QUALITY OF ON-BOARD

CRYOGENICALLY FROZEN

SEA SCALLOPS (PLACOPECTEN MAGELLANICUS)

by

JYOTI MUKERJI

Thesis submitted to the faculty of

Virginia Polytechnic Institute and State University

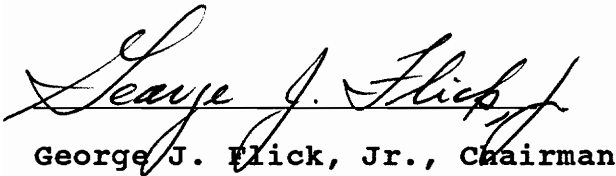
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

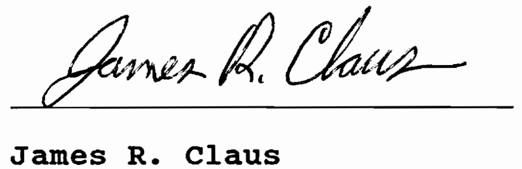
in

FOOD SCIENCE AND TECHNOLOGY

APPROVED:



George J. Flick, Jr., Chairman



James R. Claus

Janet M. Johnson

Thomas E. Rippen

May, 1992

Blacksburg, Virginia

c.2

LD
5655
V855
1992
M843
C.2

QUALITY OF ON-BOARD CRYOGENICALLY FROZEN SEA SCALLOPS (PLACOPECTEN MAGELLANICUS)

by

JYOTI MUKERJI

Committee Chairman: George J. Flick, Jr.

Food Science and Technology

(ABSTRACT)

Scallops have traditionally been blast or sharp frozen. This study compared the quality of at-sea cryogenically frozen scallops with fresh and mechanically frozen scallops. A liquid CO_2 batch freezer was installed on-board the scallop boat. Samples were analyzed for microbiological, physical, chemical and sensory qualities. Sample types included fresh scallops, mechanically frozen scallops and 4 hr and 24 hr (on ice) cryogenically frozen scallops.

The thaw loss mean of 4 hr cryogenically frozen scallops was 2.41 percent compared to means of 4.21 percent for 24 hr (on ice) cryogenically frozen scallops and mechanically frozen scallops, $P < 0.0001$. Cook loss for the 4 hr cryogenic frozen scallop was also reduced ($P < 0.01$) by 27 percent when baked. Cook method did not affect cook loss. Color measurements on the CIE L* a* b* scale did not differ significantly for raw or baked scallops. Instron peak force measurements had a very high standard error and

therefore were not be analyzed statistically. The 4 hr cryogenically frozen scallops met the French Moisture/Protein ratio test standard of 5 ($P > 0.02$) but higher ratios were observed for 24 hr (on ice) cryogenically frozen scallops and mechanically frozen scallops. Scallops meeting this standard have greater export potential and the ability to attract high value markets. Variations observed in proximate composition were minor and may be due to biological factors. Sensory panelists found a significant difference ($P < 0.01$ to $P < 0.05$) among the randomly presented pairs of scallops. Over a 5 month storage period, the sensory characteristics of odor and taste of the cryogenically frozen scallops diminished and the mechanically frozen scallops were consistently scored higher. Mechanically frozen scallops had significantly lower cfu/gm for aerobic, psychrotrophic and coliform counts compared to fresh and cryogenically frozen scallops.

The 4 hr cryogenically frozen scallop had lower thaw and cook loss which could have a significant economic and nutritional significance. Mechanically frozen scallops had a lower microbiological population and frozen storage for 8 months did not affect its taste or odor. Improved sanitation and process control could establish cryogenically frozen scallops as a premium product.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation and gratitude to my advisor, George J. Flick, for his continued support and guidance during this research project. He set the example for me to follow.

I extend my appreciation to my committee members: James R. Claus, Janet M. Johnson, and Thomas E. Rippen for their help and valuable advise during the course of my research.

My sincere appreciation extends to the Airco Corporation, especially William Baker, for providing the cryogenic freezer to conduct this research project. Without their support this project would not have been possible.

Sincere thanks are due to Van Strickland, Captain of the Ian Nigel, John Fernandez, owner of the Ian Nigel, and Bradley and Christopher Brauer of the East Coast Fish and Scallop Co. Inc., Newport News, VA.

Special thanks are due to Robert Lane at the Virginia Seafood Agricultural Experiment Station in Hampton, Virginia. He provided invaluable liaison between personnel on the vessel, cooperating firms, and myself. This ensured that the project proceeded without interruption.

Marvin Lentner and Joe Boling provided invaluable assistance concerning the statistical analysis of my data.

Thank you.

My deepest gratitude is reserved for my family who encouraged me with my studies inspite of difficult situations. Without their support this would not have been possible. To them goes my biggest Thank You.

DEDICATION

This manuscript is dedicated to my wife, Mahrookh, who inspired me to pursue graduate study in the United States. Her constant cheerfulness, sometimes under trying conditions, and her prayers were my mainstay and helped make this course of studies easier.

This manuscript is also dedicated to my parents who taught me the most important lessons of life.

TABLE OF CONTENTS

Page

Title---i

Abstract---ii

Acknowledgements---iv

Dedication---vi

List of Tables---xi

List of Figures---xiii

I. INTRODUCTION---1

1. General Introduction---1

2. Objectives---2

II. REVIEW OF LITERATURE---6

1. Sea Scallop (Placopecten magellanicus)---6

1.1 Anatomical Overview---6

1.2 Biology---7

1.3 Adductor Muscle---8

2. Sea Scallop Fisheries---11

2.1 History---11

2.2 Economic Significance---12

2.3 Fishing Beds---12

2.4 Gear and Boats---15

3. Processing---------------------------------------18

3.1 General------------------------------------18

3.2 Freezing Preservation------------------------18

3.3 Cryogenic Freezing---------------------------20

3.4 Liquid Carbon Dioxide Freezing-------------21

4. Quality Considerations-----------------------------22

4.1 Overall Quality-----------------------------22

4.2 Rigor Condition-----------------------------23

4.3 Microbiological Quality---------------------25

4.4 Chemical Quality----------------------------28

4.5 Physical Quality----------------------------31

4.6 Organoleptic Quality------------------------33

III. MATERIALS AND METHODS------------------------------36

1. Sample Definition----------------------------------36

2. Microbiological Tests-----------------------------38

2.1 Aerobic Plate Count-------------------------38

2.2 Psychrotrophic Plate Count-----------------40

2.3 Coliforms and Fecal Coliforms---------------40

3. Chemical Tests-------------------------------------41

3.1 Moisture/Protein Ratio----------------------41

3.2 pH Measurements-----------------------------45

3.3 Proximate Analysis--------------------------45

4. Physical Tests-------------------------------------47

4.1 Thaw Loss-----------------------------------47

4.2 Cook Loss------------------------------------48

4.3 Color--50

4.4 Instron Shear----------------------------------51

5. Sensory Analysis--------------------------------51

5.1 Paired Comparison-----------------------------51

5.2 Quantitative Descriptive Analysis------------53

6. Statistical Analysis----------------------------55

IV. RESULTS AND DISCUSSION---------------------56

1. Microbiological Quality------------------------56

1.1 Aerobic or Standard Plate Count--------------56

1.2 Psychotrophic Plate Count--------------------59

1.3 Total Coliform Count-------------------------61

1.4 Fecal Coliform Count-------------------------62

2. Chemical Quality-------------------------------65

2.1 French Moisture/Protein Ratio----------------66

2.2 Proximate Analysis---------------------------69

2.3 pH---72

3. Physical Quality-------------------------------75

3.1 Thaw Loss------------------------------------75

3.2 Cook Loss------------------------------------76

3.3 Color--80

3.4 Instron Measurement--------------------------82

4. Organoleptic Quality---------------------------84

4.1 Discrimination Testing-----------------------84

4.2 Quantitative Descriptive Analysis-----------86

5. Correlations------------------------------------92

V. CONCLUSIONS---------------------------------96

VI. APPENDIX ----------------------------------100

1. Appendix I--------------------------------------100

2. Appendix II-------------------------------------105

3. Appendix III------------------------------------106

VII. REFERENCES--------------------------------108

VIII. VITAE------------------------------------117

LIST OF TABLES

TABLE PAGE

1 Scallop production of U.S.A. as landings in meat weights × (1000) lbs------------------------------------3

2 U.S. Annual per capita consumption of fish and shellfish---13

3 Microbiological quality of fresh and frozen sea scallops--57

4 French Moisture/Protein Ratio Test for frozen scallops--68

5 Proximate analysis of fresh and frozen sea scallops--70

6 Thaw loss study of frozen scallops-------------------74

7 Cook loss study on baked scallops--------------------78

7a Cook loss study comparing different cooking methods---79

8 Color Ratings on L* a* b* scale for raw and baked scallops--81

9 Instron shear results for frozen scallops in terms of peak force---83

10 Discrimination testing - Difference test-------------85

11 Quantitative descriptive analysis--------------------87

12 ANOVA showing PR > F for QDA results in Table 11-----88

13 Pearsons correlation coefficients--------------------93

LIST OF FIGURES

FIGURE PAGE

1 Significance of sea scallops fisheries in volume and value--14

2 Schematic map indicating major sea scallop fishing beds on the east coast-----------------------------16

3 Aerobic plate count of fresh and frozen sea scallops---58

4 Psychotrophic plate count for fresh and frozen sea scallops---60

5 Total coliform counts for fresh and frozen sea scallops---63

6 Fecal coliform counts for fresh and frozen sea scallops---64

7 French Moisture/Protein Ratio test------------------67

8 Mean pH values for 4 hr and 24 hr (on ice) cryogenically frozen scallops----------------------71

9 Thaw loss values for frozen scallops---------------73

10 Cook loss study on baked scallops------------------77

11 Spider web profile of QDA scores on 5 months frozen storage--------------------------------------89

12 Spider web profile of QDA scores on 7 months frozen storage--------------------------------------90

13 Spider web profile of Qda scores on 8 months frozen storage--------------------------------------91

14 Aerobic Plate Count for Inside and Outside of Scallop Shucking Tote-----------------------------101

15 Aerobic Plate Count for Scallop Shucking Bucket and Scallop Shucking Box--------------------------102

16 Psychotrophic Plate Count for Inside and Outside of Scallop Shucking Tote-----------------------------103

17 Psychotrophic Plate Count for Scallop Shucking
Bucket and Scallop Shucking Box--------------------104

I. INTRODUCTION

1. General Introduction

Scallops are among the better known shellfish and are widely distributed throughout the world (Shumaway, 1991). They are of worldwide economic importance and in North America rank second only to the American lobster in value (Shumaway, 1991;Naidu, 1991). From an economic viewpoint, the sea scallop, Placopectan magellanicus (also called giant scallop, smooth scallop, ocean scallop or Atlantic deep sea scallop) is by far the most important pectinid species in the world (Naidu, 1991). Global production figures for the years 1976-1987 indicate that about 30 percent of the mean annual global scallop production consists of sea scallops (Yearbook of Fishery Statistics). The figures for the annual U.S. scallop production (Table 1) show that 69 percent of the mean production is sea scallops.

Copland (1992), reported that up to 73 percent of the total scallop catch, may be marketed in the frozen form. Freezing is accomplished either in on-board blast or sharp freezers or in shore based facilities. On-board freezers freeze scallops in 5 lb (2.27 kg) blocks to a temperature of -23°C within 18-24 hours. Scallops destined for shore plants are packed in cloth bags containing 40 lb (18.14 kg)

of scallops and stored in crushed ice. This procedure requires a longer time for temperature stabilization to occur (Peters, 1968;Banks et al., 1977).

It has been emphasized time and again that freezing does not improve the inherent quality of a product. Freezing can only maintain the initial quality by removing heat from the product so as to lower the temperature below the freezing point of its fluids (Breyer, 1971;Dyer, 1964;Piggot and Tucker, 1990). The end result is a reduction in biochemical process rates and the suppression of microbial activity thereby allowing extended storage (Gakichko and Fonvicheva, 1983;Piggot and Tucker, 1990). Rigor plays an important role in the final quality of a frozen product. Pedraja (1972), found that post-rigor fish was desirable in filleting operations and the manufacturing of fish blocks. If pre-rigor fish were utilized, a higher drip loss was observed. Divergent results, however, have been obtained by other researchers indicating that pre-rigor meat has superior quality attributes (Dyer and Hiltz, 1974;Chung and Merritt, 1991).

2. Objectives

A cryogenic batch freezer which could freeze 6 lb (2.72 kg) of scallops on three trays was designed and

Table 1-Scallop production of U.S.A. as landings in meat weights × (1000) lbs.
Source: U.S.Dept. of Commerce, Fisheries Statistics Dept. Fisheries of the U.S.A., May 1990.

Year	U.S. Commercial Landings (1000 lbs) in Meat weight				
	Total	Bay	Calico	Sea	%(Sea)
1980	29720	968	-	28752	96.7
1981	45588	670	14641	30277	66.4
1982	34115	1780	11010	21325	62.5
1983	32422	8338	9606	20478	63.2
1984	59485	1728	39330	18427	31.0
1985	29673	1331	12513	15829	53.3
1986	22343	735	1616	19992	89.5
1987	40773	580	8155	32038	78.6
1988	42994	569	11868	30557	71.1
1989	40611	274	6580	33757	83.1
Total	377724	16973	115319	251432	66.6

constructed for this project. The freezing protocol was established at the Virginia Seafood Agricultural Experiment Station. A freezing time of 14 min was required to ensure a core temperature of -20°C. The project objective was to compare the quality of 4 hr and 24 hr (on ice) scallops (presumed in-rigor) that were cryogenically frozen to fresh as well as to mechanically frozen scallops. Quality indicators were chosen to include the following parameters:

a) Microbiological

  i) Aerobic Plate Count

  ii) Psychrotrophic Plate Count

  iii) Total Coliform Count

  iv) Fecal Coliform Count

b) Physical

  i) Thaw Loss

  ii) Cook Loss

  iii) Instron Shear

  iv) Color

c) Chemical

  i) Moisture/Protein Ratio

  ii) Proximate Analysis

  iii) pH Measurement

d) Sensory Analysis

i) Difference Testing

ii) Quantitative Descriptive Analysis.

II. REVIEW OF LITERATURE

1. Sea Scallop (*Placopecten magellanicus*)

1.1 Anatomical Overview

The term "scallop" commonly includes all bivalves in the superfamily *Pectinacea* (Boss, 1982;Waller, 1991). Waller (1984), observed that all commercial species of scallops fall within the family *Pectinidae*, a monophyletic group characterized by a true ctenolium, which is a row of successively formed denticles present at least in early post-larval (dissoconch) growth stages along the ventral edge of the byssal notch of the right valve. The family *Pectinidae* has a very well differentiated anatomical structure and its body system is complex (Beninger and Pennec, 1991). The two valves, lower or right and upper or left, are attached at the hinge which is not calcified. The hinge bears teeth which aid in guiding the proper closure of the valves (Waller, 1991).

The opening and closing of the valves is controlled by the adductor muscles. Contained within the valves are the soft body parts comprising the mantle, gills, labial palps and lips, digestive system, cardio-vascular system, excretory system, reproductive system, nervous and sensory

systems and the foot-byssal complex (Beninger and Pennec, 1991).

1.2 Biology

As a rule, scallops are hermaphrodites, the male portion of the gonads being proximal and female distal (Cragg and Crisp, 1991;Naidu, 1991). A color differentiation occurs between the male gonads and female gonads. The male gonad is cream colored while the female is red. The reproductive cycle is considered to be a genetic controlled response to environmental stimulus, with temperature, light, food and salinity being important stimuli (Cragg and Crisp, 1991). Peak spawning occurs from September to October and the nutritional reserves in the form of carbohydrate (glycogen in the adductor muscle) are depleted during gamete development (Naidu, 1991).

Although sexual maturity is achieved in the first year, initial spawning does not begin until the second year. Older scallops contribute to egg production, with a healthy 10 year old female releasing 90 to 95 million eggs a season. The release may be in the form of multiple partial evacuations or just a single one (Naidu, 1991). Fertilization and embryo development is external. The larva is mobile and planktotrophic in nature. The larva reaches

metamorphosis stage in 1 to 3 days and secretes the shell toward the end of trochophore stage. The growth of Placopecten magellanicus is marked by the appearance of growth rings on the shell and the characteristic "wings" appear at the hinge (Cragg and Crisp, 1991;Naidu, 1991).

1.3 Adductor Muscle

Scallops qualify as a gourmet food because its adductor muscle is in high demand the world over. In the U.S.A., the adductor muscle is the main meat consumed whereas in Europe the entire scallop is consumed (Chantler, 1991). Chantler (1991) points out the existence of two types of adductor muscles. The phasic adductor, usually cross-striated, is associated with the fast, repetitive closing and opening of the valves. The tonic adductor or catch muscle is a smooth muscle and is involved in keeping the valves closed for long periods of time with little expenditure of energy. He attributes the chewy nature of the catch muscle, and hence lower value as a food, to high paramyosin content.

The striated adductor muscle cell is small when compared to vertebrate skeletal muscle cells. The average fibre length for a muscle length of 2 cm is close to 650 μm and the short and long diameters of the cells are in the range of 1 and 10 μm, respectively (Nunzi and Francini,

1981;Chantler, 1991). Its contraction resembles vertebrate skeletal muscle cells in that thin filaments slide past thick filaments due to the contraction of cross-bridges (Chantler, 1991). There is a single centrally placed myofibril in each cell and the cell is bound by a surface membrane.

The thick filaments have a diameter larger than the vertebrate striated muscle and are surrounded by 10 to 12 thin filaments in the overlap regions (Millman and Bennet, 1976;Chantler, 1991). The thick filaments contain myosin, have a backbone diameter of 20 nm, a length of 1.7 μm, and are packed in a hexagonal array with an intra filament distance of 60 nm. The core of the thick filament contains 27 percent (by weight) paramyosin and is surrounded by myosin molecules (Millman and Bennet, 1976;Nunzi and Francini, 1981;Chantler, 1991). The thin filaments have a diameter of 7 to 9 nm and contain actin. The grooves in the actin contain tropomyosin. Controversy surrounds the function and amount of troponin present. When present, it forms attachments to both actin and tropomyosin (Millman and Bennet, 1976;Chantler, 1991).

Millman and Bennet (1976), Nunzi and Francini (1981), and Chantler (1991) found no evidence of M-bridges holding adjacent thick filaments together. They postulated that it may be the cause of a ragged A-band. The thin filaments are

held together by a strongly staining amorphous material at the Z-line and this alignment is easily disturbed. They pointed out the differences from vertebrate skeletal muscles:

i) A-bands have variable widths and may differ by as much as 40 percent within the same fibre

ii) The length of individual filaments within an A-band is also variable

iii) Occasionally, very long thick filaments run from one sarcomere to the next

iv) The thin filaments do not terminate in a symmetric manner.

Thus, the scallop cross-striated adductor resembles vertebrate slow striated muscle fibers (Millman and Bennet, 1976). Regulation of contraction is accomplished by the thick filaments which is unlike vertebrate muscle contraction. Researchers have concluded that the physiological properties resemble vertebrate striated muscle but contraction resembles the frog sartorius muscle. It does not exhibit "catch" properties of other molluscan muscles (Millman and Bennet, 1976;Nunzi and Francini, 1981).

2. Sea Scallop Fisheries

2.1 History

The scallop fishery in the U.S. is more than 100 years old. The early fishing focus was off the New England coast. Maine gained prominence with the discovery of beds near Mt. Desert Island in 1883. Once the offshore beds of the Georges Bank were discovered in the 1930's, New Bedford became, and remains, the most important U.S. port for the sea scallop industry (Naidu, 1991). In Canada, in 1920, exploitation of scallop beds in Digby and the Bay of Fundy were initiated. The practice of shucking scallops at sea was introduced by the Digby fishery. The lucrative beds were jointly managed by Canada and the U.S.A. under the auspices of the International Commission for the Northwest Atlantic Fisheries (ICNAF). The World Court decision, in "Convention for the Law of the Sea" in 1984, restricted offshore fleets to their own territorial waters (Naidu, 1991). Over exploitation has led to the establishment of conservation and restoration steps under the Magnuson Fishery Conservation and Management Act (Fisheries of the U.S, 1990;Naidu, 1991).

2.2 Economic Significance

The annual per capita consumption of seafood in the U.S.A. for the years 1980 to 1990 shows a steady increase from 1980 to 1986, after which it remains fairly constant (Fisheries of the U.S., 1990). More than 60 percent of the domestic consumed seafood is either fresh or frozen (Table 2). Commercial landings of crustaceans and shellfish by U.S. fishing craft totalled 446,843 metric tons in 1990. The scallop catch was 18,865 metric tons or 4.22 percent of the commercial landings (Fisheries of the U.S., 1989).

In 1989 scallops ranked sixth in value, following in a descending order, Salmon, Shrimp, Crab, Alaska Pollock and Lobster (Fisheries of the U.S., 1989). The significance of sea scallops in the total scallop catch is shown in Figure 1.

2.3 Fishing Beds

The sea scallop is confined to the Northwest Atlantic Ocean. The geographical location ranges from the north shore of the Gulf of St. Lawrence, Canada to Cape Hatteras, North Carolina (Naidu, 1991).. It is primarily a continental shelf species found at depths ranging from 10 to 100 meters

Table 2-U.S. Annual per capita consumption of fish and shellfish. Source: U.S. Dept. of Commerce, Fisheries Statistics Dept. Fisheries of the U.S.A., May 1990.

