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PROSPECTS FOR DISTINGUISHING MORPHOMETRICALLY MATURE AND IMMATURE CRABS: AN ALTERNATE MANAGEMENT STRATEGY FOR THE SNOW CRAB FISHERY.

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Abstract

A new snow crab fishery management strategy geared toward differentially fishing morphometrically mature male snow crabs should be considered. The advantages of the new strategy include:

1) harvesting of 'pygmy' males, currently a wasted resource.

2) protection of 'morphometrically immature' crabs, which are still growing.

3) possible enhancement of stock fecundity.

4) possible improvement of yield per recruit.

5) lower incidence of soft shell crab in the catch.

The success of the strategy depends on distinguishing morphometrically mature from morphometrically immature crabs. Two types of guages designed for this purpose are discussed: a claw size guage and a hardness guage (durometer).

A claw size guage would use a single claw measurement to separate most morphometrically mature crabs from immature crabs. While a single measurement only approximates morphometric maturity, this type of guage would be inexpensive and easy to use.

An alternate approach would be to use a hardness guage (durometer), since morphometrically immature crabs have more flexible claws than morphometrically mature individuals. A prototype durometer has already been developed, and its main advantage lies in its ability to separate morphometrically mature and immature crabs *as well as* hard and soft shell crabs. However, claw weakening from repeated measurements may cause enforcement problems.

The durometer is probably most useful as a management tool for fisheries that catch high proportions of soft shell crabs. A claw size guage is recommended as a practical regulatory tool and should be implemented on an experimental basis. Area 5 of the Cape Breton fishery is suggested as a pilot site.

Résumé

Il convient d'envisager une nouvelle stratégie de gestion de la pêche du crabe des neiges axée sur la sélection des crabes des neiges mâles ayant atteint la maturité morphologique. Une telle stratégie offrirait les avantages suivants :

1) récolte des mâles "pygmées", ressource actuellement inexploitée;

2) protection des crabes qui n'ont pas atteint la maturité morphologique et continuent donc de croître;

3) amélioration possible de la fécondité du stock;

4) amélioration possible du rendement par crabe recruté;

5) diminution des crabes à carapace molle dans les prises.

La succès de la stratégie dépend de la capacité à distinguer les crabes qui ont atteint la maturité morphologique de ceux qui ne l'ont pas encore atteinte. Il est question ici de deux types d'instruments conçus à cette fin: un dispositif de mesure de la taille des pinces et un duromètre permettant d'en mesurer la dureté.

Avec un dispositif portant sur la taille des pinces, on procéderait à une seule mesure pour différencier les crabes ayant atteint la maturité morphologique des crabes immatures. Bien qu'on ne puisse obtenir ainsi qu'une idée approximative de la maturité, la méthode a l'avantage d'être bon marché et d'utilisation facile.

Une autre solution résiderait dans l'utilisation d'un duromètre. Les crabes qui ne sont pas encore morphologiquement immatures ont en effet les pinces plus flexibles que ceux qui sont parvenus à maturité. Un prototype de duromètre a déjà été conçu. Or, il présente l'avantage de distinguer les crabes non seulement selon la maturité morphologique, mais selon la dureté de la carapace. Toutefois, l'application de la méthode peut se trouver compliquée par les pinces ramollies sous l'effet de mesures répétées.

Le duromètre est probablement un outil de gestion très utile dans les pêches à proportion élevée de crabes à carapace molle; mais on recommande l'emploi, à titre expérimental, du dispositif de mesure de la taille des pinces comme outil d'exécution de la réglementation et on propose d'en faire l'essai dans la zone 5 du Cap-Breton.

Introduction

The Snow Crab Fishery

In the past two decades the snow crab, *Chionoecetes opilio* (O. Fabricius, 1788; Family: Majidae), has gained considerable economic importance in Canada. Harvesting began in the 1960's and the fishery has expanded to become, in economic terms, the fourth largest in the Canadian Atlantic (Elner and Bailey, 1986). A substantial amount of research on snow crab ecology and reproductive biology has been conducted to aid in fisheries management.

However, our understanding of snow crab biology is incomplete, partly because this deep, cold water species is so inaccessible. The snow crab occurs in the wild at depths ranging from 13 to 1500 m and temperatures below 5°C (Williams, 1984). In addition, the fishery is relatively young in Canada, and long term data are not available.

It was originally believed that female snow crabs stop molting at maturity while males continue to grow and molt (see Watson,1970; 1972). Watson also argued, based on mating experiments and the presence of spermatophores in the vas deferens, that male snow crabs reached maturity at 50 to 70 mm carapace width. The snow crab fishery was thus believed to be naturally protected from over-exploitation since females are small compared to males and are not fished. In addition, only males above 95 mm carapace width are harvested commercially in Canada (Elner and Bailey, 1986), so mature males were thought to have a chance to mate several times before being removed by the fishery.

The paradigm of a fishery 'safe' from over-exploitation has been slowly eroded after two decades of intense fishing pressure on Canadian snow crab stocks. The actual responses of the stocks to exploitation have been erratic; in one case a stock has expanded, in another case it has remained stable, and in a third it has collapsed (Elner and Bailey, 1986). The variability in recruitment into the fishery has led to a reappraisal of snow crab biology.

