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INTRODUCTION

Most of the sea scallop (*Placopecten magellanicus*) fishery is conducted on the continental shelf where scallops are shucked at sea. The adductor muscles, or scallop meats, are landed as the commercial product form. Scallop meats are generally stored in linen bags packed in ice for the duration of the fishing trip and are further processed at shore-side facilities. Exposure of the scallop meats to ice melt or fresh water during vessel storage or shore-side processing causes an increase in moisture content with concomitant increases in weight. During 1992, the U.S. Food and Drug Administration (FDA) became increasingly concerned with vessel handling and on-shore processing practices which increased the moisture content of scallop meats. The FDA ruled that a 'natural' scallop could not have a moisture content that exceeded 80% by weight. In 1995, Canada established a moisture standard not to exceed 81%. France has defined a moisture standard for scallops based on a moisture/protein ratio not to exceed 4.99.

Prior to the present study, data on the natural moisture content of sea scallops in the northwest Atlantic Ocean has been limited and inadequate to establish regulatory provisions. The goal of this study was to assess natural and ex-vessel moisture content over an extended period of time and in most of the commercially fished areas to account for latitudinal, depth, biological and sample variability.

FACTORS AFFECTING NATURAL AND EX-VESSEL LEVELS OF MOISTURE

Factors affecting the natural moisture content of sea scallop meats are presumably both biotic and abiotic in nature (Figure 1). Biological factors such as food availability, reproductive cycle, and the general health of the animals will influence the moisture and protein levels found in scallop adductor muscles. These factors in turn, are influenced by water depth, season, latitude and interannual variation. In attempting to assess the natural moisture content of sea scallops for regulatory purposes, it must be recognized that the U.S. commercial fishery operates on a year-round basis, in water depths ranging from a few feet to over 300 feet, a latitudinal range of over 7 degrees and in the many varied micro-environments found along the continental shelf. It would be difficult if not impossible to identify any one or even a group of biotic or abiotic factors at any given time as a controlling influence in setting a standard for moisture content for commercially harvested sea scallops. Consequently, the measurement of natural moisture contents must be made over an extended period of time, during all seasons, and in all commercially fished areas. Within these measurements, a range of natural moisture contents can be identified.

Post-harvest practices aboard fishing vessels can have significant and predictable effects of scallop meat moisture content. Many of these factors have been identified and quantified (DuPaul et al 1990a, b; DuPaul et al 1993; Fisher et al 1996). Increases in moisture content can be expected during any period of time when scallop meats are subjected to ice melt or freshwater contact. This can occur on the deck of the fishing vessel when ice-seawater slushes are used to prevent thermal abuse and when bags of scallops are stored in the ice-hold for the duration of the fishing trip.

SAMPLE COLLECTION AND PREPARATION

Sea scallop meats were collected on seven commercial fishing trips from September 1992 to April 1995 at various locations from Virginia to Georges Bank (Figure 2). All samples were obtained from commercially fished areas with depths ranging from 150 to 300 meters. Scallop samples were taken during normal fishing operations and are thus representative of commercial fishing operations. Vessel handling and stowing were conducted using good manufacturing practices as identified by DuPaul et al (1993). Scallop meats were held on deck prior to bagging in a 2:1 ice-seawater mixture when surface seawater temperatures exceeded 65-70 degrees F. Scallop bags were stowed on ice from 10-15 days prior to offloading.

Scallop meat samples representative of natural conditions were taken from freshly shucked scallops at the time of harvesting. The sample was identified with regard to date, location (LORAN) and depth of water. Samples were taken at a minimum on a daily basis when fishing operations were conducted in the same resource area. Sampling frequency increased when fishing operations were conducted in various locations with different depths and resource conditions. Consequently, sample locations correspond with the cruise tracks for each trip identified in Figure 2 and in Table 1. Samples representative of scallop meats at offloading were obtained from marked bags corresponding to date of bagging and location of harvest. All scallop samples were obtained by scientists from the Virginia Institute of Marine Science, College of William and Mary while conducting research on scallop dredge selectivity and efficiency.[1]

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[1]Funded by Saltonstall-Kennedy Fishery Development Funds Grant #NA36FD0131.

