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The Effect of Shell Condition on the Male Snow Crab, *Chionoecetes opilio*, Weight-width Relationships

by

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Abstract

From August to October 1989, 710 legal-sized male snow crab, Chionoecetes opilio, from the east coast of Newfoundland were sampled in order to determine what effect shell condition had on live weight and by inference, yield. Results demonstrate that in undamaged, live individuals shell condition has little effect on weight. The implications of this information to the processing and harvesting sectors of the industry in Newfoundland are discussed.

Résumé

D'août à octobre 1989, on a échantillonné 710 crabes des neiges mâles, Chionoecetes opilio, de taille réglementaire provenant de la côte est de Terre-Neuve, afin de déterminer quels effets la condition de la carapace avaient sur le poids vif et, par voie de conséquence, sur le rendement. Les résultats révèlent que chez les spécimens vivants qui sont en bon état, la condition de la carapace a peu d'influence sur le poids. On traite ici des conséquences de cette constatation pour les secteurs de la récolte et de la transformation du crabe des neiges à Terre-Neuve.

Introduction

The snow crab, Chionoecetes opilio fishery began on the northeast coast of Newfoundland in 1968. The processing sector of the industry produces frozen or canned product, with little if any emphasis on producing cooked sections. While as many as 17 processing licensees have been active at any one time, the industry is largely dependent on 10 processing operations situated along the northeast coast.

As in any operation relying on labour-intensive processing methodologies, profitability is dependent on price, productivity, and yield from the raw product.

In most areas of Newfoundland the snow crab fishery is prosecuted from mid-April until either area quotas have been caught, or until the end of November when the fishing season ends. During July, August and September most commercial fishing areas along the coast experience a high incidence of newly-molted soft-shelled snow crab in commercial catches. Until 1986, this constituted a serious nuisance effect but a strictly enforced regulation prohibiting the landing of soft-shelled crabs, effectively prevented the problem from developing into a major concern to the processing sector.

In 1986 the regulation that had effectively prevented the landing of soft-shelled crab was struck down due to the fact that the definition of soft-shelled crab was considered as being too subjective to withstand scrutiny in a court of law. Although an attempt to devise a tool that will provide an objective means of distinguishing between hard and soft-shelled has had promising results, (Foyle et al., 1989) there is at present no regulatory means of preventing the landing of this low-yield poor-quality product.

Processors who ultimately must bear the responsibility and indeed the cost of harvesting soft-shelled crab, have long maintained that it was in the fishermen's interest to return soft-shelled crab to the water. It was reasoned that fishermen would enjoy increased benefits by harvesting these animals after they had recovered to a hard-shelled condition and the round weight per individual increased as the water absorbed following ecdysis was replaced by muscle, a period of from 2-3 months duration (Taylor et al., in press).

The dropping of this regulation prohibiting the landing of soft-shelled crab coincided with a sharp decline in resource availability (Taylor and O'Keefe, 1987). This scarcity of resource combined with high prices resulted in large quantities of soft-shelled crab being landed and accepted by processors at many Newfoundland ports (Taylor and O'Keefe, 1988). This study was undertaken in order to determine what effect if any, the harvesting of soft-shelled crab has on the whole weight of fishermen's landings.

Materials and Methods

During August, September and October of 1989, commercial-sized (>=95mm carapace width (CW)) male snow crab were sampled from commercial catches held at several processing plants along the northeast coast of Newfoundland and from catches obtained during a research cruise in Bonavista Bay.

During plant sampling, crabs were measured from randomly selected tote boxes that had been iced and stored in the facility's holding shed. The CW and degree of shell hardness (Taylor et al., in press) were determined for all sampled animals, while animals with all limbs intact were weighed to the nearest 0.1 gm on a Sartorius Model U3600 balance equipped with the MP 8-4 data input option designed to enhance accuracy in weighing live specimens.

At-sea sampling was directed exclusively at soft-shelled individuals. Specimens were obtained by means of baited traps fished during the annual time-series research cruise conducted in Bonavista Bay. Soft-shelled crabs were carefully placed in tote boxes, covered with a tarpaulin and transported to the crab processing plant in nearby Bonavista for detailed sampling and weighing.

Results

710 legal-sized male snow crab were sampled during the course of this study. Crabs were separated into groups based on shell condition and weight plotted against CW by group (Fig. 1). Widths ranged from 95 to 129 mm, while weights ranged from 275 to 1078.4 gms (Table 1).