The Morphometric Maturity Theory

Male snow crabs display two distinct patterns of claw size (Watson, 1970; Coulombe *et al.*, 1985; Conan and Comeau, 1986). Plotting the logarithm of a claw measurement against the logarithm of carapace width for animals from a wide size range results in two parallel clusters (Fig. 1). Crabs from the higher cluster have undergone a molt in which their claws change shape and increase disproportionately in volume. In other words, the claw has undergone a change in allometry. Male snow crabs achieve this claw differentiation over a considerable range of carapace widths, from 60 to 120 mm. Thus, some small crabs may have differentiated claws while some large ones may not.

Although male snow crabs were once thought to continue growing after reaching maturity, a recent theory put forward by Conan and Comeau (1986) is beginning to gain wide acceptance. They postulate that males with larger claw to carapace ratios, which they call 'morphometrically mature,' have reached terminal molt, while crabs with smaller ratios -- 'morphometrically immature' -- continue to grow. Of the 110 morphometrically mature males they kept in the laboratory for a year, none molted, while 16 of the 24 morphometrically immature males did (Conan and Comeau, 1986). O'Halloran (1985) obtained similar results.

According to Conan and Comeau (1986), the fishery, which is regulated by carapace width, is removing both large morphometrically mature and immature males while leaving small morphometrically mature males unexploited (Fig. 1). In 1987, up to 46% of the landed males from the Atlantic side of Cape Breton were morphometrically immature (Elner *et al.*, 1988). 'Pygmy' morphometrically mature males may be immune to fishing pressure since they appear to stop growing below the minimum legal catch size of 95 mm. These pygmy males could then inhibit recruitment and growth of conspecifics by using limited resources like food and space. However, they are possibly important in maintaining the reproductive potential of stocks since large males are removed by the fishery (Elner *et al.*, 1988). In any case, if regulations remain as they are, fishing pressure could eventually lead to genetic selection for small morphometrically mature males.

Conan and Comeau (1986) suggest that morphometrically immature males are also functionally (i. e. reproductively) immature, despite the presence of abundant spermatophores in their vas deferens, because their claws have not yet differentiated for carrying female crabs during mating. Although the reproductive implications of the morphometric maturity theory remain controversial, a regulation that would separate morphometrically mature and immature males appears to be an advisable management strategy.

The Soft Shell Problem

Initially, snow crab fisheries exploited 'virgin biomass,' a natural reserve of large, old, hard shelled crab accumulated over many undisturbed years. Eventually, most of these crabs were culled, and fisheries began to depend on recruitment to replenish crab stocks. As a result, current catches are prone to substantial annual variability. In addition, the composition of snow crab stocks has changed over the period of exploitation with an increasing proportion of morphometrically immature crabs. Since these crabs are still growing, catches often reflect a high incidence of newly molted males, which fishermen refer to as 'white' or 'soft shelled' crab.[1]

Soft shelled crab have been problematic in many snow crab fishing areas (e. g. Taylor and O'Keefe, 1986). Since meat yield is linearly related to hardness for morphometrically mature males (Foyle *et al.*, 1989), soft shell crabs are undesirable due to their low meat content. They are also delicate and suffer high mortality from rough handling, resulting in poor meat quality when processed. Processors thus hesitate to accept soft shell crabs, which reduce profits. Unless an enforceable regulation excluding soft shell crab from the catch is implemented, rejecting these crabs may only drive fishermen to other buyers.

An Alternate Management Strategy

The traditional carapace minimum size limit of 95 mm was originally imposed on the fishery not for rigorous biological reasons, but because processors could not efficiently extract meat from crabs of smaller sizes (Watson, 1970). With increased automation and improved machinery, it is now possible to process crabs below the legal size. *The*

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[1]Fishermen refer to crabs with semi-flexible, pale colored carapaces as 'soft shell' crab, although the shells have actually hardened for several weeks. The truly soft shell condition occurs immediately after molting, which is coincident with a period of non-feeding.

restriction may thus be an out-dated and wasteful method of managing the snow crab fishery. As Elner *et al.* (1988) state:

"...large numbers of males have attained a terminal moult below the legal minimum size; an innovative strategy to harvest this 'wasted' resource on an experimental basis may be desirable."

Simply lowering the minimum legal carapace width to remove the 'pygmy' males is not advisable, since many small morphometrically immature animals, which would otherwise grow into larger, more valuable crabs, would be culled, possibly without reproducing.

A strategy of differentially fishing morphometrically mature and immature crabs might be more appropriate. *Preferentially culling pygmies would leave behind crabs that are still growing, even large ones. This strategy might also enhance the reproductive capacity of snow crab fisheries if morphometrically immature crabs are indeed functionally immature.*

How can fishermen separate morphometrically mature and immature crabs? Theoretically, morphometric classification should be made on the basis of claw size *and* carapace width measurements, since morphometric maturity is defined by a change in the claw's shape and size relative to the carapace. However, making two measurements and calculating their ratio is not a practical field method. A single claw measurement, using an average claw size at morphometric maturity as a minimum legal cut-off, would be a better alternative, provided that the separation of morphometrically mature and immature crabs is not compromised drastically. Morphometrically immature males have not only smaller but softer, more flexible claws than morphometrically mature crabs (Foyle *et al.*, 1989). Thus, a minimum claw hardness regulation would also separate morphometrically mature and immature crabs.