A sample constituted seven (7) individual scallop meats. Freshly shucked scallop meats were rinsed in seawater and drained to remove excess water. Scallop meats obtained from bags at offloading were not rinsed.

Individual scallop meats were arranged in a roll at the bottom of one pint ziplock freezer bag and frozen. The end result was a solid roll of scallop meats free of surrounding air pockets. In preparation for moisture and protein analysis, the entire roll of scallop meats were removed, still frozen, from the bag and homogenized. The analyses were performed on the composite homogenate of the seven scallop meats.

ANALYTICAL METHODOLOGY

Determining moisture and protein:

Moisture was determined by the AOAC air drying method (950.46, 15th ed. 1990). Duplicate 2-5 g subsamples were dried 18-24 hrs. at 100-102 degrees C to constant weight and results reported as percent moisture by weight.

Protein was determined utilizing a CARLO ERBA Nitrogen Analyzer 1500 (Carlo Erba Strumentazione Nitrogen Analyzer instrument manual, 1986). Dried samples from moisture determinations were ground, weighed into tin cups (2-4 mg.) and placed into analyzer using a 60 mv (x10) scale and 4-7 mg of atropine standard. Results were reported in percent nitrogen on a dry weight basis. Percent nitrogen wet weight basis was calculated by percent dry weight basis X dry weight/wet weight. Percent protein was then calculated as follows:

Percent protein = % nitrogen wet weight basis X 6.25 where 6.25 = protein factor for meat products (15% N).

Assessing Probability and Limits:

Data on moisture and moisture-protein ratios were assessed relative to a one-tailed probability. Initially, natural moisture levels were assessed to provide a ground-truth relative to at-sea processed scallops; scallop meats typically take up moisture because of product stowage on ice. Thus, moisture levels prior to stowage on ice were assessed. Moisture levels for offloaded meats were subsequently assessed relative to natural levels in order to determine the likelihood or probability of exceeding potential limits of moisture. The same analysis was conducted on moisture-protein ratios.

The assessment of probabilities of exceeding limits was accomplished using the statistical package ABSTAT. The package enables one to assign the probability of exceeding a limit given the data and determines the mathematical value of the limit; alternatively, one can assign limits and determine the probability of exceeding that limit. We assumed that data on moisture levels and moisture-protein ratios followed a Student's t-distribution. We further considered that the t-distribution was censored relative to moisture levels; moisture levels cannot be less than zero nor can they exceed 100%.

REGULATORY REVIEW

Figure 3 identifies the chronology of events relative to the regulation of moisture content in sea scallops and scallops in general. France was the first country to establish a standard of identity using a ratio of moisture to protein to prevent processing abuses which resulted in unacceptably high moisture contents and consumer fraud. The principle of the standard consisted of determining the water/protein ratios which accommodates a 5% by weight addition through the

processes of transportation, washing and processing operations. Accordingly, a 5% by weight addition of water corresponded to a moisture/protein ratio of 4.76; for regulatory purposes, the upper limit of this radio was set at 4.99. However, it should be recognized that the studies involved to reach this conclusion were conducted with freshly shucked live *Pecten maximus*. There is no correlative fishery in Europe to the U.S. scallop fishery which shucks the scallops at sea and are stored on ice for extended periods.

During 1991, the U.S. Food and Drug Administration (FDA) sent warning letters to scallop processors stating "the soaking of scallops to increase weight and volume renders the scallops adulterated....." The FDA claimed that creating economic deception was in violation of Section 402(b) of the Food, Drug and Cosmetic Act. During this period, however, there were no established guidelines or limits for the moisture content of both domestic or imported scallops. In 1992, the FDA reached an "interim agreement" with the scallop industry to provide for label declarations on the use of tripolyphosphates and the addition of water. The "interim agreement" stated that scallops with a moisture content greater than 79.9% must be labeled as "water added scallop product" and the label must designate the degree to which water was added. Scallops with a moisture content exceeding 84% were determined to be unmarketable regardless of label and would not be allowed.

