REFRIGERATED SEA WATER
AND SURIMI PRODUCTION
FROM ALASKA POLLOCK

ALASKA FISHERIES DEVELOPMENT FOUNDATION

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ACKNOWLEDGMENTS

This report would not have been possible without the cooperative actions of a large number of individuals and organizations.

Before this project was initiated, AFDF gathered information on actual hold conditions for typical deliveries of iced fish, to establish a frame of reference for the investigation of the RSW alternative. This preliminary task was accomplished with the aid of observers Julian Bean and Ken Van Valkenburg, and the skippers of the fishing vessels "Defiant" and "Northern Challenger," Mike Haggren and Kent Helligso, all of Kodiak, Alaska.

To obtain the information necessary to investigate the effects of refrigerated sea water on surimi production, it was of course necessary to go through the entire process, from catching the fish to testing the surimi. Alyeska Ocean, Inc. (formerly Jeff Hendricks & Associates) of Anacortes, Washington, operated the fishing vessel "Arcturus" and delivered the fish to Kodiak. Specially detailed logs of hold temperatures and fish temperatures were kept during that first experimental voyage by Mike Atterberry.

Alaska Pacific Seafoods of Kodiak, Alaska took delivery of the fish from "Arcturus," and processed the pollock into surimi, under the direction of plant manager John Sevier and quality control manager Landon Asakawa. During processing, Scott Edson, a technical consultant to Alaska Fisheries Development Foundation (AFDF), took special samples in order to determine salt uptake and other factors that might be due to RSW holding. Mr. Edson also performed the laboratory tests of the surimi's quality.

Four lots of surimi resulted from the first RSW delivery to Alaska Pacific Seafoods. This report relies not only on the data describing those particular lots, but also on the extensive data collected by APS, AFDF, NMFS, and the Fishery Industrial Technology Center (FITC) in Kodiak, operated by the University of Alaska, under the direction of Dr. Jong Lee. With guidance and assistance from Dr. Jerry Babbitt of the National Marine Fisheries Service (NMFS), technicians from these organizations sampled and tested nearly every one of more than 200 lots (each lot = 8 hours' production) of surimi, compiling information on process variables and quality characteristics in a large computer database. The database framework itself was initially created by AFDF surimi production director Chris Riley.

Dr. Babbitt, Director of the NMFS laboratory in Kodiak, also supervised a statistical compilation of surimi quality data performed by Kermit Reppond and used by this report as a reference.

Particularly important to this report are investigations of surimi protein functionality carried out by John French of FITC. Without his studies of the biochemical properties seen in pollock muscle and surimi, this report could not draw meaningful conclusions.

The author of this report is Sharon Gwinn, President of First Alaska Surimi, Inc., a Seattle-based consulting firm. When the original test of RSW holding was conducted, Ms. Gwinn was Program Director of AFDF, and was responsible for organizing and managing the project.

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INTRODUCTION

The use of refrigerated seawater (RSW) for on-board preservation of pollock is a matter of controversy in the developing Alaska surimi industry. It is also a matter of economics, because RSW is considered a tool for extending the useful life of fresh (raw) pollock.

For most of the prospective shore plant locations in Alaska, weather conditions mandate the use of large vessels during at least part of the year. For these boats, a maximum allowable trip length is critical. Restricting trip length tends to reduce their efficiency and drive up the cost of fish to the processor. Since raw fish represents by far the largest single component of the processor's total production costs, even a small rise in fish cost takes a large bite out of the profit margin in surimi processing.

The original purpose of the RSW project was to determine if RSW could be used to maximize the length of fishing trips without compromising the quality of the shore plant's finished product. This basic project concept actually originated in 1980 at Marco, Inc., a Seattle shipbuilder with a vested interest in the success of its large vessels.

The problem did not go away, but it was only one part of a complex "problem network" that was holding back the development of shoreside processing capacity for Alaska pollock. The project as AFDF wanted to do it, under commercial conditions, could not be done without a complete system, from fishing boat to product quality testing, in place. Accordingly AFDF attached the RSW project to its Model White Fish Processing project, which had been designed to assist financially in the development of domestic processing capacity for underutilized (groundfish) species. Still the RSW project was thwarted because, as it turned out, Alaska pollock was not one of the species included in the latter project. Pollock processing then (1982-83) was still too risky for a shore plant, even if subsidized.

