The effect of cooking and freezing on the carapace length of the American lobster (*Homarus americanus*)

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ABSTRACT

Mallet, M., B. Frenette and F. Savoie. 2003. The effect of cooking and freezing on the carapace length of the American lobster (*Homarus americanus*). Can. Ind. Rep. Fish. Aquat. Sci. 269: iv+13p.

In the southern Gulf of St. Lawrence, there were concerns that freezing seized American lobster (*Homarus americanus*) to preserve evidence for the court could potentially reduce the carapace length, and compromise the enforcement of a fishery regulation limiting minimal legal size. Tests were performed on 30 soft- and 30 hard-shell American lobsters to study the potential for shrinkage when lobsters were cooked and/or frozen. It was found that carapace length reduction was related to the carapace condition. Except for freezing of soft-shell lobsters, all treatments produced a statistically detectable reduction in carapace length. However, the average carapace length reduction ranged from only 0.1-0.5 mm, the highest increase being for hard-shell lobsters after cooking, freezing then thawing (t-test, P-value=1.8×10^{-10}). Out of the 60 animals studied, none had a carapace length reduction over 0.7 mm, while four had a carapace length increase. Although a carapace length reduction could be detected statistically, this should not cause problems in enforcing a minimum legal size.

Keywords: American lobster, *Homarus americanus*, carapace length, cephalothorax, lobster shell.

RÉSUMÉ

Mallet, M., B. Frenette, and F. Savoie. 2003. The effect of cooking and freezing on the carapace length of the American lobster (*Homarus americanus*). Can. Ind. Rep. Fish. Aquat. Sci. 269: iv+13p.

Dans le sud du golfe du Saint-Laurent, des inquiétudes ont été exprimées au sujet des effets possibles de la congélation du homard américain (*Homarus americanus*) sur la longueur de la carapace. En effet, il est pratique courante de congeler les homards saisis en attendant la tenue du procès et la possibilité qu'une telle pratique entraîne une diminution de la longueur de carapace pourrait nuire à l'application des mesures de gestion concernant la taille minimale légale. Une étude a donc été menée sur 30 homards de carapace dure et 30 de carapace molle afin d'étudier les effets de la congélation et/ou la cuisson sur la longueur de carapace des homards. Il s'avère que la modification de la taille de carapace est reliée à la condition de la carapace du homard. À l'exception de la congélation de homards de carapace molle, tous les traitements ont entraîné une légère diminution de la longueur de carapace. Cependant la diminution moyenne de la longueur de carapace n'était qu'entre 0.1 et 0.5 mm, la plus grande diminution s'ayant produit lorsque les homards ont été cuits puis congelés (t-test, seuil observé=1.8×10^{-10}). Parmi les 60 animaux étudiés, la plus forte diminution observée de la longeur de carapace est de 0.7 mm alors que quatre homards ont subit une augmentation de leur longueur de carapace. Malgré la diminution statistiquement significative de la longueur de carapace du homard, une diminution de l'ordre observé ne devrait pas être un problème pour l'application d'une taille minimale légale.

Mots clés : Homard, *Homarus americanus*, longueur de carapace, céphalothorax, carapace du homard.

INTRODUCTION

The American lobster (*Homarus americanus*) fishery is the most valuable coastal fishery in the southern Gulf of St. Lawrence (sGSL). Although the sGSL lobster fishery is managed through five fishing areas (LFAs) (Fig. 1) and two fishing seasons (spring and summer-fall), minimum carapace length is a common management tool used in all LFAs. Carapace length (CL) is defined as the length from the posterior part of the eye socket to the back of the carapace, parallel to the medio-dorsal line. If post-catch handling of lobsters modifies their CL, there is potential for problems with the enforcement of a minimum CL regulation. In Australia, there was a concern that rock lobsters (*Jasus edwardsii*) could potentially shrink during cooking but Ibbot et al. (2001) concluded that there was no statistically detectable effect on the CL. Recently, questions were raised concerning the possible effect of freezing on the CL of lobster, since it is a common procedure to freeze seized lobsters in order to preserve evidence for the court.

This study examines the effect of freezing on the CL of American lobster as well as the effects of cooking and cooking followed by freezing. Experiments were conducted on both soft-shell and hard-shell lobsters to cover the lobster's physiological stages during the two fishing seasons in the sGSL.

MATERIALS AND METHODS

Two treatments were considered in the study: (1) freezing of live animals, and (2) cooking of live animals followed by freezing, with each treatment being applied to soft and hard shell lobsters. The experiment was carried out in two time periods to account for the seasonality in shell condition, soft-shell lobsters being related to newly molted animals (July-September) while hard-shell lobsters are considered late post-molted lobsters (October-June). The experiment on soft-shell lobsters took place from August 23 to 26, 2002, and the one on hard-shell lobsters, from October 4 to 7, 2002. All lobsters used for this study came from holding tanks of the same processing plant, which is supplied by 12 different fishermen fishing in LFA 25. Lobsters had been in holding tanks for no more than 3 days. The water in the tanks had been held at the same salinity as the nearby seawater and at a constant temperature of 5 ^{o}C to 6.1^{o}C (original temperature 42^{o}F to 43^{o}F). A total of 30 lobsters were used for each shell condition and only lobsters within 3 mm of the legal size were selected. The minimum legal CL in LFA 25 is 67.5 mm. All lobsters were alive and vigorous at the start of the experiment.