Despite the labeling provisions contained within the FDA's "interim agreement," the upper moisture limit of 79.9% was thought to be too restrictive given the degree of natural variability and the differences in harvesting and vessel handling practices over the geographic range of the U.S. sea scallop resource. In addition, imported scallops had to meet the same requirements as domestic product which caused both confusion and concern among importers and exporters of

this world-wide seafood commodity. To compound the issue, very little data existed relative to the natural moisture content in scallops to support or refute the provisions of the labeling requirements set forth by FDA.

During 1993 and 1994, a study was conducted jointly by the Department of Fisheries and Oceans (Canada) and the Fisheries Council of Canada to determine the moisture content of scallops (*Placopecten magellanicus*) harvested by commercial vessels.[2] The study focused on the offloading or ex-vessel moisture of sea scallops held in ice under normal vessel handling conditions. The results of the study indicated that an upper or maximum moisture content of 81% would accommodate all of the samples taken during the study; the 0.05 confidence limit for moisture content was found to be 80.5%. Consequently, in 1995 Canada established a maximum moisture content of 81% for the Atlantic sea scallop.

RESULTS AND DISCUSSION

Summary moisture content data for each of the seven commercial scallop trips is presented in Table 1. Natural moisture contents ranged from 73.7 to 78.9%; offloading or ex-vessel values ranged from 74.2 to 82.5%. As anticipated, the coefficient of variation (CV) was greater for the moisture contents at offloading. This was due to the additional number of variables that influence increases in moisture content due to handling and ice storage.

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[2]A Study of the Seasonal Variation of the Moisture Content of Sea Scallop Meats Harvested by Canadian Fishing Vessels in the Georges Bank Area. R. E. Mills, P. McGuiness, C. Prince and S. Flack. 1996. DRAFT REPORT.

Data for moisture, protein and calculated moisture protein ratios for all trips were combined in order to evaluate potential maximum and minimum values for regulatory purposes (Table 2).

Additional analyses for moisture and protein content were performed to determine potential sources of variation within sample groups (Table 3). Potential sources of sample variation examined were scallop size (shell height), multiple samples from a single bag of scallop meats, samples from multiple haul-backs from a single resource area, multiple samples from one haul-back and one sample each from five bags of scallops with the same history. The CV for natural moisture content within sample groups was less than 1% and not considered significant. Again, the highest CV was found for samples taken at offloading but were not considered as a significant source of variation. Consequently analytical and sampling procedures used during these experiments were not considered as a significant variable.

The results obtained from the Canadian study (footnote #2) on moisture content were similar to those obtained in our study. The Canadian study did not evaluate natural moisture content but focused on moisture and protein content at offloading. Moisture values ranged from 74.19 - 80.94% and moisture/protein ratios ranged from 4.06 - 5.65. Data were analyzed to determine the moisture content that would establish a 95.00% probability upper limit. Results established a moisture content of 80.50% and a moisture/protein ratio of 5.32 as meeting the 95.00% probability of compliance level. In order to insure that 100% of the samples would comply with a maximum limit for moisture, an 81.0% moisture content was set as that upper limit. The results of the study also indicated that a significant portion of the samples held on ice longer than six days would fail to meet the moisture/protein ratio of <5.0 set by France to control added

water in scallop meats.

A similar approach has been used for the present study with similar results. If the 95% probability level is used to establish an upper limit for moisture content at offloading, that limit would be set at 81.56% (Table 4). If a higher probability is desired, a maximum moisture content of 82.0% would provide a probability of compliance of 97.02%. Presently, the 80.0% maximum moisture content set for natural scallop meats would provide a probability of compliance of 78.21%. An established moisture/protein ratio of 5.14 would provide for a 95.00% probability of compliance; at 5.35, the probability of compliance would rise to 98.79% (Table 5).

