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Field Testing Shell Hardness Guages for the Snow Crab Fishery

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FIELD TESTING SHELL HARDNESS GAUGES FOR THE SNOW CRAB FISHERY

BY

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ABSTRACT

Hand-held gauges (durometers) modified for measuring hardness of crab shells consistently gave low readings when applied to the flexible claws of newly molted ("soft shell") snow crabs and high readings for hard shell claws. Hense this durometer would be an invaluable tool for regulating the soft shell problem in the Atlantic snow crab fishery. The bottom of the claw was the preferred position since spines are missing on this region. Repeated measurements with the gauges softened the claws so only one reading per claw should be taken. Of the three gauges tested (7, 10, 13 lbs of force), the seven lb gauge was easiest to use, softened claws the least after repeated measurements, and cracked the fewest claws. On a scale of 0 to 100 durometer units, a value of 72 (bottom of claw, seven lb gauge) is recommended as a cut-off for removing soft shell crabs from the catch. Surprisingly, hard shelled "morphometrically immature" males will also be excluded since their claws remain flexible even after the shells have hardened. Releasing "morphometrically immature" males may actually benefit the fishery since some scientists have postulated that these crabs are not yet fully grown nor mature. Specifications for the final gauge design are presented.

RÉSUMÉ

Des appareils manuels de mesure de dureté (duromètres) modifiés pour pouvoir mesurer la dureté des carapaces de crabe ont régulièrement donné des valeurs basses lorsqu'on les utilisait sur les pinces flexibles de crabes des neiges ayant récemment mué (crabes à carapace molle) et des valeurs hautes lorsqu'on les appliquait aux pinces de crabe à carapace dure. Ce type de duromètre pourrait donc s'avérer un précieux instrument pour éliminer les spécimens à carapace molle des prises de crabe des neiges dans les pêcheries de l'Atlantique. La base de la pince est la partie où il est préférable d'appliquer le duromètre, car elle est dépourvue de piquants. Il est apparu que l'usage répété du duromètre sur un crabe en ramollit les pinces; aussi ne devrait-on prendre qu'une seule mesure par pince. Des trois appareils essayés (de 7, 10, et 13 lb de force, respectivement), celui de sept livres s'est avéré le plus facile à utiliser; c'est également celui qui ramollissait et brisait le moins les pinces. On recommande une valeur de 72, sur une échelle, de 0 à 100 unités de dureté, (obtenue à la base des pinces à l'aide d'un duromètre de sept livres) comme valeur-limite pour l'élimination des crabes à carapace molle. Fait étonnant, les crabes à carapace dure qui n'auront pas atteint la maturité morphométrique se trouveront aussi éliminés des prises, car leurs pinces restent flexibles même une fois que la carapace a durci. La remise à l'eau des mâles non parvenus à la maturité morphométrique pourrait s'avérer avantageuse pour les pêcheurs, puisque certains scientifiques prétendent que ces crabes n'ont pas encore atteint leurs pleines croissance et maturité. On présente ici des paramètres techniques en vue de la conception d'un modèle définitif de duromètre.

PREFACE

We are reporting on phase two of a broadly based investigation, sponsored by the Newfoundland region of the Department of Fisheries and Oceans, Fisheries Development Division, to develop a gauge which could be used to eliminate the problematic "soft shell" snow crabs from fishermen's catches. In phase one[1], a wide range of measuring devices were tested. One gauge type (a durometer modified to measure indentation hardness of Dungeness crab shells) proved promising and detailed field trials were recommended with this prototype. This report documents the technical aspects of the modified durometers and analyses these field experiments.

For further information or copies of reports, inquiries should be made to the project authority, Mr. G. Brothers, Fisheries and Oceans Canada, Fisheries Development Branch, Box 5667, St. John's, Newfoundland, A1C 5X1.

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[1]Foyle, T.P., and G.V. Hurley. 1988. Preliminary testing of shell hardness gauges for the snow crab. Consultant's report. 23pp. Newfoundland Contribution Agreement No. 3., Department of Fisheries and Oceans. St. John's, Newfoundland.

1. INTRODUCTION

The "soft shell" problem plagues snow crab (Chionoecetes opilio) fisheries in Atlantic Canada. Soft shell crabs can predominate in catches and are highly problematic to processors since low meat yields reduce profit. Soft shell crabs are also delicate and suffer high mortality from rough handling, resulting in poor meat quality when processed.

"Soft shell" is an industry term for recently molted crabs. Molting is the mechanism by which crustaceans grow; the old skeleton is shed and the animal expands by absorbing water. Hence, the body cavity after the molt is initially filled with a large volume of blood instead of tissue. Soft shell animals can be externally distinguished by their flexible, new, shiny shells and claws which will deform when thumb pressure is applied (Miller and O'Keefe, 1981). As the new shell hardens, the volume of blood decreases while the amount of meat increases.

While molting is a natural growth phenomenon, fishing pressure itself has probably caused the high occurrence of soft shell crabs. Intensive fishing in many areas has removed the original fully grown hard shell crabs characteristic of a stable virgin biomass, allowing for greater recruitment and growth in the population.

Beginning in the late 1960's, the snow crab fishery has expanded to become, in monetary terms, the fourth largest in the Canadian Atlantic. Frozen sections and canned or frozen snow crab meat are distributed to markets in North America, Europe, and Japan. To meet this demand, male snow crabs are extensively exploited around Newfoundland, in the Gulf of St. Lawrence, and off Cape Breton. Females are small and are not fished (Elner and Bailey, 1986).

To attenuate the soft shell problem, the Department of

Fisheries and Oceans (DFO) imposed a regulation in 1975 prohibiting the landing of soft shell crabs. However, violations could not be upheld in court since shell condition was a subjective determination made by a fisheries officer (L. Rowe, DFO, Nfld., pers. comm.). Enforcement was subsequently relaxed and the regulation rescinded in 1986 (Taylor and O'Keefe, 1987).

A regulation is only enforceable if shell hardness can be determined objectively. To this end, the Department has contracted Hurley Fisheries Consulting Ltd., Dartmouth, N.S., to develop or test instruments which could quantify shell deformation ("hardness") for snow crabs. In a preliminary study, a variety of instruments were evaluated (Foyle and Hurley, 1988). One gauge (a modified Pacific Transducer Corp. durometer) showed promise and was recommended for further testing.

Many questions require addressing before a gauge can be used to regulate the snow crab fishery. Does the gauge consistently separate hard shell and soft shell crabs and are these categories related to meat yield? Which position on the claw (top or bottom) is preferred for testing? Is the gauge simple to use and read by inexperienced operators (fishermen, plant dockside graders, etc.)? Does the gauge soften claws through repeated testing? Does size of the claw affect the readings? This study analyses these aspects and describes why this durometer is a suitable tool for alleviating the soft shell problem in the snow crab fishery.

During this study, it also became evident that the two groups of male snow crabs produced different gauge readings. These two groups are distinguished by claw and carapace size and are called "morphometrically mature" and "morphometrically immature" respectively (These groups are described in detail in sections 2.3.1, 3.2, 3.4.3, and 4.2). The differences in durometer readings between these two groups are also analysed in this report.

2. METHODS

2.1 DESCRIPTION OF GAUGES

Durometers are spring-driven gauges applied in industry to measure the hardness of elastomeric compounds (foams, rubbers, plastics). The indenter of the gauge is pressed against the material to be tested and sufficient force applied until the indentor is no longer visible. The force required to accomplish this varies with the hardness of the material. An ancillary pointer in the dial ("lazy hand") holds the highest durometer reading until reset with a thumb screw.