At the beginning of each experiment, the 15 males and 15 females lobsters were randomly divided into two groups of 15, and identified on their claws by a unique combination of rubber bands used to keep claws closed. The rubber bands were also numbered with a permanent ink marker. Shell firmness criterion (i.e. thumb/finger pressure test) suggested by Ennis (1977) was used to determine the shell condition for the soft-shell experiment at the lobster processing plant. At the lab, the carapace hardness of hard-shell lobsters was determined by two durometer readings (Model 307HF, PTC Instruments™) on the cephalothorax, one at the anterodorsal region (point A, Fig. 2 (a)) and the other at the posterior portion of the dorsolateral region (point B, Fig. 2 (b)). The durometer is a spring-driven gauge that measures the elasticity or hardness of a material on a scale of 0 to 100. The durometer was not used for soft-shell lobsters in order to avoid breaking the carapace. A lobster was classified as hard-shell when the readings at points A and B were above 70, and soft-shell when at least one of the two readings were below 70 (Comeau and Savoie 2001). Furthermore, a pleopod reading was performed on all lobsters from the October sample to confirm that they were in the postmolt period (Aiken and Waddy 1980).

The carapace length of lobsters was randomly measured twice at each step in the experiment using an electronic calliper (Model CD-8", Mitutoyo Corporation™) (Fig. 2 (c)). For both the soft- and hard-shell experiments, all lobsters were first measured alive. One group of 15 lobsters was then frozen at -20 ± 1^{o}C. The other group of 15 lobsters was cooked in boiling salted water for 17 min and then cooled down for 1 hr. at room temperature (20 ± 1^{o}C). The lobsters were measured again after cooking then frozen as the uncooked ones. After 48 hr., lobsters were measured frozen then left to thaw at room temperature (20 ± 1^{o}C) for 4 hr. and measured for the last time. In order to avoid manipulation variation, the same individual performed all lobster measurements and another individual recorded the measurements.

Statistical tests were carried out on the average of the two random measurements to compare CLs before and following the two treatments. Differences in average CL before and after processing were tested using a one sided paired t-test, the alternative hypothesis being that lobster's CL decreases after freezing and or cooking. A difference was considered statistically detectable if significant at the 5% level.

RESULTS

Although the same person performed all of the measurements, there were variations between any two CL measurements of the same lobster at a given step of the experiment (Fig. 3; Appendix 1). The standard error of the mean of the 2 measurements was 0.1 mm.

The thumb/finger-pressure test on the lobster carapace of the August sample confirmed that all were in soft-shell condition. However, 6 of the 30 lobsters in the October sample were just at the end of their postmolt, with readings on the posterior portion of the dorsolateral region slightly under 70. They were identified as new hard-shell lobsters (Appendix 2). Pleopod samples also confirmed that none of the October lobsters were getting ready to molt before the end of the fishing season.

Average CL variation depended on the shell condition and treatment received. Except for soft-shell freezing then thawing, all treatments produced a statistically detectable reduction in CL (Table 1). The average CL of frozen only soft-shell lobsters stayed the same (paired t-test, P-value = 0.14) while the CL for hard-shell lobsters decreased by 0.1 mm (paired t-test, P-value = 0.003) (Table 1). Cooking produced a significant average CL reduction of 0.2 mm (paired t-test, P-value = 7.6×10^{-7}) and 0.4 mm (paired t-test, P-value = 0.8×10^{-10}) for soft-shell and hard-shell lobsters respectively (Table 1). When cooked lobsters were further frozen then thawed, the CL reduced another 0.1 mm for both shell conditions (P-value = 1.2×10^{-7} for soft-shell and 1.8×10^{-11} for hard shell).

The proportion of lobsters that had a CL change varied depending on the treatment received. When frozen, soft-shell and hard shell lobsters combined, 13.3% of the 30 lobsters studied increased in CL, 50% stayed the same and 36.7% decreased after treatment (Tables 2). There was no CL increase when lobsters were cooked, or when cooked then frozen. All cooked soft-shell lobsters had a CL decrease ranging from 0.0 to 0.5 mm while hard-shell lobsters had a CL decrease varying between 0.3 mm and 0.5 mm (Table 3). When cooked lobsters were further frozen then thawed, the CL decrease varied from 0.0 to 0.6 mm and 0.3 to 0.7 mm for soft and hard-shell lobsters respectively (Table 4).