Year	Population (millions)	Per Capita Consumption (lbs meat)			
		Total	Fresh & Frz.	Canned	Cured
1980	225.7	12.5	7.9	4.3	0.3
1981	227.9	12.7	7.8	4.6	0.3
1982	230.3	12.5	7.9	4.3	0.3
1983	232.6	13.4	8.4	4.7	0.3
1984	234.8	14.2	9.0	4.9	0.3
1985	237.0	15.1	9.8	5.0	0.3
1986	239.4	15.5	9.8	5.4	0.3
1987	241.7	16.2	10.7	5.2	0.3
1988	244.1	15.2	10.0	4.9	0.3
1989	246.6	15.6	10.2	5.1	0.3
1990	249.2	15.5	10.1	5.1	0.3

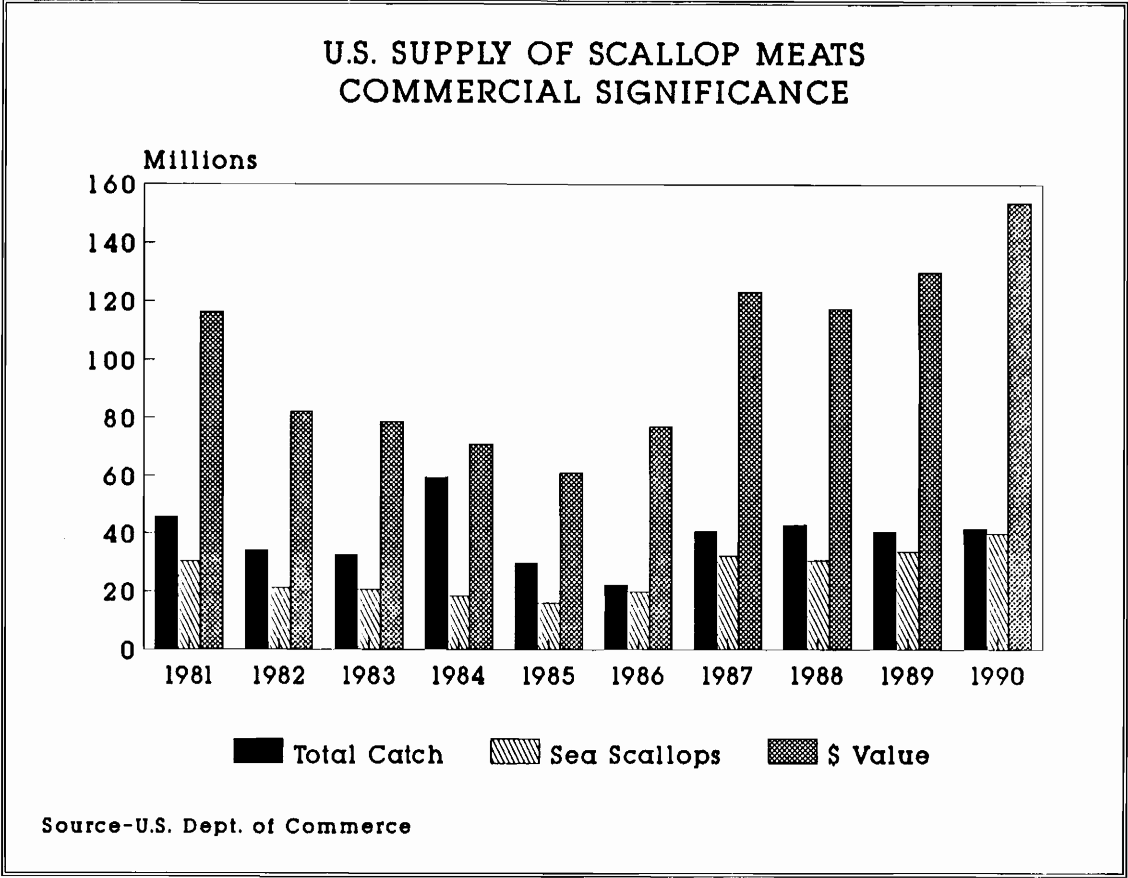


Fig. 1-Significance of Sea Scallop Fisheries in Volume and Value.

but may be found in shallow water. Its growth is restricted to waters having a maximum temperature of 20°C. If found further south, the depth can increase to 384 meters (Naidu, 1991). Commercial exploitation is concentrated mainly on Georges Bank, the Bay of Fundy, the Gulf of Maine, the Mid-Atlantic Shelf, Browns Bank, German Bank, Lurcher Shoals, Grand Manan, and St. Pierre Bank (Brand, 1991;Naidu, 1991). Georges Bank contains the world's largest, single natural scallop resource. The fishing areas are indicated on the map (Figure 2).

2.4 Gear and Boats

Scallop boats are either in-shore or deep sea type. The in-shore boats are under 65 ft, LOA (length on alongside) and the deep sea boats are up to 150 ft, LOA (Naidu, 1991). Scallop crews average about 13 and 24 men, respectively. The deep sea boats are rugged, normally steel hulled and capable of an average fishing trip lasting 15 to 18 days.

Scallops are fished by dredging or dragging the ocean beds. Since the scallops lie semi-buried in the bed, rugged gear is required for retrieval. The most popular types are the Digby-type rake, the Green sweep drag, and the Cayenne drag for inshore waters and the New Bedford scallop drag for

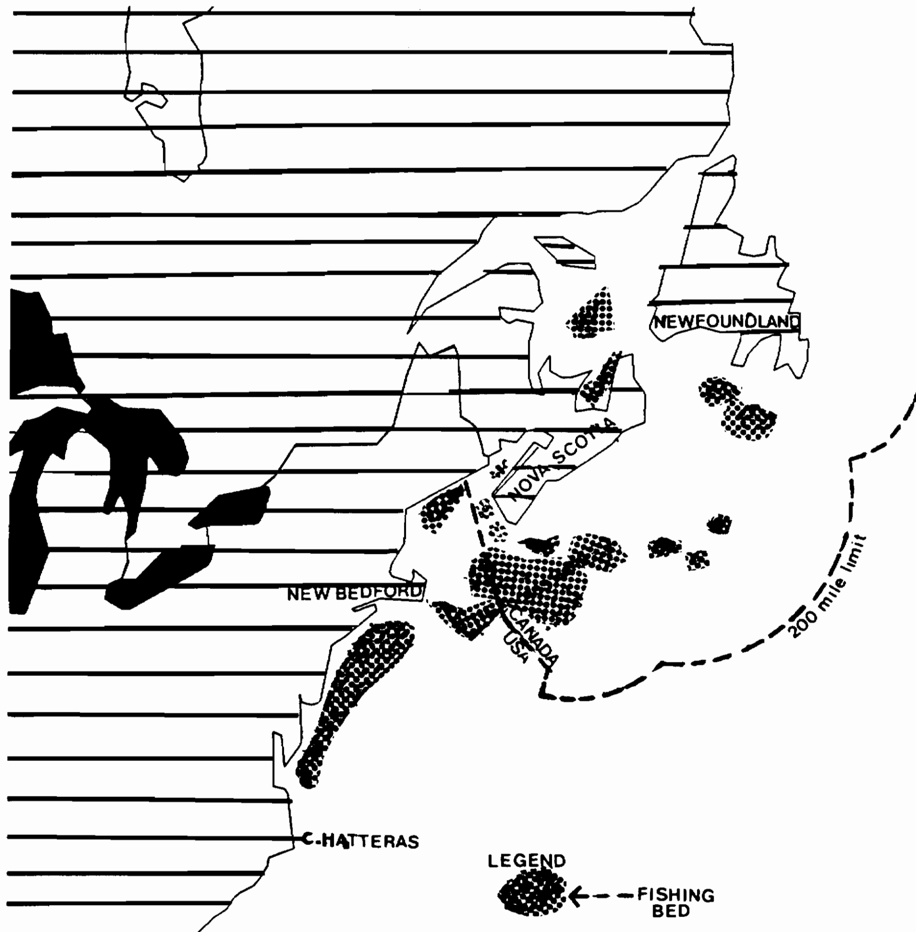


Fig. 2-Schematic map indicating major sea scallop fishing beds on the east coast.

offshore beds. A drag is a heavy metal frame carrying a bag whose mesh is constructed of steel rings 3 to 4 inches in diameter. Caddy (1989), calculated dredge efficiency "e" as:

$$e = \# \text{ of scallops caught} \div \# \text{ in dredge path}$$

and obtained an average efficiency of 15 percent for both _Pecten_ and _Placopecten_ scallops. He attributed this low efficiency to the active and prolonged swimming escape response of young _Placopecten magellanicus_ to divers, predators or scallop dredges. Bourne (1965) made an extensive study of offshore scallop drags and determined the feasibility of regulations requiring standardization of 4 inch mesh rings. This study gave an efficiency, for recruitment of six year old scallops (100 mm and larger, shell height), that was only 6 percent higher than that with the current three inch rings. He therefore concluded that the desired selection of larger scallops was not achievable with only a ring size change.

3. Processing

3.1 General

Processing of foods is performed to meet the demands of

the modern world. Food needs to be transported over vast distances, stored for extended periods or modified to meet the consumers fancy. These aims have to be satisfied within the frameworks of safety and quality of the food products.

Processing may be carried out by either adding or removing heat, controlling water activity or by irradiation (Piggot and Tucker, 1990). Piggot and Tucker (1990) further stated that there has been a major worldwide upswing for the demand of fresh and frozen seafood. This increased demand has been observed earlier in Table 2. In the case of sea scallops, 73 percent of the catch is marketed in the frozen state (Copland, 1992).

3.2 Freezing Preservation.

Freezing, as a method of food preservation, gained commercial importance only at the end of the 19th century (Commercial Freezing Methods, 1986). Breyer (1971), reiterates that the beginning of commercial refrigeration was the installation of an ammonia refrigeration plant designed by Carl von Linde. The product being frozen retains much of its original freshness and flavor (Piggot and Tucker, 1990; Chung and Merritt, 1991).

Tarr (1947) and Sikorsky et al. (1990) identified three principal causes of spoilage in fish:

i) Increase in bacterial population due to conditions of high moisture and nutrients

ii) Denaturation as a result of change in myosin protein and

iii) Rancidity of fatty acids due to oxidation.

Enzyme reactions continue during the freezing process and can contribute to spoilage. Fink (1979) observed effects of subzero temperatures on the structure of enzymes and found in most cases no detectable effects. Trimethylamine oxide (TMAO) exists in a large number of fish and shellfish due to oxidation of Trimethylamine (TMA) by obligate and facultative methylotrophs. Reduction of TMAO to TMA and then to DMA and formaldhyde takes place due to endogenous enzymes in fish and exogenous enzymes produced by bacteria, causing spoilage (Hebard et al., 1982). Freezing tries to address these causes by removing heat from the body being frozen, so as to lower the temperature below the freezing point of the body fluids (Gakichko and Fonicheva, 1983). The end result would be to slow down the biochemical processes in the tissue and to suppress microbial activity thus permitting extended storage. The extent of influence exerted on these processes would depend on the rate of temperature change. Due to freeze concentration effect, the unfrozen phase changes significantly in such properties as

pH, ionic strength and all other colligative properties. It often favors increased reaction rates (Fennema, 1985). Quality is also affected by storage temperature and variations in temperature during storage (Commercial Freezing Methods, 1986). The fastest freezing rates are achievable using cryogenic liquids (Breyer, 1971;Minard, 1973;Commercial Freezing Methods, 1986)

3.3 Cryogenic Freezing

Cryogenic freezing is generally carried out using liquid nitrogen (LN_2) or liquid carbon dioxide (LCO_2). This process involves exposure of the food products to an atmosphere below -60°C (Commercial Freezing Methods, 1986). Due to the rapid heat transfer, ice crystals formed are small and uniform. The time taken for the product to pass through the critical range (0°C to -5°C) is shorter thereby reducing the effect of freeze concentration. During slower freezing, seeding and growth of larger, longer and sharper ice crystals occurs due to axis of growth. These larger crystals expand and rupture cell walls, which cause greater moisture losses through drip when thawed (Piggot and Tucker, 1990). In practical applications, there is a mixture of crystal sizes due to quicker freezing of surface parts compared to the interior (Commercial Freezing Methods,

1986).

3.4 Liquid Carbon Dioxide Freezing

Carbon dioxide exists as a gas or a solid at atmospheric pressure. It is stored in the liquid form at a pressure of 300 psig. When this liquid is released into the atmosphere, half of it becomes dry ice snow at -78°C and half becomes -78°C vapor. The latent heat of sublimation of the snow constitutes 80 percent of the refrigeration capacity and the sensible heat of the gas represents the remaining 20 percent (Minard, 1973;Commercial Freezing Methods, 1986). The latent heat of the snow is 119 Btu and the sensible heat of the gas, assuming an exit temperature of -46°C, is 12 Btu giving a total of 131 Btu/lb (Breyer, 1971). In a well designed system, 60-75 percent of the available Btu's will be transferred to the product. The highest rates of heat transfer come with the direct contact of the product with the snow (Minard, 1973;Commercial Freezing Methods, 1986). The above two sources state that efficiency can be improved by using highly directional nozzles so that very small snow particles can impinge upon the product surface and improve sublimation rates.

Advantages of this type of rapid freezing have been enumerated by Breyer (1971), as:

i) Superior to slow freezing for retention of color, flavor and nutritive value

ii) Less drip loss on thawing due to small ice crystals

iii) Improved texture and appearance of product due to quicker freezing.

4. Quality Considerations

4.1 Overall Quality

Quality is the overall perception of a product by a consumer and includes nuances of appearance, texture and flavor (Dyer, 1964). It is the visible sign of invisible changes due to enzymic, microbial and physical processes. Factors which govern final quality include (Breyer, 1971;Pedraja, 1972):

i) Quality of raw material

ii) Handling prior to freezing

iii) Freezing process

iv) Handling after freezing

v) Packaging and

vi) Storage conditions.

Pedraja (1972), felt that in assessing quality, one must study the interplay of these factors and try to understand the principles governing changes so as to improve process technology.

4.2 Rigor Condition

The catabolic process taking place in a dead animal body leading to stiffening of muscles is known as rigor mortis. Rigor is caused by the bonding of myosin heads on the thick filaments to the active center on actin units on the thin filaments in a rigid structure of interconnected myofilaments (Hultin, 1985). In living muscle tissue calcium pumps in the cell membrane and sarcoplasmic reticulum keeps the concentration of the free Ca below 10^{-7}M by active transportation. The energy to work these pumps is supplied by ATP hydrolysis. After death, depletion of ATP takes place due to exhaustion of arginine phosphate and glycogen reserves. Free Ca levels rise above 10^{-6}M or ATP levels fall below 10^{-4}M inducing rigor mortis due to persistent bonds between actin and myosin. Resolution takes place due to endogenous protease attacking structural muscle proteins (Sikorsky et al., 1990).

As long as fish is in the pre-rigor or rigor state, its freshness and appearance is maintained. Resolution of rigor

results in flaking or gaping in some fish due to the weakening of connective tissue (Commercial Freezing Methods, 1986). This is a major problem when rigor is rapid and intense as at warm temperatures in summer (Rippen, 1992). In scallops, the post-rigor weakening of the myofibrillar structure is due to weakening of actin attachment to the Z-line of the myofibril (Dyer and Hiltz, 1974). Rigor is delayed in a well nourished and unexhausted fish and is more intense (Sikorsky et al., 1990). Korhonan et al. (1990) developed a simple rigorometer and found that the pH of rested pre-rigor fish was much higher than an exhausted fish but final pH values were similar. Excellent quality and texture is maintained by freezing pre-rigor sea scallop meats (Dyer and Hiltz, 1973). Chung and Merritt (1991) found frozen pre-rigor sea scallops meats markedly superior with respect to drip, texture and acceptability to meats held on ice for up to ten days. Dyer and Hiltz (1974) found the tender texture of pre-rigor scallops is retained during quick freezing and thawing. Dyer and Hiltz (1974) established that maximum rigor occurred at approximately four days in iced sea scallops. It has been observed that severe rigor may occur within hours in scallops exposed to very warm deck conditions (Rippen, 1992).

4.3 Microbiological Quality

The most important aspect of food quality is microbiological in nature since it has a direct effect on the health of the consumer. The majority of all seafood illnesses in the U.S. are connected with the consumption of bivalves (Anon, 1988). Matches and Abeyta (1983), analyzed the 120 outbreaks caused by mollusks and crustaceans from 1970-1978. Their data implicates scallops in only one instance. The concern is not as critical for scallops as other mollusks since only the scallop adductor muscle is consumed and this is primarily eaten cooked. There has been a recent trend, however, to consume scallops in the raw state chiefly as lightly marinated dishes. In addition, some marketing groups are promoting the consumption of half shell bay scallops (Rippen, 1992). Scallops, as also other seafood, are a rich source of nutrients and its high moisture levels provides an ideal medium for microbial growth.

Aerobic plate counts (APC) and psychrotrophic plate counts (PPC) have been quantitated and used as indices of quality of _Placopecten magellanicus_ (Dyer and Hiltz, 1974;Hiltz and Dyer, 1971), _Argopecten gibbus_ (Waters, 1964;Webb et al., 1967), _Aquipecten irradians_ (Webb et al., 1967), and _Hinnites multirugosus_ (Maxwell-Miller et al.,

1982). Wholesale market level shellfish meats should have a 35°C aerobic plate count of < 500,000/gm (Cook, 1991). He also puts the APC of freshly harvested bivalves at 10^{-3}- 10^{-5} bacteria/gm. Maxwell-Miller et al. (1982) obtained counts of 22.6 × 10^{6} cfu/gm for scallops stored on ice (14 days) for rinsed samples and 5.2 × 10^{4} for the same samples when homogenized. Power et al. (1964) observed that plate counts of scallops rose to 4.6 × 10^{5} cfu/gm after 18 days on ice while their frozen controls had counts ranging from 4.0 × 10^{2} to 6.0 × 10^{3}. The microbial flora was predominantly *Pseudomonas sp*. Poole et al. (1990) obtained a total viable count in the range of 1.2 × 10^{5} to 8.4 × 10^{7} cfu/gm for chilled scallops. A microbial survey was made of various fresh and frozen fish (Foster et al., 1977) and the aerobic plate count obtained for scallops ranged between 5.4 × 10^{5} and 5.4 × 10^{8}. Aurell et al. (1976) found that blast freezing reduced the number of spoilage bacteria while quick freezing methods left them unaffected.

Coliform organisms like *Aeromonas* and *Serratia* are non enteric in origin and therefore the total coliform count serves only as an indicator of post sanitation or post processing contamination (Fishbein et al., 1976). Cook (1991) identified the microorganisms of concern in shellfish to be *Vibrio*, *Salmonella*, *Shigella*, *E. coli*, *Pleisomonas* and *Aeromonas hydrophilia* among others. Estimation of fecal

coliforms is recommended, for it is the best fecal indicator available at present (Fishbein et al., 1976). Chordash and Insalata (1978), urged its enumeration as an indicator of fecal pollution and/or poor sanitation practices. Cook (1991) indicates that the acceptable level for fecal coliforms should be $< 230/100$ gm. This is the level recommended by the National Shellfish Sanitation Program (NSSP) for fecal coliforms. However scallops are not included in the NSSP program. Foster et al. (1977) enumerated coliforms as well as fecal coliforms in scallops by the MPN method and observed a range of < 3 to 2.4×10^4 for coliforms and < 3 to 3.6/gm for fecal coliforms. Hastback (1981) applied the standard of $< 230/100$ gm, fecal coliforms, as an indicator of quality for scallops as well as other shellfish.

Psychrotrophic bacteria assume significance in frozen foods at the retail level when they are thawed for sale. Even large numbers are not detrimental until temperature abuse occurs and cause food spoilage (Gilliland et al., 1976). Mollusks caught in unpolluted waters probably have flora similar to crustaceans and fish in the same area (Simmonds and Lamprecht, 1985). Shewan et al. (1960), studied the psychrotrophic bacterial flora of north sea white fish and found *Pseudomonas*, *Achromobacter* and *Flavobacter* to be dominant. Levels in the 10^7 range are

likely to cause spoilage during refrigeration. Poole et al. (1990) enumerated psychrotrophic bacteria in chilled scallops and obtained counts of 4.1×10^6 cfu/gm which rose to 10^7 cfu/gm with 7 days chilled storage. Power et al. (1964), earlier, had identified this flora to be predominantly Pseudomonas.

4.4 Chemical Quality

Food composition is often the basis for establishing the nutritional value and overall acceptance from the consumers standpoint (Pomeranz and Meloan, 1987). They have also defined proximate analysis as the determination of the major components (moisture, minerals, carbohydrates, protein and lipids) of food. The proximate composition of a food is influenced by geographical and environmental factors (Piggot and Tucker, 1990). Moisture and lipid contents tend to vary more than the protein or ash contents. Faturoti (1984), and Villareal and Howgate (1987), found a negative correlation between percent moisture and percent protein with r=0.760. Lazos et al. (1989), analyzed fresh water fish and found that variations occur due to age, sex, physiological state, season and region of catch. The proximate composition of raw scallops (Agricultural Handbook # 8) have been reported to be:

i) Water = 79.80%

ii) Protein = 15.30%

iii) Fat = 0.20%

iv) Carbohydrate= 3.30% and

v) Ash = 1.40%.

As mentioned above, researchers found the percent moisture to vary inversely with the percent protein. Scallop muscles have the ability to absorb an enormous amount of water and this has given rise to economic abuse. The French Moisture/Protein ratio test was designed to reduce the incidence of economic fraud in the case of scallops bought by the French importers. As a negative correlation exists between moisture and protein percentages, excessive uptake of water is likely to give ratios in excess of the set limit of 5. The French government and importers established a standard of identity in order to preserve the brand image of the product (Loreal and Etienne, 1990). This specification has:

i) A sampling plan (codex plan NQA 6, 5, S3)

ii) The water/protein ratio on deglazed scallop muscle as an analytical method and

iii) A maximum water/protein ratio of 5.0 as a criterion of conformity.

Loreal and Etienne (1990) studied data on P. maximus, A. purpuratus and Patinopecten yessoensis and in their opinion, the limit of M/P = 5, takes into account the uptake of water that is unavoidable as in washing procedures.

pH effects the water holding capacity and tenderness of food. Cowie and Little (1966) found high cook losses and toughness in cod muscle at a pH below 6.4 while tenderness and lower cook losses resulted at a pH above 6.8. Benson (1928) and Sikorsky (1990) analyzed the pH of various fish in connection with rigor mortis and found:

i) Fatigued muscles have an acidic pH which changes little with time

ii) Rested muscle of fish are alkaline and gradually becomes acidic and

iii) The pH of different fish species vary.

Bouton et al. (1971) found a beneficial effect of high pH on cook loss and a high negative correlation for cook loss as well as instron shear with respect to ultimate pH in mutton. The hardness and cook loss increased below pH 6.3. Chung and Merritt (1991) observed pH values in the range of 6.71 to 6.97 for scallops that were shucked immediately after catching and a pH range of 6.25 to 6.69 if scallops were held alive a few days before freezing.

4.5 Physical Quality

The physical quality of a food is what the consumer initially encounters. These attributes can take the form of thaw losses of defrosting frozen products, cook losses or changes in texture.

Cook losses of 33 percent for in-rigor and 20-23 percent for pre or post-rigor scallop meats have been reported by Dyer and Hiltz (1974). Maxwell-Miller et al. (1982), stored Hinnites multirugosus on ice before evaluating cook loss and reported losses in the range of 8-14 percent which is probably due to shorter cooking times. Marsh and Leet (1966) and Marsh and Thompson (1957), found that increases in thaw and/or cook loss increased dramatically once the muscle entered the delta state of ca 40 percent contraction, at which point it reached its limits of elasticity. Dyer and Hiltz (1974) obtained values of 20 percent and 35 percent for cook loss for samples stored on ice for 1 day and 6 days, respectively.