The durometer scale (0-100) is in arbitrary units. However, the actual force applied can be calculated since the force-scale relationship is linear (Appendix E). Thus, a standard 10 lb gauge produces 10 lbs of force (44.48 N) at 100 durometer units and five lbs of force (22.24 N) at 50 durometer units of deflection.

Standard durometers are unsatisfactory for measuring shell hardness in snow crabs since the pointed indenter is too sharp and pierces the shells (Foyle and Hurley, 1988). The durometer (model 307LCRB, Pacific Transducer Corporation, Los Angeles, Calif., U.S.A.) used in this study (Fig. 1) contains modifications developed for the Alaskan Dungeness crab (*Cancer magister*) fishery (Hicks and Johnson, 1988). A broad 1/8" (3.175 mm) diameter hemispherical indenter replaces the standard point which does not penetrate the shell. A 4.0" (10.2 cm) stainless steel or aluminum extension rod separates the indenter from the body of the instrument.

The modified durometers used in Alaska delivered 10 lbs of force at full needle deflection. In an effort to optimize the gauge, we examined 3 durometers calibrated by the manufacturer to

FIGURE 1. One of the modified Pacific Transducer durometers used in the study. The ancillary pointer (lazy hand), resting on 2 on the dial, is difficult to see in the photograph.

deliver different forces, 7 lb (31.14 N), 10 lb (44.48 N), 13 lb (57.83 N) since the force applied to a crab claw would influence the amount of needle deflection, ease of use, and damage of the claw. The gauges were returned to the manufacturer for recalibrating after the experiments to ascertain if spring tension had declined with usage.

2.2 INFORMAL DEMONSTRATIONS OF THE GAUGES

During the field experiments, durometers were demonstrated for and used by several fisheries officers, fishermen, and biologists. Informal interviews were conducted with these and other individuals involved in the crab fishing industry to evaluate the effectiveness of the gauges.

2.3 SELECTION OF CRABS

The field experiments were conducted in June, 1988 on recently landed snow crabs at a processing plant in Bonavista, Newfoundland. A wide range in size (79.5 -125.5 mm carapace width) and a mixture of soft and hard shell male crabs were chosen. Twenty three percent of the crabs tested were smaller than the legal size limit of 95 mm carapace width.

The crabs were weighed to the nearest 0.1 gm. The width of the carapace and the length, width, and height of the right claw of each crab were measured. Live animals with most or all of their limbs intact were used whenever possible. However, many soft shell animals died before landing due to membrane rupture and loss of blood. If a crab appeared to be dead, a triangular section of the carapace was often removed and the heart inspected for pumping action. If a substantial amount of blood had drained from the body cavity, this cavity was filled with water before the crab was weighed.

2.3.1 Subjective Categorization

The animals were subjectively categorized as follows, depending on the hardness of the left claw and on the appearance of the shell, based on a modified (D. Taylor, DFO, Newfoundland, pers. comm.) scale from Miller and O'Keefe (1981):

TYPE 1: Claw deforms under thumb pressure, shell appears new, brightly coloured and lacks fouling organisms; claw is iridescent on outer edge; shell white or bright pink underneath ("soft shell").

TYPE 2: Slight or no deformation in claw under moderate thumb pressure but shell appears new, brightly coloured and lacks fouling organisms; claw is iridescent on outer edge; shell white or bright pink underneath. ("new hards", molted in year caught.)

TYPE 3: Shell older than type 2; orange-brown with some calcareous growths and bryozoan colonies; claw is iridescent on outer edge; shell white or pink underneath ("old hards").

TYPE 4: Shell dull, with numerous calcareous growths and bryozoan colonies, and commonly yellow underneath ("old hards").

TYPE 5: Shell dark, soft in places, usually with calcareous growths and bryozoans; black spots common with decay at some joints ("old hards").[2]

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[2]Type 4 and 5 animals were rare in catches and were lumped with type 3 crabs for analysis.

2.3.2 Distinguishing "Morphometrically Mature" and "Immature" Crabs

Two groups of male snow crabs can be distinguished when a claw measurement is plotted against a carapace measurement (Watson, 1970). Individuals may have the identical carapace size but some males will have large claws while others will have small claws. The large and small clawed males have been termed "morphometrically mature" and "morphometrically immature" respectively (Conan and Comeau, 1986). A trained eye can sometimes distinguish between the two groups. The relationship between claw and carapace dimensions is allometric and probably differs between areas so a male can only be definitively categorized graphically or statistically.

In this study, the two groups were separated statistically. Logarithms of the claw measurements (claw length, width, height) were individually plotted against the logarithms of carapace width and discriminant analysis (Conan and Comeau, 1986) was used to segregate "morphometrically mature" and "immature" males in each of the three plots.

Usually all three discriminant analyses agreed. For 7 males, the segregations were ambiguous. For example, the crab would be categorized as "morphometrically mature" using claw width versus carapace width but "immature" using claw length versus carapace width. The scores based on the three plots were therefore compared and an animal was assigned to the appropriate category if at least two of the three discriminant analyses placed the animal in this group.

The two groups were separated only for the analysis of durometer readings versus meat yield (Section 3.5). Due to a smaller sample size, all claws were pooled in the repeated measures analysis (Section 3.4).

2.4 REPEATED MEASURES

Field observations (D. Taylor, pers. comm.) and preliminary measurements (Foyle and Hurley, 1988) have revealed that repeated measurements weaken or "soften" claws. To evaluate this change, the three gauges were repeatedly applied to the top and bottom areas of right claws which were relatively flat and lack spines (Fig. 2), areas where thumb testing is usually carried out. Only one gauge was used per crab and 51 animals were examined in total.

Readings taken after claws cracked were eliminated from the analysis. Simple regression lines were separately fitted to the top and bottom of each claw. The main regression parameters for each of these analyses are listed in Appendix A. Slopes calculated from data sets containing two or three repeated measurements were not included in the subsequent analyses.

Since the degree of "softening" of the claws caused by repeated applications of the gauge depended on the initial claw hardness, the slopes calculated from each data set were plotted against the y-intercepts (durometer readings). Regression lines for these plots were then determined for each gauge.