DISCUSSION AND CONCLUSIONS

When comparing the size of lobsters before and after treatment, one has to take into consideration measurement errors. Measurement errors are either random or systematic. In this study, to reduce the size of error, the same individual performed the lobster manipulations and an electronic calliper was used to reduce reading errors. Lobsters were measured twice at each step of the study. Often, both measurements differed slightly even though they were on the same lobster and no treatments had been applied (Fig. 3; Appendix 1). If the second measurement was always larger (or always smaller) than the first measurement, we could suspect a systematic error caused by changes in the manipulations or the calliper which resulted in constantly larger (or smaller) values. In such a case, differences in CL before and after treatment could be attributed to systematic errors in manipulations rather than the treatment itself. There are often no solutions to data with systematic errors and the results are biased. Random errors are present when both lobsters' measurements at each stage are not always going in the same direction, which is the case in this study. For instance, in the soft-shell freezing then thawing study (Fig. 3 (a)), four out of 15 live lobsters were larger at the second measurement, five were smaller and six were the same. The largest observed standard error of the mean was 0.1 mm and this value represents the random error. Random error is always present in a study and represents the smallest value that can be reasonably detected considering the measuring tools used. Thus, in this case, a difference of less than 0.1 mm between any before and after treatment can be attributed simply to random error. This 0.1 mm level of precision is believed to be very good. In comparison, for the sea-sampling studies carried out by researchers, the measurement precision is 1 mm (Robichaud et al., 1996).

Freezing of live soft-shell lobsters had no statistically detectable impact on their CL. All CL differences before and after freezing were equal to or below the 0.1 mm random error level. For hard-shell lobsters, freezing of living animals produced a statistically detectable reduction of 0.1 mm in the CL, but this reduction is within the random error and could be considered insignificant. However, cooking had both a statistical and physical effect on the CL and all values observed were above the 0.1 mm random error level. The average CL reductions were 0.2 mm for the cooked soft-shell and 0.3 mm for cooked frozen then thawed soft-shell, 0.4 mm for the cooked hard-shell and 0.5 mm for the cooked frozen then thawed hard-shell lobsters (Table 1). If this type of experiment was repeated, say 100 times, by taking 15 lobsters and measuring them alive, cooked and/or frozen then thawed, then 95 of those 100 times, we would obtain *average* shrinkage values within the confidence intervals listed in Table 1. A lobster carapace could go through a larger size reduction, but the average of all 15 lobsters should fall within the confidence interval 95% of the time.

With the freezing-only treatment, four lobsters had an increase in CL of 0.1 mm. The observed increases in CL were mostly for soft-shell lobsters and could be explained by the water content of those lobsters. After molting, the integument (carapace) of the lobster is not fully developed with all the membranous layers, and it is still soft and flexible in order to allow body distension through water absorption (Cockcroft and Goosen, 1995, Waddy et al 1995). Lowndes and Panikkar (1941) found that lobsters absorb about 47% of of their fresh weight in water 34 ± 6 hours after molting. Since water expands when frozen (total expansion of 9%, Waldron 1998), water filled lobsters would have a tendency to increase in length with the expanding freezing water rather than to decrease. In this study, water lost after freezing was noticed for all lobsters, but more importantly for the uncooked ones.

The maximum observed CL reduction was 0.7 mm and only one of the 15 frozen soft-shell lobsters had a decrease in CL higher than the random error of measurement of 0.1 mm. Tables 2, 3 and 4 give the probability (p) of occurrence for various CL decreases based on the observations. For example, the probability that freezing-only will produce a CL reduction of 0.3 mm or more is nil for the soft-shell lobsters and p=20% for hard-shell lobsters (Table 2). Since each lobster is considered an independent Bernoulli trial, the probability that the CL of N lobsters will decrease is p^N. Hence, for six hard-shell lobsters, we would have a probability of 0.2^6=0.000064 or 0.0064% that all of them have a CL reduction of 0.3 mm or more when frozen then thawed.

As a reference measure, the length of the cilia at the end of a lobster carapace is approximately 1.5 mm for near legal size lobsters (67.5-69 mm). Whether the lobster was frozen then thawed, cooked, or cooked, frozen then thawed, if the legal measuring tool does not touch or barely touches the cephalothorax cilia, the lobster was certainly below legal size when alive. The cilia length represents over twice the maximum CL decrease observed during the study. For comparison purposes, a list of other common articles were also measured and are presented in Appendix 3.

In this study, we focused our research on near legal size lobsters to investigate the possibility that a legal size lobster could be transformed into an undersize lobster by common post-catch manipulations. We found that the effect of cooking and/or freezing on the lobster CL depended on the lobster's carapace condition. However, as with Ibot et al. (2001), we found that the average CL reduction varied between 0 and 0.5 mm, and that none of the lobsters in our study experienced a reduction in CL larger then 0.7 mm. Ibot et al. (2001) also found that CL change was not proportional to the initial length. From these results, we conclude that cooking and/or freezing has a small impact on the lobster CL and should not be considered significant for enforcement purposes.