Finally in 1984, with its surimi processing project, AFDF was able to turn its attention to the Alaska pollock and the commercial economics of catching and processing this small, fragile species. In this new context the RSW project became even more important, and also more complex. We would have to concern ourselves not only with the effects of RSW on fish muscle, but also with the subsequent influence of the surimi process on the muscle proteins. The effects were bound to overlap and obscure each other. Nevertheless it remained crucial to determine the feasibility of making good surimi after preserving pollock in RSW for several days between catch and delivery.

When surimi processing began in Kodiak, there was virtually no information available concerning the characteristics of surimi made from pollock held in RSW. Rumors from the Japanese surimi industry suggested that RSW was not a good idea, but gave no supporting explanation. Some skeptics translated their counsel as saying "it is just not done that way in Japan," and believed that the demurral could well be based on industry tradition rather than on scientific or practical principles governing surimi quality. Perhaps the Japanese technicians even knew RSW would work, and wanted to discourage the U.S. operations from using it.

Jeff Collins and his research group at the NMFS laboratory in Kodiak had done carefully controlled experiments using small-scale simulations of holding pollock in RSW and other alternative systems. Their conclusions were discouraging; the RSW appeared to have negative effects on protein functionality. However, the study was designed to test acceptability of fillets, in which the parameters of "quality" would be taste (salt uptake) and toughness, particularly after a period of frozen storage.

The only measures of functionality used in the NMFS study were emulsifying capacity and viscosity. In contrast, the most important functional property of surimi, and the primary factor determining its acceptability to the customer, is its gel strength. In surimi processing, the fish muscle is washed in fresh water, which enhances its gel strength and would leach out at least some of whatever salt had been absorbed while the fish was in RSW. The washing process would also be expected to affect emulsifying capacity and viscosity of the protein. Thus the results of the study on fillets suggested there might be drawbacks to the use of RSW with pollock, but no definite parallels could be drawn to predict its effects on surimi.

The NMFS study, published by Reppond et.al. in 1985, did show the rate of salt uptake that occurred in the muscle of whole pollock held in RSW for up to eight days. Based on the principles of meat science and protein biochemistry, the increase in salt concentration would be expected to cause changes in the shape and behavior of muscle (myofibrillar) proteins, particularly related to their water holding capacity. However, there seemed no way to predict the magnitude or the reversibility of the anticipated effects.

THE EXPERIMENT

In November 1985, it was at last possible (and necessary) to conduct a study of RSW and its effects on pollock surimi under typical commercial conditions. Fall surimi production had been underway for a few weeks at Alaska Pacific Seafoods in Kodiak, under contract to AFDF.

During the previous spring, all deliveries had been made by smaller vessels (3000-4000 cu.ft. total hold capacity), using ice or slush ice to cool and preserve the catch. The smaller boats were well suited for the initial production period, when short trips were desired, to avoid complications that might arise in processing "older" fish.

However, if weather was very poor, fish would scatter, lengthening the time needed to fill the holds, and the smaller boats were unable to travel safely, thus delaying deliveries even further. Thus when weather was marginal or fishing productivity was unpredictable, it was difficult to determine the amount of ice needed for the trip, but costly and cumbersome to over-ice. Scientists at Oregon State University (Dr. Edward Kolbe et.al.) had recently developed a mathematical method for estimating ice requirements under various conditions. However, this would not help the situation in Kodiak at times when the smaller vessels could not fish at all.

Large vessels could not afford short trips, but might be able to bring in sufficiently "fresh" fish by using their RSW systems. With the Gulf of Alaska winter approaching, it was time to test this theory.

The purpose of the RSW project was to (1) determine whether surimi of acceptable quality can be made from pollock held on-board the fishing vessel in RSW, and (2) assess the influence of RSW preservation on the resulting surimi.

To create some reference points during the spring deliveries, AFDF had placed observers aboard two trips by non-RSW boats. At that time, sea surface temperatures were 36 to 40 degrees F., and internal temperatures of pollock when brought on board were about 40 degrees. Thus there was a significant gradient between the fish's initial temperature and that of its iced environment in the boat's hold. The only real difficulties occurred when holds were too densely packed with fish or when fish had to be stored without ice. Under those conditions the temperature of the fish at delivery could easily exceed 40 degrees F., and the pollock's rate of spoilage (bacterial and enzymatic) was maintained or accelerated, uninterrupted by chilling.

