include the installation costs. Also, the estimates of some costs were based on what would happen if the pilot plant were to be set up at Macdonald Campus. In doing so, the expense of rent was considered instead of the purchasing cost of the land and any needed construction expenses. Further research in this area is required before starting any venture.

Overall, these estimates can be used as preliminary estimates and can be an incentive to invest in a more detailed feasibility study for a full scale plant design.

The third paper estimates the potential market of high-grade chitosan in Quebec. Of all market segments for chitin and chitosan, the health care sector offers the most potential. Therefore, we focused our target on the pharmaceutical and medicine industry in Quebec. It should be noted that chitosan is not yet produced in Quebec.

In general, demand estimation for a new product is difficult and involves a complex set of problems. These problems include difficulties in modeling the growth of a new product when market response data are not practically obtainable prior to launch. (Thomas, 1985b). The concept of analogy offers an opportunity to manage the problem of estimating future demand for chitin and chitosan. As a result, cellulose derivatives were identified as being similar to chitosan (because of their common properties) and its related data was used to forecast sales for chitosan.

The Bass model was used to forecast sales of high-grade chitosan. We estimate the potential sales of high-grade chitosan to reach 1.6 million dollars in the first year of marketing it in Quebec and 3.2 million in Canada. It is also estimated that the cumulative sales of chitosan (all grades) will reach a potential of $ 37million by the 20th year. However, the Bass model ignores variables such as marketing efforts (of chitosan producers and their competitors), economic conditions and consumer attitudes. Finally, in spite of the efforts of Statistics Canada to produce an accurate database, some factors can affect the quality of the data such as sampling errors, the response rate and the respondent errors.

To overcome these limitations, it would be appropriate to perform a market study. Given the "newness" and "uncertainty" of the product and confidential nature of the information that will be requested, it is recommended that free samples of chitosan be distributed to the pharmaceutical companies. After that, one-on-one interviews with decision-makers are appropriate to measure the willingness of these firms to buy the product and test all the variables that can affect the purchase decision.

The finding of this study shows that there is a good potential for a chitin and chitosan industry in Quebec and in Canada. There is enough raw materials to support the industry, the production costs are low compared to other substitutes and the sale forecasts for the introduction period are encouraging.

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APPENDIX 1
Quantities of Shrimp Waste in Quebec:
Results of Different Forecasting Methods

Table A1-1: Naïve Forecast: $PROC_{t+1} = PROC_t$

Period	Production	Forecast	Error
1	2619	*	*
2	1804	2619	815
3	2763	1804	-959
4	2645	2763	118
5	2802	2645	-157
6	2837	2802	-35
7	2784	2837	53
8	2402	2784	382
9	2900	2402	-498
10	3412.3	2900	-512.3
11	3520.6	3412.3	-108.3
12	5163.7	3520.6	-1643.1

Accuracy Measures
MSE: 416199.90
MAD: 440.06
MAPE: 14.67%

Table A1-2: Moving Average: Length = 2

Period	PROC	MA	Predict	Error
1	2619.0	*	*	*
2	1804.0	2211.50	*	*
3	2763.0	2283.50	2211.50	551.50
4	2645.0	2704.00	2283.50	361.50
5	2802.0	2723.50	2704.00	98.00
6	2837.0	2819.50	2723.50	113.50
7	2784.0	2810.50	2819.50	- 35.50
8	2402.0	2593.00	2810.50	-408.50
9	2900.0	2651.00	2593.00	307.00
10	3412.3	3156.15	2651.00	761.30
11	3520.6	3466.45	3156.15	364.45
12	5163.7	4342.15	3466.45	1697.25

Accuracy Measures
MAPE: 14
MAD: 470
MSD: 431276

Table A1-3: Single Exponential Smoothing. Smoothing Constant: Alpha: 0.839925

Time	PROC	Smooth	Predict	Error
1	2619.0	2601.99	2512.73	106.27
2	1804.0	1931.74	2601.99	-797.99
3	2763.0	2629.94	1931.74	831.26
4	2645.0	2642.59	2629.94	15.06
5	2802.0	2776.48	2642.59	159.41
6	2837.0	2827.31	2776.48	60.52
7	2784.0	2790.93	2827.31	-43.31
8	2402.0	2464.26	2790.93	-388.93
9	2900.0	2830.25	2464.26	435.74
10	3412.3	3319.13	2830.25	582.05
11	3520.6	3488.35	3319.13	201.47
12	5163.7	4895.52	3488.35	1675.35

Accuracy Measures
MAPE: 15
MAD: 441
MSD: 408131

Table A1-4: Double Exponential Smoothing.
Constants: level (α) = 0.21267, trend (γ) = 4.48991