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Table 1. Average CL differences between live and cooked and/or frozen lobsters for soft- and hard-shell, statistical significance for a one-sided t-test of the average difference being zero and 95% confidence intervals. Negative CL values indicates length increases.

Treatment	Shell condition	Average carapace length difference (mm)	Statistical significance	95% Confidence interval for difference
Freezing only	Soft (August)	0.0	0.14	(-0.1 ; 0.0)
	Hard (October)	0.1	0.003	(0.0 ; 0.1)
Cooking only	Soft (August)	0.2	7.6×10^{-7}	(0.2 ; 0.3)
	Hard (October)	0.4	0.8×10^{-10}	(0.3 ; 0.4)
Cooking and freezing	Soft (August)	0.3	1.2×10^{-7}	(0.2 ;0.4)
	Hard (October)	0.5	1.8×10^{-11}	(0.4 ; 0.5)

Table 2. Observed frequencies (percentages) of the average difference in CL between live and frozen lobsters. Negative values indicate CL increases**.**

Difference observed in CL (mm)	Soft-shell (n/15)	Hard-shell (n/15)	Total (n/30)
-0.1	3 (20.0%)	1 (6.7%)	4 (13.3%)
0.0	10 (66.7%)	5 (30.0%)	15 (50%)
0.1	1 (6.7%)	2 (13.3%)	3 (10%)
0.2	1 (6.7%)	4 (26.7%)	5 (16.7%)
0.3	0	3 (20.0%)	3 (10%)
0.4 or more	0	0	0

Table 3. Observed frequencies (percentages) of the average difference in CL between live and cooked only lobsters. Negative values indicate CL increases**.**

Difference observed in CL (mm)	Soft-shell (n/15)	Hard-shell (n/15)	Total (n/30)
-0.1	0	0	0
0.0	1 (6.7%)	0	1 (3.3%)
0.1	0	0	0
0.2	2 (13.3%)	0	2 (6.7%)
0.3	7 (46.7%)	5 (30.0%)	12 (40%)
0.4	2 (13.3%)	3 (20.0%)	5 (16.7%)
0.5	3 (20.0%)	7 (46.7%)	10 (33.3%)

Table 4. Observed frequencies (percentages) of the average difference in CL between live and cooked then frozen lobsters. Negative values indicate CL increases**.**

Difference observed in CL (mm)	Soft-shell (n/15)	Hard-shell (n/15)	Total (n/30)
-0.1	0	0	0
0.0	1 (6.7%)	0	1 (3.3%)
0.1	0	0	0
0.2	0	0	0
0.3	10 (66.7%)	3 (20.0%)	13 (43.3%)
0.4	2 (13.3%)	2 (13.3%)	4 (13.3%)
0.5	1 (6.7%)	7 (46.7%)	8 (26.7%)
0.6	1 (6.7%)	2 (13.3%)	3 (10%)
0.7	0	1 (6.7%)	1 (3.3%)