Although it is known that this spoilage exerts negative influences on quality and yield of surimi, it is outside the scope of this report to estimate the conditions (time and temperature) under which the problem becomes significant for surimi production. No comparisons have been drawn between the spring deliveries of iced fish and the fall deliveries of RSW fish, because factors such as seasonal variation in flesh composition and changes made to the surimi processing system would invalidate any such comparison.

To address the questions surrounding the use of RSW, AFDF contracted in November, 1985 with Alyeska Ocean, Inc. to conduct one experimental fishing trip, during which an obsever would keep detailed records on the temperature of fish and their ambient RSW in each of four holds, until delivery of the fish. The F/V "Arcturus", accustomed to delivering cod-ends at sea to foreign processors, thus made its first shoreside delivery of pollock.

The vessel log accompanying this report details the thermal histories of the four lots of fish while they were held on-board. Internal temperature of the fish when brought aboard was about 40 degrees F., and in general they were chilled within two hours to about 32 degrees or colder. For larger loads of fish, chilling time was extended further, and did not quite reach such low temperatures. At the time of processing the four tanks of fish had been held in RSW for varying lengths of time, with the "oldest" fish being about 135 hours after catch, and the "youngest" being processed about 40 hours after catch.

During processing of the fish at APS, samples of fillets were taken from each lot for later analysis of salt uptake. After processing, one block of surimi from each lot of fish was analyzed using the standard AFDF acceptance sampling procedure. The protocol includes tests for moisture content, gel strength, color, and contamination (scales, skin, bone). The experimental lots were tested a second time about 2.5 months later, to assess changes in the surimi that might have occurred during frozen storage.

Meanwhile, at the University of Alaska's Fishery Industrial Technology Center (FITC) in Kodiak, biochemist John French was looking at the actual molecular structure of surimi proteins. Part of his purpose was to examine the relationship, if any, between that structure and the water holding capacity of surimi. The issue of water holding capacity (WHC) had been brought to FITC's attention by Richard Rhoda, broker for AFDF's surimi. Through his work with kamaboko manufacturers who were buying the surimi, Rhoda had learned that it sometimes would not hold as much water as the users expected.

For the kamaboko makers, the decreased water holding capacity resulted in a proportional decline in the value of the surimi. The water holding behavior of proteins is known to be related to their spatial configuration. Thus French put his biochemists' tools to work on the problem, using gel electrophoresis and high pressure liquid chromatography to determine the structural state of the proteins in 47 samples of surimi. It was speculated at the time that the water holding properties of surimi might be influenced by such factors as pH (acidity/alkalinity) of processing water, or phosphate types and levels used during surimi processing.

Unexpectedly, French's investigations provided some intriguing pieces to the puzzle surrounding the use of RSW in surimi production. Initial results suggested that decreased water holding capacity was associated with (but not necessarily caused by) extended holding of round pollock in RSW. French undertook further tests to compare the effects of RSW with those of slush ice on the protein structure of minced pollock and surimi. His findings as they relate to the purpose of the RSW project are summarized later in this report.

RESULTS

On November 12, 1985, the fishing vessel "Arcturus" delivered approximately 245,000 pounds of pollock to the dock at Alaska Pacific Seafoods in Kodiak. The fish were distributed among four holds, in which the refrigerated sea water had been kept as cold as possible without freezing the fish. In the hold carrying the most recently caught fish, the temperature was slightly higher than in the other three holds, since fish had been densely packed in it and had not cooled as quickly. The internal temperatures of the fish had been cooled within a few hours after catch from an initial 40 - 43 degrees F., to about 32 degrees. The vessel log, which details these temperatures, is included with this report as an appendix.

Even before the results concerning surimi quality were available from the laboratory, "Arcturus" departed for a second trip, based on APS' observation that the RSW pollock produced surimi of apparently decent quality, with no special processing difficulties, even from fish that were more than five days "old" since catch. The laboratory data confirmed that the RSW had no obvious negative effects on surimi quality, and in fact seemed to extend dramatically the time that could be permitted between catch and processing. By the end of the processing season the following spring, APS had taken delivery of more than 7 million pounds of pollock in

RSW. In general they were able to achieve surimi quality equivalent to that of a mothership, while the overall average "age" (time between catch and processing) of RSW pollock was over 70 hours. Thus the first objective of the RSW project, to determine whether surimi of acceptable quality could be made from pollock held in RSW, was achieved with positive results.