Time	PROC	Smooth	Predict	Error
1	2619.0	1815.19	1598.07	1020.93
2	1804.0	2235.93	2352.60	-548.60
3	2763.0	2466.63	2386.57	376.43
4	2645.0	2860.04	2918.12	-273.12
5	2802.0	2997.84	3050.74	-248.74
6	2837.0	2926.78	2951.03	-114.03
7	2784.0	2773.84	2771.09	12.91
8	2402.0	2581.88	2630.47	-228.47
9	2900.0	2364.90	2220.36	679.64
10	3412.3	2813.95	2652.33	759.97
11	3520.6	3761.88	3827.05	-306.45
12	5163.7	4627.26	4482.36	681.34

Accuracy Measures
MAPE: 15
MAD: 438
MSD: 273699

Table A1-5: Fitted Values of PROC with Respect to the Regression (1)

Period	Production	Forecast	Error	Error Squared	Absolute Error	Abs % Error
1	2619	2692.682	73.68167	5428.989	73.68167	0.02
2	1804	1944.128	140.1282	19635.91	140.1282	0.07
3	2763	2256.025	-506.975	257023.2	506.9745	0.18
4	2645	2256.025	-388.975	151301.2	388.9745	0.14
5	2802	2817.441	15.44059	238.4117	15.44059	0.00
6	2837	3098.148	261.1481	68198.35	261.1481	0.09
7	2784	3347.666	563.666	317719.3	563.666	0.20
8	2402	3347.666	945.666	894284.1	945.666	0.39
9	2900	3347.666	447.666	200404.8	447.666	0.15
10	3412.3	3347.666	-64.634	4177.557	64.63403	0.01
11	3520.6	3347.666	-172.934	29906.18	172.934	0.04
12	5163.7	3849.821	-1313.88	1726279	1313.879	0.25

Accuracy Measures
MSE: 306216.43
MAD: 407.90
MAPE: 13.39%

Table A1-6: Forecasted Values of PROC Derived from the Fitted Values of LnPROC with Respect to the Regression (2)

Period	Production	Forecast	Error	Error Squared	Absolute Error	Abs % Error
1	2619	2261.147	-357.853	128058.6	357.8528	0.13
2	1804	1972.776	168.7763	28485.42	168.7763	0.09
3	2763	2369.727	-393.273	154663.6	393.2729	0.14
4	2645	2516.088	-128.912	16618.31	128.912	0.04
5	2802	3009.092	207.0917	42886.95	207.0917	0.07
6	2837	3143.096	306.0965	93695.05	306.0965	0.10
7	2784	3375.406	591.4061	349761.2	591.4061	0.21
8	2402	3028.395	626.3949	392370.5	626.3949	0.26
9	2900	3298.283	398.2835	158629.7	398.2835	0.13
10	3412.3	3369.032	-43.2677	1872.09	43.26766	0.01
11	3520.6	3407.964	-112.636	12686.9	112.6361	0.03
12	5163.7	3856.653	-1307.05	1708372	1307.047	0.25

Accuracy Measures
MSE: 257341.71
MAD: 386.75
MAPE: 12.60%

Table A1-7:

a) Correlation Matrix for Total Processed Shrimp (PROC), Total Allowable Catches (TACs) and the Shrimp Landings (CATCH)

	PROC	TACs	CATCH
PROC	1.000		
TACs	0.729	1.000	
CATCH	0.725	0.753	1.000

b) The Regression Equation

PROC = - 2038 + 0.328 TACs Regression (1)

11 cases used 1 cases contain missing values

Predictor	Coef	StDev	T	P
Constant	-2038	1583	-1.29	0.230
TACs	0.3282	0.1029	3.19	0.011

S = 618.8 R-Sq = 53.1% R-Sq(adj) = 47.9%

c) Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	3898487	3898487	10.18	0.011
Error	9	3446366	382930		
Total	10	7344853			

R denotes an observation with a large standardized residual

Durbin-Watson statistic = 0.93 (d_L = 0.971& d_U = 1.331)

Table A1-8:

a) Correlation Matrix for the Logarithm of the Total Processed Shrimp (LnPROC), Total Allowable Catches (LnTACs) and of the Shrimp Landings (LnCATCH)

	LnPROC	LnTACs	LnCATCH
LnPROC	1.000		
LnTAC	0.745	1.000	
LnCATCH	0.731	0.722	1.000

b) The Regression Equation

LnPROC = - 5.20 + 0.445 LnCatch + 0.927 LnTACS **Regression (2)**

11 cases used 1 cases contain missing values

Predictor	Coef	StDev	T	P
Constant	-5.201	4.330	-1.20	0.264
LnCatch	0.4450	0.3343	1.33	0.220
LnTACs	0.9272	0.6221	1.49	0.174