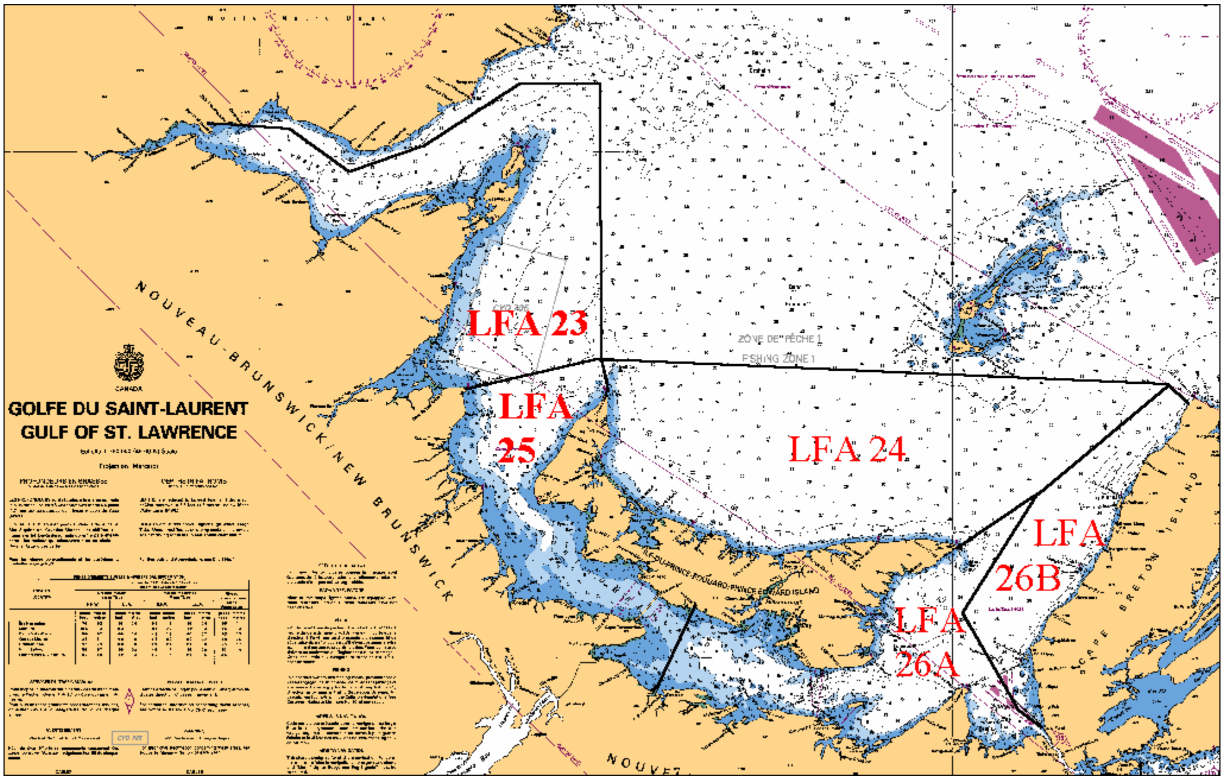

Figure 1. Lobster Fishing Areas (LFA) in the southern Gulf of St. Lawrence.

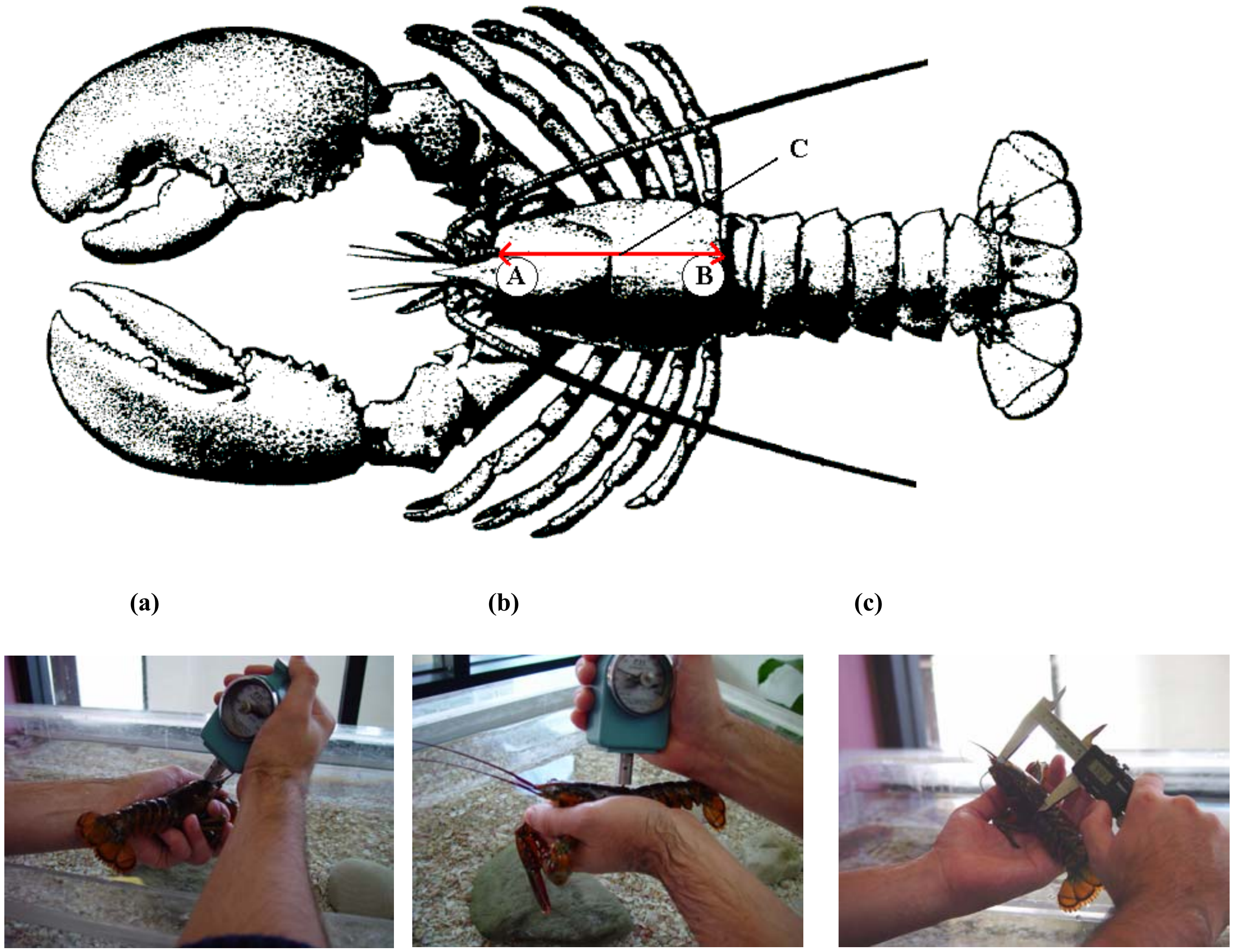

Figure 2. Durometer reading positions on the cephalothorax (a) anterodorsal region A and (b) dorsolateral region B, as well as (c) the measurement of the lobster carapace length with an electronic caliper.