Thaw drip is defined by Chung and Merritt (1991) as "fluid that separates from meats freely by gravity during thawing without application of external force". They reported a substantial variation in thaw loss ranging from 1 to 14 percent, for scallops frozen after being held on ice. Drip loss, however, was reduced as holding time on ice prior

to freezing was reduced.

Chung and Merritt (1991) used non destructive and destructive compression at 50 percent and 80 percent deformation as well as shear peak force and obtained correlation coefficients of 0.89, 0.78 and 0.82 respectively, with sensory tests. Based on these results, they suggested replacement of sensory methods for evaluation of sea scallop texture. Maxwell-Miller et al. (1982), found Instron shear declined with months in frozen storage and that weight and age had a greater influence than storage. However, they could not correlate their results with sensory data. Dyer and Hiltz (1974) also could not find a correlation between compression modulus and sensory scores. Findlay and Stanley (1984) on the other hand reported good correlation with an $R^2=0.86$ for a linear regression model at $P=0.004$. Very often a single value mechanical test will correlate with the sensory note of seafood texture (Hamman and Lanier, 1986).

Scallop color is due to the presence of carotenoids (Simpson, 1982). Scallops are not capable of de novo synthesis of carotenoids and obtain the compounds by consumption of carotenoid containing substances such as bacteria. Bourne and Bligh (1965) examined the orange-red colored meats of the so called "salmon scallop" and identified the responsible pigment to be zeaxanthin. This

carotenoid is present in the ripe roe of scallops giving them a coral red color. King and Ryan (1977) and Young and White (1985), developed systems for color classification based on Munsell standards and Hunter *L, a, b* values respectively. The brown color which develops on scallops during cooking is due to a maillard reaction. Slow thaw results in higher levels of glucose-6-phosphate formation in pre-rigor meats which leads to excessive browning reactions (Dyer and Hiltz, 1973).

4.6 Organoleptic Quality

"Sensory evaluation is a scientific discipline used to evoke, measure, analyze and interpret reaction to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing" (Anon, 1975). "The main aim of sensory evaluation is to assess the properties of a food and to determine the importance of these properties to the consumer product acceptance" (Stone and Sidel, 1985).

Paired comparison is one type of discrimination testing where two samples are presented simultaneously to the panelist for a decision. It is a forced choice type of situation and the panelist must be made aware of the characteristics, among a multitude of sensations, being

tested. Charlene (1986) performed paired comparison preference testing and suggested that a no-difference option as well as 'two-like' samples presentation should be incorporated into this test. McBride et al. (1984) experimentally substantiated the null hypothesis $p=\frac{1}{2}$ for paired comparison tests.

Quantitative Descriptive Analysis (QDA), belongs to the class of testing known as Descriptive Analysis which is the most sophisticated level of sensory analysis. Stone et al. (1974), described QDA as "a technique in which trained individuals identify and quantify, in order of occurrence, the sensory properties of a product". The salient features of QDA are:

i) Is a response to all sensory characteristics
ii) Is a multiproduct test
iii) Uses a small number of panelists
iv) Subjects are screened for qualifications
v) Scoresheet is developed by the panelists
vi) Is quantitative and
vii) Has data which can be manipulated.

This test has been used variously for monitoring competition, testing shelf life, product development and quality control. McTigue et al. (1989) compared Flavor

Profile Analysis, Category Scaling and QDA and found that panelists evaluated similarly but at different intensity levels. He concluded that choice of method should be based on type, amount and depth of sensory information required.

III. MATERIALS AND METHODS

1. Sample Definition

Sea scallops, Placopecten magellanicus, were obtained from the East Coast Fish and Scallop Co., Newport News, VA. A (LCO_2) batch freezer, containing three 2 lb (0.91 kg) capacity trays, was installed into the hold of the scallop boat, the Ian Nigel. Gas cylinders with an on/off valve supplied the cryogen to the freezer. Scallops were obtained from May through October, 1991 on the Atlantic coast from Virginia to Massachusetts with New Bedford type dredges.

Scallops were shucked as per commercial practice and divided into four groups:

i) Cryogenically frozen immediately after shucking. Twenty lbs (9.1 kg) of scallops were frozen within four hr of shucking in the LCO_2 freezer, with a residence time of 14 min. This constituted the 4 hr sample.

ii) Cryogenically frozen 24 hr after shucking. Twenty lbs (9.1 kg) of scallops were kept on ice for 24 hr after shucking. These were then cryogenically frozen as before and constituted our 24 hr (on ice) sample. Core temperatures achieved

for cryogenically frozen scallops were -20°C. The frozen samples were placed in freezer bags with identity tags and stored in the boat freezer at -23°C.

iii) Blast frozen within six hr of shucking.
Ten lbs (4.5 kg) of scallops were put into 5 lb (2.3 kg) boxes and frozen in the on-board blast freezer. These scallops were maintained in the freezer at -23°C and formed our mechanically frozen sample.

iv) Fresh scallops held on ice.
These were taken from the 40 lb (18.1 kg) cloth bags of fresh scallops on the days which the frozen samples were prepared and held on ice until analysis.

Samples were collected on the first and last fishing days of a trip and also on one or two intermediate days. A normal trip lasted ca 15 days. Samples were collected four times, once each in the months of June, July, August, and October. The days sampled, on each of these trips were:

i) June trip - 9th, 15th and 20th of June.
ii) July trip - 5th, 10th, 17th and 21st of July.
iii) August trip - 3rd, 9th and 16th of August.

iv) October trip - 10th, 19th and 27th of October.

On landing, the frozen samples were placed in ice chests containing dry ice. The fresh scallops were held in ice chests with crushed ice. All samples were immediately transported to Virginia Tech, Blacksburg, VA for analysis. At Virginia Tech, the fresh scallops were held on ice in a cooler maintained at 4.5 ± 1°C. The frozen scallops were stored in the freezer at -26 ± 2°C. Analyses were initiated within 24 hr after arrival in Blacksburg.

2. Microbiological Tests

2.1 Aerobic Plate Count

The aerobic plate count is intended to indicate the level of microorganisms in a product (Messer et al., 1984). Scallops (ca 100 gm) were randomly selected from freezer bags of 4 hr, 24 hr (on ice) cryogenically frozen and fresh scallops and placed in sterile bags on ice in the cooler at a temperature of 4.5 ± 1°C to temper the cryogenically frozen scallops. A sterile hole saw was used to obtain cylinders of meat from the 5 lb (2.3 kg) blocks of mechanically frozen scallops. One of these cylinders was placed in a sterile bag and left to temper as described.

All samples were analyzed within 12 hr.

The samples were homogenized in a stomacher using 50 gm of scallops and 450 mL of Butterfield's buffered phosphate diluent in an aseptic environment (AOAC 46.013, 1984). Butterfield's buffered phosphate dilutions blanks (100 mL) were used to prepare 10^{-1}, 10^{-2} and 10^{-3} dilutions. Tempered Standard Methods Agar was used to pour duplicate plates (AOAC 46.015, 1984). Plates containing 25-250 cfu/plate were counted after 48 ± 2 hr of incubation at 35°C (Messer et al., 1984). Unusual cases were handled as per APHA guidelines (APHA, 1972).

Materials Used:

i) Plate Count Agar; Difco Laboratories, Detroit, MI.

ii) KH_2PO_4 P285-500; Fisher Scientific, Fair Lawn, NJ 07410.

iii) 1.0 N NaOH SS226-1; Fisher Scientific, Fair Lawn, NJ 07410.

iv) UL-Seaward Lab-Blender 400, stomacher and Seaward Medical stomacher bags; 131 Great Suffolk Street, U.K.

v) Quebec Darkfield Colony Counter; Cambridge Instruments, Inc., Buffalo, NY 14215.

2.2 Psychrotrophic Plate Count

It has been suggested that the term "psychrotrophic" be applied to those organisms able to grow relatively rapidly at commercial refrigeration temperatures (Gilliland et al., 1976). Samples were prepared as previously described in the aerobic plate count. Incubation temperature was 7°C for a period of 10 days (APHA, 1972).

Materials Used: as previously for aerobic plate count.

2.3 Coliforms and Fecal Coliforms

The definition of the coliform group is given as "the coliform group includes all the aerobic and facultative anaerobic, gram negative, non-sporeforming, rod shaped bacteria which ferment lactose with gas formation within 48 hr at 35°C" (Mehlman, 1984). Presumptive testing for the coliform group, using the MPN method, was performed in conformance with AOAC (AOAC, 1975) and APHA recommended methods (APHA, 1970).

Five replicate tubes of LST broth were inoculated with 1 mL of 10^{-1}, 10^{-2} and 10^{-3} dilutions of the homogenized samples. The tubes were incubated for 24 and 48 ± 2 hr at 35 ± 0.5°C. Positive tubes were enumerated using the 5 tube

MPN dilution table. Confirmed testing for coliforms was done by subculturing all positive LST tubes into BGB broth which was incubated at 35 ± 0.5°C for 48 ± 2 hr. All positive tubes indicating gas production were enumerated using the 5 tube MPN dilution tables. The fecal coliform group was enumerated by subculturing the positive LST tubes into EC broth and reading tubes positive for gas production after incubation for 24 ± 2 hr at 44.5 ± 0.2°C (APHA, 1970). The MPN table was used as previously described.

Materials Used:

i) Oxford Automatic Dispenser; Monoject Scientific, St. Louis, MO.

ii) Lauryl Sulfate Broth (LS); Becton Dickinson Microbiology Systems, Cockeysville, MD 21030.

iii) Brilliant Green Bile 2% (BGB); Difco Laboratories, Detroit, MI.

iv) EC Medium; Difco Laboratories, Detroit, MI.

3. Chemical Tests

3.1 Moisture/Protein Ratio

Frozen scallops (ca 300 gm) were deglazed by immersion in fresh water until the glaze was removed. The samples

were carefully dried between paper towels and weighed while frozen. The frozen scallops were ground in a blender and placed in air tight plastic containers to prevent dehydration. Approximately 10 gm of ground scallops were weighed in preheated, cooled and tared aluminum dishes for moisture analysis. Samples for protein analysis (ca 4 gm) were weighed on Whatman filter paper # 541 and put into Kjeldahl tubes for digestion (Paris Directorate of Veterinary Services, 1987).

Moisture samples were dried in a hot air oven at 103 ± 2°C (Paris Directorate of Veterinary Services, 1987). These samples were weighed every six hr until two consecutive weights varied by not more than 5 mg. Moisture content as a percentage by weight was expressed by:

$$[(M_1 - M_2) \times 100] \div (M_1 - M_0)$$

M_0 = weight of heated and cooled aluminum dish

M_1 = M_0 + weight of sample before drying

M_2 = M_0 + weight of sample after drying

Protein samples were digested with 15 gm K_2SO_4 and 0.5 gm $CuSO_4$ catalyst in 20 mL of concentrated nitrogen-free H_2SO_4 having a density of 1.83. Digestion continued for 1½ hr after a clear blue-green liquid was obtained. This

digest was distilled with 20 mL distilled water and 80 mL of 38 percent (v/v) NaOH solution for six min in a rapid Kjeldahl system. The distillate was collected under indicator solution (20 mL colored indicator solution + 10 mL alcoholic indicator solution) whose composition is given on page 43 and titrated with 1.0 N HCl. The end point was indicated by a color change from pale green to pale pink. The gram percent protein was obtained by:

$$[1.4 \times (V \div M)] \times 6.25$$

V = burette drop in mL of 1.0 N HCl

M = weight of sample in grams

The Moisture/Protein Ratio was defined as:

$$\% \text{ moisture} \div \% \text{ protein}$$

Materials Used:

1) Fisher Scientific XT Top Load Balance; Fisher Scientific, Fair Lawn, NJ 07410.

ii) Fisher Scientific XA-200DS Analytical Balance; Fisher Scientific, Fair Lawn, NJ 07410.

iii) Lab-Line Imperial III radiant Heat Oven; Lab-Line Instruments Inc., Melrose Park, IL.

iv) Labconco Rapid Kjeldahl System, Rapid Still II;

Labconco Scientific Co. Inc., Kansas City, MO.

v) $CuSO_4$ C493-500; Fisher Scientific, Fair Lawn, NJ 07410.

vi) K_2SO_4 P305-500; Fisher Scientific, Fair Lawn, NJ 07410.

vii) H_2SO_4 A300-212; Fisher Scientific, Fair Lawn, NJ 07410.

viii) Boric Acid A74-1; Fisher Scientific, Fair Lawn, NJ 07410.

ix) C_2H_5OH 90 ± 1% (v/v) A962-4; Fisher Scientific, Fair Lawn, NJ 07410.

x) NaOH 40% (w/w) SS414-4; Fisher Scientific, Fair Lawn, NJ 07410.

xi) Bromocresol Green B-383; Fisher Scientific, Fair Lawn, NJ 07410.

xii) Methyl Red M-219; Fisher Scientific, Fair Lawn, NJ 07410.

xiii) HCl 1.0 N SA48-500; Fisher Scientific, Fair Lawn, NJ 07410.

Colored Indicator Solution - 10 gm boric acid + 200 mL 90 percent ethanol. Dissolved and made up the volume with 700 mL distilled water.

Alcoholic Indicator Solution - 33 mg bromocresol green + 66 mg methyl red dissolved in 1000 mL 90 percent ethanol.

3.2 pH Measurements

pH measurements of 4 hr cryogenically frozen scallops were performed using ca 8 gm homogenized sample in 10 volumes of 5 mM Sodium Iodoacetic Acid (NaIAc) in 50 mM KCl solution (Bendall, 1973). The 24 hr (on ice) cryogenically frozen scallops were homogenized in distilled water and analyzed according to the procedure for Cereal Foods and Cacao Products (AOAC 13.010 and 14.021, 1984).

Materials Used:

i) Corning pH Meter 240; Fisher Scientific, Fair Lawn, NJ 07410.

ii) Iodoacetic Acid Sodium Salt BP 440-100; Fisher Scientific, Fair Lawn, NJ 07410.

iii) KCl P217-500; Fisher Scientific, Fair Lawn, NJ 07410.

3.3 Proximate Analysis

Ash quantities were obtained using ca 2 gm dry sample in 5 drops of olive oil. This mixture was heated in a furnace initially at 100°C and finally at 550°C. The ash was moistened, dried and re-ashed at 550°C to a constant weight (AOAC 18.025 and 31.012, 1984). Calculation of

percent ash was as:

$$\% \text{ Ash} = [\text{Wt of Ash} \div \text{Wt of Sample}] \times 100$$

Protein was estimated by potentiometric end point determination. Two hundred and fifty grams of dry sample were digested with 6 gm of catalyst and 12 mL of concentrated H_2SO_4 for 30 min. Seventy five mL of distilled water and 50 mL of 38 percent (w/w) NaOH were added for the distillation reaction. The back titration was performed with 0.1 N HCl using bromocresol green as an indicator. The catalyst composition was:

$$9.9 \text{ gm } K_2SO_4 + 80 \text{ mg Selenium} + 410 \text{ mg } CuSO_4$$

The ether extract procedure utilized 0.5 gm of dry sample and a procedure patented by Randall (AOAC, 1974). Samples were dried overnight at 50°C and weighed in tared Whatman thimbles. Petroleum ether (5 mL) was added into the tared soxlet flask and the capsules containing the samples were lowered into ether. After boiling for 30 min, the thimbles were raised above the ether and an extraction rinsing procedure was performed for 60 min. The ether in the flasks were then allowed to evaporate in the apparatus for 15 min and the flasks were dried in a 90°C oven for 10

min. The flasks were transferred to a desiccator and weighed after cooling to room temperature.

% Ether extract = [Wt of Ether extract ÷ Wt of Sample] × 100

The nitrogen free extract was obtained by subtracting moisture and ash, protein and ether extract corrected to wet weight from total sample weight.

Materials Used:

i) Kjeltec Auto 1030 Analyser; Itecator, Sweden.

ii) Soxtec System HT; Itecator, Sweden.

iii) Petroleum Ether P480-4; Fisher Scientific, Fair Lawn, NJ 07410.

iv) Concentrated H_2SO_4, 38% (w/w) NaOH, 0.1 N HCl, Selinium, K_2SO_4, and $CuSO_4$; Provided by Forage Testing Laboratory, Virginia Tech.

4. Physical Tests

4.1 Thaw Loss

Frozen samples were removed from the freezer (-26°C), placed in preweighed freezer bags and the net frozen weights determined. These bags were then placed in a refrigerator

($4 \pm 0.5°C$) and thermocouples were placed in the center of the frozen mass. A datalogger was used to provide a continuous readout of the temperature changes. The thaw process was considered complete when temperatures of the frozen samples were > 0°C and < 0.5°C. Samples were carefully dried between paper towels and reweighed. Thaw loss was calculated as:

$$(\text{Loss in Wt} \div \text{Initial Wt}) \times 100$$

Materials Used:

i) Campbell 21X Micrologger; Campbell Scientific Inc., Logan, UT 84321.

ii) Type T Thermocouples PP-T-24; Omegalux, Camden, NJ.

4.2 Cook Loss

Mechanically frozen samples were thawed over 24 hr. The samples were packed in ice and placed in a cooler at $4.5 \pm 1°C$. Cryogenically frozen 4 hr, 24 hr (on ice) scallops were taken directly from the frozen state. All samples (5 to 7 for each treatment) were weighed, wrapped in aluminum foil and baked by placing in an oven preheated to 203°C. Internal temperatures were monitored by a datalogger

using type J thermocouples. Both oven and sample temperatures were monitored. The cooking procedure followed the AOAC (King, 1983) guidelines. Samples were cooked for 20 min to ensure an internal temperature of 70°C. The samples were unwrapped, dried carefully between paper towels and weighed when they attained room temperature.

Comparison was made between baking, broiling and microwave cooking methods. For broiling, samples were prepared as previously stated and placed in a preheated oven in the broil mode. As the internal temperature reached 35 ± 2°C, the samples were removed, turned over and replaced in the oven. Cooking was complete when the internal temperature reached 70°C. Microwave samples were placed unwrapped on a microwave safe dish. Internal temperature of the samples were monitored by fibre optic probes. Cooking was discontinued when an internal temperature of 70°C was attained. Final weights were noted as before. Cook loss was calculated as:

$$(\text{Loss in Wt} \div \text{Initial Wt}) \times 100$$

Materials Used:

i) Campbell 21X Micrologger; Campbell Scientific Inc., Logan, UT 84321.

ii) Type J Thermocouples GG-J-24 SLE; Omegalux,

Camden, NJ.

iii) Luxtron 755 Multichannel Fluoroptic Thermometer and Non-Medical Probes # 35-10872-01, Rev. B.; Luxtron, CA 94043.

iv) Whirlpool MW 8900XS Microwave (750 watts); Whirlpool, Benton Hills, MI.

4.3 Color

Raw and cooked scallops were evaluated for color using a Minolta Chroma Meter. Five scallops were randomly selected from each treatment type for each fishing day. Each scallop was measured three times. Areas of visible differences due to caramelization were avoided.

Calibration of the meter was performed before each sample set using the standard (L^*=97.91, a^*=-0.7, b^*=2.44) plate provided. Color was expressed in CIE L^* a^* b^* values. L^* scale measures darkness-lightness variations on a 0-100 scale. The a^* scale measures red-green transitions on a a^+- a^- scale and the b^* scale measures yellow-blue transitions on a b^+- b^- scale.

Materials Used:

i) Minolta Chroma Meter Model CR200; Minolta Corporation, Osaka, Japan.

4.4 Instron Shear

Scallops were baked as previously described for sensory panels. Random samples were picked (10 to 12) from among the sensory panel samples and put aside for Instron measurements. Cooked scallops were cored into cylinders 1.0 ± 0.25 cm (l) and 1.0 ± 0.1 cm (d) using a punch. A modified Warner-Bratzler shear device (appendix II) was used to measure shear peak force transverse to the muscle fibers at room temperature. A 50 kg load cell was used and the cross head speed was set at 200 mm/min with full scale calibration at 5 kg.

Materials Used:

i) Instron Universal Testing Instrument Model 1011; Instron.

5. Sensory Analysis

5.1 Paired Comparison

Paired comparison testing was initiated to establish if differences in sensory perception existed between cryogenically frozen, mechanically frozen and fresh scallops. Panelists (volunteers) were trained based on the

guidelines of Stone and Sidel (1985b) with fresh scallops obtained directly from a scallop vessel and commercially available samples from a local grocer. Only panelists who could discern differences during training were retained for the panel. The hypothesis tested for in these comparisons was:

Ho: No difference exist between samples if $p = \frac{1}{2}$ at the selected probability level and

Ha: Difference exists between samples if $p \neq \frac{1}{2}$ at the selected probability level.

The test for single proportion was used where:

$z = p' - \frac{1}{2} \div \sqrt{(\frac{1}{2})(\frac{1}{2})^{1}/_{n}}$ and the probability levels examined were .05 and .01. Ho was rejected if:

$z \geq 1.96$ or $z \leq -1.96$ @ $\alpha = 0.05$ level and

$z \geq 2.58$ or $z \leq -2.58$ @ $\alpha = 0.01$ level.

Scallops were baked and presented to the panelists in the standard coded form (appendix III). All testing was carried out in testing booths in a sensory lab. Pairs of comparisons included:

i) fresh scallop (last days catch) with mechanically frozen scallop (first days catch)

ii) fresh scallop (last days catch) with 4 hr cryogenically frozen scallop (first days catch)

iii) fresh scallop (last days catch) with 24 hr (on ice) cryogenically frozen scallops (first days catch)

iv) mechanically frozen scallops (first days catch) with 4 hr cryogenically frozen scallop (first days catch)

v) mechanically frozen scallops (first days catch) with 24 hr (on ice) cryogenically frozen scallop (first days catch)

vi) 4 hr cryogenically frozen scallop (first days catch) with 24 hr (on ice) cryogenically frozen scallops (first days catch) and

vii) fresh scallop (last days catch) with fresh scallop (last first catch).

Panelists were asked to indicate if a difference existed and if it did, which did they think was fresher. Combinations included AB, BA, AA, and BB. Retraining was repeated after the second fishing trip.

5.2 Quantitative Descriptive Analysis

Quantitative Descriptive Analysis (QDA) was carried out after the discriminatory tests were completed. Panelists from the difference testing panels were retained for QDA as

they had undergone training and were familiar to the scallop taste sensation. The panelists were presented with fresh scallops recently obtained from a fishing vessel and commercially available samples from a local grocer. They developed the score sheet which was used for QDA (appendix III) which also indicates protocol. The panelists selected seven attributes to describe the scallop sensory experience. These included: color; odor; taste; mouthfeel; firmness; mushiness; and grittiness and encompassed all aspects of the tasting sensation. The attributes were evaluated on an unstructured scale 15 cm long and the panelists choose the anchors for each attribute.