CAFSAC has already recommended development of a claw guage to aid in fishery management on an experimental basis:

"CAFSAC notes that despite increased understanding of the biology of the snow crab, questions remain as to the appropriateness of the current minimum size (95 mm carapace width) and the target harvest rate (50-60% of the available stock) in achieving the objective of protecting the reproductive potential of the stock...other management strategies may be more appropriate. One such alternative strategy may be the adoption...of a strategy to harvest male crabs that have reached their final size below 95 mm carapace width. Such crabs can be distinguished by their larger claws in comparison to crabs that are still growing, and this difference can be determined using a ring guage." (CAFSAC Advisory Document 88/3).

Practical claw guages are required to separate morphometrically mature and immature crabs and to provide an unequivocal basis for enforcing new regulations. This report discusses two potentially useful types of guages: a claw size guage calibrated to a proposed minimum chelal dimension, and a hardness guage (durometer).

The Claw Size Guage

Claw length, width, and height are all greater in morphometrically mature than in morphometrically immature male snow crabs of a given carapace width (Conan and Comeau, 1986). An effective claw size guage would measure one of these dimensions against a legal standard determined through scientific studies. Minimum legal size might vary among fisheries, depending on regional differences in claw size and shape.

A minimum chelal size limit would *approximate* morphometric maturity. Thus, some morphometrically immature crabs would still be retained and some morphometrically mature crabs would still be thrown back (Fig. 2). However, their relative proportions in the catch would change, and crabs of a much wider range of carapace widths would be caught .

A claw size guage does not directly address the soft shell issue. Nevertheless, *a claw size regulation would probably decrease the incidence of soft shell crabs in the landings* since morphometrically mature males, which have presumably stopped molting, would principally be harvested.

Design and Operation

Numerous claw size guage designs are conceivable; for example, cross-sectional claw area could be measured with a ring guage. Interference from spines and variations in claw shape among individuals could seriously hinder use of a ring guage, but measuring a single dimension (i. e., height, width, or length) would alleviate these difficulties. A claw guage which measured claw length (see Fig. 3b) would avoid virtually all spines and would result in a fairly good separation of morphometrically mature and immature crabs (Fig. 2). A practical and simple claw length guage could resemble the carapace width caliper used for lobsters (Fig. 4).

Advantages

1) A claw size guage would be extremely easy to use. Conceptually it is very similar to the existing carapace width guage for lobsters.

2) The guage would be inexpensive.

3) A claw size guage would have no working parts that could be damaged.

4) The guage does not require recalibration.

Disadvantages

1) The single claw dimension measurement is only an approximation for morphometric maturity. Some morphometrically immature males will therefore be retained, and some morphometrically mature males will be thrown back. Relative quantities of retained and culled crabs will vary annually with the population size structure.

2) The allometric relationship between claw size and carapace width varies geographically (Conan and Comeau, 1986; Foyle *et al.*, 1989), which limits the applicability of the guage and necessitates region-specific modifications.

3) Morphometrically mature crabs that have disproportionately small claws due to a previous loss could appear to be sub-legal using a claw size guage. These crabs, though relatively few, would be thrown back unnecessarily.

5) The claw size guage has yet to be deployed or trialed.

The Hardness Guage

In 1975, the Department of Fisheries and Oceans (DFO) imposed a regulation that prohibited landing of soft shell crabs, but the regulation was unenforceable because shell condition was a subjective determination (L. Rowe, DFO, Nfld., pers. comm.). Enforcement was subsequently relaxed and the regulation rescinded in 1986 (Taylor and O'Keefe, 1987).

The modified Pacific Transducer durometer allows shell hardness to be determined objectively and may thus enable reinstatement of soft shell regulations. Such regulations may be particularly important for fisheries that catch a high proportion of soft shell crabs -- for example, the offshore fishery in the Gulf of St. Lawrence.

The durometer has been tested to address the 'soft shell problem' in a Newfoundland snow crab fishery (Foyle *et al.*, 1989). During the course of testing, it was discovered that hard shelled morphometrically immature males have not only smaller but softer, more flexible claws than morphometrically mature crabs. *The durometer can thus separate hard shelled morphometrically mature males from both soft shell and morphometrically immature crabs.*

Prototype durometers have been distributed to selected fisheries officers in Newfoundland for field evaluation. A workshop explaining the mechanical design, method of use, and limitations of these gauges was conducted in August, 1989.

Design and Operation

Durometers are spring-driven gauges used to measure the hardness of elastomeric compounds (foams, rubbers, plastics). The indenter of the gauge is pressed against the material and sufficient force applied until the indenter 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") records the highest durometer reading until reset with a thumb screw.

A modified durometer (model 307LCRB, Pacific Transducer Corporation, Los Angeles, Calif., U.S.A.) developed for use on the Alaskan Dungeness crab (*Cancer magister*) (Hicks and Johnson, 1988) has been tested successfully on snow crab (Foyle *et al.*, 1989). Several additional modifications were suggested after testing. Foyle *et al.* (1989)

recommended the following durometer design (Fig. 5) to separate hard and soft shell snow crab:

1. seven lb (31.14 N) maximum force production for easy application and minimal claw damage.
2. 1/8" (3.175 mm) diameter hemispherical indenter, which, unlike the standard point, does not penetrate the shell.
3. 1" (25 mm) stainless steel extension rod which separates the indenter from the body of the instrument.
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 indenter is rapidly depressed.

Foyle *et al.*(1989) stated that durometer readings were most accurate when:

1. Only one durometer reading per claw was taken, as repeated measurements softened claws.
2. Durometers were applied with a slow, even force to prevent spuriously high readings.
3. Measurements were made on the bottom of the claw (see Fig. 3), where spines are absent.