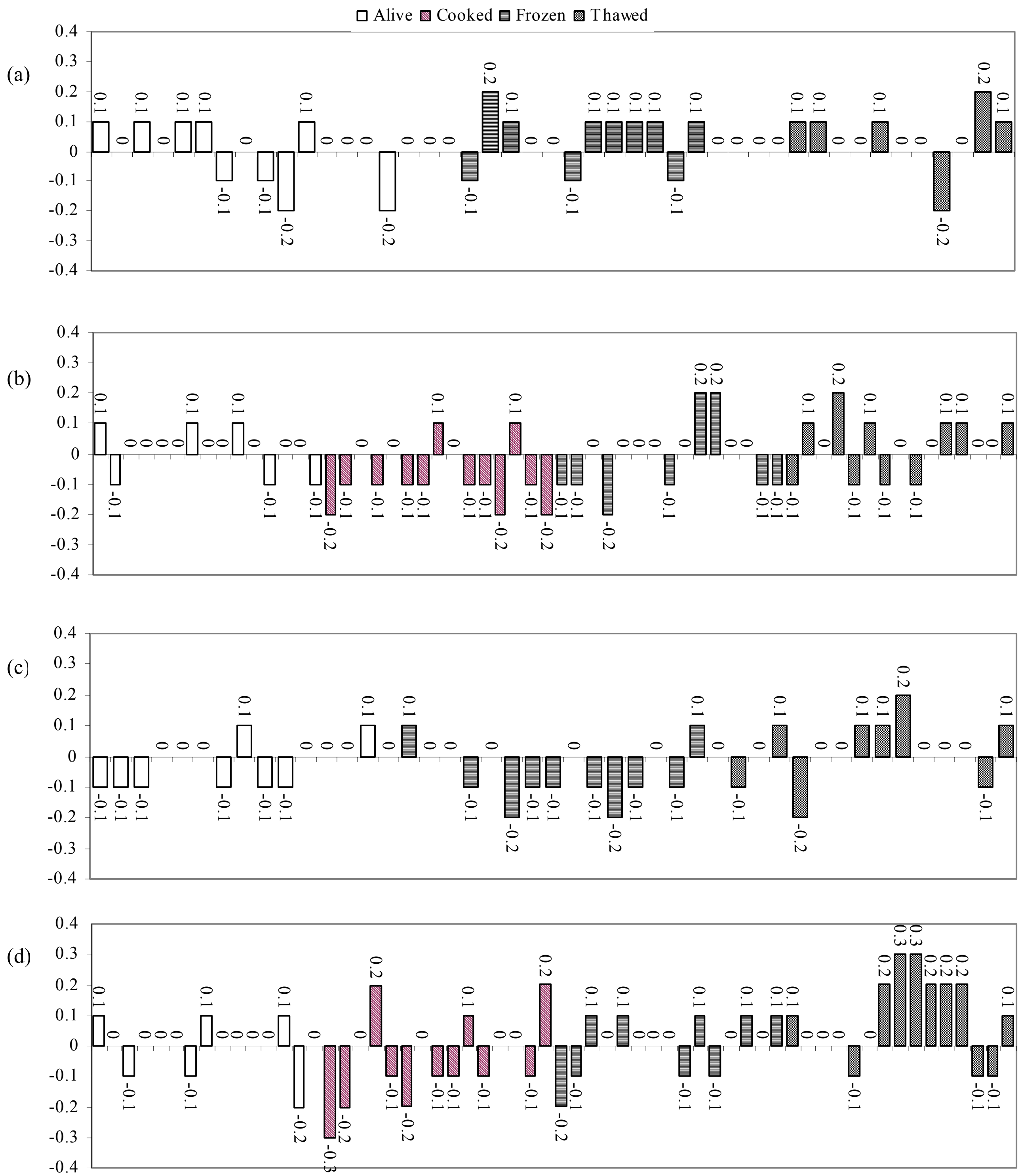

Figure 3. Difference between the two random measurements of the carapace length (mm) at any given post-catch handling stage for (a) soft-shell frozen (b) soft-shell cooked-frozen (c) hard-shell frozen and (d) hard-shell cooked-frozen lobsters.