One day from each of the trips, except the first, was randomly selected as the test date for the three types of frozen samples. Each freezing treatment for the three selected days was presented thrice to each panelist. A fresh off-the boat sample was included to serve as a standard. All samples were presented to panelists on a randomly chosen basis. These were presented to the panelists in a manner designed to eliminate bias. On any given day a panelist evaluated six samples. The objective was to quantify the attributes of a good scallop and to observe the effect of frozen storage, over a period of time, on these attributes. ANOVA was executed to contrast each attribute of the frozen scallop sample types with that of

fresh scallops. As a result of the fishing days selected, scallops stored for periods of 5, 7 and 8 months were tested against the fresh scallops. Significance of differences obtained by ANOVA was confirmed by one and two sided Dunnet's Comparison at a 5% level.

6. Statistical Analyses

Log (base10) transformation was performed on microbiological data obtained for APC, PPC, and TCC. Data for FCC was untransformed. Data obtained for microbiological, physical, chemical and Sensory tests (QDA) were analyzed by the General Linear Models procedure of the Statistical Analysis Systems (SAS, 1985). Comparison of means was done through Duncan's Multiple Range test for means separation in those cases where the F test was significant ($P < 0.05$).

Difference testing data was analyzed using the Standard normal cumulative probabilities. QDA data analyzed as stated earlier, was tested by the Dunnet's test for differences of means of multiple sample types against a standard. Relationships between data sets was observed using the Pearson's correlation coefficients.

IV. RESULTS AND DISCUSSION

1. Microbiological Quality

The microbiological tests were performed in order to judge the initial quality of the raw material, ascertain its potential for extended storage and observe the presence or absence of human pollution/contamination under the current practice of scalloping. The summary of results (Table 3) shows means (x) and standard deviations (s) for fresh as well as for the three types of frozen scallops, for each trip with regard to aerobic plate count (APC), psychrotrophic plate count (PPC), total coliform count (TCC) and fecal coliform count (FCC). It must be noted that other than FCC, counts are in log numbers.

1.1 Aerobic or Standard Plate Count

It has been specified that some freshly processed mollusk meats should have a SPC < 500,000 cfu/gm (FDA, 1989). Cook (1991) indicated that if the SPC exceeded 1,000,000 cfu/gm, the meat was substandard. In this study, the limit of 1×10^6, was never reached. On the third sample of the first trip, counts higher than 5×10^5 for fresh and mechanically frozen samples were observed.

Table 3-Microbiological quality of fresh and frozen sea scallops.
Legend: F=fresh, Z=mechanically frozen, P=4 hr cryogenic, I=24 hr cryogenic frozen
Text: for missing FCC data. Counts < 2/gm are indicated as 1.00.
Means with different superscripts are significantly different for a freezing treatment between the four trips
Means with different subscripts are significantly different for freezing treatments within the same trip
x = mean, s = standard deviation

Trip	Type	APC		PPC		TCC		FCC	
		log x	s	log x	s	log x	s	x	s
I	F	5.36^{a}_{a}	0.41	5.38^{b}_{a}	0.27	2.90^{a}_{a}	0.27	-	-
	Z	3.93^{a}_{b}	1.26	3.35^{a}_{b}	0.83	1.01^{a}_{b}	1.22	-	-
	P	4.85^{ab}_{a}	0.46	4.63^{ab}_{a}	0.27	2.77^{a}_{a}	0.28	-	-
	I	4.52^{ab}_{a}	0.27	4.42^{a}_{a}	0.67	2.55^{a}_{a}	0.93	-	-
II	F	4.97^{a}_{a}	0.10	6.23^{a}_{a}	0.22	1.88^{a}_{a}	0.77	1.00	0.00
	Z	4.66^{a}_{a}	0.61	5.09^{a}_{b}	0.39	1.28^{a}_{a}	0.70	1.00	0.00
	P	5.18^{a}_{a}	0.41	5.80^{a}_{ab}	0.34	1.85^{ab}_{a}	1.09	1.00	0.00
	I	4.79^{ab}_{a}	0.65	5.25^{a}_{b}	0.61	1.40^{ab}_{a}	0.17	1.00	0.00
III	F	5.29^{a}_{a}	0.18	5.97^{a}_{a}	0.14	2.82^{a}_{a}	0.20	1.33	0.47
	Z	4.89^{a}_{a}	0.56	4.90^{a}_{b}	0.18	2.02^{a}_{a}	1.34	1.33	0.47
	P	5.37^{a}_{a}	0.24	5.22^{ab}_{b}	0.33	2.01^{ab}_{a}	0.69	2.33	1.70
	I	5.22^{a}_{a}	0.11	4.85^{a}_{b}	0.12	2.14^{a}_{a}	0.76	6.33	7.54
IV	F	4.35^{b}_{a}	0.36	5.27^{b}_{a}	0.25	1.37^{a}_{a}	1.30	1.00	0.00
	Z	3.10^{a}_{b}	0.28	3.62^{a}_{b}	0.22	0.00^{a}_{a}	0.00	1.00	0.00
	P	3.39^{b}_{b}	0.67	4.36^{b}_{a}	0.62	0.51^{b}_{a}	0.52	1.00	0.00
	I	4.11^{b}_{ab}	0.36	4.33^{a}_{b}	0.11	0.37^{b}_{a}	0.53	1.00	0.00

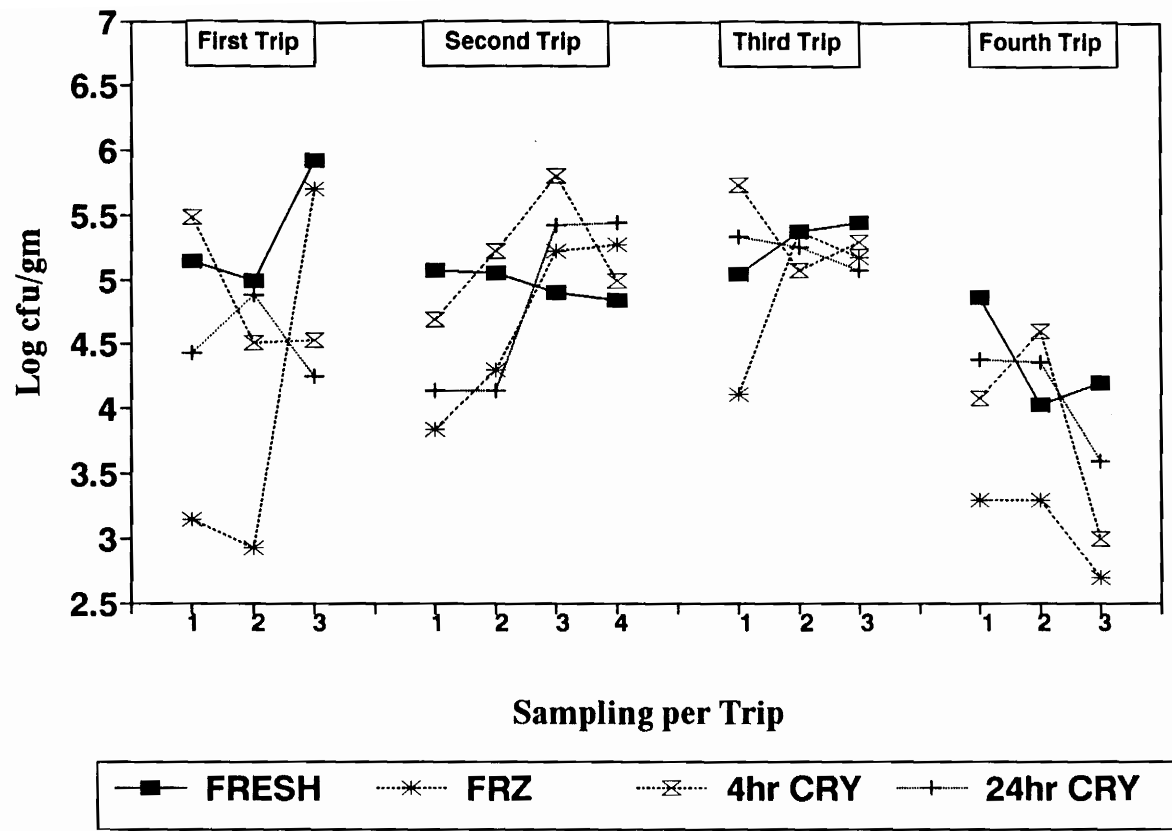


Fig. 3-Aerobic plate count of fresh and frozen sea scallops. Samples associated with each trip are indicated on X-axis.

These high counts were also observed in Fig. 3, for 4 hr cryogenically frozen (4 hr Cry) meats of the second trip (sixth sample) and third trip (eighth sample). High counts in the case of the fresh and mechanically frozen (frz) samples could be the result of a delay in post harvest processing or due to inefficient product cooling. The high counts reported for (4 hr Cry) meats were difficult to explain since simultaneously processed fresh, mechanically frozen, and 24 hr (on ice) cryogenically frozen (24 hr) scallops had lower counts. Post processing contamination seemed to be the most probable cause.

The APC log counts were affected by freezing method ($P < 0.003$) and trip ($P < 0.0001$). However, interaction of trip and freezing treatment was not significant. Significantly lower counts were observed for the last trip and this could be attributed to the use of sanitizers. There may have been a delay in temperature stabilization during the second and third trip resulting in higher counts observed for the mechanically frozen scallops.

1.2 Psychrotrophic Plate Count

Frozen foods are normally not affected by psychrotrophic bacteria until temperature abuse takes place. Liuzzo and Novak (1975) observed a significant correlation

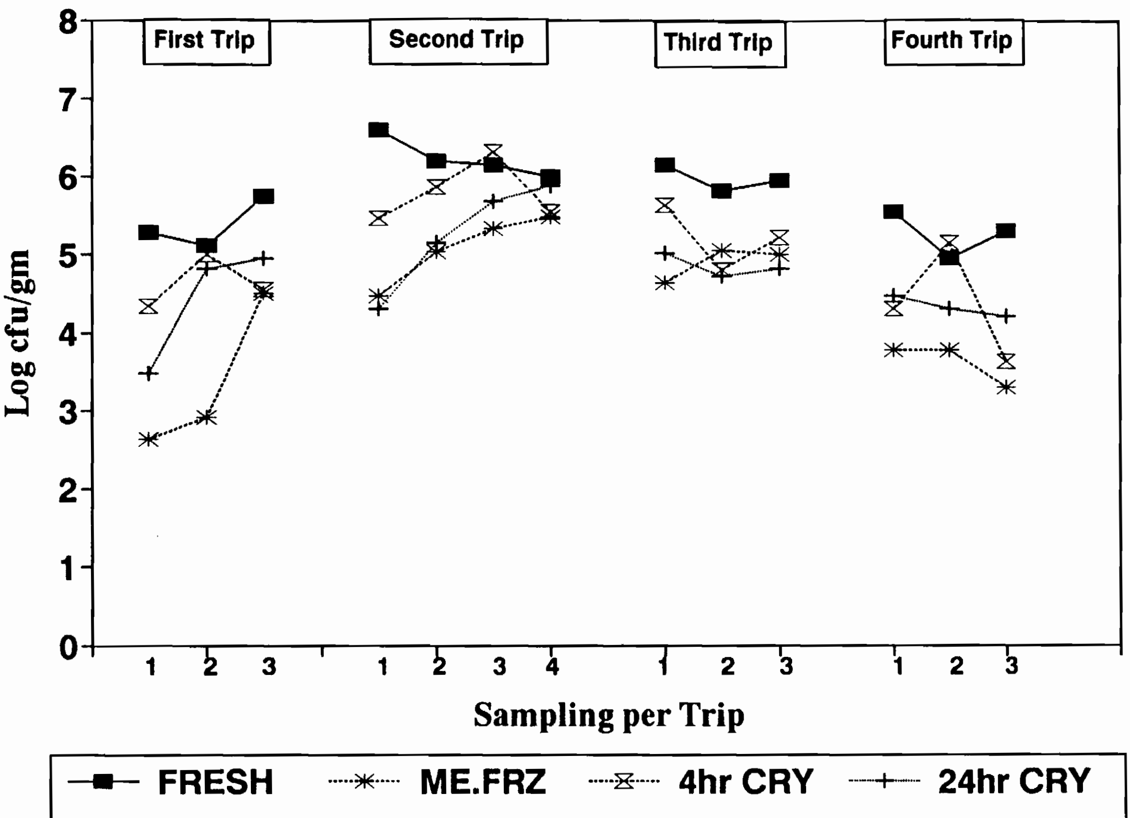


Fig. 4-Psychrotrophic plate count for fresh and frozen sea scallops. Samples associated with each trip are indicated on X-axis.

between the psychrotrophic plate count (PPC) and a decrease in organoleptic scores for oysters. In this study, the upper limit recorded was log 6.23 cfu/gm (Fig. 4 and Table 3). Fresh scallops had a consistently higher count when compared to the frozen scallops. This was expected, as temperature stabilization for the 40 lb cloth bags held in ice, took much longer. Thus fresh scallops are a perishable commodity. The microbial levels observed should not pose a problem during frozen storage.

The PPC log counts were affected by freezing method ($P < 0.0001$) and trip ($P < 0.0001$). No significance was observed for interaction of trip and freezing treatments. The inference about delayed temperature stabilization during the second and third trips was reinforced by higher counts observed for these trips for mechanical freezing.

1.3 Total Coliform Count

The total coliform count is not a very good indicator of contamination with material of human enteric origin. It does, if present in significant numbers, indicate either poor sanitation or post process contamination. Counts of log 3/gm were observed as the maximum over the four trips (Fig. 5 and Table 3) and this agrees with the results of Foster et al. (1977) who obtained a range of < 3 to log 4/gm

for coliforms in scallops. Significance for trip ($P < 0.0001$) was observed to be greater than that for freezing treatment ($P < 0.03$). This may be due to changes in crew, weather and/or fishing location (last two trips) having a greater effect on total coliforms than the freezing treatment.

1.4 Fecal Coliform Count

In this study, the tenth sample (third trip) 4 hr Cry and 24 hr (on ice) Cry samples would have unacceptable levels of fecal coliforms if judged by the National Shellfish Sanitation Program standards. This program does not cover scallop meats and no federal or state food regulatory agency has suggested a standard for scallops. The results from this study indicate poor processing on board the vessel and sanitation practices (Fig. 6 and Table 3). Data is missing for the first trip (sample 1 to sample 3) as unstable incubation temperatures during analysis resulted in false positive results. The ANOVA test does not show any significance for individual effects or interaction. This was expected as the source of contamination was not an inherent part of the process. The problem, however, needs to be identified and a control plan implemented.

Unless the microbial counts of fresh scallops are

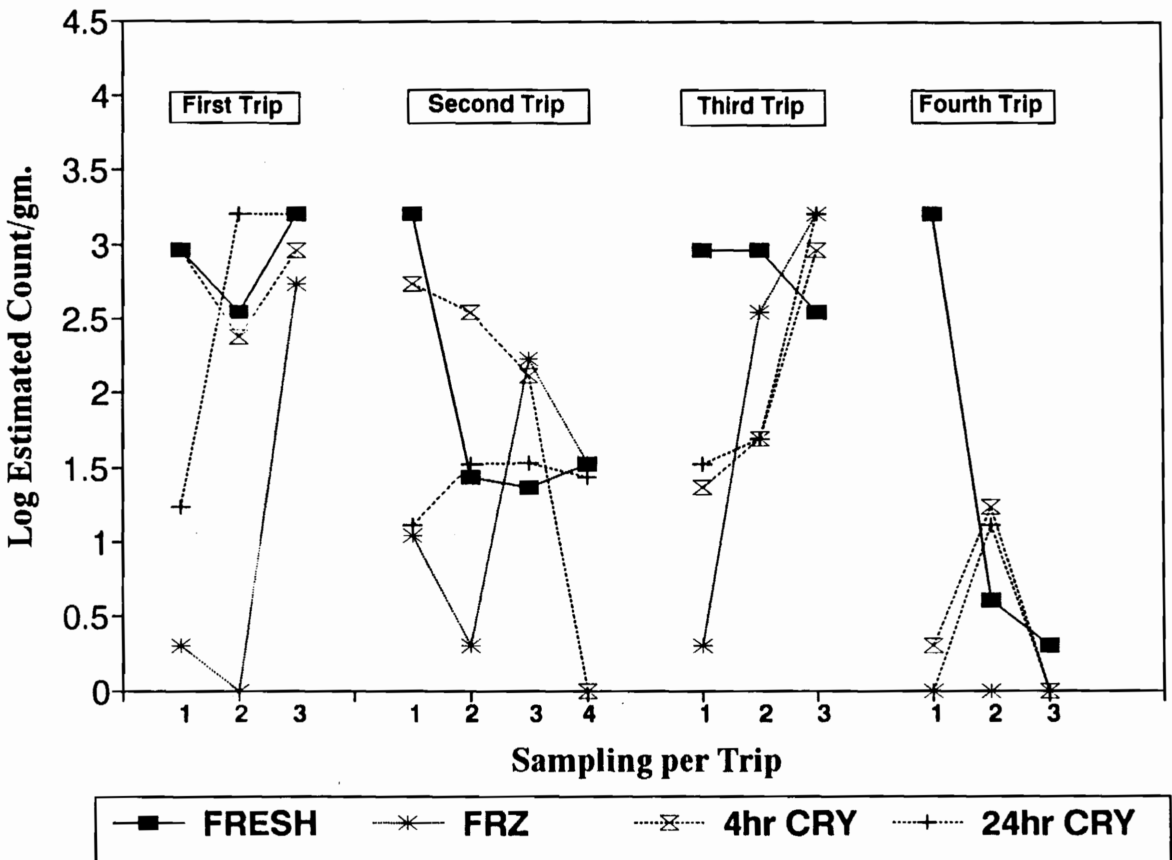


Fig. 5-Total coliform counts for fresh and frozen sea scallops. Samples associated with each trip are indicated on X-axis.

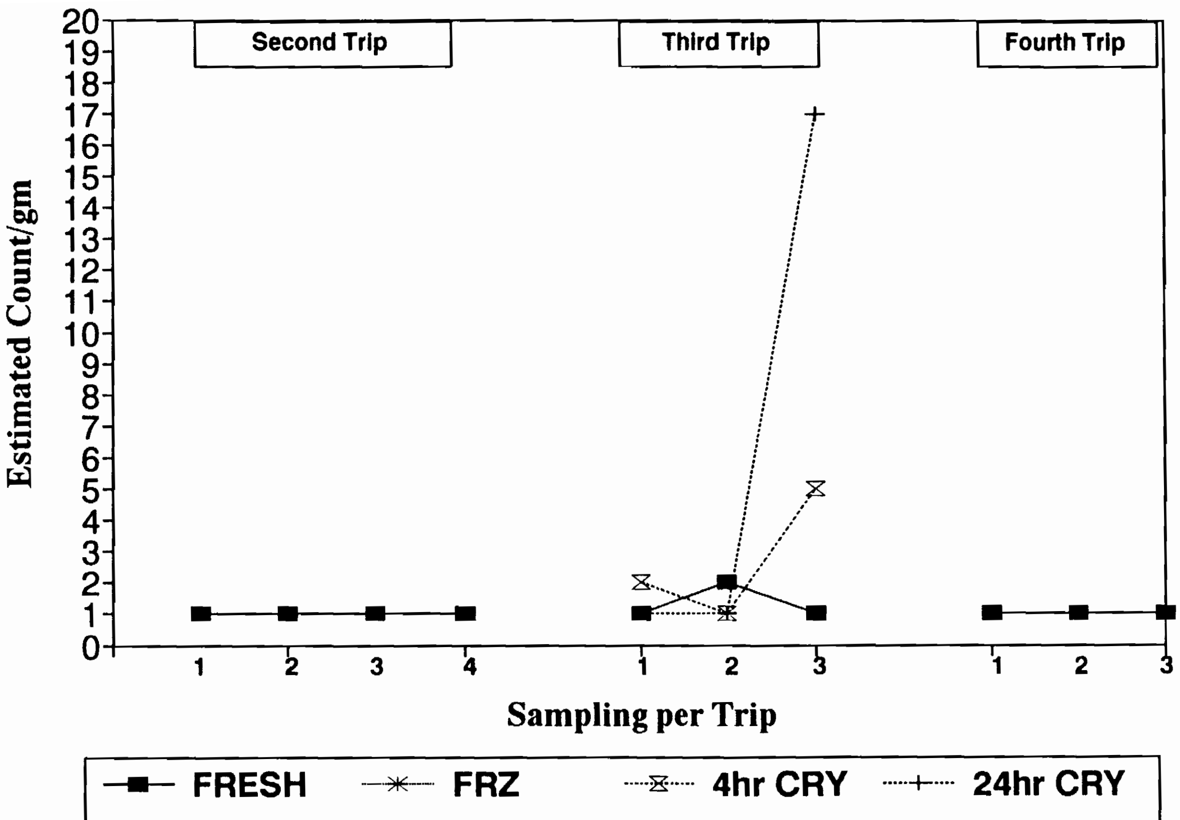


Fig. 6-Fecal coliform counts for fresh and frozen sea scallops. Samples associated with each trip are indicated on X-axis. Data for fishing days 1-3 associated with trip 1 have been omitted.

substantially reduced, spoilage will occur rapidly due to storage temperature maintained and freezing may be the preservation method of choice which could stabilize the microbiological quality. The data obtained indicated that the mechanically frozen scallops had a better overall microbiological quality than either the 4 hr or the 24 hr (on ice) cryogenic frozen scallops. This may have been due to the formation of large and jagged ice crystals as a result of a slower rate of freezing which caused damage to the bacterial cells (Piggot and Tucker, 1990) or poor handling practices associated with the cryogenic freezing process. The higher fecal coliform counts for the cryogenic frozen scallops, without a concomitant increase in counts for fresh or mechanical frozen scallops, was indicative of this post process contamination and requires identification. Variation observed in counts, between trips, may be due to seasonal temperature changes and delayed processing.

A preliminary sanitation survey was performed on board the scallop fishing vessel for three days during the fourth trip. The results are presented in the appendix I.

2. Chemical Quality

Of major concern was: a) the determination of the moisture/protein ratio and how it was affected by different

freezing treatments; b) the suitability of pH as an indicator of rigor onset for scallops frozen at sea; c) the effect of fishing location and season on the proximate composition of scallops.