Advantages

1) The durometer separates both hard from soft shelled *and* morphometrically mature from immature crabs (Fig. 6).

2) The durometer's effectiveness in separating morphometrically mature and immature males is independent of the size of the claw or carapace. This hardness guage can therefore separate morphometrically mature and immature males over their entire size range with equal accuracy.

3) As an objective measure of shell hardness, the durometer has numerous uses in industry. For example, processors can use the guage to anticipate meat yields and to regulate their buying practices.

4) The durometer can also be a useful scientific tool. It can be used, for example, to assist in determining time since last molt (Foyle *et al.*, 1989).

5) The modified Pacific Transducer durometer is portable and easy to use.

6) A prototype guage is already available.

Disadvantages

1) Durometer readings are not repeatable, since multiple measurements soften claws. Problems of enforcement might arise as a result. For example, fishermen could argue that fisheries officers or plant inspectors erroneously classified 'hard' animals as 'soft' because their measurements were made on previously measured or handled claws. A regulation specifying that fishermen make only one measurement per claw would minimize but not eradicate this problem.

2) Separating morphometrically mature and immature crabs on the basis of claw hardness *depends* on making measurements. Visual discrimination of crabs under the legal hardness limit is impossible, whereas a person experienced in sorting crabs on the basis of claw length often need not make a measurement. The durometer's strict reliance on measurements may make enforcement tedious or impractical.

3) Spurious high lazy hand readings can occur if the indenter is rapidly depressed, and fishermen could potentially retain soft shell crabs by pressing the guage too quickly. 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.

4) The durometer cannot separate *all* morphometrically mature males from immature males due to some overlap in hardnesses. In addition, there is some variability in the durometer's readings.

5) Since durometers are spring driven guages, calibration could change over the course of a fishing season. However, according to the manufacturer, the mainspring is heat treated and quite stable. The company will also annually recalibrate its guages free.

6) The durometer is relatively expensive (about $500 Cdn.).

A comparison of the durometer and claw length guage is given in Table 1.

Impact of a Claw Size or Hardness Regulation on the Fishery

Converting from a carapace width minimum size regulation to a minimum claw size regulation would have profound effects on the fishery. Large immature crabs would no longer be harvested, but, on the other hand, previously sub-legal crabs would (Fig. 2).

The snow crab population structure and the size frequency distribution should change with time after a claw regulation is introduced. A predictive model is essential (1) to help biologists understand the resulting changes in biomass and population structure once an experimental fishery is underway, and (2) for fisheries managers to properly advise industry of the potential implications of a change in regulations.

Mohn and Elner (1988) devised a yield per recruit model that can simulate differential fishing pressures on morphometrically mature and immature males. Yields and biomass were calculated for a wide range of fishing pressures (F=0.0-2.0) on both morphometrically mature and immature crabs. *The highest total yields per recruit were obtained when morphometrically mature males were fished preferentially but not exclusively.*

Mohn and Elner (1988) assert that *a differential fishing strategy would reduce the incidence of soft shell crab in the catch.* Selective fishing would also smooth annual recruitment pulses because crabs from a greater number of size classes would contribute. Mohn (1988) developed two additional models, representing dynamic and equilibrium situations, which demonstrated that stocks were very resilient to exploitation when only reproducing males were harvested. This finding is particularly relevant if morphometrically immature males are also functionally immature.

Table 2 shows the minimum carapace widths of morphometrically mature and immature crabs that would be retained for various claw height limits.

Table 2. Minimum carapace widths that could be caught for various chela height limits. Data are taken from sea samples of Areas 5 and 6 in Cape Breton, August and September 1988.

	-- minimum carapace width fished --	
chela height (mm)	*MM	MI
12.2	63	63.4
15.6	65	77.5
20.1	75	93.7
25.8	90	113.3
33.1	108	____

*MM = morphometrically mature
MI = morphometrically immature

Source: R. W. Elner, DFO, Halifax, N. S.

A large proportion of soft-shelled crabs that are thrown back probably die. A claw size regulation will *not* alleviate this problem.

A Pilot Management Initiative

An area within a snow crab fishery should be managed on an experimental basis, using either claw size or claw hardness criteria to separate morphometrically mature and immature males. Area 5 in Cape Breton would be an appropriate site, since it supports relatively few fishermen. In addition, long term catch data for this area are available. Area 6 can serve as a control site with which to contrast the results of the Area 5 management program.

We recommend using a claw length guage to regulate fishing in the area. The guage is easy to use, as spines will not interfere with its operation. The legal cut-off should be based on morphometric data from Area 5 crabs. In addition, the guage is simple in design and can be developed immediately. The final choice of guage design and experimental area ultimately rests with DFO.

The following issues should be addressed in conjunction with this pilot management initiative:

1) The *mortality of soft shell crabs* returned to the water should be examined since they are delicate and easily killed by rough handling. Fishermen should also be trained *in proper handling techniques*. New management strategies may be ineffectual if the majority of soft shell crabs die when thrown back.

2) The ability of claw size and hardness measurements to separate soft from hard, and morphometrically mature from immature crabs of a sample catch should be *compared directly* in a blind test. The test should be conducted on snow crabs from Area 5 in Cape Breton, so that minimum cut-off for a claw length regulation can be determined as well.