APPENDIX 1

Carapace length measurements (mm) and averages used for analyses

(a) Soft-shell, from August 23 to 26, 2002 (Live - Frozen -Thawed)

Lobster	Sex	Live CL			Frozen CL			Thawed CL		
		1	2	Average	1	2	Average	1	2	Average
1	F	69.3	69.2	69.3	69.2	69.2	69.2	69.3	69.3	69.3
2	F	68.2	68.2	68.2	68.2	68.2	68.2	68.1	68.1	68.1
3	M	68.2	68.1	68.2	68.1	68.1	68.1	68.2	68.2	68.2
4	F	67.3	67.3	67.3	67.2	67.3	67.3	67.4	67.4	67.4
5	F	69.4	69.3	69.4	69.5	69.3	69.4	69.5	69.4	69.5
6	F	68.3	68.2	68.3	68.3	68.2	68.3	68.3	68.2	68.3
7	M	67.0	67.1	67.1	66.9	66.9	66.9	67.1	67.1	67.1
8	M	66.8	66.8	66.8	66.8	66.8	66.8	66.8	66.8	66.8
9	F	69.0	69.1	69.1	69.1	69.2	69.2	69.2	69.1	69.2
10	F	70.0	70.2	70.1	70.2	70.1	70.2	70.0	70.0	70.0
11	F	68.8	68.7	68.8	68.8	68.7	68.8	68.8	68.8	68.8
12	M	68.5	68.5	68.5	68.4	68.3	68.4	68.5	68.7	68.6
13	F	67.5	67.5	67.5	67.5	67.4	67.5	67.5	67.5	67.5
14	M	67.6	67.6	67.6	67.6	67.7	67.7	67.8	67.6	67.7
15	F	68.2	68.4	68.3	68.3	68.2	68.3	68.3	68.2	68.3

(b) Soft-shell, from August 23 to 26, 2002 (Live - Cooked - Frozen - Thawed)

Lobster	Sex	Alive CL			Cooked CL			Frozen CL			Thawed CL		
		1	2	Avg.	1	2	Avg.	1	2	Avg.	1	2	Avg.
1	F	68.0	67.9	68.0	67.7	67.9	67.8	67.6	67.7	67.7	67.6	67.7	67.7
2	M	67.9	68.0	68.0	67.5	67.6	67.6	67.4	67.5	67.5	67.7	67.6	67.7
3	M	68.6	68.6	68.6	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3	68.3
4	M	67.8	67.8	67.8	67.3	67.4	67.4	67.2	67.4	67.3	67.6	67.4	67.5
5	M	69.4	69.4	69.4	69.1	69.1	69.1	68.9	68.9	68.9	69.1	69.2	69.2
6	F	69.2	69.2	69.2	69.2	69.3	69.3	68.8	68.8	68.8	69.2	69.1	69.2
7	M	69.0	68.9	69.0	68.6	68.7	68.7	68.6	68.6	68.6	68.6	68.7	68.7
8	M	69.9	69.9	69.9	69.8	69.7	69.8	69.6	69.7	69.7	69.7	69.7	69.7
9	M	67.3	67.3	67.3	67.0	67.0	67.0	66.8	66.8	66.8	66.9	67.0	67.0
10	F	66.8	66.7	66.8	66.4	66.5	66.5	66.5	66.3	66.4	66.5	66.5	66.5
11	F	69.8	69.8	69.8	69.4	69.5	69.5	69.5	69.3	69.4	69.4	69.3	69.4
12	M	67.5	67.6	67.6	67.3	67.5	67.4	67.3	67.3	67.3	67.3	67.2	67.3
13	M	68.5	68.5	68.5	68.1	68.0	68.1	67.9	67.9	67.9	67.9	67.9	67.9
14	M	69.3	69.3	69.3	68.9	69.0	69.0	68.8	68.9	68.9	68.9	68.9	68.9
15	F	67.4	67.5	67.5	67.0	67.2	67.1	67.0	67.1	67.1	67.1	67.0	67.1

APPENDIX 1 (*continued*)
Raw data of CL measurements (mm)

(c) Hard-shell, from October 4 to 7, 2002 (Live - Frozen - Thawed)

Lobster	Sex	Live CL			Frozen CL			Thawed CL		
		1	2	Average	1	2	Average	1	2	Average
1	F	68.5	68.6	68.6	68.5	68.4	68.5	68.7	68.7	68.7
2	F	68.9	69.0	69.0	68.8	68.8	68.8	68.8	68.9	68.9
3	M	68.0	68.1	68.1	67.9	67.9	67.9	68.1	68.1	68.1
4	F	67.0	67.0	67.0	66.8	66.9	66.9	67.0	66.9	67.0
5	F	68.5	68.5	68.5	68.5	68.5	68.5	68.4	68.6	68.5
6	F	67.6	67.6	67.6	67.4	67.6	67.5	67.5	67.5	67.5
7	M	68.5	68.6	68.6	68.3	68.4	68.4	68.4	68.4	68.4
8	M	69.0	68.9	69.0	68.8	68.9	68.9	68.8	68.7	68.8
9	F	68.8	68.9	68.9	68.8	68.8	68.8	68.9	68.8	68.9
10	F	66.6	66.7	66.7	66.5	66.6	66.6	66.7	66.5	66.6
11	F	68.8	68.8	68.8	68.6	68.8	68.7	68.6	68.6	68.6
12	M	68.9	68.9	68.9	68.8	68.9	68.9	68.8	68.8	68.8
13	F	69.7	69.7	69.7	69.5	69.5	69.5	69.5	69.5	69.5
14	M	68.2	68.1	68.2	68.1	68.2	68.2	68.1	68.2	68.2
15	F	66.9	66.9	66.9	66.8	66.7	66.8	66.8	66.7	66.8