The results from the present study indicate that a maximum moisture content of 82% for scallop meats at offloading would provide nearly the same degree of compliance as established by the Canadian study. The difference in the upper limit (82.0 versus 81.0%) between the present study and the Canadian study is due to different vessel handling practices. Some of the commercial trips in the present study were longer than 10 days and in some cases, ice/seawater slushes were used on deck to prevent thermal abuse. In addition, the rate of ice melt in the vessel holds is greater in warmer climates. Consequently, it is not surprising to find a higher upper limit in moisture content to provide for a similar level of compliance probability.

In conclusion, in light of the present study and the information provided by the Canadian report, the present standard for moisture content in sea scallops set by FDA should be reexamined.

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Figure 1. Factors Affecting Moisture Content in Sea Scallops.

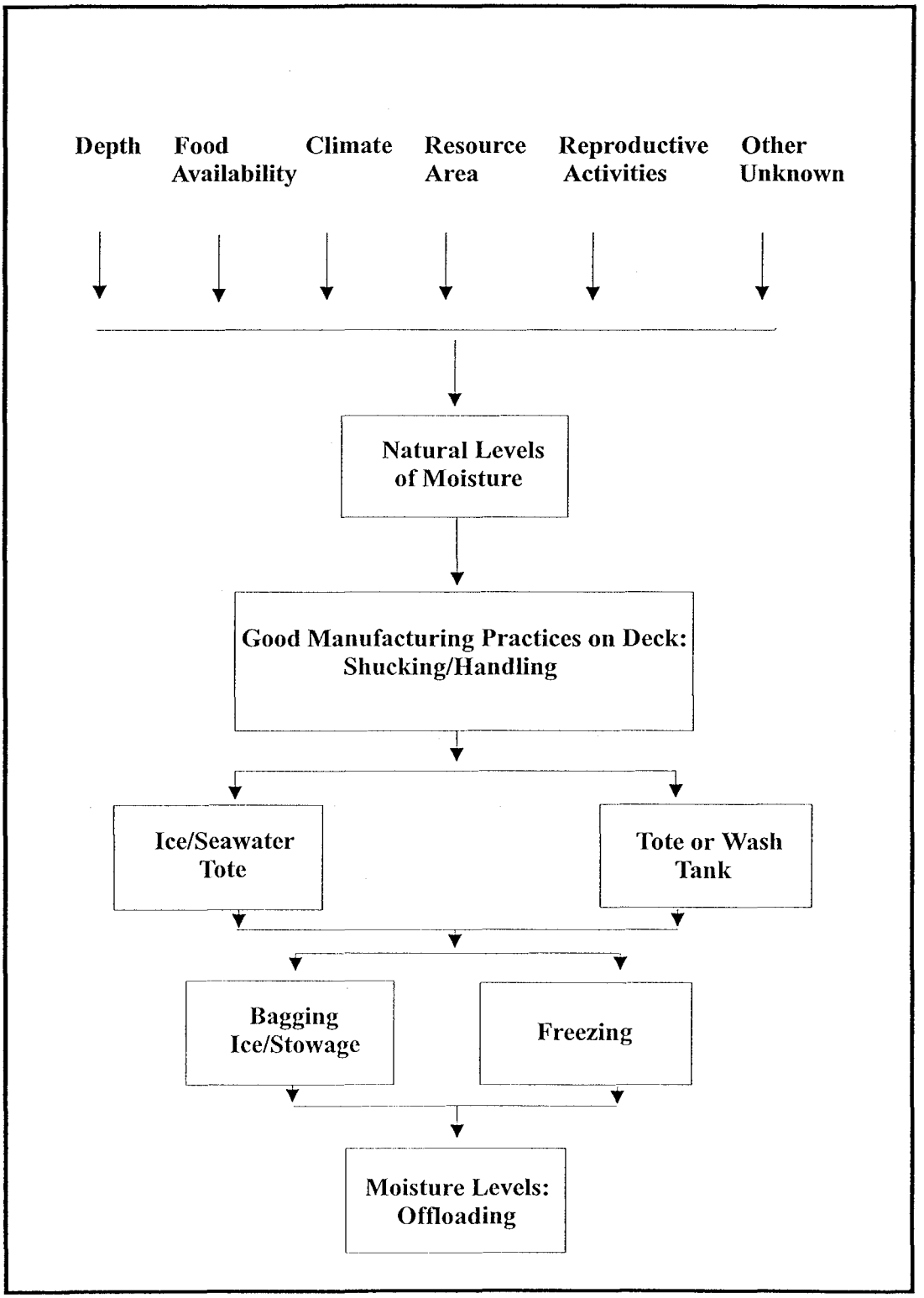

Figure 2. Location and Date of Commercial Fishing Operations, 1992-1995.