S = 0.1762 R-Sq = 63.6% R-Sq(adj) = 54.5%

c) Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.43343	0.21671	6.98	0.018
Error	8	0.24844	0.03106		
Total	10	0.68187			

Source	DF	Seq SS
LnCatch	1	0.36443
LnTACS	1	0.06899

Durbin-Watson statistic = 1.12 (d_L = 0.812 & d_U = 1.579)

APPENDIX 2
Costs Breakdown for Chitin, Carotenoprotein and Chitosan
Distribution of the Common Costs
Production Costs at the Pilot Level
Production Costs at the Industrial Level
Summary

Table A2-1

Joint Costs Breakdown

Direct Equipment Cost

ITEM	Cost	Energy Required	Expected Life	Annual Equivalent Cost of Capital	Portion allocated to the process	Portion of investment	Depreciation	Power required*
Grinder	$15,740.00	1.7 kw	25	$1,734.05	100.00%	$15,740.00	$1,734.05	$9.18
Balance	6,400.00	360 w	25	705.08	25.00%	1,600.00	176.27	0.49
Containers	193.00	-	5	50.91	50.00%	96.50	25.46	0.00
Cheese Cloth & Sieve	192.00	-	1	211.20	100.00%	192.00	211.20	0.00
Centrifuge	45,344.00	0.9 kw	25	4,995.46	0.00%	0.00	0.00	0.00
Freeze Dryer	45,000.00	1.66 kw	25	4,957.56	0.00%	0.00	0.00	0.00
Incubator Shaker	19,500.00	1.7 kw	25	2,148.28	0.00%	0.00	0.00	0.00
Ph-meter	900.00	90 w	25	99.15	0.00%	0.00	0.00	0.00
Steam Kettle	4,000.00	2.5 kw	25	440.67	0.00%	0.00	0.00	0.00
Drum Dryer	47,000.00	2.5kw	25	5,177.90	0.00%	0.00	0.00	0.00
Total	**$184,269.00**					**$17,628.50**	**$2,146.97**	**$9.67**

*Consumption per batch

Direct Input Cost

Raw material	$27.50
Protease 1	$25.00
HoAc	$0.82
Total material	**$25.82**

Table A2-2

Chitin Cost Breakdown

Direct Equipment Cost

ITEM	Cost	Energy Required	Expected Life	Annual Equivalent Cost of Capital	Portion allocated to the process	Portion of investment	Depreciation	Power required*
Steam Kettle	$4,000.00	2.5 kw	25	$440.67	100.00%	$4,000.00	$440.67	$6.75
Balance	6,400.00	360 w	25	705.08	25.00%	1,600.00	176.27	0.49
Ph-meter	900.00	90 w	25	99.15	34.00%	306.00	33.71	0.12
Centrifuge	45,344.00	0.9 kw	25	4,995.46	0.00%	0.00	0.00	0.00
Grinder	15,740.00	1.7 kw	25	1,734.05	0.00%	0.00	0.00	0.00
Cheese Cloth & Sieve	192.00	-	1	211.20	0.00%	0.00	0.00	0.00
Freeze Dryer	45,000.00	1.66 kw	25	4,957.56	0.00%	0.00	0.00	0.00
Incubator Shaker	19,500.00	1.7 kw	25	2,148.28	0.00%	0.00	0.00	0.00
Containers	193.00	-	5	50.91	0.00%	0.00	0.00	0.00
Drum Dryer	47,000.00	2.5kw	25	5,177.90	100.00%	47,000.00	5,177.90	27.00
Total	**$184,269.00**					**$52,906.00**	**$5,828.55**	**$34.36**

*Consumption per batch

Other Direct Costs

Direct Input Cost^	
HoAc	$1,750.00
Labor cost Assigned*	$21,095.00
Heat**	$394.07
Maintenance***	$2,116.24

^ Inputs required to process one batch (50 kg dried waste)

* The annual labor cost is shared by all the products produced by the pilot plant, the allocation was done by using the net realizable value method

The Labor cost is supposed to be linearily dependent on the capacity use of the plant. This amount is the cost when the plant is used at 100% capacity

** The same technique was applied for the heat cost. It is a fixed cost

*** The maintenace cost is equal to 4% of the portion of investment allocated to the process. It is linearily dependent of the capacity use of the equipments