3) The *lower size limit for processing* crab should be assessed, since a claw size regulation of, for example, 20 mm claw height, could permit capture of crabs as small as 75 mm carapace width.

Conclusion

The guage used in new snow crab management initiatives should depend on the individual management objectives of each fishery. Fisheries that catch a high proportion of soft shell crab may find the durometer an essential regulatory tool. On the whole, however, a claw size guage -- and in particular a claw length guage -- appears a more practical regulatory tool. It is cheaper, easier to use, and need not be applied to every crab by the experienced user. In addition, claw length measurements should be repeatable, which frees the guage from the enforcement difficulties that may plague the durometer.

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Attributes	Durometer	Length guage
Ease of use	◐	●
Portability	●	●
Cost	○	●
Separation efficiency MM & MI*	●	◐
Separation efficiency hard and soft	●	◐
Repeatability	○	●
Need for calibration	◐	●
Universality	● ?	○ ?

● = good
◐ = fair
○ = poor

*MM = morphometrically mature crab
MI = morphometrically immature crab

Table 1. The claw length guage and the durometer are each rated in terms of attributes of an ideal guage.

	MI crabs #	MI crabs %	MM crabs #	MM crabs %	Soft crabs #	Soft crabs %	Total catch
crabs > 72 durometer units	1	2	49	98	0	0	50
crabs > 95 mm carapace width	21	17	103	83	80	65	124

Sample size: 174

	MI crabs #	MI crabs %	MM crabs #	MM crabs %	Total catch
crabs > 40 mm claw length	7	4.8	139	95.2	146
crabs > 95 mm carapace width	21	15.4	115	84.6	136

Sample size: 185

MI = morphometrically immature
MM= morphometrically mature

Table 1. a) The composition (morphometrically mature vs. immature, hard vs. soft) and size of total catches are compared for the 95 mm carapace width regulation and a hypothetical 72 durometer unit hardness regulation. b) Catch size and composition (morphometrically mature vs. immature) are compared for the 95 mm carapace width regulation and a hypothetical 40 mm claw length regulation. The data are based on a non-random sample of crabs from Newfoundland (a disproportionately large number of soft shell crabs were selected for testing).

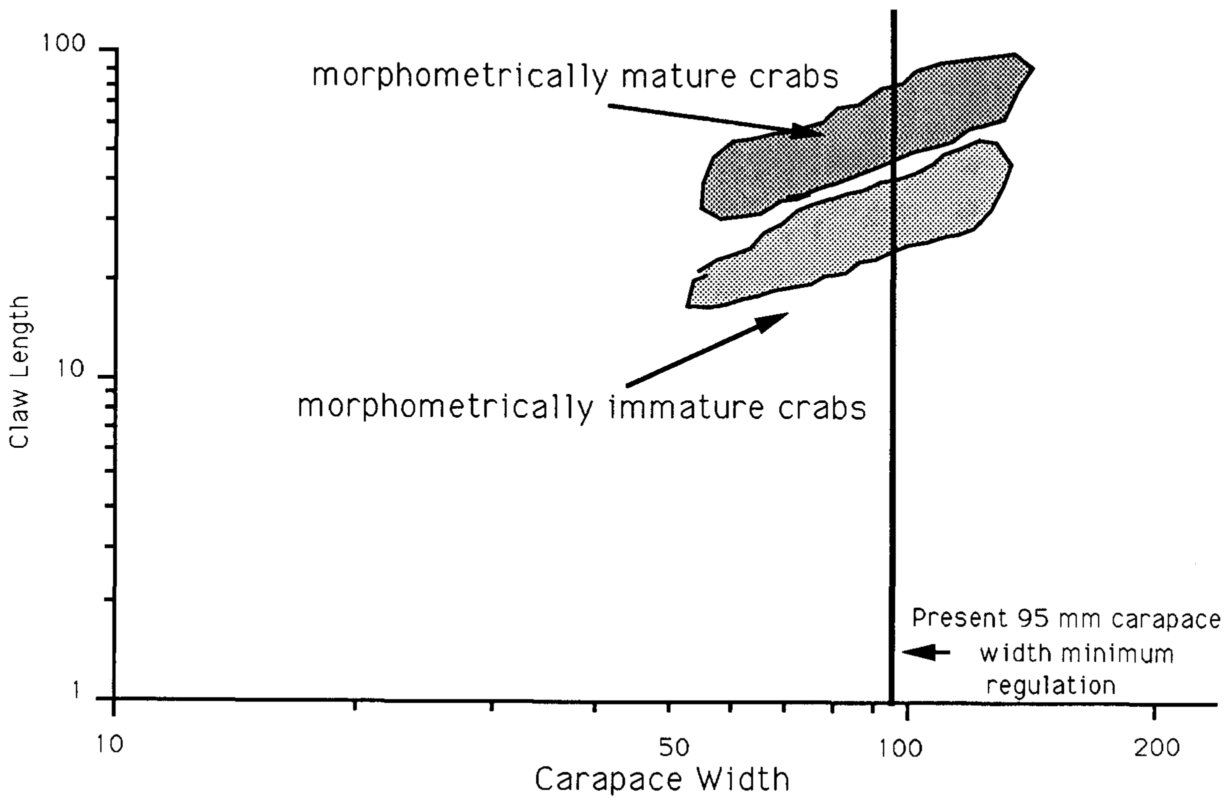

Figure 1. Schematic diagram of present carapace width minimum and proposed claw size minimum regulations.