Achieving the project's second objective, to assess effects of RSW on the quality of surimi, proved to be much more complex. At every step of the surimi process, from the delivery dock to the plate freezer, multiple factors act on the material at the same time. Temperature, salt content, pH, water content, and all the other factors interact and modulate each other, so no single influence can be named responsible for any individual characteristic of surimi. Without the ability to do a controlled experiment that would isolate the effects of RSW from other influences on surimi quality, it is not possible to validate any suspected cause & effect relationships.

To complicate matters further, the effects of RSW on pollock flesh change with duration (and temperature) of exposure. The information most needed by industry would concern optimal holding time and <u>relative</u> risks of extended holding time. To study these questions, one would need to know the exact amount of time spent in RSW by the fish that went into each lot of surimi. Such detailed record-keeping is unfortunately impractical in the course of commercial operations. APS did keep records of the estimated <u>average</u> time spent in RSW by the fish in each delivery, and it was hoped that through observation of a large number of deliveries, some patterns would emerge with respect to surimi quality and duration of exposure to RSW.

The laboratory data for the surimi made from the initial experimental delivery are shown below. They indicate that sometime between 60 and 135 hours after catch, there is a change in quality of RSW-held pollock that results in a considerable drop in surimi quality.

Lot 3161, made from pollock held 135 hours in RSW and then unloaded into iced totes and processed during the next eight hours, shows definite signs of deteriorating quality. The low deflection value of the puch test (8.6 mm) is a particularly pointed indication that the protein has undergone some denaturation or other degradative change. It is interesting that the water content of this lot is low enough to classify it with surimi of much better functional quality.

The water holding data, expressed in gm H2O per gram protein, are given for surimi mixed with fresh water, and for surimi mixed with a 3% salt (NaCl) solution. As the pollock spend more time in RSW, the ability of the resulting surimi to hold water appears to decline, while its ability to hold salt water increases.

For Lot 3171, held 60 hours in RSW and another 24 hours in ice before processing, indicators of surimi quality are mixed. Water holding capacity and strain value (deflection) are still high, but water content at 77.2% disqualifies this lot from the "high quality" category. The high water content is probably directly responsible for the anomalously low force (stress) value of the punch test. It is possible that the <u>only</u> shortcoming of Lot 3171 is that it was not dewatered sufficiently.

As is often the case in the first stages of a research and development project, the laboratory data served better to help formulate questions than to provide answers. Was the apparent extension of "freshness" due to the salt content of the RSW, or to the rapid and thorough chilling that had been performed on "Arcturus"? If the same chilling regime were effected with ice, would the same extension of "freshness" be achieved? After how many hours in RSW did the "turning point" in surimi quality occur? Was salt uptake in the flesh responsible for that "turning point"? Did salt uptake make the flesh more difficult to dewater, even after mincing and washing in fresh water? Was there any relationship between duration of holding in RSW and the alleged loss of water holding capacity in surimi? Even after all the technical questions had been conceived, the most difficult practical questions would remain -- Fishermen and processors would have to evaluate the actual benefits and costs symbolized by the scientific data.

Fortunately the quality of the surimi made from the first RSW fish was good enough that the processor decided to continue accepting pollock deliveries in RSW. Thus the collection of data could continue, although not with as much precision and detail. It was hoped that the sheer volume of data that could be compiled over a full season would compensate for the complexity of "surimi biophysics," so that the positive and negative efffects of RSW could be sorted out.

By the time surimi processing was interrupted for the spring 1986 spawning season, 24 deliveries in RSW had been made. Seven deliveries had been made in ice or slush ice. The RSW deliveries were larger, comprising 165 lots of surimi, with each lot representing the product of one eight-hour shift. Surimi lots from iced deliveries totaled 14.

As it turned out, large volumes of data were no match for the complex processes occurring in pollock flesh as it went from swimming to surimi. The following discussion summarizes the data, comparing iced lots and RSW lots in terms of quality, yield, and shelf life. Also discussed are selected measures of surimi quality as they relate (or don't relate) to duration of exposure to RSW. The good news is that even prolonged holding of pollock in RSW does not result by itself in poor quality surimi. The bad news is that we don't know what factors are responsible for the substandard quality seen in some RSW surimi lots.