Table A2-3

Pigment Cost Breakdown

Direct Equipment Cost

ITEM	Cost	Energy Required	Expected Life	Annual Equivalent Cost of Capital	Portion allocated to the process	Portion of investment	Depreciation	Power required*
Centrifuge	$45,344 00	0.9 kw	25	$4,995 46	100 00%	$45,344 00	$4,995 46	$4.86
Balance	$6,400.00	360 w	25	$705 08	25 00%	$1,600.00	$176 27	$0.49
Ph-meter	$900.00	90 w	25	$99 15	33 00%	$297.00	$32 72	$0.12
Grinder	$15,740 00	1.7 kw	25	$1,734 05	0 00%	$0 00	$0.00	$0.00
Cheese Cloth & Sieve	$192.00	-	1	$211 20	0 00%	$0 00	$0.00	$0.00
Freeze Dryer	$45,000 00	1.66 kw	25	$4,957 56	0.00%	$0 00	$0.00	$0.00
Incubator Shaker	$19,500 00	1.7 kw	25	$2,148 28	0 00%	$0 00	$0.00	$0.00
Containers	$193 00	-	5	$50 91	0.00%	$0 00	$0.00	$0.00
Steam Kettle	$4,000.00	2.5 kw	25	$440 67	0 00%	$0.00	$0.00	$0.00
Drum Dryer	$47,000 00	2.5kw	25	$5,177 90	0.00%	$0.00	$0 00	$0.00
Total	**$184,269.00**					**$47,241.00**	**$5,204.45**	**$5.47**

*Consumption per batch

Other Direct Costs

Direct Input Cost^	
Hcl	$37.50
Labor cost Assigned*	$1,486.86
Heat**	$27.78
Maintenance***	1889.64

^ Inputs required to process one batch (50 kg dried waste)

* The annual labor cost is shared by all the products produced by the pilot plant, the allocation was done by using the net realizable value method
The Labor cost is supposed to be linearly dependent on the capacity use of the plant This amount is the cost when the plant is used at 100% capacity

** The same technique was applied for the heat cost It is a fixed cost

*** The maintenace cost is equal to 4% of the portion of investment allocated to the process It is linearly dependent of the capacity use of the equipments

Table A2-4

Chitosan Cost Breakdown

Direct Equipment Cost

ITEM	Cost	Energy Required	Expected Life	Annual Equivalent Cost of Capital	Portion allocated to the process	Portion of investment	Depreciation	Power required*
Incubator Shaker	$19,500.00	1.7 kw	25	$2,148 28	100.00%	$19,500.00	$2,148 28	$330.48
Freeze Dryer	45,000.00	1.66 kw	25	4,957 56	100.00%	45,000.00	4,957.56	44.82
Ph-meter	900.00	90 w	25	99 15	33.00%	297.00	32.72	0.12
Balance	6,400.00	360 w	25	705 08	25.00%	1,600.00	176.27	0.49
Container	193.00		5	50 91	50.00%	96.50	25.46	0.00
Steam Kettle	4,000.00	2.5 kw	25	440 67	0.00%	0.00	0.00	0.00
Centrifuge	45,344.00	0.9 kw	25	4,995 46	0.00%	0.00	0.00	0.00
Grinder	15,740.00	1.7 kw	25	1,734 05	0.00%	0.00	0.00	0.00
Cheese cloth & Sieve	192.00	-	1	211 20	0.00%	0.00	0.00	0.00
Drum Dryer	47,000.00	2.5kw	25	5,177 90	0.00%	0.00	0.00	0.00
Total	**$184,269.00**					**$66,493.50**	**$7,340.29**	**$375.91**

*Consumption per batch

Other Direct Costs

Direct Input Cost^	
Chitin~	$2,080.01
NaOH	$99.95
Labor cost Assigned*	$13,418.14
Heat**	$250.66
Maintenance***	$2,659.74

^ Inputs required to process one batch (50 kg dried waste)

~This amount is the production cost of chitin resulted from the process of one batch (50 kg) of shrimp waste

* The annual labor cost is shared by all the products produced by the pilot plant, the allocation was done by using the net realizable value method
The Labor cost is supposed to be linearily dependent on the capacity use of the plant This amount is the cost when the plant is used at 100% capacity

** The same technique was applied for the heat cost It is a fixed cost

*** The maintenace cost is equal to 4% of the portion of investment allocated to the process It is linearily dependent on the capacity use of the equipments

Table A2-5

Distribution of Common Costs Amongst the Three Final Products

The pilot plant will process shrimp waste in order to produce chitin, chitosan and pigments
The processing of all the products will be done at the same place, by the same people Furthermore, a couple of products will be processed at the same time.
Given this, the labor costs, the rent, the heating costs will be considered as joint costs
The distribution of these common costs (joint costs) to the different outputs will be based on the net realizable value method (Humphreys and English,1993).