Let x_{ij} and y_{ij} denote, respectively, the CW and the weight of the j^{th} crab of the i^{th} category, the categories being 1 - soft-shell, 2 - new/hard and 3 - old/hard. Of the models relating weight to CW the two leading competitors appear to be

$$y_{ij} = a_i + b_i x_{ij} + \varepsilon_{ij}$$

and

$$y_{ij} = a_i x_{ij}^{b_i} \eta_{ij}$$

or, equivalently,

$$\log(y_{ij}) = \log(a_i) + b_i \log(x_{ij}) + \varepsilon_{ij}$$

where $\log(\eta_{ij}) = \varepsilon_{ij}$ and the ε_{ij} are assumed to be independent random variables with zero mean and constant variance. These will be referred to as Model 1 and Model 2, respectively. It is sometimes convenient to think of η_{ij} as equal to $1+\varepsilon_{ij}$ with the ε_{ij} small, so that $\log(\eta_{ij}) \approx \varepsilon_{ij}$.

We are interested in testing the hypothesis that weight - carapace-width relationship is independent of the category, i.e. that $a_1=a_2=a_3$ and $b_1=b_2=b_3$.

We begin by fitting, by conventional least-squares methods, separate lines for each category under each of the above models. (For convenience, in fitting model 1, the weights (in grams) have been divided by 1000). The residual sums of squares, on 704 degrees of freedom (d.f.), are then

Model 1: 107.4499; Model 2: 4.5141.

These residual sums of squares contain two components which are commonly referred to as the "pure error" and the "lack of fit". To explain these note that, for any given value of CW, there is a range of weights. Regressing weight on carapace width cannot do anything to reduce the variation between individual weights at a given width. This is the "pure error". The best tracking of the dependent variable that can be made from a single independent, or predictor, variable (including transformations) would pass through the mean values of the dependent variable at each of the values of the independent variable. The departure of the fitted line from these means defines the "lack of fit". If the fit is good, the measure of the lack of fit should be comparable to the pure error. A lack of fit substantially less than the pure error is suggestive of a fit that is "too good to be true". For example, the lack of fit can be made zero by use of a sufficiently high-order polynomial in the independent variable, but such would almost certainly be meaningless. In this study multiple observations of weight are available at most carapace widths; various authors have, however, developed methods for the construction of pure error in the absence of multiple observations. For the data of the study we find

Model 1

Source	D.F.	Sum of Squares	Mean Square
Lack of fit	80	19.2108	0.2401
Pure error	624	88.2391	0.1414

Model 2

Source	D.F.	Sum of Squares	Mean Square
Lack of fit	80	0.4825	0.0060
Pure error	624	4.0316	0.0065

Thus, for Model 1, a test for lack of fit is given by $F = 0.2401/0.1414 = 1.70$, and by $F = 0.0060/0.065 = 0.93$ for Model 2, both on 80 and 624 d.f. Although under Model 1 the lack of fit is clearly not large, it is formally significant at the 1% level, primarily because of the large number of degrees of freedom available. On the other hand, under Model 2, there is no indication a lack of fit. Accordingly, in what follows we focus on Model 2.

If we fit a single line, i.e. assume $a_1=a_2=a_3$ and $b_1=b_2=b_3$, we obtain a residual sum of squares of 4.8136 on 708 d.f. The difference between this and the separate-line model is 4.8136-4.5141 = 0.2995 on 4 d.f. For testing the hypothesis, it is inconsequential whether we use the pure error mean square of 0.0065 on 624 d.f. of the residual mean square of 4.5141/704 = 0.0064 on 704 d.f. With the latter, the test statistic is $F = 0.2995/(4 \times 0.0064) = 11.7$. Clearly the single-line hypothesis should be rejected.

The step from separate lines to a single line can be broken into meaningful components. Firstly we may test whether the lines are parallel, i.e. $b_1=b_2=b_3$ and then, given that they are parallel, the hypothesis that they are coincident i.e. $a_1=a_2=a_3$ given $b_1=b_2=b_3$. Note that the second subhypothesis becomes meaningful only if the first subhypothesis can be accepted. The residual sum of squares from the distinct parallel-line model (the first subhypothesis) is 4.5731 on 706 d.f. A test of the subhypothesis is, therefore, given by $F = (4.5731-4.5141)/(2\times0.0064) = 4.61$. This value is formally significant at close to the 1% level; thus the hypothesis of parallel lines is not acceptable, and it would be inappropriate to proceed to the second subhypothesis.