Table 2 outlines the average characteristics and differences between surimi lots made from RSW fish and those from iced deliveries. Overall, with the average elapsed time between catch and processing almost a day longer for the RSW lots, the RSW surimi edged out the ice lots in quality. There are not many large differences between the two, and the differences that are indicated are difficult to explain.

Some differences, like the greater contamination (skin and bone particles) in RSW surimi, are certainly not the direct result of the use of RSW. Other parameters show patterns that would not have been predicted: For example, based on the previous four-lot data set, one might have expected RSW surimi to show higher water content, on average, than surimi made from iced fish. Still, the 1% difference, with RSW surimi falling closer to the target for high quality, is not great.

In gel characteristics, RSW surimi appears to outperform ice lots, primarily by means of producing higher deflection (strain) values. These values indicate the elasticity of the gel formed by chopping the surimi with (2%) salt, stuffing the paste into a sausage casing and heating the sausage in a water bath. The deflection value is the distance travelled by a ball-tipped punch into the cooked gel before the gel "fails" or ruptures. The force (strain) value is the force on that punch at the moment of failure. Force and deflection values are multiplied together to produce a "gel strength" measure. The reader will note that there are two rows of values in the table for each of these three parameters and

Table 2. Comparison of average quality characteristics for surimi made from RSW and ice deliveries.

	RSW AVG	ICE AVG	DIFF	% DIFF
COLOR-L.raw	52.8	53.9	-1.1	-2.1%
COLOR-L.cook	78.3	79.0	-0.8	-1.0%
contamination	4.1	2.5	1.6	39.5%
H_2O %	76.1	76.9	-0.8	-1.0%
GEL CHARACTERISTICS - PUNCH TEST				
force (40-90)	498.0	510.3	-12.3	-2.5%
force (90 cook)	445.0	477.6	-32.6	-7.3%
setting eff.	11.9%	6.8%		174.0%
std.dev. frc40	107.0	141.6		
std.dev. frc90	95.0	126.2		
std.dev./frc40	21.5%	27.7%		77.4%
std.dev./frc90	21.3%	26.4%		80.8%
deflection 40	13.4	12.2	1.2	9.0%
deflection 90	12.9	12.1	0.8	6.2%
setting eff.	3.9%	0.8%		469.0%
std.dev. def.40	1.4	1.1		
std.dev. def.90	1.2	1.3		
std.dev./def.40	10.4%	9.0%		115.9%
std.dev./def.90	9.3%	10.7%		86.6%
stiffness 40	37.8	42.3	-4.5	-11.9%
stiffness 90	35.1	36.7	-1.6	-4.6%
GEL 40-90 cook	665.0	621.8	43.2	6.5%
GEL 90-90 cook	570.0	572.7	-2.7	-0.5%

NOTES:

#LOTS RSW = 165
ICE = 14

AVERAGE "AGE" OF FISH
AVGAGE RSW = 72.6
ICE = 51.2
HRS, CATCH TO PROCESS

DLV TEMP RSW = 36.7 F.
ICE = 38.9 F.
frc = force (punch)
def. = deflection

their derivatives. That is because the surimi gels were tested after two different cooking regimes, one which kept them at 90 C. for 30 minutes, and one which kept them at 40 C. for 15 minutes followed by 15 minutes at 90 C. In this table and elsewhere in this report, the numbers "90" and "40" signify the two cooking regimes, respectively.

The difference between the results using the 40 degree "pre-cook" and the straight 90 degree cook are labelled, in this table, "setting efficiency." As the numbers in Table 2 suggest, the 40 degree pre-cook has the effect of enhancing gel strength. One of the few outstanding differences between the two classes of surimi compared here is that RSW lots exhibit the enhancement to a greater degree than the surimi made from iced fish. Note that the difference is greater for strain than for stress values.

Examining the compared stress (force) values, it can be seen that in this category the RSW surimi does not perform quite as well as the ice lots. Since its water content tends to be lower, the lower force values cannot be attributed to higher water contant. It is possible that the slightly lowered stress values are a tradeoff for greater consistency (less variance). Variance in stress values for RSW surimi is only 80% of that shown by ice lots, but this <u>may</u> be accounted for simply by sample size (165 lots v. 14).