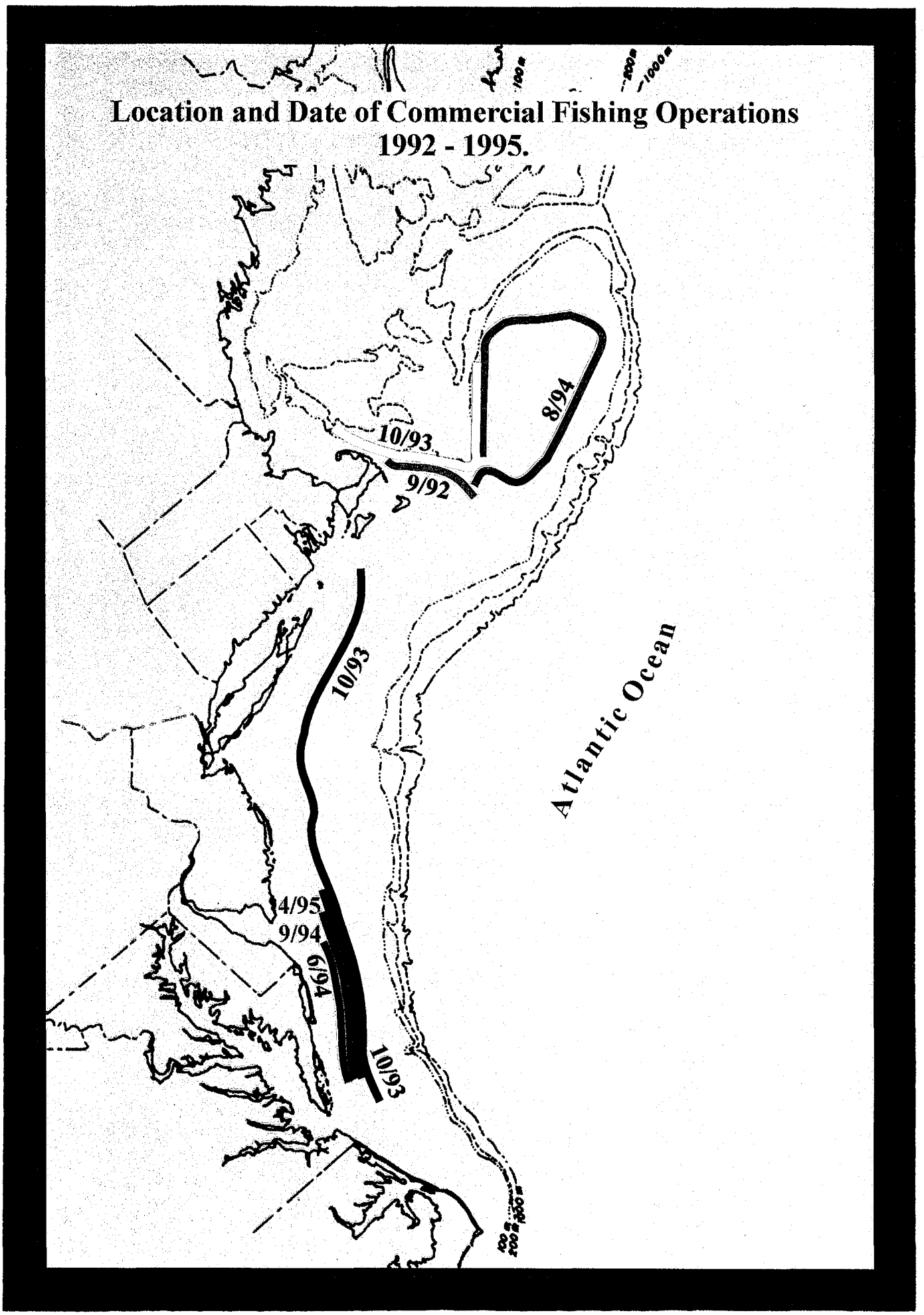

Figure 3. Chronology of Regulatory Provisions Addressing Moisture Content in Scallops.

1987-1988. FRANCE ACTS TO ELIMINATE EXCESSIVELY SOAKED SCALLOPS.

.....the amount of added water, by weight, should not exceed 5%...a 5% increase in weight by the addition of water corresponds to a moisture:protein ratio of 4.76....a moisture:protein ratio of less than 5.0 is set as an upper limit.

1991-1992. US FDA WARNING LETTERS.

".....soaked scallops substantially increased moisture content...the soaking of scallops to increase weight and volume renders the scallops adulterated..."

1992. US FDA INTERIM AGREEMENT.

".....any scallop that contains a moisture content of 80% or more should be labeled"..... "X% Water Added Scallop Product".... "the maximum content for a scallop treated with phosphate compounds and water should not exceed 84%".... the 84% moisture level converts to a maximum of 25% water (by weight) added to the scallop product...."

1995. CANADA CONDUCTS SCALLOP MOISTURE STUDY.

.....data from natural and offloaded (ex-vessel) scallop meats indicate that scallop moisture should not exceed 81%.

TABLE 1.
Moisture Content (%) of Sea Scallops, August 1992 - April 1995.[a]

Year/Month/Area/Depth	Natural Moisture	Offloading Moisture
Year: 1992 Month: August/September Area: Georges Bank/New England	Minimum: 74.70 Maximum: 77.40 Mean: 76.17 CV%: 1.26 Sample Size: 18	Minimum: 77.90 Maximum: 81.40 Mean: 79.13 CV%: 1.11 Sample Size: 14