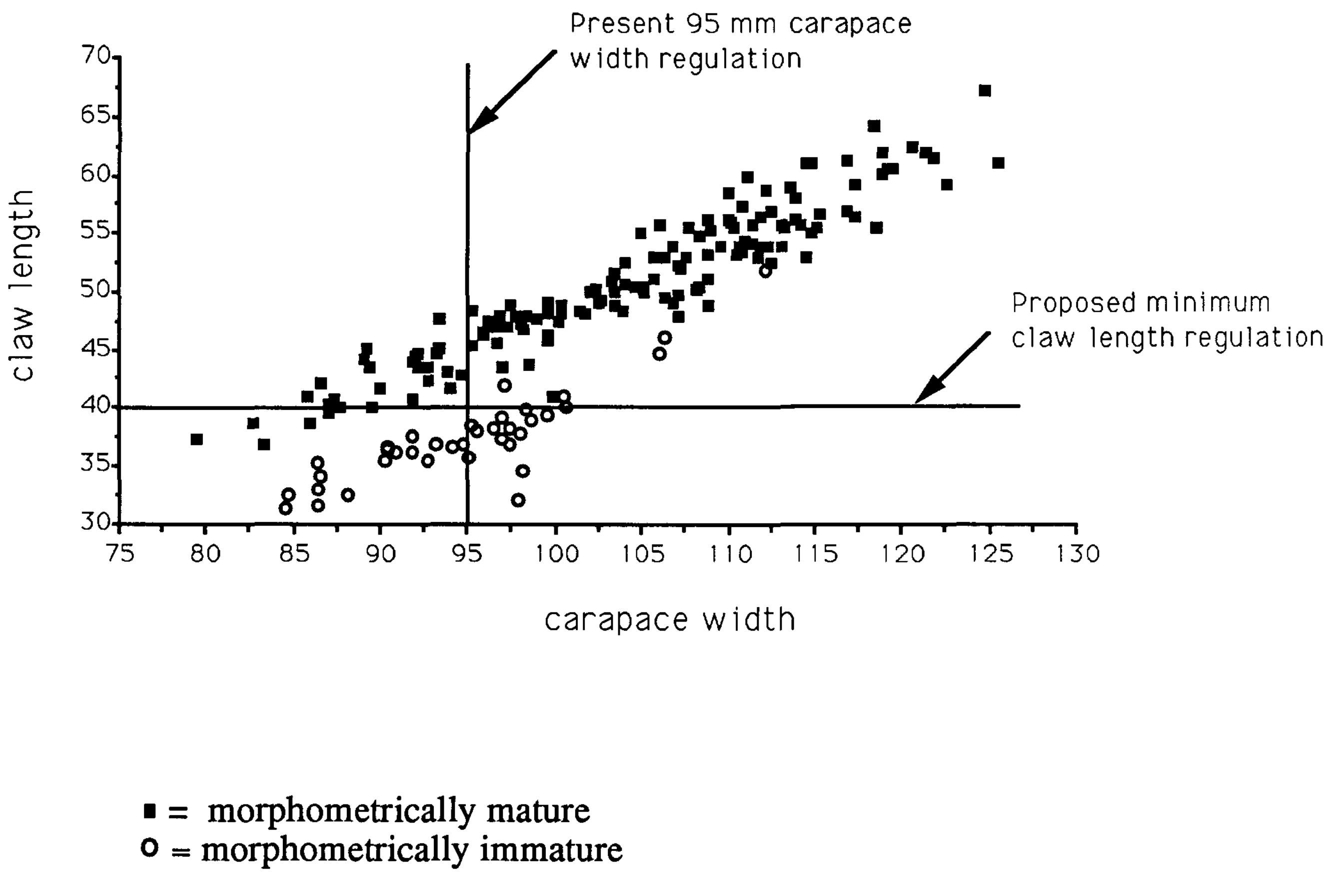

Figure 2. Crab retention under the current 95 mm carapace width regulation versus a proposed 40 mm claw length regulation for a non-random sample of 174 Newfoundland crabs.