Stiffness values (gm/cm^2) are slightly greater for ice surimi than for RSW lots, due to the lower stress (force) scores of the latter.

Based on this comparison between the quality characteristics of RSW lots and ice lots, it can be generalized that RSW-held pollock can produce surimi equivalent to that from iced fish that are a day "fresher." In fact, some RSW lots in which the fish spent four days in RSW and another day on ice before processing produced surimi with gel strengths over 530 gm*cm. But how can we explain the fact that several RSW deliveries that arrived at the dock within 48 hours after catch produced less inspiring results, gel strengths between 350 and 500? This question will come up again during the discussion of duration of exposure to RSW and surimi quality, but it must already be clear that there are no easy answers to be found in the data.

The use of RSW appears to have no negative effect on surimi yields as compared to ice-holding of pollock. As Table 3 indicates, the RSW surimi <u>appears</u> to show a slightly lower yield (by .6%) than the average for ice lots, based on yield overall. However, when water content is taken into account, and yield of actual protein is calculated, the RSW surimi comes out ahead.

Table 3. Comparison of yields between RSW and ice deliveries. YIELD.OA = Yield overall, including #2 (twice-refined). PRO*Y = Yield of protein. STD = standard deviation.

	DLV#	TYPE	YIELD.OA	H2OAVG	PRO%	PRO*Y
	1	ice	10.41	76.88	14.12	1.47
	2	ice	13.66	76.46	14.55	1.99
	3	ice	21.46	75.83	15.17	3.26
	4	ice	17.25	76.23	14.77	2.55
	601	ice	24.49	77.70	13.31	3.26
	605	ice	17.79	78.57	14.43	2.57
	608	ice	21.11	79.09	13.91	2.94
(excludes first two deliveries)		AVG	20.42	77.48	14.32	2.91
		STD	2.65	1.27	0.65	0.31
(includes all deliveries)		AVG	18.02	77.25	14.32	2.57
		STD	4.49	1.14	0.56	0.61
	5	rsw	13.92	76.60	14.40	2.00
	6	rsw	14.12	76.58	14.43	2.04
	7	rsw	16.56	76.50	14.50	2.40
	8	rsw	19.75	75.23	15.77	3.12
	9	rsw	18.95	74.70	16.30	3.09
	10	rsw	18.15	74.88	16.12	2.93
	11	rsw	15.70	74.40	16.61	2.61
	602	rsw	21.34	77.92	13.08	2.79
	603	rsw	17.76	77.18	14.62	2.60
	604	rsw	17.82	77.14	15.86	2.83
	606	rsw	17.17	77.77	15.23	2.61
	607	rsw	21.22	79.09	13.91	2.95
	609	rsw	19.97	77.46	15.54	3.10
	610	rsw	23.35	75.80	15.20	3.55
	611	rsw	21.62	76.46	14.54	3.14
	612	rsw	18.61	75.44	15.56	2.90
	613	rsw	19.79	74.97	16.03	3.17
	614	rsw	19.52	76.51	14.49	2.83
	615	rsw	17.13	75.57	15.43	2.64
	616	rsw	15.05	75.32	15.68	2.36
	617	rsw	18.53	75.55	15.45	2.86
	618	rsw	15.79	75.29	15.71	2.48
	619	rsw	13.80	75.85		
	620	rsw	15.48	75.64		
(includes all deliveries)		AVG	17.96	76.16	15.20	2.77
		STD	2.54	1.14	0.84	0.37
(excludes first 2 &last 3 deliveries)		AVG	18.84	76.20	15.26	2.87
		STD	2.07	1.25	0.86	0.29

As soon as it was established that RSW-held pollock would produce good surimi, the next question that naturally arose was whether the quality would be maintained in frozen storage. Based on re-tests of RSW and ice lots done approximately 2.5 months after production (Table 4), there is no evidence that the quality of the RSW surimi attenuates more rapidly. In fact, gel characteristics, especially elasticity, seem to hold up better in the RSW lots than in the ice lots. It should be noted, however, that these observations are based on a small amount of data and a short storage period.

From the data so far gathered, then, it would seem that RSW is at least as suitable as ice for preserving pollock catches intended for surimi manufacture on shore. However, the large fishing vessels and their sophisticated refrigeration systems can not have a place in the surimi industry unless they can pay for themselves. It is the value of the fish that must justify the costs of the delivery system. Looking back to the results of the first experimental RSW delivery, it can be seen that in the interests of maximizing the value of surimi, it is important to fix the point of diminishing returns. In this task the data are disappointing -- No clear patterns can be found relating duration of exposure to RSW and resulting surimi quality or yield. Table 5 illustrates this unfortunate truth.