Year: 1993 Month: September/October Area: Georges Bank/New England	Minimum: 75.10 Maximum: 78.90 Mean: 77.46 CV%: 1.56 Sample Size: 28	Minimum: 76.30 Maximum: 81.70 Mean: 78.60 CV%: 1.69 Sample Size: 16
Year: 1993 Month: November Area: Southern New England/Mid-Atlantic	Minimum: 75.00 Maximum: 78.70 Mean: 77.26 CV%: 0.96 Sample Size: 29	Minimum: 77.50 Maximum: 82.50 Mean: 80.26 CV%: 1.94 Sample Size: 7
Year: 1994 Month: June Area: Mid-Atlantic	Minimum: 76.50 Maximum: 77.60 Mean: 77.24 CV%: 0.39 Sample Size: 17	Minimum: 78.00 Maximum: 80.80 Mean: 79.63 CV%: 1.02 Sample Size: 20
Year: 1994 Month: July/August Area: Georges Bank/New England	Minimum: 73.70 Maximum: 77.50 Mean: 75.60 CV%: 1.12 Sample Size: 21	Minimum: 74.60 Maximum: 77.90 Mean: 76.51 CV%: 1.44 Sample Size: 14
Year: 1994 Month: October/November Area: Mid-Atlantic	Minimum: 75.80 Maximum: 78.10 Mean: 77.16 CV%: 0.93 Sample Size: 10	Minimum: 78.50 Maximum: 81.90 Mean: 79.79 CV%: 1.49 Sample Size: 10
Year: 1995 Month: April Area: Mid-Atlantic	Minimum: 74.50 Maximum: 76.10 Mean: 75.35 CV%: 0.66 Sample Size: 13	Minimum: 74.20 Maximum: 78.40 Mean: 76.44 CV%: 2.24 Sample Size: 10

[a]MIN indicates the minimum observed value; MAX indicates the maximum observed value; MEAN is the average value; CV indicates the coefficient of variation, CV = σ / MEAN where σ is the standard deviation.