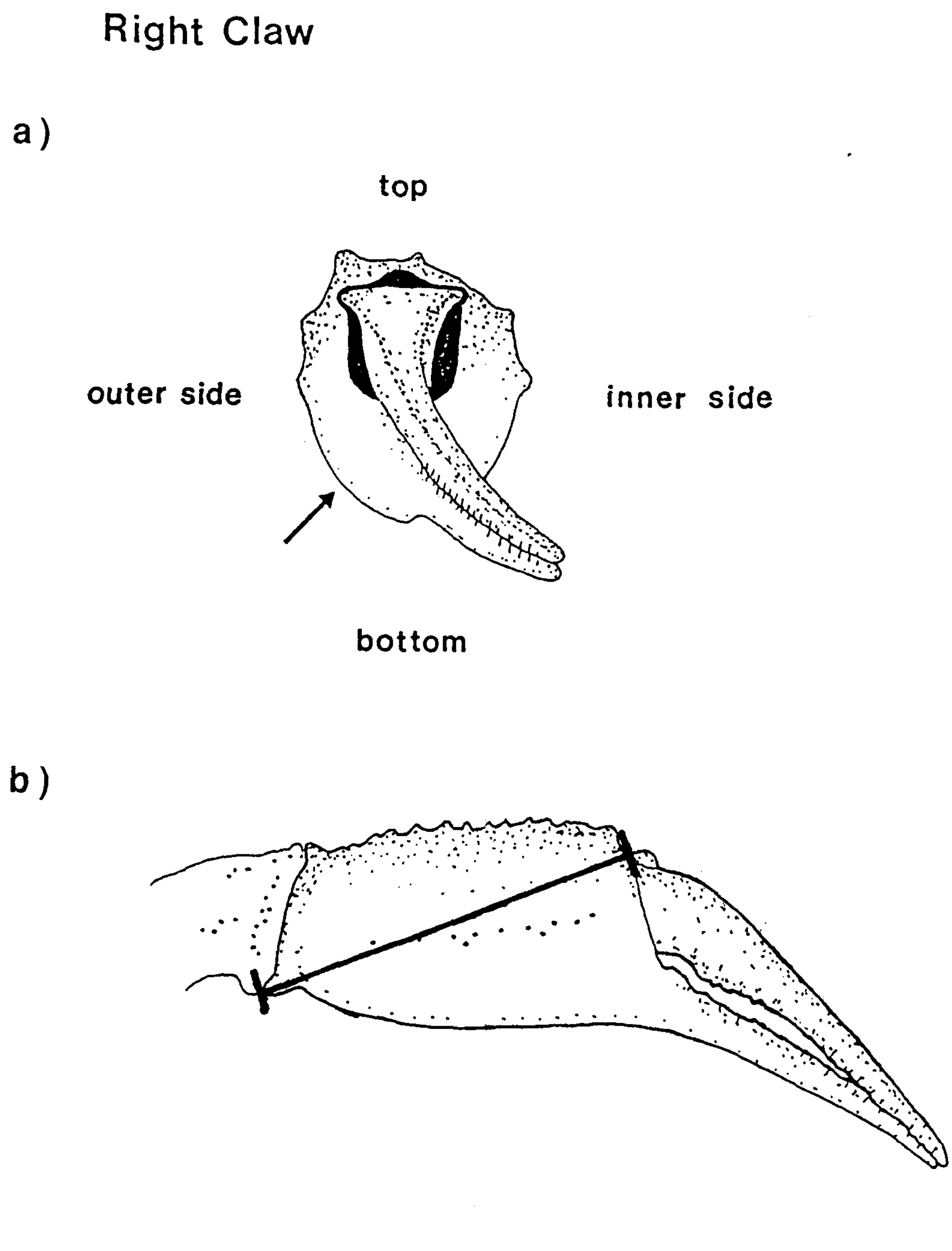

Figure 3. a) The solid arrow on this diagram illustrates the bottom position on a snow crab claw where durometer readings should be made. b) Measuring the length of the claw would avoid interference from spines.

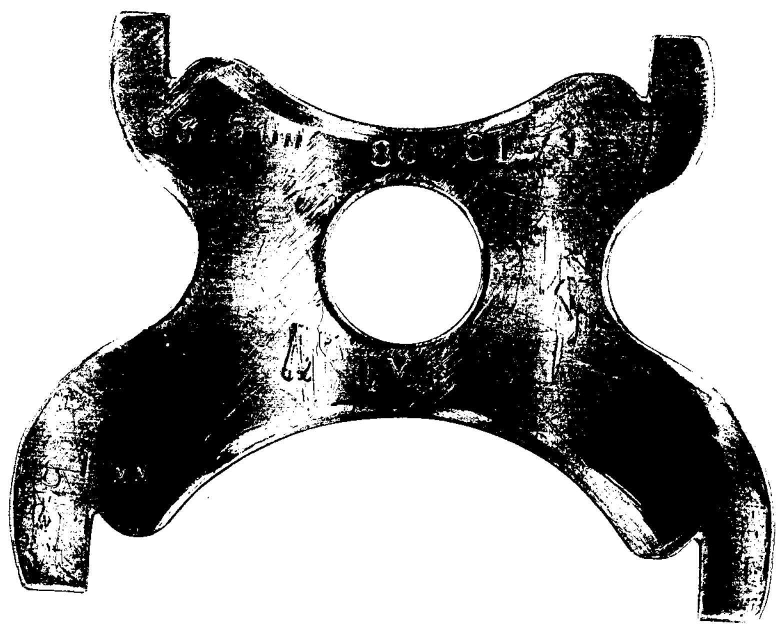

Figure 4. A claw length guage could resemble this lobster carapace width guage.