On the basis of the earlier findings regarding water holding capacity of RSW surimi, an attempt was made to relate WHC and duration of holding in RSW. Again the data are confounding, showing no consistent pattern (see Tables 6 and 7). However, the investigations into RSW effects on protein structure by John French at FITC provide clues that may help explain what looks like pure randomness.

French's examinations of the protein structure of various samples of surimi show that low WHC is associated with protein hydrolysis and with loss of tropomyosin, a minor component of myofibrillar protein. In minced pollock made from fish held experimentally in RSW, these phenomena are correlated with that of salt uptake in the fish's flesh. French determined that 88% of the salt absorbed during a four-day holding period was washed out in the surimi process. Based on these observations, it is possible to speculate on why there is no apparent relationship between holding time in RSW and quality of resulting surimi. Perhaps the salt uptake that occurs in RSW does cause changes, but most of them are partially reversible if the washing and rinsing phases of surimi processing are adjusted properly. It appears that gel strength is more easily maintained than water holding capacity in the processing system that is in use now. The

Table 4. Shelf life of surimi made from RSW and ice deliveries.

	% CHANGE RSW AVG	% CHANGE ICE AVG
COLOR-L.cook	0.86	1.78
pH	3.30	3.86
H2O %	1.12	0.30
GEL CHARACTERISTICS - PUNCH TEST		
force (40-90)	-0.09	-8.51
force (90 cook)	-3.44	-10.81
deflection 40	21.47	9.84
deflection 90	17.36	6.86
stiffness 40	-17.35	-16.80
stiffness 90	-16.67	-16.58
GEL 40-90 cook	21.14	0.81
GEL 90-90 cook	13.00	-4.23

NOTES: #LOTS RSW = 4
ICE = 7

Table 5. "Freshness" of fish and quality of surimi.

DLVAGE = Hours (avg) between catch and delivery.
AVGAGE = Hours (avg) between catch and processing.
All punch test values are for gels cooked at 90 degrees.

ICE DELIVERIES

DLV#	DLVAGE	AVGAGE	H2O	FORCE	DEFLEC	GEL
2	21.5	34.0	76.5	490	12.2	595
601	34.8	35.9	77.7	323	13.1	424
4	35.8	38.8	76.2	571	12.6	717
605	39.5	39.5	78.6	325	11.7	381
3	39.5	44.8	75.8	537	11.4	616
1	51.3	58.1	76.9	465	12.0	550
608	57.5	57.5	79.1	255	12.9	328
AVG	40.0	44.1	77.2	424	12.3	516

RSW DELIVERIES

DLV#	DLVAGE	AVGAGE	H2O	FORCE	DEFLEC	GEL
607	23.5	53.7	79.1	329	12.6	419
606	24.5	48.1	77.8	418	12.9	539
7	26.8	46.4	76.3	482	13.3	642
612	27.0	65.4	75.7	451	13.2	594
615	32.0	59.8	75.6	469	13.5	635
9	34.5	58.6	74.7	500	10.8	542
614	34.5	73.8	76.4	415	13.1	542
613	35.0	69.2	75.1	556	13.2	729
610	35.5	63.4	75.8	348	13.6	475
616	36.3	59.4	75.3	503	14.2	713
611	38.5	82.8	76.4	378	13.0	490
11	39.3	41.6	74.4	485	10.6	514
617	39.3	72.1	75.5	453	13.8	623
604	40.5	44.5	77.1	455	13.2	601
620	41.0	76.1	75.7	458	12.8	584
10	54.0	72.8	74.9	589	11.8	691
603	56.0	59.3	76.1	490	13.3	650
619	58.0	78.0	75.9	403	12.7	509
618	58.4	89.5	75.3	475	13.1	619
609	58.5	86.4	77.5	387	12.8	497
6	58.8	81.8	76.6	480	12.9	616
602	62.4	74.4	77.9	283	14.0	396
5	84.0	107.4	76.6	441	12.1	531
8	96.0	120.0	75.2	490	11.4	550
	45.6	70.2	76.1	447	12.8	571

Table 6. Water holding capacity of RSW surimi lots.