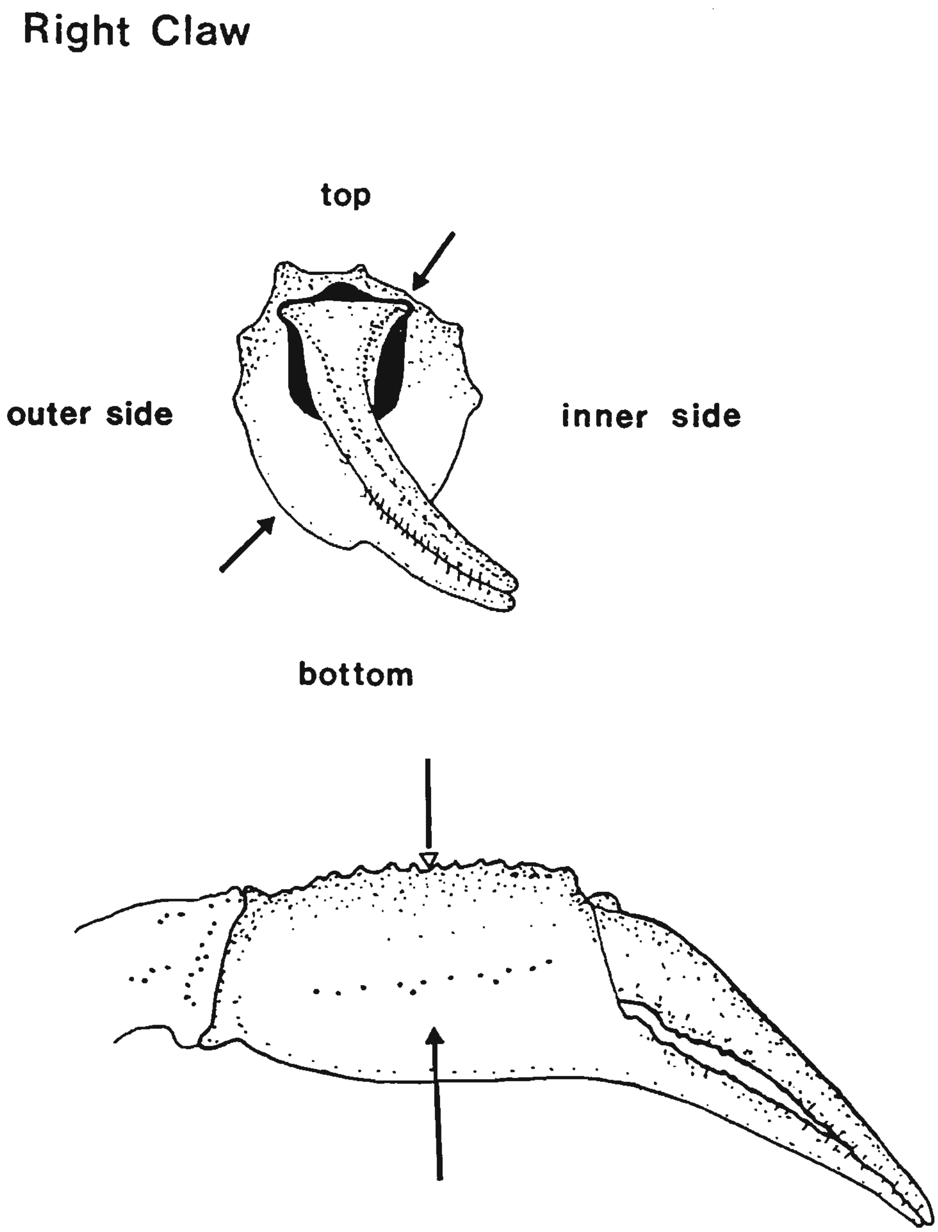


FIGURE 2. Arrows in this diagram indicate the top and bottom positions of snow crabs claws where the durometers were tested. Note that these positions are skewed from the vertical plane to avoid rows of spines.

2.5 GAUGE READINGS AND MEAT YIELD

After crabs were weighed, categorized by shell type, and measured, readings with the durometers were taken on right claws of 185 crabs. The three gauges were applied in the following sequence: seven lb, 10 lb, 13 lb, to the top and bottom areas of the claws (Fig. 2).

Crabs were identified with spaghetti tags, communally placed in large plastic onion bags, and boiled in the batch cooker of the processing plant for five minutes. After cooling in a water bath, crabs were emptied from the bags and their right claws sliced off at the joints. To compensate for blood loss during removal, the claws were filled with water before being weighed. Meat was then carefully extracted from each claw, blotted on a paper towel to remove excess moisture, weighed, and the percent claw meat yield calculated.

An experienced plant worker then removed the meat by hand ("shaking") from the whole body using an aluminum mallet and block. The drained meat (which included meat of the right claw) was weighed and individual meat content calculated for each animal.

Graphs of durometer readings from the three gauges versus meat yield were visually examined for effectiveness in separating shell types. Since the seven lb gauge was applied to the claw first and had several practical advantages over the other two gauges (see results), detailed statistical analysis was conducted on the seven lb durometer readings using regression analysis, t-tests, and analysis of covariance. Statview (Apple Computers Ltd., Cupertino, California) and Systat (Systat Inc., Evanston, Ill., U.S.A.) software were employed in all analyses.

3. RESULTS

3.1 DEMONSTRATIONS OF THE GAUGES

3.1.1 Opinions of Users

People did not have problems operating or reading the durometers after the gauges were demonstrated to them. The durometers resembled other hand-held meters like vacuum or pressure gauges and the lazy hand (ancillary pointer) proved simple to read. The seven lb durometer was the easiest to use because the main-spring offered less resistance to hand pressure.

Generally, opinions about the gauges were favourable. Fishermen were very curious about the durometer and the gauge was commonly passed amongst crew members for testing. Often, the same claw was repeatedly tested by a fisherman two or three times and the readings carefully scrutinized. One fisherman, referring to his hold full of crabs, remarked "Never be able to test it on all of them."

The fishermen surmised that the durometer would be more of a nuisance than a benefit to them and saw no reason in lobbying for it. However, processors believed a gauge was essential for disciplining their buying practices to exclude soft shell crabs at dockside. Without a regulation governing soft shell crab, they feared that by rejecting a portion of the catch, the fisherman would decide to sell to other buyers.

3.1.2 User Variability

The gauge readings were more variable if the indenter was rapidly depressed than if slow, even hand pressure was applied. In extreme cases when rapid force was applied, the lazy hand would be propelled well above the actual reading. Rapid depression of the indenter probably imparts inertia to the pointer or mainspring.

3.2 SEPARATION OF "MORPHOMETRICALLY MATURE" AND "IMMATURE" CRABS

The larger clawed "morphometrically mature" crabs occurred over the entire size range sampled (Fig. 3). The smaller clawed "morphometrically immature" crabs were generally restricted below 100 mm carapace width, although a few individuals were categorized as "immature" which had carapace widths above 100 mm. The two groups could easily be distinguished by examining the graph relating any of the three claw dimensions (e.g. claw height, Fig. 3) to carapace width. The plots of all three claw measurements against carapace widths are given in Appendix B.

3.3 REPEATED MEASURES

In most cases, the decline in gauge values with repeated application of the durometer was linear (Fig. 4a). In a few trials, durometer readings fell greatly at first but then stabilized, decreasing smaller increments between measurements (Fig. 4b).

To examine overall trends and to amalgamate the individual data sets (Appendix A), the slopes of the repeated measures lines were plotted against the y intercepts (Table 1). The expected softening (measured by the slope) was calculated for any gauge by simply substituting the initial gauge measurement into the x value of the appropriate equation. These equations are at best approximations since variability is high (low r^2 values). Nevertheless, three important findings were revealed by this analysis:

(1) when low initial durometer readings were substituted into the equations, the slopes are greater than when high initial durometer readings were used. Therefore, for all gauges, the soft claws (low initial durometer values) softened to a greater