(d) Hard-shell, from October 4 to 7, 2002 (Live - Cooked - Frozen - Thawed)

Lobster	Sex	Live CL			Cooked CL			Frozen CL			Thawed CL		
		1	2	Avg..	1	2	Avg..	1	2	Avg.	1	2	Avg.
1	F	67.4	67.3	67.4	66.8	67.1	67.0	66.9	67.1	67.0	67.1	67.0	67.1
2	M	67.7	67.7	67.7	67.2	67.4	67.3	67.1	67.2	67.2	67.2	67.2	67.2
3	M	69.1	69.2	69.2	68.8	68.8	68.8	68.7	68.6	68.7	68.9	68.9	68.9
4	M	69.3	69.3	69.3	69.1	68.9	69.0	68.9	68.9	68.9	69.0	69.0	69.0
5	M	68.3	68.3	68.3	67.8	67.9	67.9	67.9	67.8	67.9	67.8	67.9	67.9
6	F	67.5	67.5	67.5	66.9	67.1	67.0	67.0	67.0	67.0	67.1	67.1	67.1
7	M	69.0	69.1	69.1	68.6	68.6	68.6	68.7	68.7	68.7	68.7	68.5	68.6
8	M	67.2	67.1	67.2	66.8	66.9	66.9	66.6	66.6	66.6	66.8	66.5	66.7
9	M	68.2	68.2	68.2	67.8	67.9	67.9	67.7	67.8	67.8	67.9	67.6	67.8
10	F	69.4	69.4	69.4	68.9	68.8	68.9	68.6	68.5	68.6	68.9	68.7	68.8
11	F	69.3	69.3	69.3	68.8	68.9	68.9	68.7	68.8	68.8	68.8	68.6	68.7
12	M	69.6	69.6	69.6	69.1	69.1	69.1	69.2	69.2	69.2	69.2	69.0	69.1
13	M	69.8	69.7	69.8	69.6	69.6	69.6	69.5	69.4	69.5	69.1	69.2	69.2
14	M	68.1	68.3	68.2	67.8	67.9	67.9	67.7	67.7	67.7	67.6	67.7	67.7
15	F	68.1	68.1	68.1	67.8	67.6	67.7	67.9	67.8	67.9	67.8	67.7	67.8

APPENDIX 2

Durometer readings at the anterodorsal region (A) and dorsolateral region (B) for the October lobsters.

Treatment	Lobster	Sex	Durometer Readings (scale of 0 to 100) A	B	Shell condition
Freezing	1	F	82	69	New hard-shell
	2	F	81	68	New hard-shell
	3	F	89	85	Hard-shell
	4	F	85	83	Hard-shell
	5	F	82	69	New hard-shell
	6	M	90	85	Hard-shell
	7	F	82	69	New hard-shell
	8	M	83	82	Hard-shell
	9	F	89	80	Hard-shell
	10	F	82	80	Hard-shell
	11	M	90	81	Hard-shell
	12	M	91	83	Hard-shell
	13	M	89	83	Hard-shell
	14	M	95	84	Hard-shell
	15	M	87	85	Hard-shell
Cooking, then freezing	1	M	81	69	New hard-shell
	2	F	89	69	New hard-shell
	3	F	88	78	Hard-shell
	4	M	87	81	Hard-shell
	5	F	83	78	Hard-shell
	6	F	81	79	Hard-shell
	7	M	89	84	Hard-shell
	8	F	85	80	Hard-shell
	9	M	90	85	Hard-shell
	10	F	83	78	Hard-shell
	11	M	90	81	Hard-shell
	12	F	89	80	Hard-shell
	13	M	90	85	Hard-shell
	14	M	89	79	Hard-shell
	15	M	89	80	Hard-shell

APPENDIX 3

Thickness of common objects

Thickness of common objects	Millimetres (mm)
Adhesive tape “Scotch Tape™”	0.03
Phone book page	0.04
Brown standard envelope	0.08
Human hair	0.09
Sheet of regular white paper	0.10
Side of a can of “Pepsi™”	0.12
Grain of white granulated sugar	0.30
Side of a waxed-cardboard “Tim Horton™” coffee cup	0.37
Standard paper staple	0.42
An average human finger nail	0.49
Pencil lead HB 0.7	0.68
Credit card (without the printed numbers)	0.81
Standard paper clip	0.84
10¢ Canadian coin	1.08
CD	1.31
1¢ Canadian coin	1.35
25¢ Canadian coin	1.55
5¢ Canadian coin	1.72
$ 2 Canadian coin	1.76
$ 1 Canadian coin	1.83
Computer floppy disc	2.86