2.1 French Moisture/Protein Ratio

Errors in protein estimation gave false high ratios for the first trip samples and these have been discarded (Figure 7 and Table 4). In the subsequent three trips, 4 hr cryogenic frozen scallops had the lowest M/P ratios. The overall means and standard deviations did not exceed the established limit of 5. The mechanical frozen scallops in the second trip exceeded this set limit. The 24 hr (on ice) cryogenically frozen scallops had the highest ratios and exceeded the maximum ratio of 5 in half of the samples. This was expected (Loreal and Etienne, 1990) as scallops placed on ice for 24 hr would absorb water from melted ice.

Analysis of data by ANOVA indicated that the moisture percentage was significantly dependent on the freezing treatment ($P < 0.02$) but not on trip. Trip or freezing treatment had no effect on protein percentage. There was a significant interaction of trip and treatment ($P < 0.02$) on the M/P ratio. This did not indicate a beneficial effect of cryogenic freezing on the M/P ratio of 4 hr Cry meats. M/P

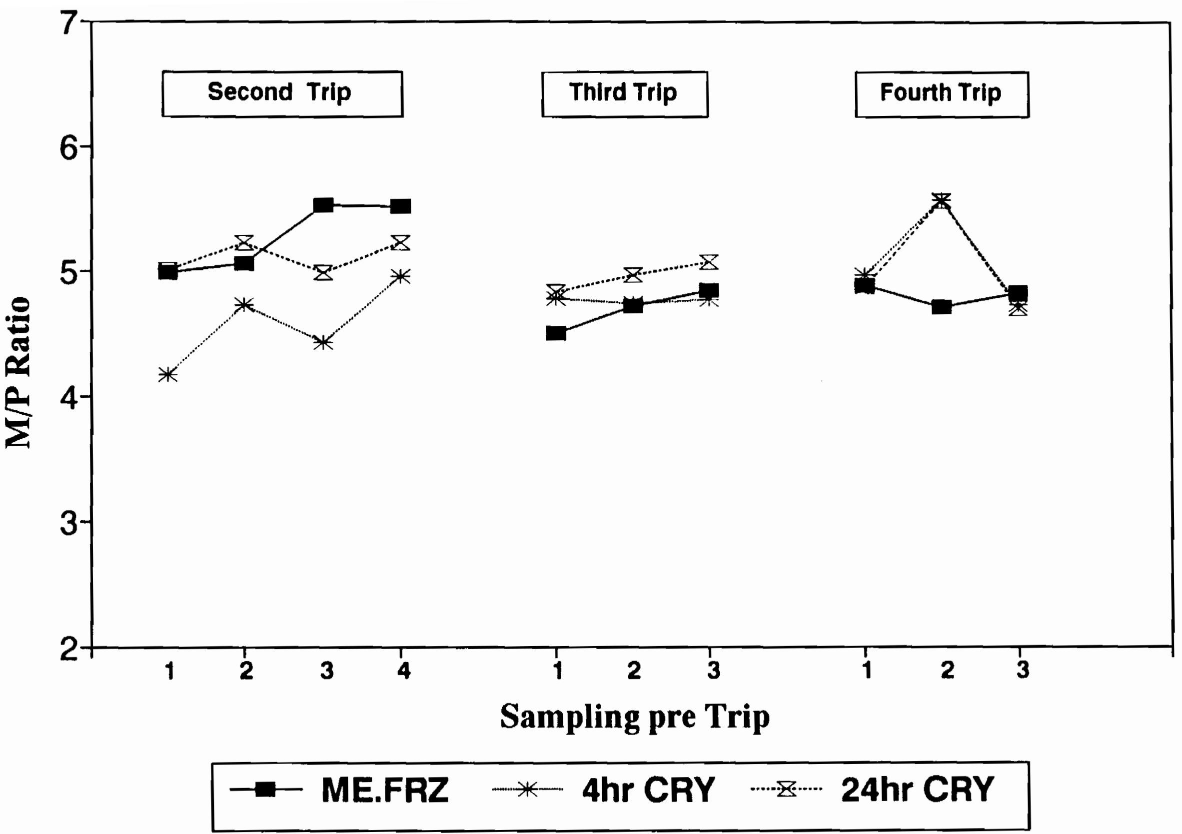


Fig. 7-French moisture/protein ratio test. Data from first trip has been discarded. Samples associated with each trip are indicated on X-axis.

Table 4-French Moisture/Protein Ratio Test for Frozen Scallops. Fresh scallops are not evaluated as this test is of concern for export of frozen scallops.
Data from trip I has been discarded.
Trip is as identified on figure 7.
Means with different superscripts are significantly different for a freezing treatment between the four trips
Means with different subscripts are significantly different for freezing treatments within the same trip
x = mean, s = standard deviation

MOISTURE PROTEIN RATIO				
Trip	Day	Mec.Frz	4 hr Cry	24 hr Cry
II	1	4.99	4.17	5.01
	2	5.06	4.73	5.23
	3	5.53	4.44	4.99
	4	5.53	4.96	5.24
	x	5.28^{a}_{a}	4.58^{b}_{b}	5.12^{a}_{a}
III	1	4.51	4.79	4.84
	2	4.72	4.74	4.97
	3	4.85	4.77	5.07
	x	4.69^{b}_{b}	4.77^{b}_{ab}	4.96^{a}_{a}
IV	1	4.89	4.97	4.88
	2	4.71	5.57	5.56
	3	4.83	4.73	4.70
	x	4.81^{b}_{a}	5.09^{b}_{a}	5.05^{a}_{a}
x		4.96	4.69	5.05
s		0.34	0.24	0.24

ratio was below 5 for mechanically frozen scallops on the last two trips and Duncan's test gave a means seperation that indicated that good handling practices can give a high quality product. Draining of water prior to freezing should improve product quality.

2.2 Proximate Analysis

The mean values for proximate analysis of raw scallops for each treatment type for each trip is represented in Table 5. An ash estimation was not performed on samples obtained from the first trip and therefore the Nitrogen free extract included the percent ash. ANOVA analysis indicated that freezing treatment had a significant effect on both moisture and ether extract percent ($P < 0.02$). Trip had an effect on both the Nitrogen free extract and on ash ($P < 0.02$). An interaction was observed between trip and freezing treatment ($P < 0.0025$) for ether extract with low values observed for trip 4. This could be attributed to post spawning depletion. Seperation of means for N_2 free extract was not significant and probably indicated a stable glycogen reserve.

Table 5-Proximate analysis of fresh and frozen sea scallops expressed as a percentage.
Legend: F=fresh, Z=frozen, P=4 hr Cry, I=24 hr Cry, * = Ash + N_2 free extract.
Means with different superscripts are significantly different for a freezing treatment between the four trips
Means with different subscripts are significantly different for freezing treatments within the same trip

Trip	Type	Moisture	Protein	Ether Extract	N_2 Free Extract	Ash
I	F	-	-	-	-	-
	Z	79.38^{b}_{a}	17.06^{a}_{a}	0.28^{a}_{a}	3.28*	*
	P	79.95^{a}_{a}	16.32^{a}_{a}	0.31^{b}_{b}	3.42*	*
	I	80.11^{b}_{a}	16.22^{a}_{a}	0.30^{b}_{ab}	3.37*	*
II	F	81.24^{a}_{a}	16.27^{a}_{ab}	0.17^{b}_{a}	1.01^{a}_{a}	1.32^{a}_{a}
	Z	79.64^{ab}_{c}	17.52^{a}_{a}	0.18^{b}_{a}	1.42^{a}_{a}	1.26^{ab}_{a}
	P	79.99^{a}_{bc}	17.19^{a}_{a}	0.12^{a}_{a}	1.36^{a}_{a}	1.34^{a}_{a}
	I	80.82^{b}_{ab}	16.70^{a}_{ab}	0.14^{a}_{a}	1.06^{a}_{a}	1.26^{ab}_{a}
III	F	80.55^{a}_{b}	16.98^{a}_{a}	0.37^{a}_{a}	0.90^{a}_{b}	1.18^{a}_{a}
	Z	80.63^{a}_{b}	16.46^{a}_{a}	0.13^{bc}_{b}	1.22^{a}_{ab}	1.21^{b}_{a}
	P	80.88^{a}_{b}	16.33^{a}_{a}	0.08^{a}_{b}	1.47^{a}_{a}	1.21^{a}_{a}
	I	83.03^{a}_{a}	14.55^{b}_{b}	0.17^{a}_{b}	1.12^{a}_{b}	1.13^{b}_{a}
IV	F	80.83^{a}_{a}	16.27^{a}_{a}	0.04^{c}_{a}	1.46^{a}_{a}	1.40^{a}_{a}
	Z	80.01^{ab}_{a}	16.82^{a}_{a}	0.06^{c}_{a}	1.53^{a}_{a}	1.58^{a}_{a}
	P	80.58^{a}_{a}	16.47^{a}_{a}	0.09^{a}_{a}	1.56^{a}_{a}	1.29^{a}_{a}
	I	80.35^{b}_{a}	16.61^{a}_{a}	0.05^{a}_{a}	1.53^{a}_{a}	1.46^{a}_{a}

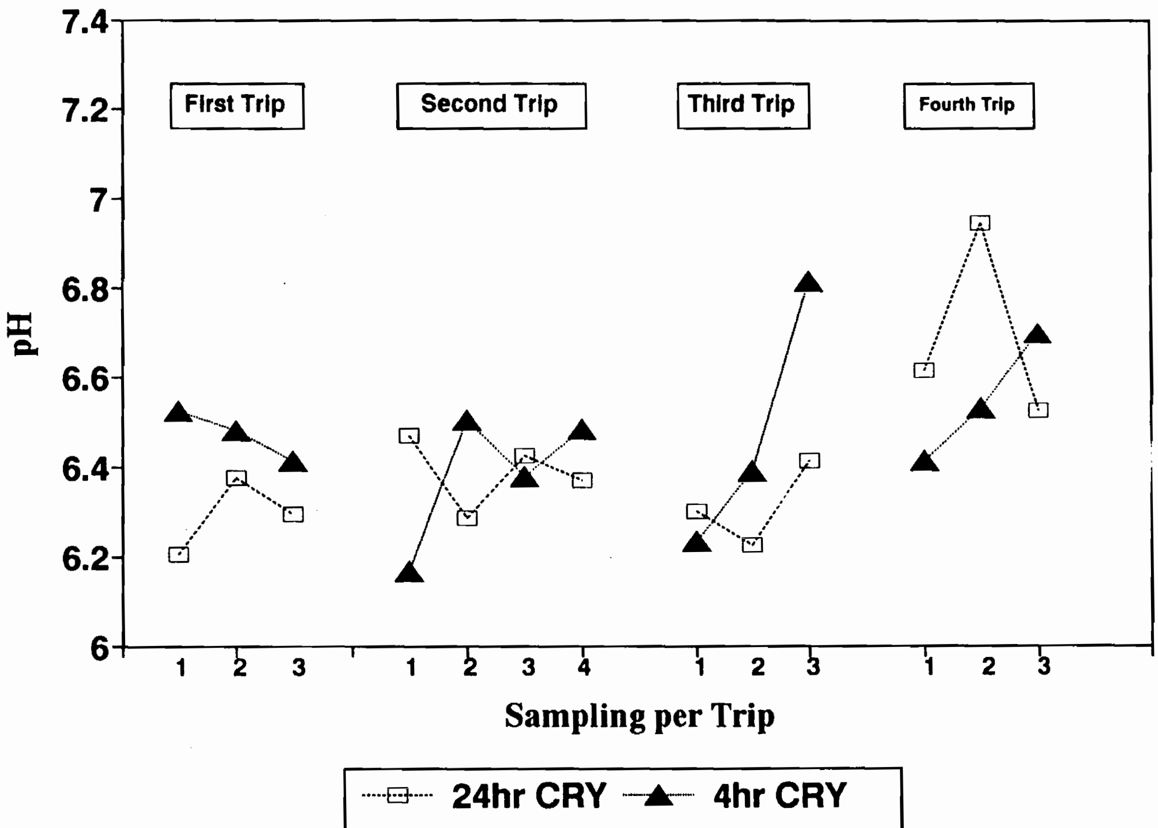


Fig. 8-Mean pH Values for 4 hr and 24 hr (on ice) cryogenically frozen scallops. Samples associated with each trip are indicated on X-axis.

2.3 pH

The graph (Fig. 8) showed an erratic pattern for pH measurements. pH was an unreliable indicator of rigor condition for this study. Chung and Merritt (1991) had reported pH values ranging from 6.25 to 6.97 and this study had a similar range. ANOVA did not indicate any significant effect of treatment or trip on pH. Deamination reactions, both endogenous and bacterial, would increase pH causing erratic results as observed(Hebard et al., 1982). Biological variation and physiological response may also be determining factors for pH values observed.

Based on the chemical tests of quality that were performed, only the 4 hr cryogenic frozen scallops consistently met the standard set for the M/P ratio. Therefore cryogenic freezing of scallops can be recommended for export products when the French Moisture/Protein ratio test is used as a grading or quality standard. Improved handling practice can significantly improve the quality and marketability of mechanically frozen scallops. Variations in proximate composition may be due to season, location and/or age and sexual maturity of scallops. A high nutritive value (high protein, low fat) was observed throughout the period of testing.

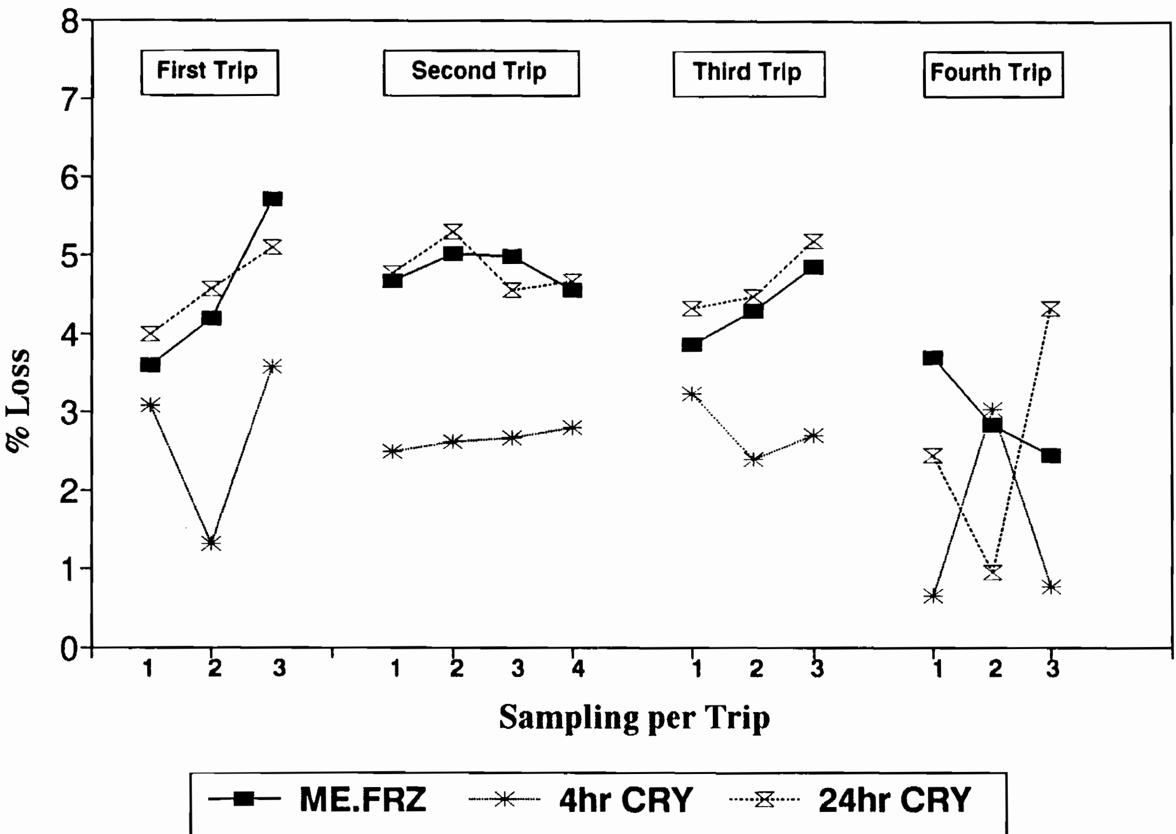


Fig. 9-Thaw loss values for frozen scallops. Samples associated with each trip are indicated on X-axis.

Table 6-Thaw Loss Study of Frozen Scallops.
Days indicate number of fishing days within a trip.
Means with different superscripts are significantly different for a freezing treatment between the trips
Means with different subscripts are significantly different for freezing treatments within the same trip
x = mean and s = standard deviation.

THAW LOSS (%)				
Trip	Days	Mec.Frz	4 hr Cry	24 hr Cry
I	1	3.60	3.08	4.00
	2	4.19	1.32	4.58
	3	5.72	3.57	5.10
	x	4.50^{a}_{a}	2.66^{a}_{b}	4.56^{a}_{a}
II	1	4.67	2.50	4.78
	2	5.02	2.61	5.31
	3	4.99	2.67	4.56
	4	4.56	2.80	4.68
	x	4.81^{a}_{a}	2.65^{a}_{b}	4.83^{a}_{a}
III	1	3.86	3.23	4.33
	2	4.29	2.40	4.47
	3	4.86	2.69	5.19
	x	4.34^{a}_{a}	2.77^{a}_{b}	4.66^{a}_{a}
IV	1	3.70	0.66	2.44
	2	2.83	3.03	0.96
	3	2.45	0.78	4.33
	x	2.99^{b}_{a}	1.49^{b}_{a}	2.58^{b}_{a}
x		4.21	2.41	4.21
s		0.88	0.88	1.16

3. Physical Quality

Since 73 percent of scallops are landed frozen or frozen on shore, one objective of the study was to quantify scallop thaw losses. A second objective was to observe the effect of freezing method on cook losses. The firmness/hardness of differently frozen and cooked scallops was also measured instrumentally.

3.1 Thaw Loss

Fig. 9 and Table 6 both clearly show the reduced thaw loss for 4 hr cryogenically frozen scallops. The average loss drops from 4.2 percent to 2.4 percent, a 42 percent change. This was significant for freezing treatment ($P < 0.0001$) and trip ($P < 0.0006$). The 24 hr (on ice) cryogenic frozen and mechanically frozen scallops had an average thaw loss of 4.21 percent. This was expected as uptake of water took place (Loreal and Etienne, 1990) in the case of 24 hr sample which was released upon thawing. In the case of mechanically frozen scallops, the large ice crystals damage the muscle protein thereby reduce its water holding capacity (Piggot and Tucker, 1990).

3.2 Cook Loss

Comparisons for cook loss between differently frozen scallops were made on baked samples. Fig. 10 and Table 7 show that the 4 hr cryogenic frozen scallops lost the least during cooking. Table 7 indicates mean values of 5 to 10 samples for each fishing day. Only one fishing day was evaluated for the second fishing trip and this data was included in the table. However, the results were indicated in the graph. Mean value of cook loss of 4 hr cryogenically frozen scallops was 28% lower than the mechanical frozen or 24 hr cryogenically frozen scallops. ANOVA indicated that trip and freezing treatment were both significant ($P < 0.0014$ and $P < 0.017$) respectively. The 4 hr cryogenically frozen sample had the best water holding capacity which indicated undamaged muscle structure. This was not expected as freezing and thawing of pre-rigor meat followed by cooking causes extensive damage to the muscle fibre and water holding capacity is lost (Marsh and Thompson, 1957;Marsh and Leet, 1966). This may indicate a different rigor/cook contraction mechanism in scallop meat which needs to be studied.

Two replications, each of 13 samples, of 4 hr and 24 hr cryogenically frozen scallops, were used for comparison of cook loss resulting from different cooking methods. The

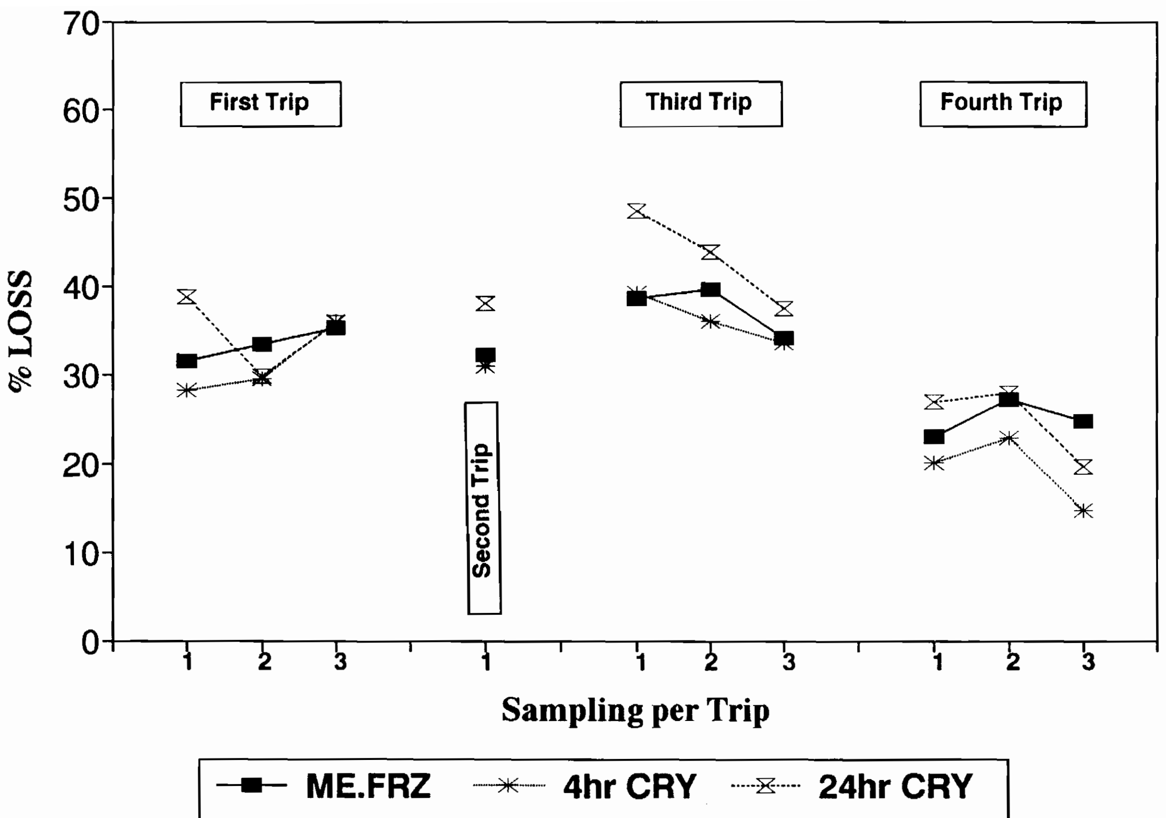


Fig. 10-Cook loss study on baked scallops. Only one days data is available for Trip 2. Samples that are analyzed have been identified with trip.