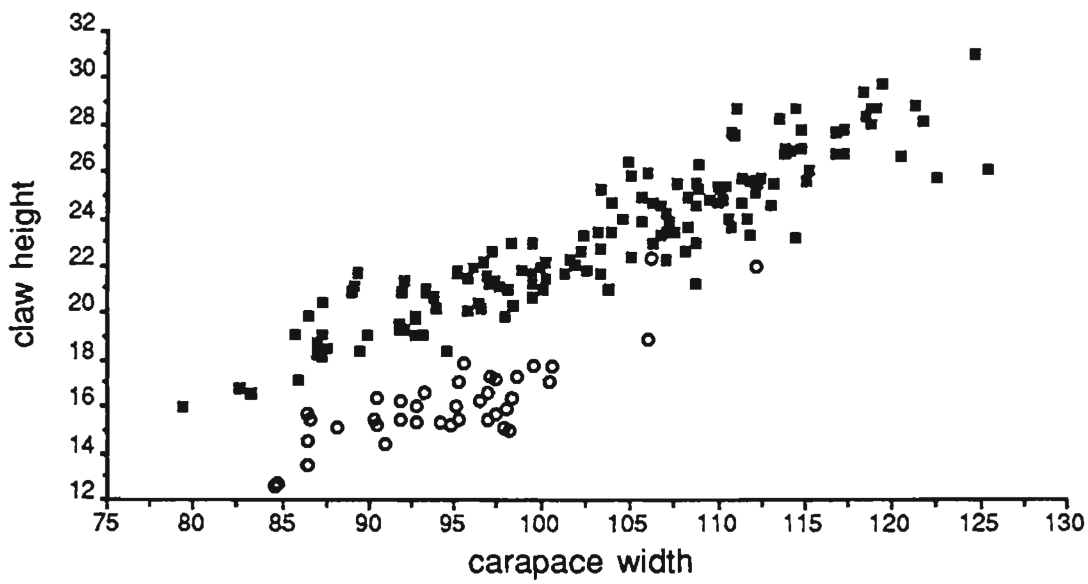


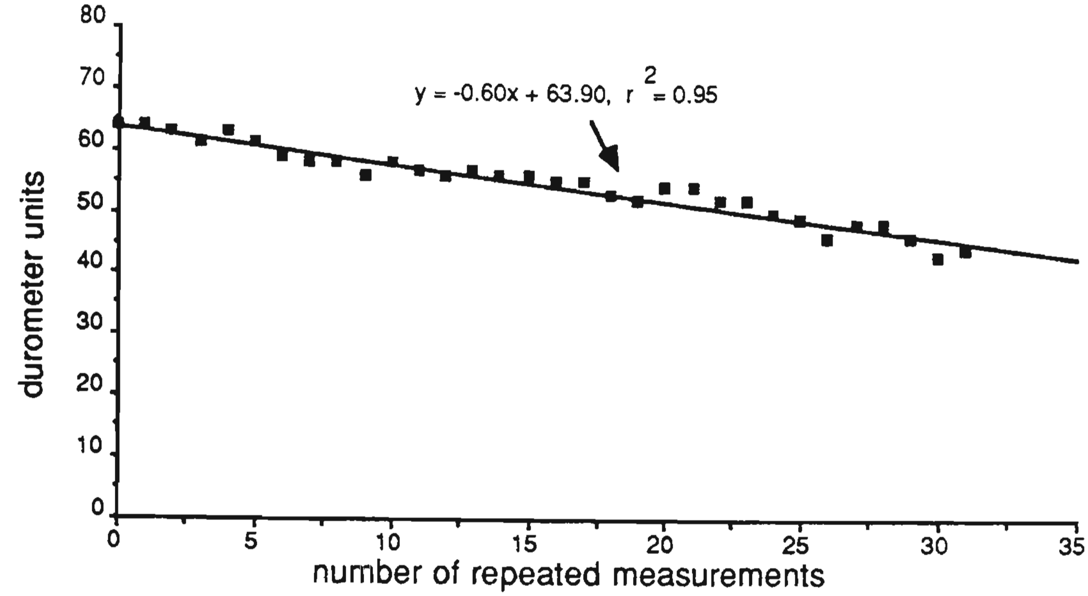
FIGURE 3. Plot of claw height versus carapace width revealing the distinction between "morphometrically mature" (■) and "immature" (o) crabs.

extent between measurements than hard claws. The slopes for hard claws were shallow so the amount of softening from consecutive measurements was not great.

(2) the slopes for the bottom of the claw were greater than the slopes for the top indicating that the bottom of the claw was more susceptible to weakening from repeated measurements.

(3) the slopes generally increased as the force of the gauge rises. Therefore, repeated use of the 10 and 13 lb gauges softened claws to a much greater extent than the seven lb gauge.

The 13 lb gauge had a lower calculated slope than the 10 lb gauge when applied to the top of the claw (Table 1). However, the effects of repeated use of the 13 lb gauge were underestimated by these equations since the 13 lb gauge was very harsh on soft claws; in many cases this gauge cracked these claws before slopes could be calculated (c.f. Appendix A). The seven lb gauge cracked the fewest number of soft claws.



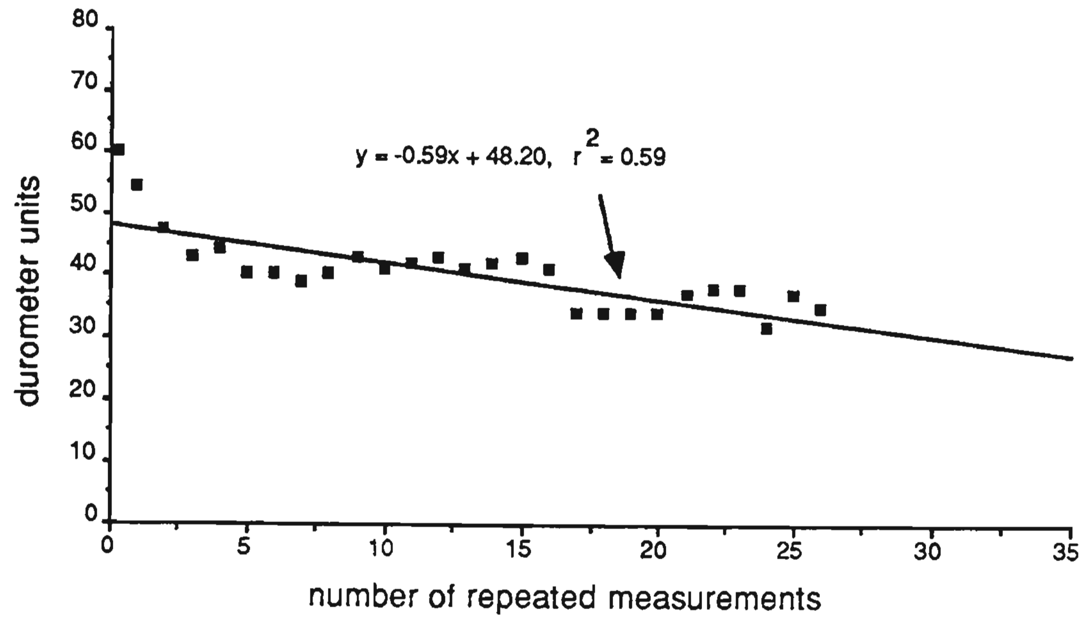


FIGURE 4. Two samples of individual repeated measures trials. Readings generally decreased in a linear fashion as in (a); in some cases, the durometer measurements decreased greater amounts during the initial measurements (b). Naturally, straight regression lines fit data sets like (a) better than (b). (a) = seven lb durometer, bottom of claw; (b) = seven lb durometer, top of claw.

TABLE 1. Repeated measures analysis: slopes from individual data sets versus y-intercepts. The individual data sets are listed in Appendix A.