TABLE 2.
Moisture and Protein Content (%) and Moisture Protein Ratios of Sea Scallop Meats. Data from the Seven Commercial Trips Conducted Between August 1992 to April 1995 were Combined.[b]

Analysis	Sample Size	Minimum	Maximum	Mean	Coefficient of Variation
Natural Moisture	136	73.70	78.90	76.70	1.51
Natural Protein	79	16.10	21.20	18.65	6.53
Natural Moisture/ Protein Ratio	79	3.48	4.73	4.12	7.08
Offloading Moisture	91	74.20	82.50	78.61	2.26
Offloading Protein	70	14.80	19.40	17.12	5.63
Offloading Moisture/ Protein Ratio	70	3.85	5.50	4.58	7.28

[b] MIN indicates the minimum observed value; MAX indicates the maximum observed value; MEAN is the average value; CV indicates the coefficient of variation, CV = σ / MEAN where σ is the standard deviation.

TABLE 3.
Moisture, Moisture:Protein Ratio (M/P) of Sea Scallop Meats.
Summary Statistics for Within Sample Groups.[c]

SAMPLE VARIABLE	MOISTURE %		M/P	
Shell Height (Size) 5 mm intervals, N=15 60-135 mm	MIN MAX MEAN CV	77.5 78.8 78.1 0.47		
Five Replicates from One Bag at Offloading N=5	MIN MAX MEAN CV	78.1 78.7 78.8 0.67		
Five Replicates from One Bag at Offloading N=5	MIN MAX MEAN CV	74.3 76.5 76.4 1.17	MIN MAX MEAN CV	4.27 4.77 4.65 6.15
Seven Replicates from One Haul-Back N=7	MIN MAX MEAN CV	75.3 76.1 75.7 0.39	MIN MAX MEAN CV	4.09 4.26 4.27 3.95
Six Replicates from One Resource Area; 11 Haul- backs at Same Location N=6	MIN MAX MEAN CV	74.5 75.1 74.9 0.45	MIN MAX MEAN CV	4.48 4.67 4.61 1.52
One Sample from 5 Bags (Same Bag-up) at Offloading N=5	MIN MAX MEAN CV	77.4 78.4 78.0 0.57	MIN MAX MEAN CV	4.09 4.61 4.27 3.95

[c] MIN indicates the minimum observed value; MAX indicates the maximum observed value; MEAN is the average value; CV indicates the coefficient of variation, CV = σ / MEAN where σ is the standard deviation; and N indicates the number of samples.

TABLE 4.
Limits and Probability of Compliance for Natural and Offloading Moisture Content of Sea Scallop Meats.

PROBABILITY (%)	LIMITS (%)	
	Natural Moisture	Offloading Moisture
75.00	77.48	79.81
90.00	78.19	80.90
95.00	78.61	81.56
99.00	79.39	82.82

MOISTURE LIMIT (%)	PROBABILITY (%)	
	Natural	At Offloading
79.0	97.55	58.69
80.0	99.75	78.21
81.0	100.0	90.91
82.0	100.0	97.02
83.0	100.0	99.23
84.0	100.0	99.84
85.0	100.0	99.97

TABLE 5.
Limits and Probability of Compliance for Natural and Offloading Moisture Protein Ratios of Sea Scallop Meats.

PROBABILITY (%)	LIMITS (%)	
	Natural M/P	Offloading M/P
75.00	4.32	4.81
80.00	4.49	5.01
95.00	4.60	5.14
99.00	4.80	5.38

MOISTURE/PROTEIN RATIOS Limits	PROBABILITY (%)	
	Natural	Offloading
4.95	99.72	86.36
4.96	99.75	87.00
4.97	99.77	87.61
4.98	99.79	88.20
4.99	99.81	88.77
5.00	99.83	89.32
5.01	99.85	89.85
5.05	99.90	91.78
5.15	99.97	95.37
5.25	99.99	98.56
5.35	100.00	98.79