Annual Labor Cost:	**$36,000.00**
Annual Rent:	**$4,200.00**
Annual Heating Cost:	**$672.50**

Final Product	Quantity Produced (kg)*	Reference Price /(g)**	Net Realizable Value	Weighting	Labor cost assigned	Rent Cost assigned	Heat Cost assigned
Chitin	890.95	**$6.67**	$5,942,636 50	58 60%	$21,095 00	$2,461 08	$394 07
Chitosan	540.00	**$7.00**	$3,780,000 00	37 27%	$13,418 14	$1,565 45	$250 66
Pigments	117 00	**$3.58**	$418,860 00	4 13%	$1,486 86	$173 47	$27 78
Total			**$10,141,496.50**	**100.00%**	**$36,000.00**	**$4,200.00**	**$672.50**

* The quantity produced when the plant is used at its 100% capacity

** these are the lowest price estimates

Table A2-6

Preliminary Operating Cost Estimate for Chitin & Pigment

	Dried shrimp waste				
	1170 kg	**2340 kg**	**3510 kg**	**4680 kg**	**5850 kg**
Plant Capacity use	**20%**	**40%**	**60%**	**80%**	**100%**
Direct production costs					
Raw Material	$632 50	$1,265.00	$1,925 00	$2,585 00	$3,217.50
Processing	$593.86	$1,187.72	$1,807 40	$2,427 08	$3,020 94
Power	$222 32	$444.64	$676 62	$908 60	$1,130.92
Maintenance	$141 03	$282 06	$423 08	$564 11	$705.14
Contengencies	$47 69	$95.38	$144 96	$194 54	$242.24
Indirect production costs					
Depreciation	$2,146.97	$2,146.97	$2,146 97	$2,146.97	$2,146.97
Insurance	$220.36	$220.36	$220 36	$220 36	$220.36
Plant Overhead	$56.41	$112 82	$169 23	$225 64	$282.06
Total Production cost	**$4,061.14**	**$5,754.94**	**$7,513.63**	**$9,272.31**	**$10,966.12**
Total production of chitin (kg)	178.191	356.382	534 573	712 764	890 955
Total production of pigments (kg)	23 400	46 800	70 200	93 600	117 000
Price of 1 gram chitin	**$6.67**				
Price of 1 gram pigments	**$3.58**				
Joint cost assigned to chitin	**$3,793.74**	**$5,376.02**	**$7,018.91**	**$8,661.80**	**$10,244.08**
Joint cost assigned to pigments	**$267.40**	**$378.92**	**$494.72**	**$610.51**	**$722.04**

Table A2-7

Production Cost of Chitin

		Dried shrimp waste				
		1170 kg	**2340 kg**	**3510 kg**	**4680 kg**	**5850 kg**
Plant Capacity use		**20%**	**40%**	**60%**	**80%**	**100%**
Direct production costs						
Processing		$40,250.00	$80,500.00	$122,500.00	$164,500.00	$204,750.00
Power		$790.22	$1,580.45	$2,405.03	$3,229.61	$4,019.83
Heat		$394.07	$394.07	$394.07	$394.07	$394.07
Labor		$4,219.00	$8,438.00	$12,657.00	$16,876.00	$21,095.00
Supervision		$632.85	$1,265.70	$1,898.55	$2,531.40	$3,164.25
Payroll charges		$1,633.86	$3,267.71	$4,901.57	$6,535.42	$8,169.28
Maintenance		$423.25	$846.50	$1,269.74	$1,692.99	$2,116.24
Contengencies		$1,450.30	$2,888.77	$4,380.78	$5,872.78	$7,311.26
Indirect production costs						
Depreciation		$5,828.55	$5,828.55	$5,828.55	$5,828.55	$5,828.55
Rent		$2,461.08	$2,461.08	$2,461.08	$2,461.08	$2,461.08
Insurance		$661.33	$661.33	$661.33	$661.33	$661.33
Plant Overhead		$2,110.04	$4,220.08	$6,330.12	$8,440.16	$10,550.20
Total operationg costs		$60,854.54	$112,352.23	$165,687.81	$219,023.40	$270,521.09
Joint cost assigned to chitin		$3,793.74	$5,376.02	$7,018.91	$8,661.80	$10,244.08
Total Production cost		**$64,648.28**	**$117,728.26**	**$172,706.73**	**$227,685.19**	**$280,765.17**
Total production of chitin (kg)		178.191	356.382	534.573	712.764	890.955
Cost per gram		**$0.36**	**$0.33**	**$0.32**	**$0.32**	**$0.32**
Gross Margin %		**94.56%**	**95.05%**	**95.16%**	**95.21%**	**95.28%**

Reference Price $/g **$6.67**

Table A2-8

Production Cost of Carotenoprotein (Pigments)