Gauge	Equation	r^2	p
	TOP OF CLAW		
7 lb:	slope = 0.009 i - 1.06	0.26	*
10 lb:	slope = 0.044 i - 3.57	0.53	*
13 lb:	slope = 0.039 i - 3.15	0.39	*
	BOTTOM OF CLAW		
7 lb:	slope = 0.032 i - 2.97	0.50	*
10 lb:	slope = 0.057 i - 5.06	0.55	*
13 lb:	slope = 0.104 i - 8.12	0.51	*

In these equations, i represents the initial gauge reading.
* = significant at $p<0.05$

EXAMPLE

As an example, the seven lb gauge is applied to the top of the claw, producing and initial reading (i) of 50. The slope of the repeated measures line would equal:

slope = 0.009 (50) - 1.06

= -0.61

That is, for every consecutive measurement, the gauge reading drops 0.61 durometer units. The repeated measures line would be

durometer reading = -0.61 x + 50

where x in the number of repeated measurements done on that region of the claw (x = 0 for initial gauge reading; x = 1 for first repeated measure, etc.).

3.4 DUROMETER READINGS AND MEAT YIELD

3.4.1 The Three Durometers

Overall, the readings shifted downward as the force rating (7, 10, 13 lb) of the gauge increased (Table 2). For example, the seven lb gauge furnished an average reading of 51.0 for the bottom of the claw in type 1 "morphometrically mature" crabs compared to 82.6 for their type 3-5 counterparts. The 13 lb gauge generated lower values of 22.4 and 65.0 respectively for the same groups.

The three gauges appeared to be equally successful at separating the various groups of crabs (Fig. 5 and Appendix C). However, the difference in means of the groups was greater for the 13 lb than the seven and 10 lb durometers (Table 2). This was probably caused by the order of application of the gauges rather than differences in the gauges themselves. The 13 lb durometer was applied last and the initial measurements with the seven and 10 lb gauges had undoubtedly softened the claws (Section 4.3) by the time the 13 lb gauge was used. These repeated measurements would have weakened claws of newly molted crabs (type 1) more than old shelled crabs (type 3-5) resulting in greater differences between the groups. This artifact would also explain the greater variability in the 13 lb durometer readings (Table 2). Since the greater separation for the 13 lb gauge was not readily visible on the graphs (Appendix C), all three gauges can be considered approximately equal at separating the groups.

TABLE 2. Means and standard deviations of readings from the three gauges and percent total and claw meat yield.

	-----Durometer Readings or Percent Meat Yield----- Means ± standard deviations					
	TYPE 1	n	TYPE 2	n	TYPE 3-5	n
	"Morphometrically Immature" Crabs					
7 lb, top	48.8 ± 6.6	11	47.0 ±17.1	3	55.5 ± 7.1	20
7 lb, bottom	59.9 ± 5.7	11	63.3 ±10.2	3	65.1 ± 3.9	19
10 lb, top	41.1 ± 6.3	11	42.3 ±12.3	3	46.4 ± 6.8	20
10 lb, bottom	52.1 ± 6.6	11	52.0 ±12.8	3	58.2 ± 3.1	19
13 lb, top	21.3 ± 9.1	11	28.0 ±15.4	3	31.6 ± 8.5	20
13 lb, bottom	28.5 ±11.8	11	38.7 ±17.0	3	45.3 ± 6.6	19
% total yield	21.4 ± 8.3	13	29.9 ±10.5	2	33.7 ± 3.2	22
% claw yield	37.8 ±12.0	14	34.1 ±19.5	3	53.3 ± 3.8	22
	"Morphometrically Mature" Crabs					
7 lb, top	48.1 ± 8.7	60	70.2 ± 5.4	6	77.9 ± 7.0	35
7 lb, bottom	51.0 ±10.0	60	74.2 ± 5.0	6	82.6 ± 6.3	33
10 lb, top	38.2 ± 9.9	62	59.8 ±11.9	6	69.3 ± 8.0	35
10 lb, bottom	44.1 ± 9.0	60	63.7 ± 8.2	6	74.5 ± 7.1	32
13 lb, top	19.6 ±11.9	62	47.0 ± 7.8	6	57.9 ± 8.7	35
13 lb, bottom	22.4 ±12.2	60	51.5 ± 7.8	6	65.0 ± 7.8	33
% total yield	17.6 ± 3.9	62	24.8 ± 8.0	8	32.5 ± 3.8	52
% claw yield	22.8 ± 7.2	74	37.9 ±11.9	9	50.2 ± 5.2	50

n = number of observations.

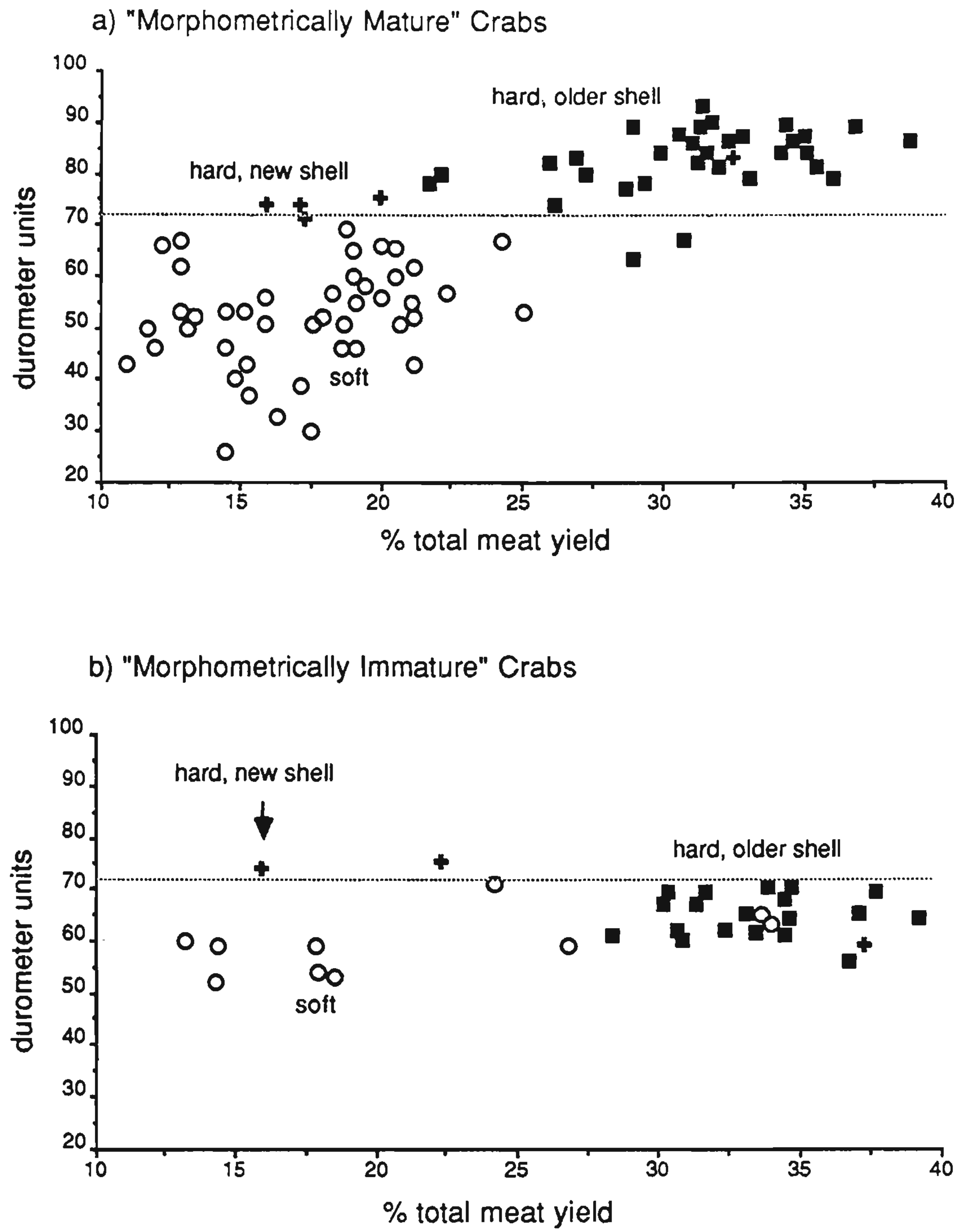


FIGURE 5. Plots of seven lb durometer readings against percent total meat yield for the bottom of the claw. Dotted line indicates cut-off reading (72) which would effectively eliminate type 1 (soft shell) crabs from commercial catches.