The estimates of the three separate lines are:

Category 1: $\log(y) = -9.2030 + 3.2949x$
Category 2: $\log(y) = -8.5610 + 3.1649x$
Category 3: $\log(y) = -6.7029 + 2.7711x$

This suggests the possibility that the lines for Categories 1 and 2 might be parallel, or even coincident. Accordingly, we may test the hypothesis $b_1=b_2$ but with b_3 possibly distinct. This leads to a residual sum of squares of 4.5254 on 705 d.f. and a test statistic $F = (4.5254-4.5141)/0.0064 = 1.77$, which is clearly not significant at conventional levels. Some caution must be exercised here, however, since the hypothesis being tested has been suggested by the data. If we now add the hypothesis $a_1=a_2$ (meaningful since $b_1=b_2$ has been accepted) we obtain a residual sum of squares of 4.6928 on 706 d.f. The test statistic would be $F = (4.6928-4.5254)/(4.5254/705) = 26.1$; clearly the hypothesis must be rejected.

The most parsimonious acceptable fit is that of parallel but distinct lines for Categories 1 and 2 with a separate line, of shallower slope, but greater intercept, for Category 3.

Interestingly, essentially the same conclusion is reached if Model 1 is used. The residual sum of squares for the single-line model is 112.7102 on 708 d.f., leading to a test statistic of $F = (112.7102-107.4499)/(4 \times 0.1526) = 8.62$; the single-line model is, thus, rejected. (Note that the use of Model 1 implies the tacit ignoring of the lack of fit and hence the use of the residual mean square for subsequent hypothesis tests).

Under the distinct parallel-line model the residual sum of squares is 108.3963 on 706 d.f., leading to a test statistic of

$$F = (108.3963-107.4499)/(2 \times 0.1526) = 3.10.$$

Because of the large number of d.f. of the denominator, this value is formally significant at the 5% level.

The residual sum of squares under the subhypothesis $b_1=b_2$ is 107.4622 on 705 d.f., leading to a test statistic $F = (107.4622-107.4499)/0.1526 = 0.08$, but under the additional hypothesis, $a_1=a_2$ the residual sum of squares is 110.9351 on 706. d.f., leading to a test statistic

$$F = (110.9351-107.4622)/(107.4622/705) = 22.8$$

and the rejection of the latter.

The fact that the most parsimonious acceptable model still has three distinct lines in a somewhat natural ordering would appear to have more an academic than practical value. Relative to the range of the data, the three lines are remarkably close. In particular, it can be readily seen that there would be a high frequency of misclassification if the weight for a given carapace width were used to classify individuals as to shell type.

Discussion

Miller and Watson (1976) present a weight-width regression for C. opilio from the Western Gulf of St. Lawrence but do not specify whether it is based on animals of various shell conditions, or whether only undamaged complete crabs were used. Similarly, Phinney (1977) fails to report either the shell condition or degree of leg loss of the crabs sampled in deriving the regression equation he used to determine the weight-width relationship for C. bairdi from Alaska. It must be recognized however, that at the time these two studies were conducted, the landing of soft-shelled crab was not a problem in their study areas.

The implications of these results to the crab fishing industry are quite clear. Processors who purchase soft-shelled crabs are paying virtually the same price for these animals as they would for more-desirable hard-shelled individuals. In Newfoundland, fisherman are paid for the landed weight of their catches prior to butchering. Therefore the difference in yield is not evident until after processing of the catch has been completed. In purchasing soft-shelled crabs and basing payment on landed rather than butchered weight all incentive for the crab fishermen to return soft-shelled crabs to the fishing grounds is removed. It is hoped that the results of this study will encourage processors to refuse to accept these crabs on the basis of sound economics which is, as they themselves so frequently say, the bottom line.

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Table 1. Summary of snow crab, Chionoecetes opilio, width-weight-shell condition data collected from the northeast coast of Newfoundland, August-October, 1989.

Shell Condition	No.	Width (mm)			Weight (gms)		
		Min	Mean	Max	Min	Mean	Max
Soft-shell	183	95.0	106.8	127.0	289.4	498.5	840.8
New-hard	457	95.0	104.3	129.0	275.0	476.9	1078.4
Old-hard	70	95.0	105.1	121.0	340.1	496.1	810.5

Fig. 1. Plot of snow crab, Chionoecetes opilio, whole weight (gm $\log_e$) versus carapace width (mm $\log_e$). Solid circles (solid line) - soft-shelled; open circles (dashed line) - new/hard; solid triangles (dotted lines) - old/hard.