	Dried shrimp waste				
	1170 kg	**2340 kg**	**3510 kg**	**4680 kg**	**5850 kg**
Plant Capacity use	**20%**	**40%**	**60%**	**80%**	**100%**
Direct production costs					
Processing	$862.50	$1,725.00	$2,625.00	$3,525.00	$4,387.50
Power	$125.75	$251.51	$382.73	$513.95	$639.70
Heat	$27.78	$27.78	$27.78	$27.78	$27.78
Labor	$297.37	$594.74	$892.11	$1,189.49	$1,486.86
Supervision	$44.61	$89.21	$133.82	$178.42	$223.03
Payroll charges	$181.99	$363.99	$545.98	$727.98	$909.97
Maintenance	$377.93	$755.86	$1,133.78	$1,511.71	$1,889.64
Contengencies/Misc	$57.54	$114.24	$172.24	$230.23	$286.93
Indirect production costs					
Depreciation	$5,204.45	$5,204.45	$5,204.45	$5,204.45	$5,204.45
Rent	$173.47	$173.47	$173.47	$173.47	$173.47
Insurance	$590.51	$590.51	$590.51	$590.51	$590.51
Plant Overhead	$287.96	$575.92	$863.89	$1,151.85	$1,439.81
Total operating costs	$8,231.86	$10,466.68	$12,745.75	$15,024.83	$17,259.65
Joint cost assigned to pigments	$267.40	$378.92	$494.72	$610.51	$722.04
Total Production cost	$8,499.25	$10,845.60	$13,240.47	$15,635.34	$17,981.69
Total production of pigments (kg)	23.400	46.800	70.200	93.600	117.000
Cost per gram	**$0.36**	**$0.23**	**$0.19**	**$0.17**	**$0.15**
Gross Margin %	**89.85%**	**93.53%**	**94.73%**	**95.33%**	**95.71%**

Reference Price $/g **$3.58**

Table A2-9

Production Cost of Chitosan

		Dried shrimp waste				
		1170 kg	2340 kg	3510 kg	4680 kg	5850 kg
Plant Capacity use		20%	40%	60%	80%	100%
Direct production costs						
Processing		$66,947.13	$122,325.96	$179,703.23	$237,080.49	$292,459.32
Power		8,645.87	17,291.75	26,313.53	35,335.31	43,981.18
Heat		250.66	250.66	250.66	250.66	250.66
Labor		2,683.63	5,367.26	8,050.88	10,734.51	13,418.14
Supervision		402.54	805.09	1,207.63	1,610.18	2,012.72
Payroll charges		1,089.71	2,179.42	3,269.13	4,358.84	5,448.54
Maintenance		531.95	1,063.90	1,595.84	2,127.79	2,659.74
Contengencies		2,416.54	4,478.52	6,611.73	8,744.93	10,806.91
Indirect production costs						
Depreciation		$7,340.29	$7,340.29	$7,340.29	$7,340.29	$7,340.29
Rent		1,565.45	1,565.45	1,565.45	1,565.45	1,565.45
Insurance		831.17	831.17	831.17	831.17	831.17
Plant Overhead		1,447.25	2,894.50	4,341.74	5,788.99	7,236.24
Total Production Costs		$94,152.19	$166,393.94	$241,081.27	$315,768.60	$388,010.35
Total production of chitosan (kg)		107.991	215.982	323.973	431.964	539.955
Cost per gram		**$0.87**	**$0.77**	**$0.74**	**$0.73**	**$0.72**
Gross Margin %		**87.54%**	**88.99%**	**89.37%**	**89.56%**	**89.73%**

Reference Price $/g **$7.00**

Table A2-10

Scalled-Up Preliminary Operating Cost Estimate for Chitin & Pigment

cost factor **0.7**

		Dried shrimp waste					
		5,850 kg	**15,000 kg**	**30,000 kg**	**150,000 kg**	**300,000 kg**	**600,000 kg**
Direct production costs							
Raw Material		3,217 50	8,250 00	16,500 00	82,500 00	165,000.00	330,000 00
Processing		3,020.94	7,746 00	15,492 00	77,460 00	154,920 00	309,840 00
Power		1,130 92	2,899 80	5,799 60	28,998 00	57,996 00	115,992 00
Maintenance		705 14	1,363 11	2,214 37	6,831 72	11,098 16	18,029.02
Contengencies		242.24	607 77	1,200 18	5,873 69	11,670.42	23,215 83
Indirect production costs							
Depreciation		2,146.97	4,150 31	6,742 20	20,800 84	33,791 07	54,893 75
Insurance		220.36	425 97	691 99	2,134 91	3,468 18	5,634 07
Plant Overhead		282.06	545 24	885.75	2,732 69	4,439.27	7,211 61
Total Production cost		10,966 12	25,988 20	49,526.10	227,331 86	442,383.10	864,816 28
Total production of chitin (kg)		890.96	2,284 50	4,569.00	22,845 00	45,690.00	91,380 00
Total production of pigments (kg)		117.00	300.00	600.00	3,000 00	6,000 00	12,000 00
Price of 1 gram chitin		**6.67**					
Price of 1 gram pigments		**3.58**					
Joint cost assigned to chitin		$10,244 08	$24,277.07	$46,265.17	$212,363 72	$413,255.42	$807,874.48
Joint cost assigned to pigments		$722.04	$1,711 13	$3,260.93	$14,968 13	$29,127.68	$56,941 80