3.4.2 Position on Claw

Spines in the top region interfered with gauge use for the smaller animals making it difficult to push the flat surface of the extension bar to the surface of the claw. The top of the claw also proved to be more flexible than the bottom producing lower and slightly more variable durometer readings overall (see Tables 2, 5, 6).

3.4.3 Differences in Gauge Readings between "Morphometrically Mature" and "Immature" Crabs

The three subjective groupings fell into distinct clusters for the "morphometrically mature" males (Fig. 5a):

(1) type 1 (soft shell) males had low meat yields (10-25%) and low durometer readings (25-70 units; seven lb gauge, bottom of claw).

(2) type 2 ('new hards') animals were scarce in the sample and, as expected, generally had low meat yields (12-22%) but high durometer readings (70-80 units; seven lb gauge, bottom).

(3) type 3, 4, 5 (old shell) had high meat yields (22 - 40%) and high durometer readings (70-90 units; seven lb gauge, bottom).

For the bottom of the claw (Fig. 5a), a value of 72 on the seven lb gauge would effectively separate virtually all type 3-5 from type 1 crabs. Two of the old shell crabs had durometer readings below this cut-off value. One of these animals was type 5, (very old shell), which were rare in catches, indicating that hardness perhaps declines when a crab becomes very old. The second low reading could not be explained but the bottom of the claw may have been damaged before the measurement was taken.

For the "morphometrically immature" crabs, the three subjective categories of crabs also formed distinct clusters (Fig. 5b). The type 3-5 old shell crabs had high meat yields as expected (27-40%) but, surprisingly, durometer readings were consistently low (50-70 units). Type 3-5 "immature" crabs therefore form a separate cluster below their "mature" counterparts.

While percent meat yields were similar, durometer readings were significantly different (t-tests) between the "mature" and "immature" crabs (Table 3). This was confirmed by an analysis of covariance (Table 4), a more sophisticated statistical test, since the slopes of the "morphometrically mature" and the "immature" crabs were significantly different from one another (significant M-I, YD interactions).

A strong positive relationship (simple and multiple regressions) existed between meat yield and durometer units for "morphometrically mature" crabs but the slopes of "morphometrically immature" crabs were shallow or not significant (Table 5, 6). This is not surprising since the "morphometrically immature" claws of old shell crabs were essentially soft. This was also evident using thumb pressure since most of these "immature" crabs were categorized as having "soft" claws even though their carapaces were old. A cut-off value of 72 which would separate type 1 from type 3-5 "morphometrically mature" crabs would exclude <u>all</u> "immature" animals (Fig. 5b).

TABLE 3. Results of t-tests comparing different groups of crabs.

	p
Comparison: All type 1 crabs to type 3,4,5 "morphometrically immature" crabs.	
1. % total meat yield	***
2. seven lb gauge readings, top of claw	***
3. seven lb gauge readings, bottom of claw	***
Comparison: All type 1 crabs to type 3,4,5 "morphometrically mature" crabs.	
1. % total meat yield	***
2. seven lb gauge readings, top of claw	***
3. seven lb gauge readings, bottom of claw	***
Comparison: Type 3,4,5 animals only; "morphometrically mature" to "morphometrically immature" crabs	
1. % total meat yield	n.s.
2. seven lb gauge readings, top of claw	***
3. seven lb gauge readings, bottom of claw	***

*** = significant at $p<0.001$.
n.s. = not significant.

TABLE 4. Analysis of covariance results.

Dependent variable = durometer readings, seven lb gauge.

Position on Claw	M-I	ChH	YD	Interactions: M-I,ChH	Interactions: M-I,YD	Interactions: ChH,YD	r^2
Top	n.s.	n.s.	n.s.	*	**	n.s.	0.64
Bottom	n.s.	n.s.	n.s.	n.s.	***	n.s.	0.64

The morphometrically mature and immature data sets were pooled for the analysis. Claw height is used as a measure of claw size. The M-I term (a categorical variable) tests whether the means of durometer values are significantly different for the "morphometrically mature" and "morphometrically immature" crabs. The ChH and YD terms respectively test whether the slopes of durometer readings on claw height and percent total meat yield are significant for the overall data set. The M-I,ChH interaction examines whether status of the crabs (M-I) affects the regressions of durometer readings on claw height (ChH) (i.e. tests whether the slopes of the morphometrically mature and immature regression lines are different); similarly the M-I,YD interaction examines the effect of maturity status for the regressions of durometer units on percent total meat yield (YD); the ChH,YD interaction tests whether claw height is affecting the regression of durometer readings on yield.

* = significant at $p<0.05$
** = at $p<0.01$
*** = at $p<0.001$
n.s. = not significant.

TABLE 5. Simple regressions.

Dependent variable = durometer readings, seven lb gauge.

Position on Claw	Constant	---Slope--- % Total Meat Yield	r^2
----"MORPHOMETRICALLY IMMATURE" CRABS----			
Top	44.90	0.27	0.07
	(***)	(n.s.)	
Bottom	54.09	0.32	0.19
	(***)	(*)	
----"MORPHOMETRICALLY MATURE" CRABS----			
Top	23.42	1.63	0.62
	(***)	(***)	
Bottom	24.59	1.78	0.65
	(***)	(***)	

Significance level presented in parentheses.

* = significant at p<0.05
** = at p<0.01
*** = at p<0.001
n.s. = not significant.

TABLE 6. Multiple regressions.

Dependent variable = durometer readings, seven lb gauge.

Position on Claw	Constant	Slopes: Claw Height	Slopes: % Total Meat Yield	r^2
----"MORPHOMETRICALLY IMMATURE" CRABS----				
Top	7.23	2.33	0.26	0.39
	(n.s.)	(***)	(n.s.)	
Bottom	28.54	1.59	0.31	0.41
	(**)	(**)	(**)	
----"MORPHOMETRICALLY MATURE" CRABS----				
Top	20.82	0.10	1.64	0.61
	(***)	(n.s.)	(***)	
Bottom	25.41	0.03	1.78	0.65
	(*)	(n.s.)	(***)	

Significance level presented in parentheses.

* = significant at p<0.05
** = at p<0.01
*** = at p<0.001
n.s. = not significant.

3.4.4 Effect of Claw Size on Durometer Readings

Although a statistically significant positive relationship was found between durometer measurements and claw height for the "morphometrically immature" crabs (multiple regressions, Table 6), the plot of durometer units versus claw height did not reveal a strong visible trend (Fig. 6). This relationship for the "morphometrically mature" crabs was not statistically significant (Table 6).