Table 7-Cook Loss Study on Baked Scallops.
Data from trip II is missing. Only day 4 data is available from trip 2 and is shown on fig. 10. Total loss includes thaw and cook loss. Cryogenically frozen samples were cooked from the frozen state without thawing.
Means with different superscripts are significantly different for a freezing treatment between the four trips
Means with different subscripts are significantly different for freezing treatments within the same trip
x = mean and s = standard deviation.

COOK LOSS (%) WHEN BAKED

Trip	Days	Mechanically Frozen			Cryogenic 4 hr	Cryogenic 24 hr (on ice)
		Thaw	Cook	Total		
I	1	3.60	31.52	35.12	28.29	38.79
	2	4.19	33.44	37.63	29.57	29.82
	3	5.72	35.32	41.04	36.10	36.01
				$x=37.93^{bc}_{a}$	$x=31.32^{a}_{b}$	34.87^{bc}_{a}
III	1	3.86	38.50	42.36	38.42	43.68
	2	4.29	39.67	43.96	33.29	41.51
	3	4.86	34.29	39.15	26.52	36.74
				$x=41.82^{ab}_{a}$	$x=32.74^{a}_{b}$	40.64^{ab}_{a}
IV	1	3.70	27.63	31.33	20.15	26.91
	2	2.83	36.65	39.48	22.86	28.01
	3	2.45	29.75	32.39	14.70	19.74
				$x=34.40^{c}_{a}$	$x=19.24^{b}_{b}$	24.89^{c}_{ab}
x		3.94	34.09	38.05	27.77	33.47
s		0.99	3.49	4.35	3.96	5.09

Table 7a-Cook loss study comparing different cooking methods. Methods used were baking, broiling, and microwave. Two replications, each of 26 samples, were used for the study.
x = mean and s = standard deviation.

COOK METHOD COMPARISON FOR CRYOGENIC FROZEN SCALLOPS (Loss %)		
Cook Method	4 hr Cry	24 hr Cry
Baking	x=29.08, s=8.4	x=34.94, s=8.7
Broiling	x=36.92, s=1.6	x=37.24, s=4.2
Microwave	x=33.76, s=1.8	x=33.56, s=4.2

methods used were baking, broiling and microwave cooking. ANOVA did not indicate any significant variations for losses as a result of cooking method variations.

3.3 Color

Color measurement results are contained in Table 8. No significant variations were observed within treatment types or against a target standard. Fresh scallops of highest quality, as determined by experienced scallop graders at the East Coast Fish and Scallop Co., Newport News, VA were taken from a fishing vessel and measured, to arrive at target color standards. The L* a* b* values for these measurements on raw as well as baked samples were:

Raw scallop	i) L* =	64.14 ± 1.39
	ii) a* =	-2.02 ± 0.30
	iii) b* =	-2.24 ± 1.13
Baked scallop	i) L* =	73.88 ± 2.72
	ii) a* =	-1.13 ± 1.36
	iii) b* =	18.97 ± 1.74

Color developed on cooking was mainly due to maillard reactions (Dyer and Hiltz, 1973) and gelation of

Table 8-Color Ratings on L* a* b* scale for Raw and Baked Scallops. Mean color values for each type of frozen scallop is shown. Legend: Z= mechanically frozen, P=4 hr cryogenic, I=24 hr cryogenic frozen scallops.

Trip	Type	Raw			Cooked		
		L*	a*	b*	L*	a*	b*
I	Z	63.70	-2.20	-1.09	75.15	-1.90	16.55
	P	61.05	-2.26	-1.30	75.11	-2.06	16.23
	I	62.01	-2.36	-1.13	75.14	-2.29	16.05
II	Z	65.70	-2.32	-0.62	75.91	-2.86	17.09
	P	57.67	-1.78	-2.16	76.12	-3.12	15.56
	I	61.26	-1.55	0.51	71.90	-2.28	17.94
III	Z	59.90	-1.77	-1.85	75.95	-3.21	14.03
	P	59.35	-1.95	-1.70	78.12	-3.80	12.78
	I	62.90	-2.25	-1.85	78.12	-3.32	13.30
IV	Z	57.53	-1.98	-0.57	75.80	-3.41	15.01
	P	56.04	-1.74	0.21	75.09	-4.13	11.34
	I	56.28	-1.84	-0.71	76.56	-3.80	12.57

proteins gave it an opacity. Pigments like zeaxanthine and lutein also played a role in final color (Simpson, 1982)

3.4 Instron Measurement

Peak force measurements were made on randomly chosen scallop samples from those prepared for the QDA sensory panels. The results are summarized in Table 9. The fresh scallop sample was the hardest/firmest as determined by Instron values. Subsequent sensory analysis confirmed that a firm rather than soft textured scallop was preferred. Results indicated that mechanically frozen and 4 hr cryogenic frozen scallops were softer in texture up to 5 months in storage subsequent to which firmness increased. No statistical analysis was performed due to the high standard error obtained.

The results obtained from physical property measurements indicated that 4 hr cryogenically frozen scallops were superior among the scallops compared, with respect to thaw and cook losses. This may be of considerable economic and nutritive significance and its value cannot be overlooked.

Table 9-Instron Shear Results for Frozen Scallops in terms of Peak Force. Results are represented in terms of means (x) and standard deviation (s).
* Fresh scallop measurements were made in order to set a standard of firmness.
Each type within a trip was measured thrice, with n = 10 to 12
Samples from first trip were not included in this study.

Trip	Type	Storage Period (mth)	Instron Peakforce (kgf)	
			x	s
-	Fresh *	<0.25	2.25	0.96
II	24 hr Cry	8	1.88	0.91
	4 hr Cry	8	1.51	0.73
	Frozen	8	1.47	1.02
III	24 hr Cry	7	1.69	0.91
	4 hr Cry	7	1.79	1.08
	Frozen	7	1.63	0.81
IV	24 hr Cry	5	1.60	0.88
	4 hr Cry	5	0.83	0.64
	Frozen	5	0.66	0.71

4. Organoleptic Quality

4.1 Discrimination Testing

The results of the paired comparison tests are recorded in Table 10. The rejection of Ho at .05 level is indicated by '+' and at the .01 level by '*'. The results indicated that differences were perceptible in all cases except when mechanically frozen scallops of the first fishing day were compared to the freshest scallop of the last fishing day. It is also interesting to note that when the same sample types were presented, significant errors were recorded for the mechanical frozen samples. The response to the question as to which scallop of a pair was fresher indicated:

i) Fresh scallops of the last fishing day were considered fresher than fresh scallops of first fishing day

ii) Fresh scallops of the last fishing day were considered fresher than either 4 hr or 24 hr cryogenically frozen scallops of the first fishing day

iii) Mechanically frozen scallops of the first fishing day were considered fresher than fresh scallops of the last fishing day

Table 10-Discrimination Testing - Difference Test.

Legend: F = fresh, Z = mech. frozen, P = 4 hr Cry, I = 24 hr Cry
1 = 1st fishing day, 2 = intermediate fishing day
3 = final fishing day of a trip.

+ = significant @ α =.05
* = significant @ α =.01

Paired Comparison Tests				
Pairs Presented	Number of Pairs n	Difference Correct Resp	Freshness Selection	
F1 & F3	52	45^{*}	F1(14)	F3(27)
F3 & Z1	92	51	F3(26)	Z1(34)
F3 & P1	86	67^{*}	F3(33)	P1(25)
F3 & I1	86	55^{+}	F3(40)	I1(18)
P1 & I1	66	44^{*}	P1(28)	I1(17)
P1 & Z1	62	45^{*}	P1(21)	Z1(25)
I1 & Z1	104	68^{*}	I1(28)	Z1(43)
F3 & F3	22	7	-	-
Z1 & Z1	22	4^{*}	-	-
P1 & P1	20	10	-	-
I1 & I1	20	6	-	-

v) Mechanically frozen scallops of the first fishing day were considered fresher than 24 hr cryogenically frozen scallops of the same day

vi) The 4 hr cryogenically frozen scallops of the first fishing day were considered fresher than 24 hr cryogenically frozen scallops of the same day.

vii) The 4 hr cryogenically frozen scallops were not significantly different from fresh or mechanically frozen scallops when panelists selected for fresher scallop among a pair.

viii) All scallops were edible.

This indicated that mechanically frozen scallops were selected as being fresher a greater number of times but could not be very well differentiated from fresh or 4 hr cryogenically frozen scallops.

4.2 Quantitative Descriptive Analysis

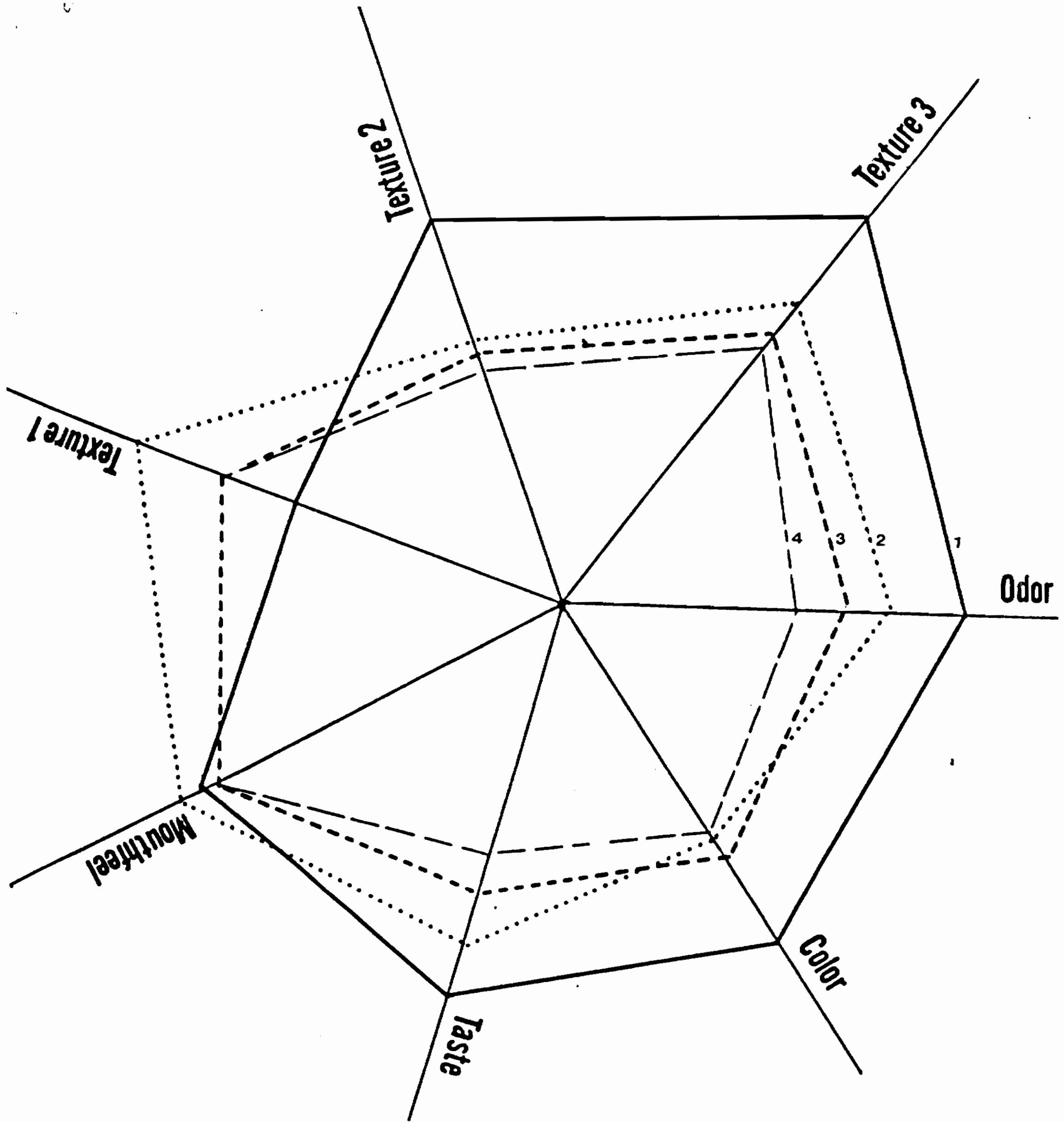
A summary of results from QDA testing is tabulated in Table 11. Mean scores of three replications for each frozen type for fishing days 7/10/91, 8/3/91, and 10/19/91 are recorded and pictoral representation of QDA scores are seen as spider webs (Fig. 11-13). Fresh scallop samples obtained from a fishing vessel were presented as the standard of

Table 11-Quantitative Descriptive Analysis.
Samples were randomly chosen from each of last three trips.
Legend: Odor=Stale to Fresh, Color=Yellow to White, Taste=Stale to Fresh, Mfeel=Dry to Moist, Text 1=Rubbery to Firm, Text 2=Mushy to Firm, Text 3=Gritty to Non-Gritty.
Numbers indicate scores in cm on a 15 cm unstructured scale.

Type	Storage	Average Scores						
		Odor	Color	Taste	Mfeel	Text 1	Text 2	Text 3
FRESH	5 days	10.17	10.22	10.30	10.10	6.95	10.70	12.80
24 hr CRY	5 mths	5.97	7.19	6.55	9.49	8.24	6.47	8.58
4 hr CRY	5 mths	7.12	7.79	7.64	9.51	8.90	7.04	9.01
MECH. FRZ	5 mths	8.30	6.93	9.05	10.50	11.11	7.23	9.93
24 hr CRY	7 mths	5.76	7.12	5.92	6.50	6.53	9.76	10.50
4 hr CRY	7 mths	6.19	7.74	6.65	6.30	8.03	7.95	10.01
MECH. FRZ	7 mths	8.52	7.46	8.75	8.08	7.75	8.07	9.73
24 hr CRY	8 mths	7.95	8.14	7.43	7.40	7.75	10.07	10.86
4 hr CRY	8 mths	5.64	5.51	4.85	4.78	5.20	12.27	10.65
MECH. FRZ	8 mths	9.81	9.00	9.29	7.39	7.68	9.39	11.59

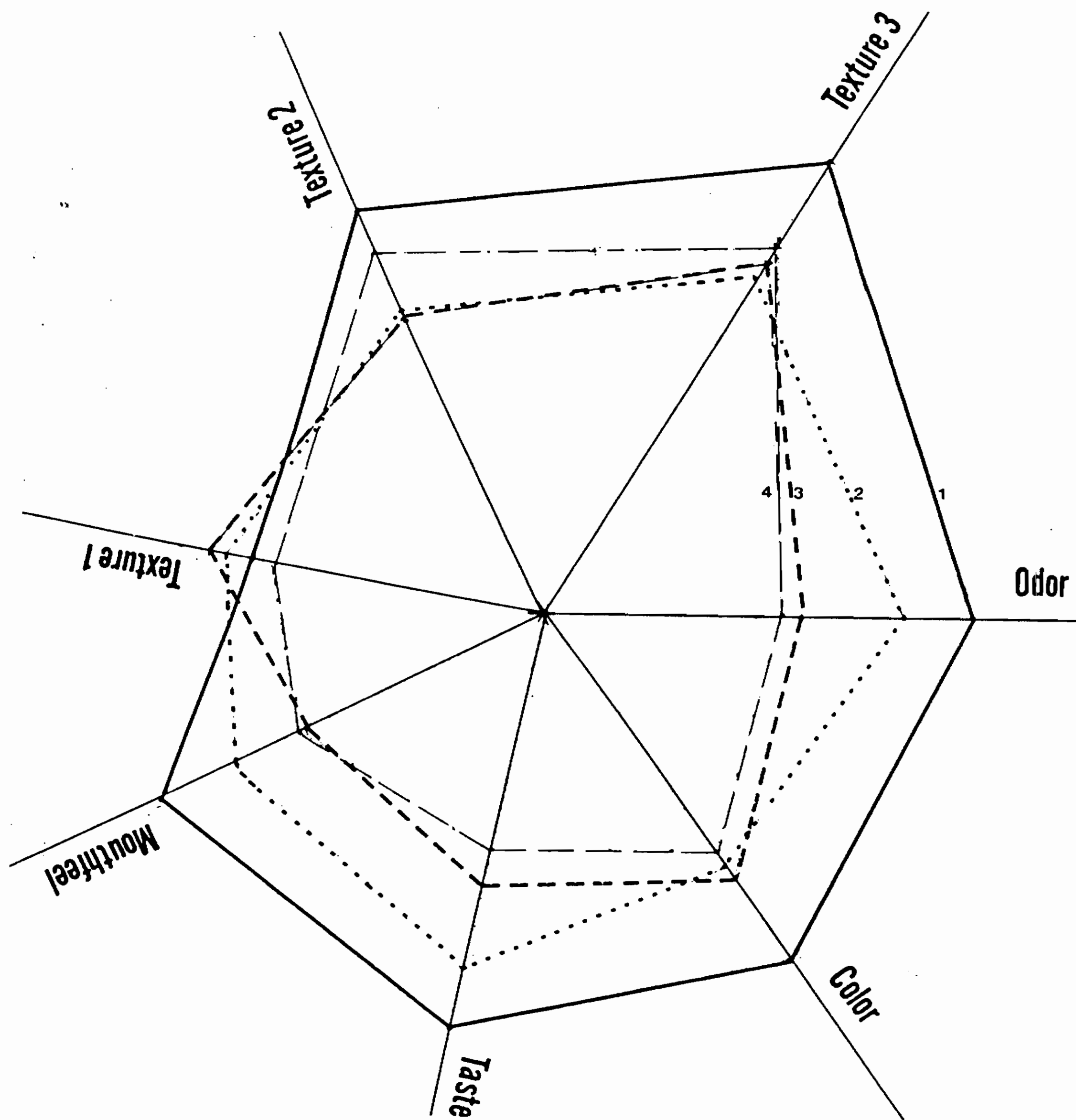
Table 12-ANOVA showing PR > F for QDA Results in Table 11. NS indicates not significant.

CONTRAST	ODOR	COLOR	TASTE	M.FEEL	TEXT1	TEXT2	TEXT3
FRESH VS FRZ							
5 MONTHS	NS	0.003	NS	NS	0.03	NS	0.004
7 MONTHS	NS	0.0004	NS	0.03	NS	NS	0.0001
8 MONTHS	NS	NS	NS	0.008	NS	NS	NS
FRESH VS IN-RIG							
5 MONTHS	0.002	0.006	0.0001	NS	NS	0.04	0.0001
7 MONTHS	0.0001	0.0001	0.0001	0.0003	NS	NS	0.003
8 MONTHS	NS	0.004	0.002	0.007	NS	NS	NS
FRESH VS PRE-RIG							
5 MONTHS	0.005	0.004	0.003	NS	NS	0.04	0.0002
7 MONTHS	0.0003	0.002	0.001	0.0002	NS	NS	0.0003
8 MONTHS	0.0001	0.0001	0.0001	0.0001	NS	NS	0.04



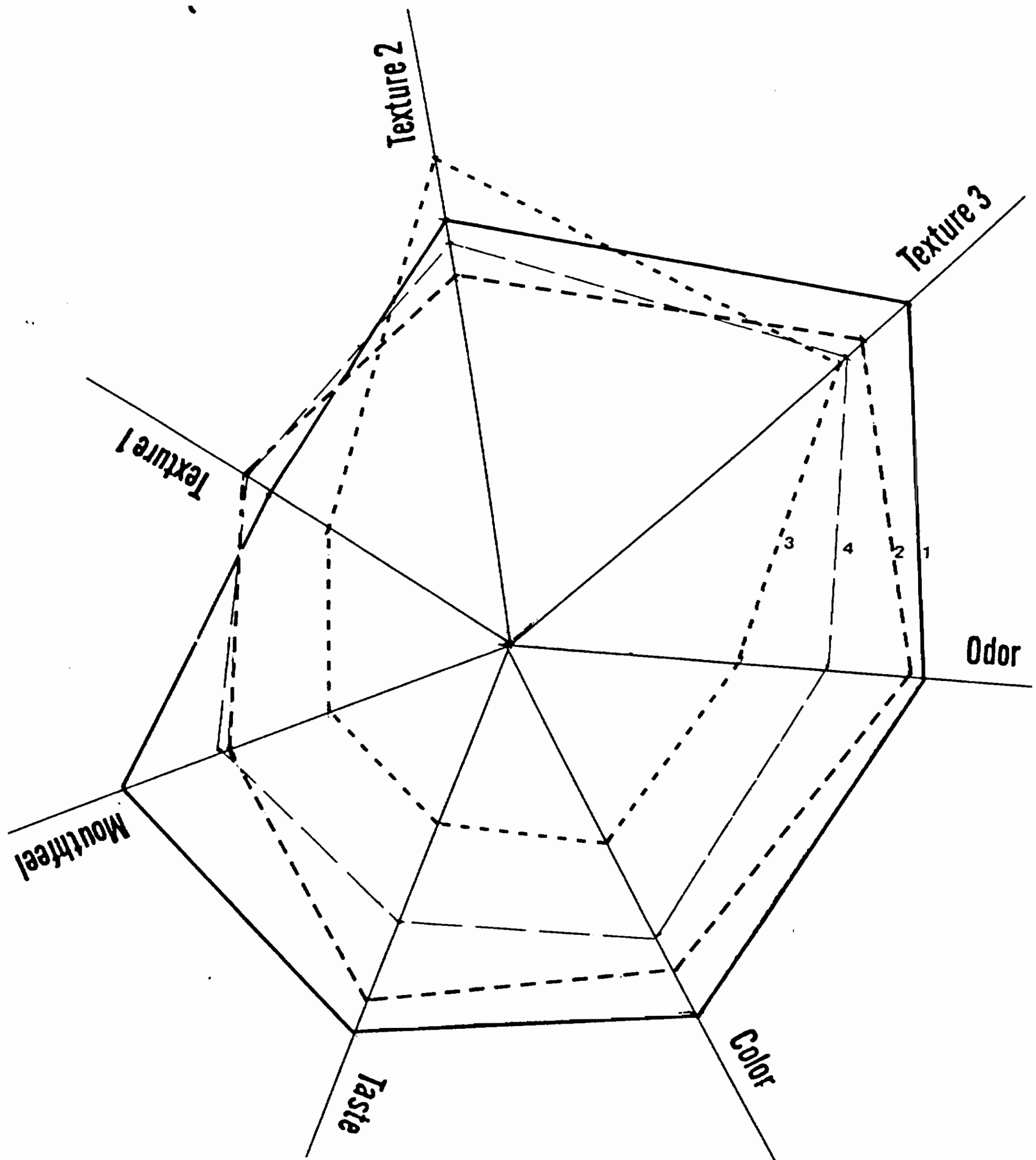
LEGEND: 1- fresh scallops
2- mechanically frozen scallops
3- 4 hr cryogenically frozen scallops
4- 24 hr (on ice) cryogenically frozen scallops

Fig. 11-Spider web profile of QDA scores obtained for fresh scallops and frozen scallops after 5 months storage. Figure is 56 percent of full scale.