LOT#	DLV#	SEQ# IN DLV	#LOTS IN DLV	AVGAGE	WATER HOLDING in H2O	WATER HOLDING in NaCl
3161	5	1	7	84.0	21.8	28.2
3162	5	2	7	92.0	57.0	20.1
3163	5	3	7	99.5	58.4	19.4
3171	5	4	7	107.5	50.4	21.0
3172	5	5	7	115.5	55.5	21.5
3173	5	6	7	128.5	51.1	21.5
3181	5	7	7	130.0	57.8	29.7
			DLV.AVG	108.1	50.3	23.1
3211	6	1	8	58.8	63.0	21.5
3212	6	2	8	66.5	62.8	15.7
3213	6	3	8	65.0	55.7	23.7
3221	6	4	8	73.0	52.5	15.8
3222	6	5	8	81.0	56.0	13.3
3223	6	6	8	89.0	48.8	12.1
3231	6	7	8	106.0	53.4	15.3
3232	6	8	8	114.5	47.8	20.0
			DLV.AVG	81.7	55.0	17.2
3292	7	1	6	26.8	63.0	22.7
3293	7	2	6	34.3	51.5	11.5
3301	7	3	6	42.3	51.6	24.3
3302	7	4	6	50.8	46.5	19.4
3303	7	5	6	58.3	44.5	25.4
3311	7	6	6	66.3	44.8	29.0
			DLV.AVG	46.5	50.3	22.1
3312	8	1	7	96.0	36.0	21.6
3313	8	2	7	104.0	38.7	22.6
3321	8	3	7	112.0	48.0	15.9
3322	8	4	7	120.0	35.3	21.2
3323	8	5	7	128.0	41.5	24.0
3331	8	6	7	136.0	37.4	17.0
3332	8	7	7	144.0	37.5	21.1
			DLV.AVG	120.0	39.2	20.5
3333	9	1	7	34.5	31.4	23.3
3341	9	2	7	42.5	36.6	20.6
3343	9	4	7	58.5	36.3	24.5
3351	9	5	7	66.5	36.3	19.5
3352	9	6	7	74.5	39.5	25.9
			DLV.AVG	55.3	36.0	22.8
3413	10	5	6	85.0	49.8	18.4
3421	10	6	6	91.0	42.1	20.4
			DLV.AVG	88.0	46.0	19.4
3461	11	1	2	39.3	41.2	21.9
3462	11	2	2	44.0	38.5	10.7
			DLV.AVG	41.7	39.9	16.3

Table 7. Water holding capacity of RSW surimi lots, summarized using averages.

H2O PELLET = gm H2O/gm protein in water.
NaCl PELLET = gm H2O/gm protein in 3% salt solution.

DLV#	#LOTS IN DLV	AVGAGE	DLVAGE	WATER HOLDING H2O PELLET	NaCl PELLET
7	6	46.5	26.8	50.3	22.1
9	7	55.3	34.5	36.0	22.8
11	2	41.7	39.3	39.9	16.3
10	6	88.0	54.0	46.0	19.4
6	8	81.7	58.8	55.0	17.2
5	7	108.1	84.0	50.3	23.1
8	7	120.0	96.0	39.2	20.5

disorder in the data may follow from the combination of varying levels of salt uptake and varying intensities of washing.

Based on the experience gained during the 1985-86 season at Alaska Pacific Seafoods in Kodiak, it is clear that refrigerated sea water can be an acceptable on-board preservation system for pollock being delivered to a shore-based surimi plant. The length of time that pollock can be held in RSW without compromising the processor's ability to achieve adequate yield and quality is still undetermined. With further understanding of how salt affects the functional character of muscle proteins, it should be possible to modify the surimi process (particularly the washing step) to obtain maximum yield and quality from a given delivery of fish.

If the work described here has not answered many of the industry's questions about the effects of refrigerated sea water on pollock surimi, it has at least helped formulate the next generation of questions. With the help of Alaska Pacific Seafoods and the University's Fishery Industrial Technology Center in Kodiak, AFDF intends to continue investigations aimed at answering those questions. As more data are gathered during commercial operations and laboratory studies isolate some of the variables thought to be modulating the effects of RSW, it should become possible to draw conclusions about how to use RSW to greatest advantage.