3.4.5 Comparison of Claw and Total Meat Yields

Percent total meat yield was more variable than percent claw yield (Table 2), probably because meat loss was greater when extracted from the entire body. Predictably, a strong correlation existed between the two ($r^2 = 0.82$) so a regression equation (Fig. 7) could be used to calculate a total meat yield from claw yield. Since claw meat is easier to extract, this kind of relationship may be useful for saving time in future studies. Statistical analyses (simple and multiple regressions, analysis of covariance) using percent claw yield instead of percent total meat yield are given in Appendix D.

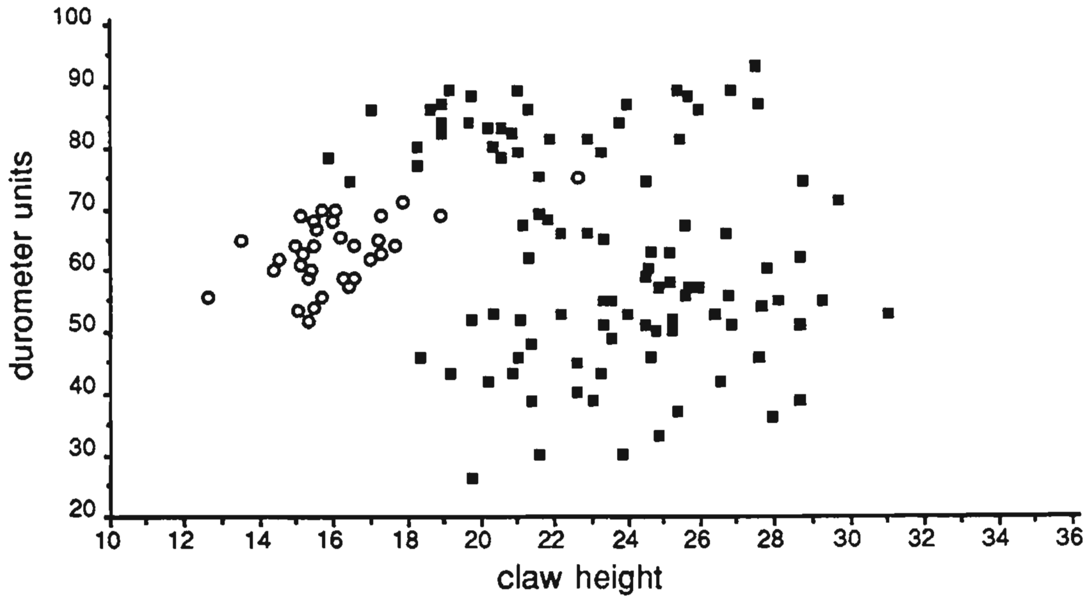


FIGURE 6. Plot of durometer readings of seven lb gauge (bottom of claw) versus claw height. (■) = "morphometrically mature". (o) = "morphometrically immature".

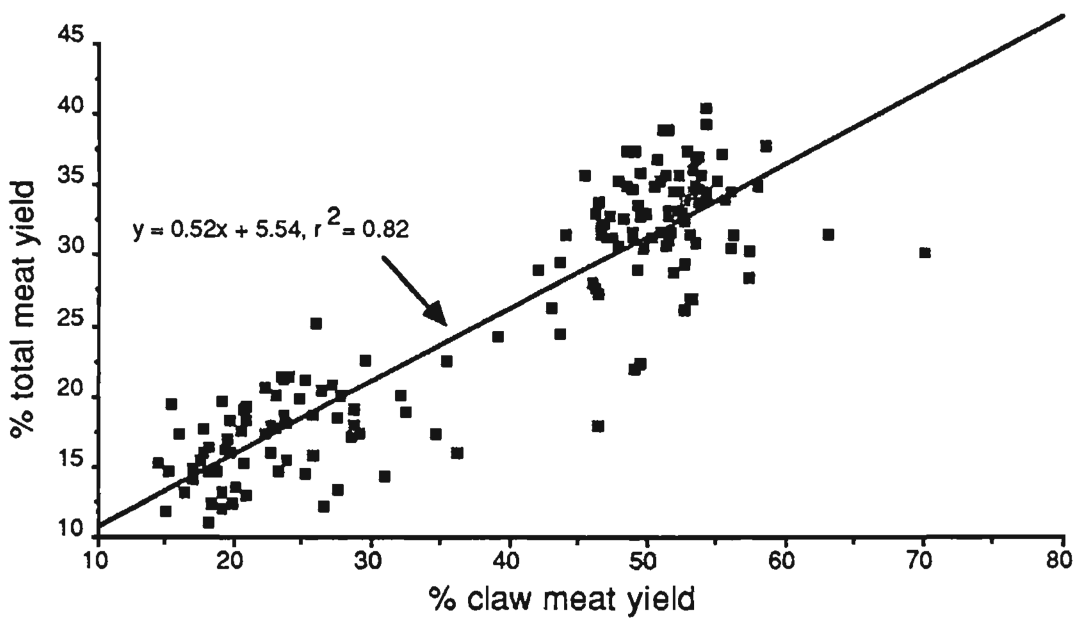


FIGURE 7. Regression of percent total meat yield against percent claw yield.

3.5 CHANGES IN DUROMETER CALIBRATION

Since durometers are spring-driven gauges, calibration could change over the course of a fishing season. According to the manufacturer, no aging of the mainspring occurs since it is heat treated and quite stable. Substantial changes in calibration are unlikely. The company has a policy of free recalibration of its gauges (Appendix E). In the Alaska Dungeness crab fishery, the gauges are usually returned for recalibration once a year after the fishery closes (J. Marcus, Pacific Transducer Corp., pers. comm.).

The three gauges used in these experiments were recalibrated by the company at the end of the study. The 10 lb and 13 lb units changed by +0.01 lb feet (0.01 N-m) and -0.02 lb feet (-0.03 N-m) respectively. The pointer rested about 1.5 units below 0 for the seven lb gauge and calibration changed approximately +0.05 lb feet (0.07 N-m).

4. DISCUSSION

4.1. CHOICE OF DUROMETER AND POSITION ON CLAW

A durometer producing seven lbs of force is recommended for measuring the hardness of snow crab claws. This durometer does not soften the claws as appreciably as the higher force gauges during consecutive measurements. Since this durometer produces less force, fewer soft claws crack during measurements and the gauge is easier to use because less hand pressure is required. All the durometers will nonetheless soften claws through repeated measurements (i.e. only one meaningful reading can be made on any claw).

Two positions (top and bottom) on the claw were tested. The bottom region softens at a greater rate during repeated measurements than the top. However, spines on the upper claw interfere with the gauge for smaller animals. The higher variability in the top measurements may have been caused by this interference. Since only the first measurement is reliable and the spines interfere with the top measurement, the bottom of the claw was preferred. Using a seven lb durometer on the bottom of claws, a cut-off value of 72 would effectively remove 'soft shell' crabs from a fisherman's catch.

Some of the statistical analyses indicated that claw size had a significant effect on the durometer readings. However, visual inspection of the graphs revealed that a strong relationship between durometer readings and claw size did not occur. Hence, claw size can be effectively disregarded in practical durometer use.

4.2 DIFFERENCES BETWEEN "MORPHOMETRICALLY MATURE" AND "IMMATURE" CRABS

Watson (1970) noted that two groups of male snow crabs could be distinguished based on claw and carapace sizes. A new theory proposes that the biology of these two groups is substantially different (Conan and Comeau, 1986). The smaller clawed males are hypothesized to be immature growing individuals, molting at regular intervals and hence are termed by these authors "morphometrically immature". However, at one of the molts, the claw size increases substantially and the crabs join the "morphometrically mature" group. The "morphometrically mature" males, which appear to cease molting and growing, may be the only ones capable of reproducing. This theory is principally based on a laboratory study and requires further validation. The termination of molt in these "morphometrically mature" crabs is beginning to gain wide acceptance but the mature, immature aspects of the theory remain controversial.