LEGEND: 1- fresh scallops
2- mechanically frozen scallops
3- 4 hr cryogenically frozen scallops
4- 24 hr (on ice) cryogenically frozen scallops

Fig. 12-Spider web profile of QDA scores obtained for fresh scallops and frozen scallops after 7 months storage. Figure is 56 percent of full scale.



LEGEND: 1- fresh scallops
2- mechanically frozen scallops
3- 4 hr cryogenically frozen scallops
4- 24 hr (on ice) cryogenically frozen scallops

Fig. 13-Spider web profile of QDA scores obtained for fresh scallops and frozen scallops after 8 months storage. Figure is 56 percent of full scale.

comparison and served thrice. In almost all cases, ANOVA significance was confirmed by Dunnet's test. The two instances in which ANOVA results were reversed were for the characteristic 'Mushiness' for the mechanically frozen samples of 5 and 7 month storage periods.

It was evident that the mechanically frozen scallops, even those stored for 8 months, had scores which were closer to fresh scallops especially with regard to "Odor" and "Taste". Cryogenically frozen scallops had lower scores for the same two sensory notes ($P < 0.02$ to $P < 0.0001$). Table 12 gives summary of ANOVA results for the QDA scores.

5. Correlations

The correlations obtained in Table 13 showed a strong negative correlation between moisture and protein percent, $R=-0.9604$ ($P < 0.0001$). This was expected as previous studies (Faturoti, 1984;Villareal and Howgate, 1987) had similar results. The interaction of trip and freezing treatment was significant for M/P ratio ($P < 0.02$) and as the 4 hr cryogenically frozen scallops had means and standard deviations for this ratio below 5, it could pass this quality test if introduced as a requirement. Adherence to Good Manufacturing Practices could ensure an export market for scallops frozen by either method studied.

Table 13-Pearsons correlation coefficients between data sets.

	DATA COMPARED	CORRELATION	PROBABILITY
1	Protein and Moisture	-0.9604	0.0001
2	Thaw Loss and Cook Loss	0.5949	0.0005
3	Odor with Taste	0.8369	0.0001
4	Odor with Mouthfeel	0.4206	0.02
5	Taste with Mouthfeel	0.6296	0.0002
6	Mouthfeel with Mushiness	-0.4193	0.02
7	Mouthfeel with Rubberiness	0.5969	0.0005

The area in which significant gains were observed for 4 hr cryogenically frozen scallops was thaw and cook losses. Rapid freezing may have caused the scallop to be rigid before the effects of cold shortening, if any, could take effect. During thawing, the reabsorption of dissolving ice crystals was more efficient due to the nature of the crystals. Moreover, the total muscle shortening during freezing, thawing (thaw rigor may be involved) and cooking must be less than the delta stage shortening. The reductions realized were significant ($P < 0.0001$) for thaw loss and ($P < 0.0014$) for cook loss. Transmission electron microscopy may be an appropriate technique to follow the changes taking place in the muscle structure as it is frozen, thawed and cooked. This may help determine appropriate freezing procedures for prevention of delta stage contraction which would also provide an accurate determination of rigor onset. It was surprising, since short cooking times at higher temperatures result in lower losses (Hamm, 1986), that microwave cooking did not give a significant reduction in cook loss compared to baking and broiling, due to its rapid short time nature of heating. This cooking method should be further studied.

Sensory studies indicated that all the frozen types of scallops in the study were edible if tested within one month of freezing. During extended storage, the attributes of

taste and odor deteriorated for the cryogenically frozen scallops but not for the mechanically frozen scallops. It may be, that the slower rate of freezing during mechanical freezing allowed some enzyme mediated nucleotide breakdown to occur. This may be causing the build up of flavor enhancers like AMP and IMP (Dyer and Hiltz, 1970). These flavor enhancers, if present in mechanically frozen meats, would explain higher scores for QDA. Some type of enzymic activity (lipase, protease or lipoxygenase) may also be responsible for the sensory quality changes observed as microbial activity would be minimum at the storage (-23°C) temperature. If the quality deterioration was enzyme mediated, the specific enzyme needs to be identified as also the reasons for their reduced activity in the mechanically frozen scallops. If higher scores for QDA were due to accumulation of nucleotide breakdown products, processing of cryogenically frozen scallops could be tailored to enhance build up of these products, prior to freezing.

V. CONCLUSION

The results obtained from microbiological, chemical, physical, and organoleptic tests of quality performed on fresh and frozen scallops lead to the following conclusions:

A) Microbiological;

i) Fresh scallops had higher microbial counts than frozen scallops and the conditions of storage and handling of fresh scallops were ideal for continued growth of psychotrophs. All counts were relatively high and could cause problems down the distribution chain.

ii) Stabilization of microbial quality is possible by freezing the scallops. Mechanical freezing ensured a lower microbial count than cryogenic freezing.

iii) In some cases, cryogenic frozen scallops had high microbial counts due to post-process contamination.

iv) The microbial data indicated that improved sanitary practices on the fishing/processing vessel would improve the marketability of higher quality products.

v) On the fourth trip, chlorine sanitizers were used

in shucking area and this resulted in scallops having an improved microbial quality when compared to the first three trips.

B) Chemical;

i) Variations observed in proximate composition may be due to differences in age, size, sexual maturity of scallops as well as environmental conditions. However, the observed differences varied by less than 3 percent.

ii) pH was not an accurate indicator of scallop rigor under conditions of this study.

iii) The 4 hr cryogenic scallops had a superior M/P ratio whose mean and standard deviation was always below the standard of 5. This makes it the only type of frozen scallop that can be recommended for export products (roe-on scallop) where the French M/P ratio test is performed as a quality standard.

C) Physical;

i) The 4 hr cryogenic scallops had a thaw loss that was almost half (47 %) that of mechanically frozen or 24 hr (on ice) cryogenic frozen scallops.

ii) Cook loss was also lower for the 4 hr cryogenic

scallops by about 28 percent compared to mechanically frozen or 24 hr cryogenic frozen scallops.

iii) No significant differences were observed in the color of fresh or differently frozen scallops.

iv) Instron measurement of shear peak force indicated that the texture of fresh scallops was firmer than frozen scallops.

v) Preparation method (baking, broiling, microwave) for cryogenically frozen scallops had a greater effect on pre-rigor than in-rigor scallops though differences were not statistically significant.

D) Organoleptic;

i) All scallops were edible when tasted within one month of freezing, however, more panelists chose mechanically frozen or fresh scallops over cryogenically frozen scallops when they selected for freshness.

ii) The 4 hr cryogenic frozen scallops were selected more often than the 24 hr cryogenic frozen scallops when panelists selected for freshness.

iii) Selection for freshness was not significant when 4 hr cryogenic frozen scallops were compared to fresh or mechanically frozen scallops.

vi) When stored for five months or more, the sensory notes of odor and taste deteriorated for cryogenic frozen scallops but improved or remained high for mechanically frozen scallops.

At present, a switch to at-sea cryogenic freezing of sea scallops *Placopecten magellanicus*, from the current freezing practice cannot be recommended for traditional scallop markets. The cost required to produce the minimum improvement in quality, would not be easily recovered. A study with greater controls on sanitation, use of sanitizers, and processing coupled with an economic analysis would be a better course of action. Cryogenic frozen scallops may be an economic proposition only in the case of high value products (roe-on scallops) or for identified high quality markets.

VI. APPENDIX I

A survey was carried out for three days, from 9th to 11th of October, on-board the fishing vessel to provide an insight into the sanitary conditions prevailing during scallop processing. One square inch areas were swabbed with sterile swabs. The swabs were then placed in tubes of sterile nutrient broth and frozen. The counts for scallop shucking totes, buckets and boxes are graphically presented for both aerobic plate counts and psychotropic plate counts in Figures 11 to 14. The APC and PPC curves have a similar profile and variable counts were observed ranging from log 1 to log 2 per sq cm to log 4 per sq cm. Low counts were observed on 10/11/91 for the scallop shucking bucket as it had just been washed. High counts were observed on 10/11/91 at 1200 hrs as the bucket has been in use for 4 hrs. Similar high counts were observed on 10/10/91 at 1800 hrs as the bucket had been in use for 2 hrs. This indicates that a sanitary plan needs to be developed and implemented to produce a scallop of a consistent high quality. A more complete sanitation survey needs to be performed in order to define the impact of each processing and handling operation on final product quality.

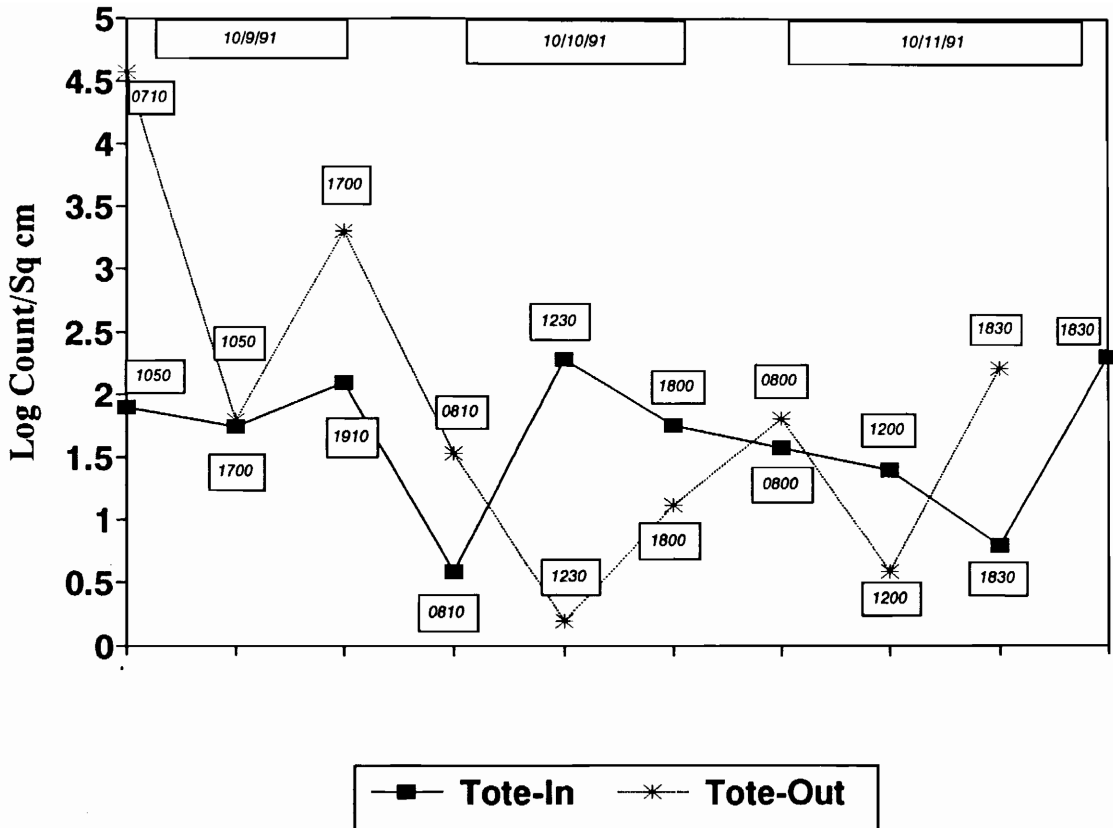


Fig. 14-Aerobic Plate Counts for Inside and Outside of Scallop Shucking Totes.

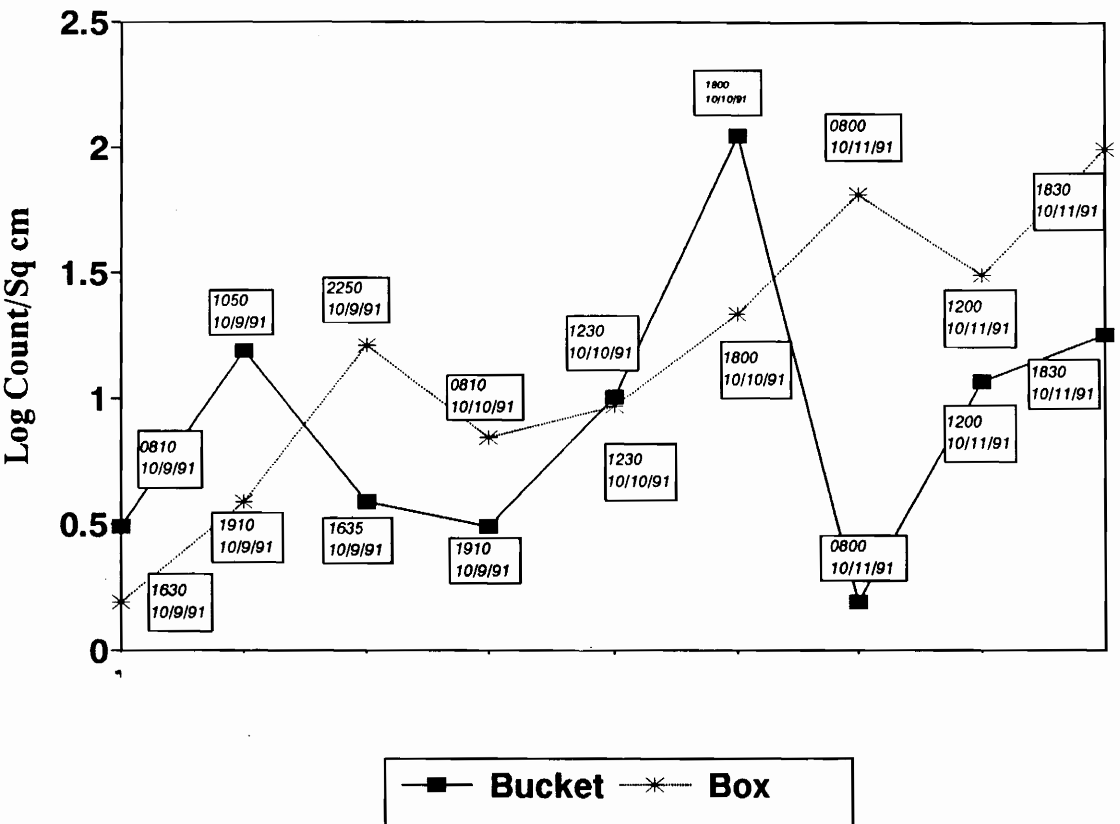


Fig. 15-Aerobic Plate Counts for Scallop Shucking Buckets and Scallop Shucking Boxes.

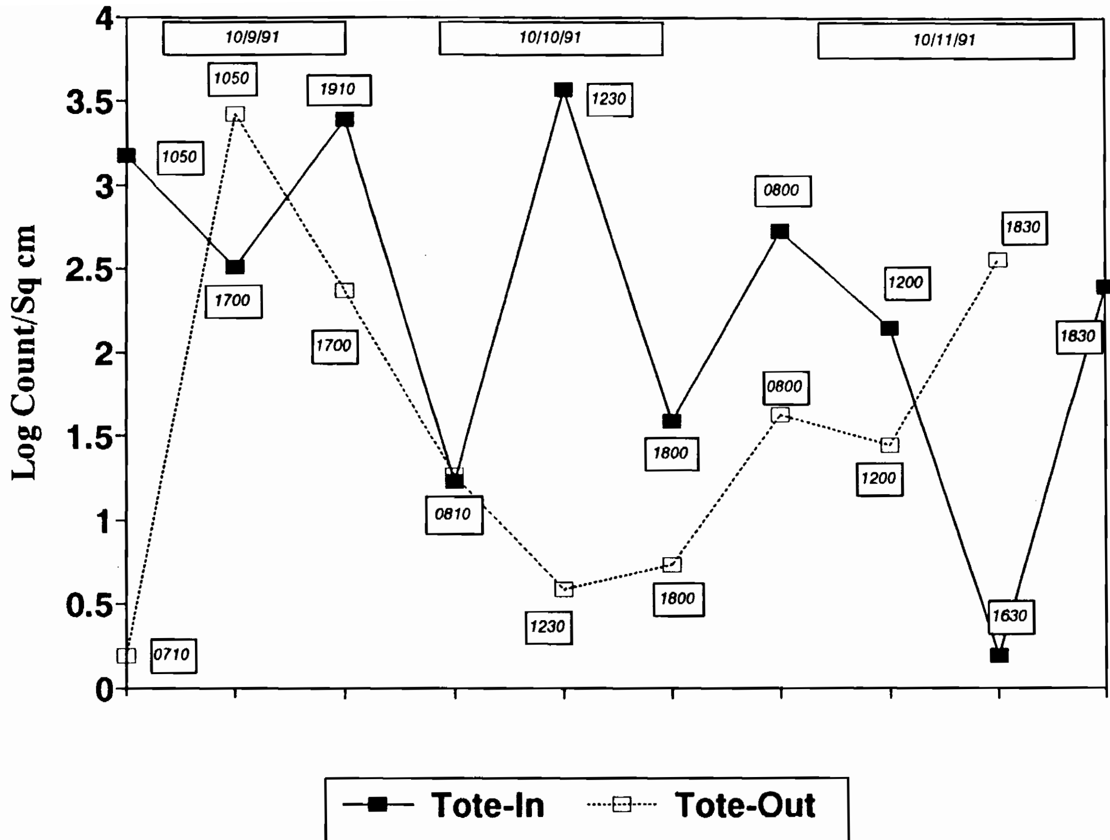


Fig. 16-Psychotrophic Plate Counts for Inside and Outside Scallop Shucking Totes.

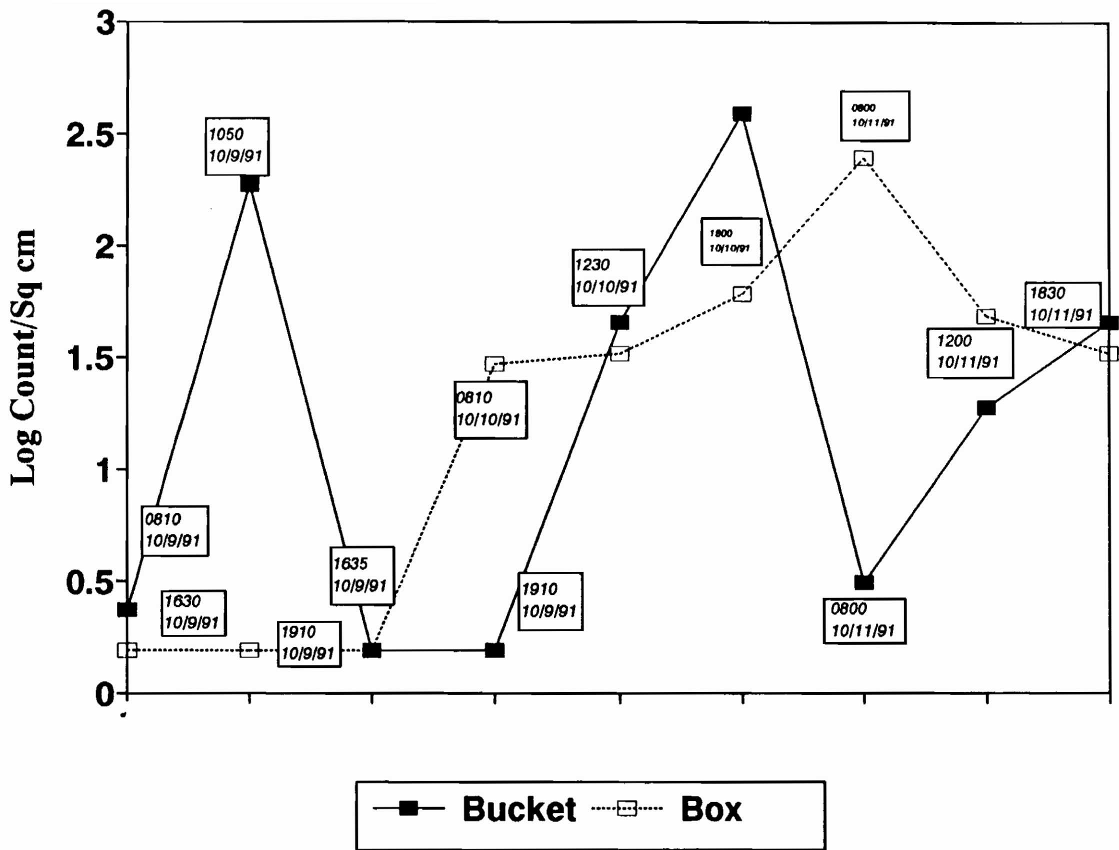
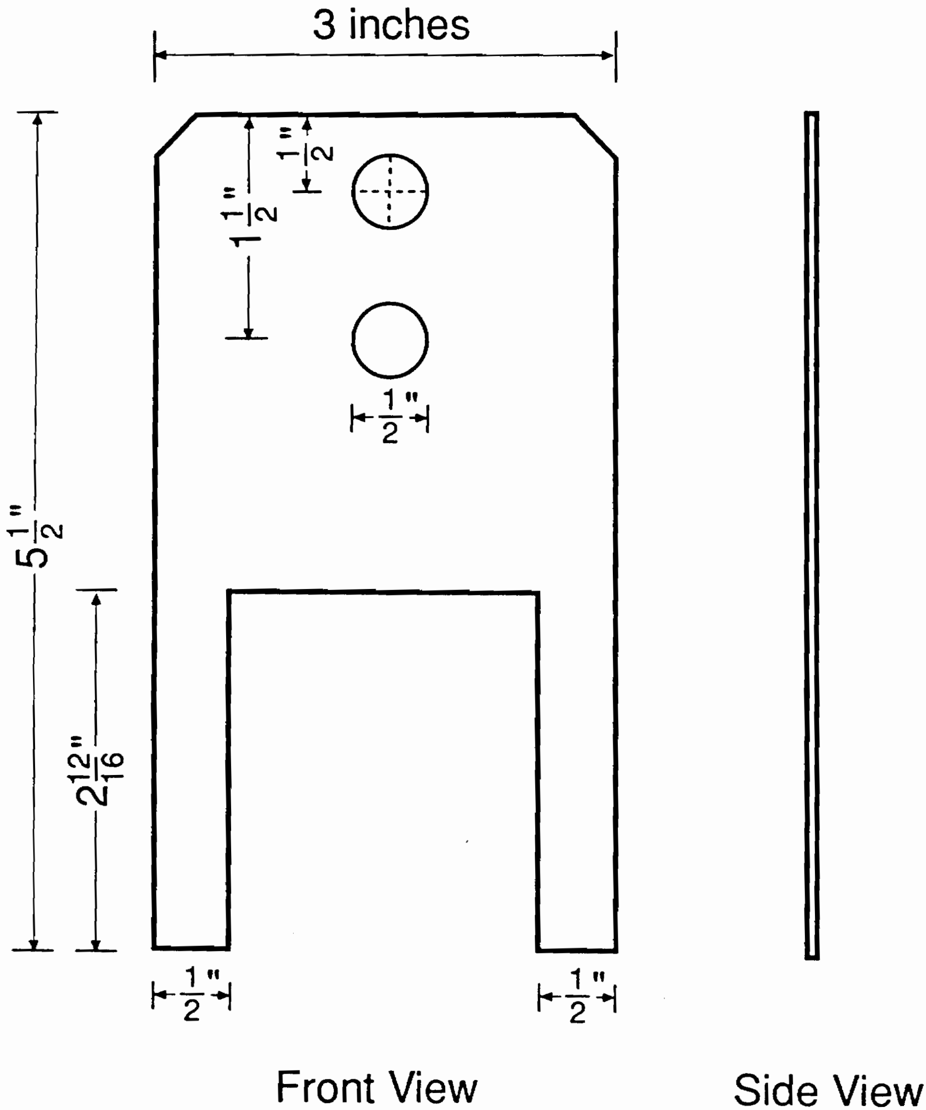


Fig. 17-Psychotrophic Plate Counts for Scallop Shucking Buckets and Boxes.