Table A2-11

Production Cost of Chitin at the Industrial Level

The Extrapolation is Based on the Cost-Capacity Factor Method for the Fixed Costs

Cost-factor **0.7**

	Dried shrimp waste					
	5,850 kg	**15,000 kg**	**30,000 kg**	**150,000 kg**	**300,000 kg**	**600,000 kg**
Direct production costs						
Processing*	$204,750	$525,000	$1,050,000	$5,250,000	$10,500,000	$21,000,000
Power*	$4,020	$10,307	$20,615	$103,073	$206,145	$412,290
Heat**	$394	$762	$1,237	$3,818	$6,202	$10,075
Labor^	$21,095	$44,686	$51,164	$68,095	$77,269	$88,063
Supervision	$3,164	$6,703	$7,675	$10,214	$11,590	$13,209
Payroll charges	$8,169	$17,230	$20,104	$28,995	$34,830	$42,796
Maintenance**	$2,116	$4,091	$6,646	$20,503	$33,307	$54,108
Contingencies	$7,311	$18,263	$34,723	$164,541	$326,080	$648,616
Indirect production costs						
Depreciation**	$5,829	$11,267	$18,304	$56,470	$91,735	$149,024
Rent**	$2,461	$4,758	$7,729	$23,844	$38,735	$62,925
Insurance**	$661	$1,278	$2,077	$6,407	$10,409	$16,909
Plant Overhead	$10,550	$22,192	$26,194	$39,525	$48,867	$62,152
Total Operating Costs	$270,521	$666,537	$1,246,467	$5,775,484	$11,385,169	$22,560,168
Joint cost assigned to chitin	$10,244	$24,277	$46,265	$212,364	$413,255	$807,874
Total Production cost	**$280,765**	**$690,814**	**$1,292,732**	**$5,987,848**	**$11,798,424**	**$23,368,042**
Total production of chitin (kg)	890.955	2,284.500	4,569.000	22,845.000	45,690.000	91,380.000
Cost per gram	**$0.32**	**$0.30**	**$0.28**	**$0.26**	**$0.26**	**$0.26**
Gross Margin %	**95.28%**	**95.47%**	**95.76%**	**96.07%**	**96.13%**	**96.17%**

Reference Price $/g **$6.67**

* These cost are variable, they are computed with respect to the quantity being processed

** These are fixed costs, we applied the cost-factor method for the scale-up

^ In order to scale-up the labor cost, we assume that the labor requirements vary by 0.25 power of the capacity ratio when processing capacities are scaled up ((Jelen and Black, 1983)

The other costs were calculated with respect to the same rules we used for the pilot plant calculation

Table A2-12

Production Cost of Carotenoprotein at the Industrial Level

The Extrapolation is Based on the Cost-Capacity Factor Method for the Fixed Costs

Cost-factor **0.7**

	Dried shrimp waste					
	5,850 kg	**15,000 kg**	**30,000 kg**	**150,000 kg**	**300,000 kg**	**600,000 kg**
Direct production costs						
Processing*	$4,388	$11,250	$22,500	$112,500	$225,000	$450,000
Power*	$640	$1,640	$3,281	$16,403	$32,805	$65,610
Heat**	$28	$54	$87	$269	$437	$710
Labor^	$1,487	$3,150	$3,606	$4,800	$5,446	$6,207
Supervision	$223	$472	$541	$720	$817	$931
Payroll charges	$910	$1,860	$2,466	$5,281	$7,714	$11,561
Maintenance**	$1,890	$3,653	$5,934	$18,308	$29,741	$48,314
Contingencies	$287	$662	$1,152	$4,748	$9,059	$17,500
Indirect production costs						
Depreciation**	$5,204	$10,061	$16,344	$50,423	$81,913	$133,067
Rent**	$173	$335	$545	$1,681	$2,730	$4,435
Insurance**	$591	$1,142	$1,854	$5,721	$9,294	$15,098
Plant Overhead	$1,440	$2,910	$4,033	$9,531	$14,402	$22,181
Total Operating Costs	$17,260	$37,189	$62,343	$230,384	$419,358	$775,615
Joint cost assigned to pigment	$722	$1,711	$3,261	$14,968	$29,128	$56,942
Total Production cost	$17,982	$38,900	$65,604	$245,352	$448,486	$832,557
Total carotenoprotein produced (kg)	117.000	300.000	600.000	3,000.000	6,000.000	12,000.000
Cost per gram	**$0.15**	**$0.13**	**$0.11**	**$0.08**	**$0.07**	**$0.07**
Gross Margin %	**95.71%**	**96.38%**	**96.95%**	**97.72%**	**97.91%**	**98.06%**