We have discovered another difference separating "morphometrically mature" and "morphometrically immature" crabs. The claws of the latter group are more flexible and probably thinner. Durometer readings for animals with the hard, older shells (type 3-5) should have been high. Surprisingly, durometer readings from the "morphometrically immature" type 3-5 crabs were low and fell as a cluster of points well below their "morphometrically mature" counterparts.

A durometer value of 72, designed to eliminate soft shell males from commercial catches would also eliminate these "morphometrically immature" old shelled crabs. If the cut-off value is lowered so as to include these crabs, some soft shell animals will also be retained by the fishermen. It may actually be meritorious to release all "morphometrically immature"' crabs since they are growing animals and will recruit into the fishery at a larger size in subsequent years. If these "morphometrically immature" crabs are in fact immature, their release could also stabilize recruitment patterns, since large numbers of immature animals would no longer be removed by the fishery.

4.3 TIME SINCE MOLT

Using this modified durometer, Hicks and Johnson (1988) examined the relationship between readings (hardness) from the lower side of the carapace and time since molting for Alaskan Dungeness crabs. The durometer measurements were accurate predictors of shell age, describable by a second order polynomial equation. Similarly, the durometer could be used to determine time since molt for snow crabs, at least for the "morphometrically mature" males. Since the claws of "morphometrically immature" crabs remain flexible even after the exoskeleton hardens, another area on the crab may have to be chosen to provide this information.

4.4 SNOW CRAB MEAT YIELD

Processors in Newfoundland are reported to obtain around 20% total meat yield by weight. We obtained an average of 18-21% for soft shell (type 1) and 33-34% yield in hard shell (type 3-5) crabs hand 'shaken' by a plant employee (Table 2, Fig. 5). Meat yields from hard shell crabs were accurately determined in the laboratory, averaging 41.2% (A-M. Hiltz, unpub.), substantially higher than reported commercial yields. The industrial meat extraction process appears inefficient so changes in yield from the exclusion of soft shell animals are difficult to estimate. Millions of dollars in additional revenue may be disappearing annually down the drains of Newfoundland crab processing plants.

4.5 POTENTIAL PROBLEMS WITH GAUGE USE IN THE FISHERY

Calibration changes - according to the manufacturer calibration will not change drastically with use (c.f. Section 4.5).

Gauge Induced Softening - Obviously a fisherman would not intentionally measure the claw repeatedly since this would soften the claw. However, the fishermen could argue that previous pressing, before the official measurement by a fisheries officer or plant inspector, had weakened the claws enough to change "hard" animals into "soft."

For hard claws, softening is not substantial (section 4.3) so the drop in durometer readings caused by five or six consecutive measurements would be inconsequential. Animals with new shells but hard claws (type 2) may soften enough from repeated measures to drop below the cut-off value. A regulation specifying one measurement per claw would resolve this problem.

Improper gauge use - The gauge is easy to operate and read making it widely usable (Section 4.1.1). However, spurious high lazy hand readings can occur if the indenter is rapidly depressed (Section 4.1.2) and fishermen could potentially retain soft shell crabs by using the gauge too quickly because an artificially high reading would result. According to the manufacturer, sealing with silicone grease would prevent the lazy hand from over-reading. Nevertheless, regulations should clearly specify that the durometer must be applied to a claw with a slow, even force.

5. CONCLUSIONS

The durometer is effective, simple to use, and should be a valuable tool for regulating the snow crab fishery. Some aspects of the gauge (e.g. lack of repeatability due to claw softening, incorrect method of application, difference in readings between "morphometrically mature" and "immature" males) require legal review before regulations can be tabled which prevent the retention of soft shell crabs. While the principal intent of the gauge is regulating the quality of landed snow crabs, the gauge could also be highly useful as a scientific instrument in biological assessments (e.g. for quantifying shell condition, determining molting frequency, as a simple method of discriminating between "morphometrically mature" and "immature" crabs).

6. RECOMMENDATIONS

6.1 GAUGE MODIFICATIONS

Originally Pacific Transducer durometers were modified from the "off-the-shelf" model (Appendix E) for the Alaskan Dungeness crab fishery by sealing the housing with silicone, enclosing and waterproofing the dial with a plastic cover, exchanging the pointed indenter for a 1/8" (3.175 mm) diameter indenter of semi-circular shape, adding a 4" (10.2 cm) extension rod between the indenter and the body of the instrument, and placing an o-ring in the indentor shaft to prevent water from entering the mechanism (J. Marcus, Pacific Transducer Corp., pers. comm.).

The extension bar was added to the Dungeness crab durometers because the indenter was pressed against the lower surface of the carapace by inserting the bar between the legs of the crab. A bar of 1" (25 mm) would be more appropriate for snow crabs since the unobstructed claw is tested, not the carapace. The bar would also serve to house the o-ring seal.

The waterproof dial is not recommended for the snow crab fishery. Since a plastic case totally encloses the waterproofed dial, the lazy hand must be reset with a magnetic wand which is very tedious when examining large numbers of animals. However, a dial which has not been waterproofed could eventually corrode so care would be required to minimize contact of the dial with seawater.

The recommended durometer design for the snow crab fishery is:

1. seven lb (31.14 N) maximum force production.
2. 1/8" (3.175 mm) diameter hemispherical indenter.
3. 1" (25 mm) stainless steel extension rod.
4. O-ring seal or silicone grease in extension rod.
5. standard thumbscrew reset lazy hand.
6. case and dial sealed with silicone grease to minimize corrosion. Lazy hand mechanism sealed with silicone grease to inhibit over-shoot when the indentor is rapidly depressed.
7. a holster for the instrument, available as an optional accessory to the purchaser, and attachable to a belt. A lid would secure the gauge and the holster would inhibit salt water spray from entering the compartment.

6.2 FUTURE STUDIES

(1) Durometers should be **distributed to selected fisheries officers** for field evaluation. A **seminar** should be organized for the officers which would explain the mechanical design, method of use, and limitations of the gauge. After the field trials, the officers should be **interviewed** to evaluate practical problems before large numbers of gauges are circulated.

(2) Many "morphometrically mature" males are smaller than the minimum legal size of 95 mm carapace width. If these small "mature" males grow no further, they represent an untapped resource, unaccessible to fishermen and processors.
A study should examine the feasibility of **eliminating the 95 mm carapace width regulation** and replacing it with one which permits the **retention of "morphometrically mature" males** yet protects growing "morphometrically immature" crabs. The role of a durometer or other gauge in enforcing this new regulation should be assessed.

(3) Laboratory experiments could be undertaken to **relate hardness readings to time since molt**. Gauge readings could then be used by fisheries biologists to calculate date of molt and growth rates in the population.

(4) The **mortality of soft shell crabs** returned to the water should be examined since they are delicate and easily killed by rough handling. Fisherman should also be **educated in proper handling techniques**. This would directly benefit fishermen since surviving crabs would enter the fishery as hard shelled individuals in subsequent years.

(5) Industrial meat extraction procedures for snow crabs are inefficient. **Meat loss in the plant(s)** should be studied with the aim of improving processing efficiency.

7. ACKNOWLEDGEMENTS

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