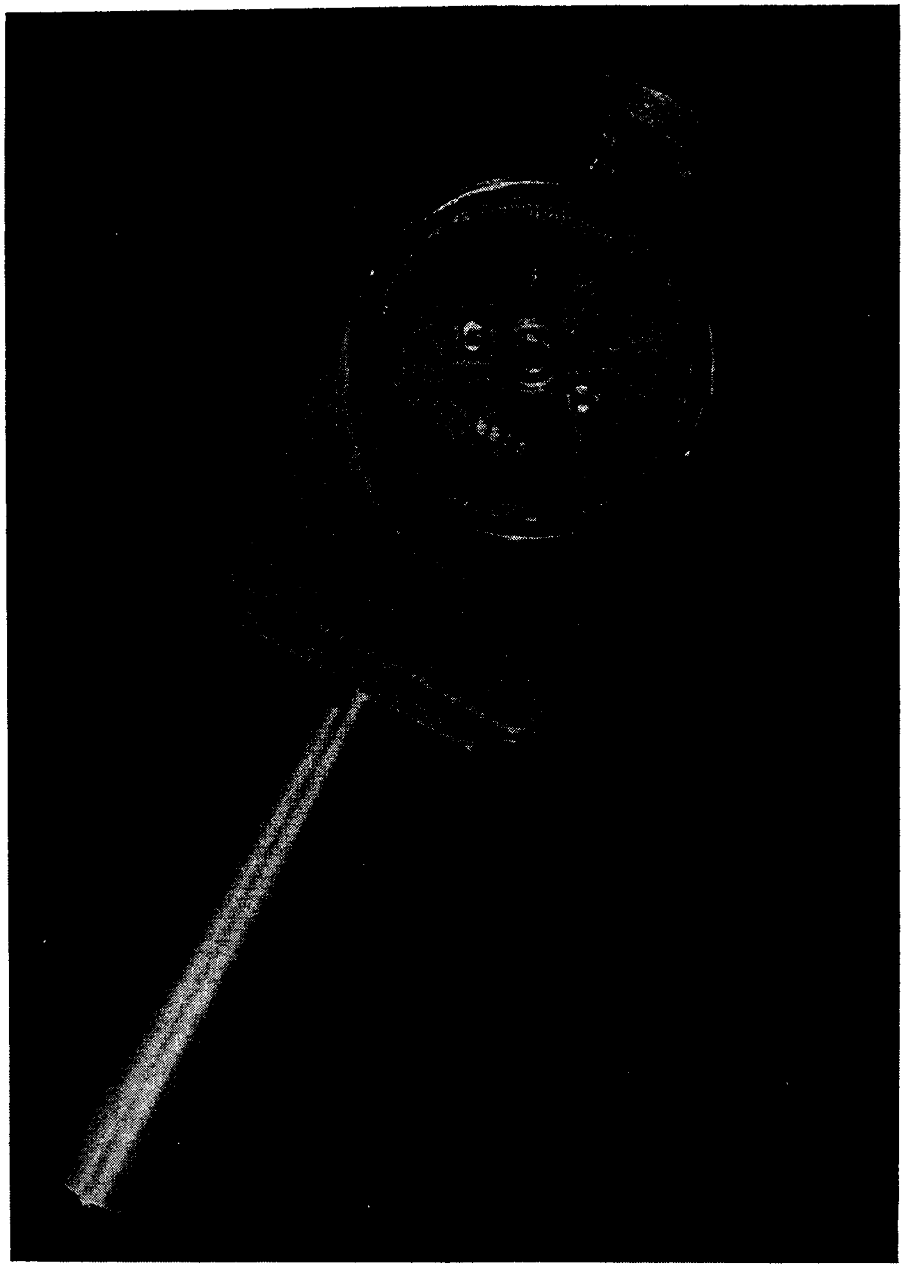

Figure 5. The modified Pacific Transducer durometer. This instrument does not include the additional modifications suggested by Foyle and Hurley (1989).

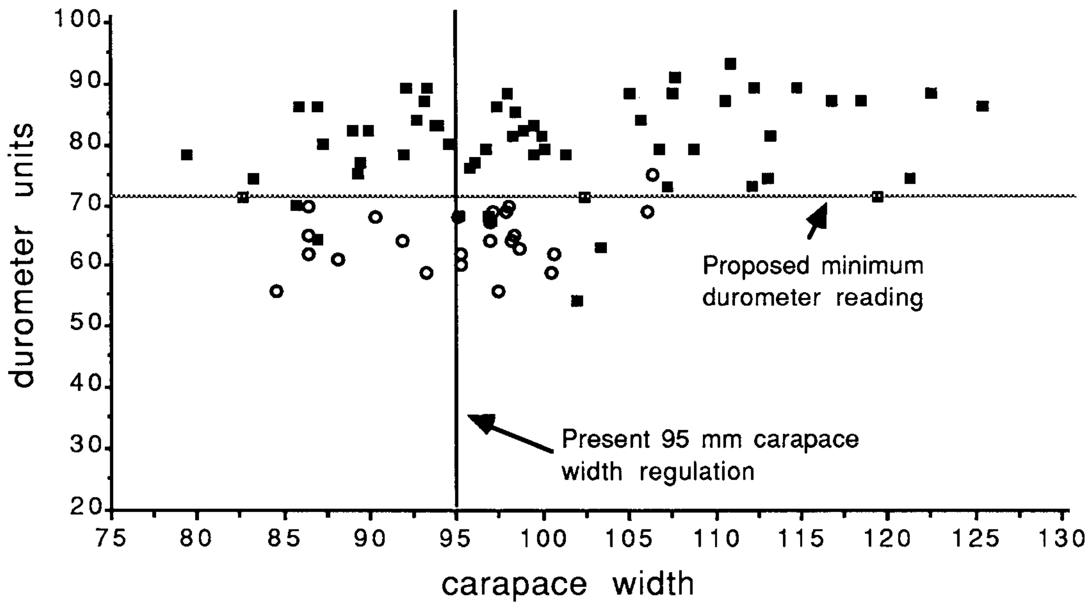

Figure 6. Plot of durometer readings versus carapace width for hard shell, morphometrically mature (■) and immature crabs (O). Durometer readings were significantly different (t-tests) between the morphometrically mature and immature crabs, since the claws of morphometrically immature old shell crabs were flexible (see Foyle et al., 1989). A cut-off value of 72 durometer units would exclude 98% of morphometrically immature animals (Foyle et al., 1989).