Reference Price $/g **3.58**

* These cost are variable, they are computed with respect to the quantity being processed

** These are fixed costs, we applied the cost-factor method for the scale-up

Table A2-13

Production Cost of Chitosan at the Industrial Level

The Extrapolation is Based on the Cost-Capacity Factor Method for the Fixed Costs

Cost-factor **0.7**

	Dried shrimp waste					
	5,850 kg	**15,000 kg**	**30,000 kg**	**150,000 kg**	**300,000 kg**	**600,000 kg**
Direct production costs						
Processing*	$292,459	$749,896	$1,499,791	$7,498,957	$14,997,914	$29,995,828
Power*	$43,981	$112,772	$225,545	$1,127,723	$2,255,445	$4,510,890
Heat**	$251	$485	$787	$2,428	$3,945	$6,409
Labor^	$13,418	$28,424	$32,545	$43,314	$49,149	$56,015
Supervision	$2,013	$4,264	$4,882	$6,497	$7,372	$8,402
Payroll charges	$5,449	$11,447	$13,580	$20,887	$26,124	$33,670
Maintenance**	$2,660	$5,142	$8,352	$25,769	$41,862	$68,004
Contingencies	$10,807	$27,373	$53,564	$261,767	$521,454	$1,040,377
Indirect production costs						
Depreciation**	$7,340	$14,190	$23,051	$71,116	$115,528	$187,676
Rent**	$1,565	$3,026	$4,916	$15,167	$24,639	$40,025
Insurance**	$831	$1,607	$2,610	$8,053	$13,082	$21,251
Plant Overhead	$7,236	$15,132	$18,311	$30,232	$39,353	$52,969
Total Production Costs	**$388,010**	**$973,756**	**$1,887,935**	**$9,111,909**	**$18,095,867**	**$36,021,517**
Total production of chitosan (kg)	539.955	1384.500	2769.000	13845.000	27690.000	55380.000
Cost per gram	**$0.72**	**$0.70**	**$0.68**	**$0.66**	**$0.65**	**$0.65**
Gross Margin %	**89.73%**	**89.95%**	**90.26%**	**90.60%**	**90.66%**	**90.71%**

Reference Price $/g **$7.00**

* These cost are variable, they are computed with respect to the quantity being processed

** These are fixed costs, we applied the cost factor method for the scale-up

Table A2-14

Scale-up Costs Using Cost-Factor Method

Cost-factor **0.7**

C2=C1(Q2/Q1)^x

Quantity of Shrimp Waste (Kg)	19,500	50,000	100,000	500,000	1,000,000	2,000,000
Dried Shrimp Shells (Kg)	5,850	15,000	30,000	150,000	300,000	600,000
Pigment Total Production Cost	$17,982	$38,900	$65,604	$245,352	$448,486	$832,557
Chitin Total Production Cost	$280,765	$690,814	$1,292,732	$5,987,848	$11,798,424	$23,368,042
Chitosan Total Production Cost	$388,010	$973,756	$1,887,935	$9,111,909	$18,095,867	$36,021,517
Pigment Produced (Kg)	117.00	300.00	600.00	3,000.00	6,000.00	12,000.00
Chitin Produced (Kg)	890.96	2,284.50	4,569.00	22,845.00	45,690.00	91,380.00
Chitosan Produced (Kg)	539.96	1,384.50	2,769.00	13,845.00	27,690.00	55,380.00
Production Cost per gram						
Chitin	**$0.32**	**$0.30**	**$0.28**	**$0.26**	**$0.26**	**$0.26**
Chitosan	**$0.72**	**$0.70**	**$0.68**	**$0.66**	**$0.65**	**$0.65**
Pigment	**$0.15**	**$0.13**	**$0.11**	**$0.08**	**$0.07**	**$0.07**

APPENDIX 3

Table A3-1:

Value of Cellulose Derivatives Used by Quebec Manufacturing Industry (1978-1993)
Sales are adjusted for Inflation using the Industrial Product Price Index
(1986 = 1.00) ($'000)

Year	Actual Sales	IPPI	Deflated Sales
1978	1524	95.0%	1448
1979	1513	98.0%	1483
1980	1661	96.0%	1595
1981	1110	111.1%	1233
1982	3145	108.7%	3419
1983	2461	109.8%	2702
1984	2410	111.5%	2687
1985	1466	105.1%	1541
1986	1503	100.0%	1503
1987	1616	104.4%	1687
1988	999	135.2%	1351
1989	660	135.0%	891
1990	1205	118.2%	1424
1991	916	120.8%	1107
1992	1087	111.7%	1214
1993	956	119.7%	1144