APPENDIX II-Modified Warner-Bratzler shear head.



APPENDIX III-Scoresheet and protocol for Paired Compairison testing.

NAME:____________________.   DATE:_______________.

Taste the pairs of samples starting from the left of each pair. Are they same or different? Do not swallow the sample. Take a bite of cracker and a sip of water between samples.

1.	SAME.	DIFFERENT.	FRESHER = QY1 ATR
2.	SAME.	DIFFERENT.	FRESHER = 654 R45
3.	SAME.	DIFFERENT.	FRESHER = ST8 TYX
4.	SAME.	DIFFERENT.	FRESHER = 1AW 73E

THANK YOU.

APPENDIX III-Scoresheet and protocol for Quantitative Descriptive Analysis testing.

NAME:____________________________________. DATE:____________________.

Taste the the samples in the order presented and record your impressions on the scales below. Ends of lines represent ends of scale. Take a bite of cracker and a sip of water between samples. Do not swallow samples. Thank You.

Odor ____
Stale Fresh

Color ____
Yellow White

Taste ____
Stale Fresh

Mouthfeel ____
Dry Juicy

Texture ____
Rubbery Firm

Texture ____
Mushy Firm

Texture ____
Gritty Not Gritty

VII. REFERENCES

American Public Health Association. 1970. Recommended Procedures for the Examination of Seawater and Shellfish. 4th edition. APHA. Washington, D.C.

American Public Health Association. 1972. Standard Methods for the Examination of Dairy Products. 13th edition. APHA. Washington, D.C.

Anon. 1975. Minutes of Sensory Evaluation Division Business Meeting at 35th Ann. Meeting, IFT. Chicago.

Anon. 1988. Seafood Safety: Seriousness of Problems and Efforts to Protect Consumers. GAO/RCED-88-135, US General Accounting Office, Washington, DC.

AOAC. 1975. Official Methods of Analysis of the Association of Analytical Chemists. 12th edition. Washington, D.C.

AOAC. 1984. Official Methods of Analysis of the Association of Analytical Chemists. 14th edition. Washington, D.C.

Aurell, T., Dagbjartsson, B. and Salomonsdottir, E. 1976. A Comparative Study of Freezing Qualities of Seafoods Obtained by using Different Freezing Methods. J. Food Sci. 41(5): 1165-1167.

Banks, A., Dassow, J.A., Feiger, E.A., Novak, A.F., Peters, J.A., Slavin, J.W. and Waterman, J.J. 1977. Freezing of Shellfish. In: Fundamentals of Food Freezing. Ed. N.W. Desrosier and D.K. Tressler. AVI Publishing Co. Inc., CT, pp 352-353.

Bendall, J.R. 1973. In: Structure and Function of Muscle. Vol. 2. Ed. G.H. Bourne. Academic Press, New York, p. 243.

Beninger, P.G. and Pennec, M.L. 1991. Functional anatomy of scallops. In: Scallops: Biology, Ecology and Aquaculture. Ed. S.E. Shumaway. Elsevier, Amsterdam, pp 133-223.

Benson, C.C. 1928. Hydrogen Ion Concentration Of Fish Muscle. J. Biol. Chem. 78(8): 583-590.

Boss, K.J. 1982. Mollusca. In: Synopsis and Classification of Living Organisms. Vol. 1. Ed. S.P. Parker. Mc-Graw Hill, NY, pp 945-1166.

Bourne, N. 1965. A Comparison of Catches by 3- and 4-Inch Rings on Offshore Scallop Drags. J. Fish. Res. Bd. Can. 22(2): 313-330.

Bourne, N. and Bligh, E.G. 1965. Orange-Red Meats in Sea Scallops. J. Fish. Res. Bd. Can. 22(3): 861-864.

Bouton, P.E., Harris, P.V. and Shorthose, W.R. 1971. Effect of Ultimate pH upon the Water Holding Capacity and Tenderness of Mutton. J. Food Sci. 36: 435-439.

Brand, A.R. 1991. Scallop Ecology Distribution and Behavior. In: Scallops: Biology, Ecology and Aquaculture. Ed. S.E. Shumaway. Elsevier, Amsterdam, pp 517-567.

Breyer, F. 1971. Refrigerant Effects on Fish. In: Applications of Cryogenic Technology. Vol 4. Ed. R.W. Vance. The Aerospace Corporation, LA, pp 190-201.

Caddy, J.F. 1989. A Perspective on the Population Dynamics and Assessment of Scallop Fisheries with Special Reference to the Sea Scallop P. magellanicus GMELIN. In: Marine Invertebrate Fisheries: Their Assessment and Management. Ed. J.F. Caddy. John Wiley and Sons, NY, pp 559-585.

Chantler, P.D. 1991. The Structure and Function of Adductor Muscle. In: Scallops: Biology, Ecology and Aquaculture. Ed. S.E. Shumaway. Elsevier, Amsterdam, pp 225-288.

Charlene, J. 1986. Paired-Comparison And Triangle Sensory Methods Compared For Use In Product Improvement. J. Food Qual. 9: 175-183.

Chordash, R.A. and Insalata, N.F. 1978. Incidence and Pathological Significance of E. coli and other Significant Indicator Organisms in Food and Water. Food Technol. 32(10): 54-58.

Chung, S.L. and Merritt, J.H. 1991. Sensory Quality of Frozen Sea Scallops. Intnl. J. Food Sci. Technol. 3(26): 695-705.

Commercial Freezing Methods. 1986. In: Refrigeration Systems and Applications. ASHRAE Handbook. ASHRAE Inc., GA, Ch 9, pp 9.1-9.8.

Cook, D.W. 1991. Microbiology of Bivalve Molluscan Shellfish. In: Microbiology of Marine Food Products. Ed. D.R. Ward and C.R. Hackney. Van Nostrand, NY, pp 19-39.

Copland, S. 1992. Personal Communication on 03/20/92.

Cowie, W.P. and Little, W.T. 1966. The Relationship between the Toughness of Cod stored at -29°C and its Muscle Protein Solubility and pH. Food Technol. 1: 335-343.

Cragg, S.M. and Crisp, D.J. 1991. The Biology of Scallop Larvae. In: Scallops: Biology, Ecology and Aquaculture. Ed. S.E. Shumaway. Elsevier, Amsterdam, pp 75-122.

Dyer, W.J. 1964. Basic Quality Changes in Frozen Seafood. In: J. ASHRAE, May, 1964, pp 40-42.

Dyer, W.J. and Hiltz, D.F. 1973. Hexose Monophosphate Accumulation and Related Metabolic Changes in Unfrozen and Thawed Adductor Muscles of the Sea Scallop (Placopecten magellanicus). J. Fish Res. Bd. Can. 30(1): 45-52.

Dyer, W.J. and Hiltz, D.F. 1974. Comparative Quality of Frozen and Thawed Scallop Meats and Post-Thaw Keeping Quality During Storage at 5°C. Bull. Jap. Soc. Sci. Fish. 40(2): 235-243.

Faturoti, E.O. 1984. Biochemical Evaluation of the Nutritive Quality of Differentially Processed Fish. Nutrition Reports International. 30(6): 1327-1335.

Fennema, O.R. 1985. Water and Ice. In: Food Chemistry Food Chemistry. 2nd edition. Ed. O.R. Fennema. Marcel Dekker, Inc., New York, pp 23-67.

Findlay, C.J. and Stanley, D.W. 1984. Texture-Structure Relationships in Scallop. J. Texture Studies. 15: 75-85.

Fink, A.L. 1979. Enzyme-Catalyzed Reactions in Unfrozen, Noncellular Systems at Subzero Temperatures. In: Proteins at Low Temperatures. Ed. O. Fennema. American Chemical Society, Washington, D.C. pp 35-54.

Fishbein, M., Mehlman, I.J., Chugg, L., Olson, Jr., J.C. 1976. Coliforms, Fecal Coliforms, E. coli, and

Enteropathogenic E. coli. In: Compendium of Methods for the Microbiological Examination of Foods. Ed. M.L. Speck. APHA. Washington, D.C.

Fishery of the United States 1989. May 1990. Current Fishery Statistics No. 8900. Ed. B.K. O'Bannon. Fisheries Statistics Division of U.S. Dept. of Commerce. NOAA. Washington, D.C.

Fishery of the United States 1990. May 1991. Current Fishery Statistics No. 9000. Ed. B.K. O'Bannon. Fisheries Statistics Division of U.S. Dept. of Commerce. NOAA. Washington, D.C.

Food and Drug Administration. 1989. Sanitation of the Harvesting, Processing and Distribution of Shellfish. In: National Shellfish Sanitation Program Manual of Operations, Part II. Public Health Service, Shellfish Sanitation Branch. Washington, D.C.

Foster, J.F., Fowler, J.L. and Dacey, J. 1977. A Microbial Syrvey of Various Fresh and Frozen Seafood Products. J. Food Prot. 40(5): 300-303.

Gakichko, S.I. and Fonicheva, K.M. 1983. Production of Frozen Fish. In: Handbook of Fishery Technology. Vol. 1. Ed. V.M. Novikov. A.A. Balkena, Rotterdam, pp 267-280.

Gilliland, S.E., Michener, H.D. and Kraft, A.A. 1976. Psychotrophic Microorganisms. In: Compendium of Methods for the Microbiological Examination of Foods. Ed. Marvin L. Speck. APHA. Washington, D.C.

Hamann, D.D. and Lanier, T.C. 1986. Instrumental Methods for Predicting Seafood Sensory Texture Quality. In: Seafood Quality Determination. Ed. D.E. Kramer and J. Liston. Elsevier, Amsterdam, pp 123-136.

Hamm, R. 1986. Functional Properties of the Myofibrilar System and Their Measurements. In: Muscles as Food. Ed. P.J. Bechtel. Associated Publications Inc., FL, pp 135-199.

Hastback, W.G. 1981. Short Incubation of Presumptive Media for Detection of Fecal Coliforms in Shellfish. Appl. Envioronmental Microbiol. 42(6): 1125-1127.

Hebard, C.E., Flick, G.J. and Martin, R.E. 1982. Occurrence and Significance of Trimethylamine Oxide and Its Derivatives in Fish and Shellfish. In: Chemistry and

Biochemistry of Marine Food Products. Ed. R.E. Martin, C.E. Hebard, G.J. Flick and D.R. Ward. AVI Publishing Co., Inc., CT, pp 141-273.

Hiltz, D.F. and Dyer, W.J. 1971. Octopine in Postmortem Adductor Muscle of Sea Scallop (Placopecten magellanicus). J. Fish. Res. Bd. Can. 28(6): 869-874.

Hultin, H.O. 1985. Characteristics of Muscle Tissue. In: Food Chemistry. 2nd edition. Ed. O.R. Fennema. Marcel Dekker, Inc., New York, pp 725-790.

King, F.J. 1983. Procedure for Cooking Seafood Products. J. Assoc. Off. Anal. Chem. 66(3): 813-815.

King, F.J. and Ryan, J.J. 1977. Development of a Color Measuring System for Minced Fish Blocks. Marine Fisheries Review. 39(2): 18-23.

Korhonen, R.W., Lanier, T.C. and Giesbrecht, F. 1990. An Evaluation of Simple Methods for Following Rigor Development in Fish. J. Food Sci. 55(2): 346-348.

Lazos, E.S., Aggelousis, G. and Alexandros, A. 1989. Metal and Proximate Composition of Edible Portion of 11 Freshwater Fish Species. J. of Food Comp. and Anal. 2: 371-381.

Liuzzo, J.A. and Novak, A.F. 1975. Correlation of Organoleptic Evaluation with Chemical and Microbiological Tests in Oysters. Food Prod. Dev. 9: 78.

Loreal, H. and Etienne, M. 1990. French Specifications and Methodology. In: XXth WEFTA Meeting - Reykjavik.

Marsh, B.B. and Leet, N.G. 1966. Studies in Meat Tenderness. III. The Effects of Cold Shortening on Tenderness. J. Food Sci. 31(2): 450-459.

Marsh, B.B. and Thompson, J.F. 1957. Thaw Rigor and the Delta State of Muscle. Short Communications. Biochim. Biophys. Acta. 24: 427-428.

Matches, J.R. and Abeyta, C. 1983. Indicator Organisms in Fish and Shellfish. Food Technol. 6: 114-117.

Maxwell-Miller, G., Josephson, R.V., Spindler, A.A., Holloway-Thomas, D., Avery, M.W. and Phleger, C.F. 1982. Chilled (5°C) and Frozen (-18°C) Storage Stability of the Purple-Hinge Rock Scallop, Hinnites multirugosus Gale. J. Food Sci. 47(6): 1654-1660.

McBride, R.L., Watson, A.J. and Cox, B.M. 1984. The Paired-Comparison Method As A Simple Difference Test. J. Food Qual. 6: 285-290.

McTigue, M.C., Koehler, H.H. and Silbernagel, M.J. 1989. Comparison of Four Sensory Evaluation Methods for Assessing Cooked Dry Bean Flavor. J. Food Sci. 54(5): 1278-1283.

Mehlman, I.J. 1984. Coliforms, Fecal Coliforms, E. Coli and Enteropathogenic E. Coli. In: Compendium of Methods for the Microbiological Examination of Foods. Ed. M.L. Speck. APHA. Washington, D.C.

Messer, J.W., Peeler, J.T. and Gilchrist, J.E. 1984. Aerobic Plate Count. In: Bacteriological Analytical Manual. 6th edition, pp 4.01-4.10.

Millman, B.M. and Bennet, P.M. 1976. Structure of Cross-Striated Adductor Muscle of the Scallop. J. Molecular Biol. 103: 439-467.

Minard, M.E. 1973. Food Freezing with Carbon dioxide. In: Applications of Cryogenic Technology. Vol 6. Ed. S.H. Booth and R.W. Vance. Scholium Intnl. Inc., NY, pp 245-250.

Naidu, K.S. 1969. Growth, Reproduction and Unicellular Endosymbiotic Alga in the Giant Scallop, Placopecten magellanicus (Gmelin) in Port au Port Bay, Newfoundland. M.Sc. Thesis, Memorial University of Newfoundland. 181p.

Naidu, K.S. 1991. Sea Scallop, Placopecten magellanicus. In: Scallops: Biology, Ecology and Aquaculture. Ed. S.E. Shumaway. Elsevier, Amsterdam, pp 861-886.

Nunzi, M.G. and Francini-Armstrong, C. 1981. The Structure of Smooth and Striated Portions of the Adductor Muscle of the Valves in a Scallop. J. Ultrastruct. Res. 76: 134-148.

Paris Directorate of Veterinary Services. 1987. Report from the Veterinary Services of the Val-de-Marne Department at the Paris-Rungis Central Market, pp 1-3.

Pedraja, R.R. 1972. Quality Aspects of Refrigerated and Frozen Fishery Products. J. ASHRAE, Nov, 1972, pp 32-38.

Peters, J.A. 1968. Oysters, Scallops, Clams and Abalone. In: The Freezing Preservation of Foods. Vol 2. Ed. D.K. Tressler, W.B. Arsdel and M.J. Copley. AVI Publishing Co., Inc., CT, pp 219-220.

Piggot, G.M. and Tucker, B.E. 1990. Adding and Removing Heat. In: SEAFOOD Effects of Technology on Nutrition. Marcel Dekker, NY, pp 104-136.

Pomeranz, Y. and Meloan, C.E. 1987. General Remarks. In: Food Analysis: Theory and Practice. Van Nostrand, NY, pp 575-580.

Poole, S.E., Wilson, P., Mitchell, C.E. and Wills, P.A. 1990. Storage Life of Chilled Scallops Treated with Low Dose Irradiation. J. Food Prot. 53(9): 763-766.

Posgay, J.A. 1962. Maximum Yield Per Recruit of Sea Scallops. ICNAF Doc. No. 73, Ser. No. 1016, 20p.

Power, H.E., Fraser, D.I., Neal, W., Dyer, W.J., Castell, C.H., Freeman, H.C. and Idler, D.R. 1964. Use of Gamma Radiation for the Preservation of Scallop Meat. J. Fish Res. Bd. Can. 21(4): 813-826.

Randall, E.L. 1974. Improved Method for Fat and Oil Analysis by a New Process of Extraction. J. Assoc. Off. Anal. Chem. 57(5): 1165-1168.

Rippen, T.E. 1992. Personal Communication on 06/28/92.

SAS Institute Inc. 1985. Sas User's Guide: Statistics, Version 5 edn. Gary, NC.

Shewan, J.M., Hobbs, G., and Hodgkiss, W. 1960. The Pseudomonas and Achromobacter Group of Bacteria in the Spoilage of Marine White Fish. J. Appl. Bact. 23(3): 463-468.

Shumaway, S.E. 1991. Preface. In: Scallops: Biology, Ecology and Aquaculture. Ed. S.E. Shumaway. Elsevier, Amsterdam, pp vii.

Sikorky, Z.E., Kolakowska, A. and Burt, J.A. 1990. Commercial Freezing Methods. Seafood: Resources, Nutritional Composition and Preservation. Ed. Z.E. Sikorsky. CRC Press Inc., Boca Raton, FL, pp 60-122.

Simmonds, C.K. and Lamprecht, E.C. 1985. Microbiology of Frozen Fish and Related Products. In: Microbiology of Marine Food Products. Ed. R.K. Robinson. Elsevier, NY, pp 169-207.

Simpson, K.L. 1982. Carotenoid Pigments in Seafood. In: Chemistry and Biochemistry of Marine Food Products. Ed. R.E. Martin, G.J. Flick, C.E. Hebard and D.R. Ward. AVI Publishing Co., Inc., CT, pp 115-137.

Stevenson, J.A. and Dickie, L.M. 1954. Annual Growth Rings and Rate of Growth of the Giant Scallop, Placopecten magellanicus (Gmelin) in the Digby area of the Bay of Fundy. J. Fish. Res. Bd. Can. 11(5): 660-671.

Stone, H., Sidel, J., Oliver, S., Woolsey, A. and Singleton, R.C. 1974. Sensory Evalution by Quantitative Descriptive Analysis. Food Technol. 28(11): 24-34.

Stone, H.S. and Sidel, J.L. 1985a. Introduction to Sensory Evaluation. In: Sensory Evaluation Practices. Academic Press, FL, pp 1-12.

Stone, H.S. and Sidel, J.L. 1985b. The Organisation and Evaluation of a Sensory Evaluation Program. In: Sensory Evaluation Practices. Academic Press, FL, pp 13-57.

Tan, F.C., Cai, D. and Roddick, D.L. 1988. Oxygen Isotope Studies on Sea Scallops, Placopecten magellanicus, from Browns Banks, Nova Scotia. Can. J. Fish. Aquat. Sci. 45(8): 1378-1386.

Tarr, H.L.A. 1947. Preservation of Quality of Edible Fish Products. Fish. Res. Bd. of Can. Progress Report #71, pp 15-20.

Villareal-Perez, B. and Howgate, P. 1987. Composition of European Hake. J. Sci. Food Agri. 40: 347-356.

Waller, T.R. 1984. The Ctenolium of Scallop Shells: Functional Morphology and Evolution of a Key Family-Level Character in the Pectinacea (Mollusca:Bivalvia). Malacologia. 25(1): 203-219.

Waller, T.R. 1991. Evolutionary Relationships among Commercial Scallops (Mollusca: Bivalvia: Pectinidae). In: Scallops: Biology, Ecology and Aquaculture. Ed. S.E. Shumaway. Elsevier, Amsterdam, pp 1-8.

Waters, M. 1964. Comparison of Chemical and Sensory Tests for Assessing Storage Life of Iced Calico Scallops (Pecten gibbus). Fish. Ind. Res. 2(3): 5.

Webb, N.B., Thomas, F.B., Busta, F.F. and Munroe, R.J. 1967. A Study of the Quality of North Carolina Scallops. (Special Scientific Report No. 12). Dept. of Conservation and Development, North Carolina.

Yearbook of Fishery Statistics, FAO, Rome, Vols 48;1979, 50; 1980, 54;1982, 56;1983, 58;1984, 62;1986, 64;1987 and 66;1988.

Young, K.W. and White, K.J. 1984. Color Measurement of Fish Minces Using Hunter L, a, b Values. J. Sci. Food Agri. 36: 383-392.

VIII. VITAE

The author, Jyoti Mukerji, was born on February 19, 1957 in Nagpur, India. After graduating with a BS degree in Chemistry from Bombay University in 1979, he pursued a MS degree in Biochemistry at the same University and was awarded the MS degree in 1981.

After a short spell of work at the Jaslok Hospital and Medical Research Center, he joined Hindustan Petroleum in September, 1982 as an Officer Trainee. His work was recognized and he rose to the position of Deputy Manager in the Aviation Operations department. While working for this organization, he obtained a post-graduate diploma in Business Management in 1984 from the Xavier's Institute of Management, Bombay, India

He resigned from this position in July, 1990 in order to pursue further studies in Food Science and Technology. In the fall of 1990, he enrolled in Virginia Polytechnic Institute and State University to obtain his MS degree in Food Science and Technology.

He is a member of the Institute of Food Technologists, the Carolina Virginia Institute of Food Technologists and the American Association of Cereal Chemists. He is also a member of the Alpha Psi chapter of the Biological Honor Society, Phi Sigma.