**Validation and Calibration of Shell Condition Observations using Cheliped Colorimetry**

**Introduction:**

Shell or carapace condition is a qualitative index of the relative age of a snow crab’s carapace its’ last moult. Individual crab are classified into categories 1 through 5, in order of increasing age of the carapace.These determinations are made by trained samplers, based on a number of visual cues, which include colour, opaqueness of the ventral surface and iridescence as well as surface characteristics such as wear of spines or dactyls and the presence and extent of epibionts. The main application of these is to separate newly moulted crab from those moulted in previous years. This allows the analyst, for instance, to distinguish between recruitment to the fishery (shell conditions 1 & 2, referred to as “new-shelled”) and what is termed the residual component (shell conditions 3, 4 and 5 referred to as “old-shelled”), i.e. the portion of the commercial population which is left over from the previous year’s fishery. Since snow crab have a terminal moult to maturity, high proportions of older shell condition 4 and 5 in the commercial categories are also useful as indicators of low fishing intensity, indicating the accumulation of unexploited crab. Though useful, identification of shell condition is subjective and there is worry that observer effects may bias the observations.

This report presents a method to validate, and possibly calibrate subjective shell condition observations against another, preferably objective method. To this aim, we analyse colour measurements from a colorimeter applied directly to the carapaces of snow crab and determine its potential for use as a reference method for validating shell condition observations, especially for distinguishing between new and old-shelled components of the commercial population.

**Methodology:**

During the 2017 and 2018 snow crab surveys, a colorimeter was used to measure the color composition of the lower ventral side of the chelipeds of male snow crab with carapace width 90mm and larger (Figure X). The surveys ran from mid-July to September.

The instrument was a XXXX colorimeter, calibrated against a (D65? Diffuse tile?) at the beginning of every survey day. Observations were measured in the CIE *L\*a\*b\** colour space, a triplet of values representing the luminance L\* or “whiteness” of the colour, with a*\** values spanning from green to magenta, and b\* values spanning the range from blue to yellow.

Up to two crab per observed shell condition (SC) were measured from each tow.

Cheliped colour was chosen as a measurement location based on more limited studies in 2015 and 2016, which showed that it had better ability than other body locations to predict shell condition. It was hoped that measured colour between the new and old-shelled components would differ to such a degree that separation of these components would be possible based on colour measurement alone.

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| **Figure X:** Colorimeter measurements were taken on the lower ventral side of the cheliped for male snow crab larger than 90mm. |

**Results:**

A total of 1143 and 1265 colour observations were made during the 2017 and 2018 snow crab surveys, respectively**.**

Shell conditions were measured by three different observers, one from July to August 2017, another during September 2017 and the third during the entire 2018 survey.

The correspondence between colorimeter and shell conditions is shown in Figure X.

The correspondence in 2017 is tight while that of 2018 is not.

Inexperience of the 2018 observer during the time the survey takes place may have led to some confusing the stage 3 for stage 2 shell conditions.

The b\* dimension regroups most of the differences between new and old shell crab.

This is supported biologically as the associated colour change ranges from whitish to yellowing of the carapace, a feature which is well known in the field.

Furthermore, the histogram of b\* values shows two identifiable modes, the first of the left ostensibly corresponding to new shelled males and the other, assocociated with males with yeollower claws, corresponding to old-shelled males.

This hypothesis is supported by a slight but significant increasing temporal trend as the mean of the first component tends toward slightly yellower shades as the survey progresses. The mean of the second component is, by contrast, shows no trend.

We conclude that while different shell conditions show different b\*distributions it is only the differences between new and old-shelled males that are large enough to yield different modes in the distribution.

We thus proceed as follows. We analyze the b\* data using parametric clustering, a two-component mixture model, which estimates a probability of belonging to the new moults for each observed b\* value.

We allow the means of each component to vary through time and the proportions of the mixture tow vary by observed shell condition and observer.

This analysis then allows us to compare the correspondence between the observed shell conditions and the classificiations between new and old shell obtained by the mixture model on the colorimeter b\* values.

In the event that shell condition identifications are deemed unreliable, the analysis yields a corrective method which translates shell conditions into probability of belonging to the new-shelled group.

We will see that while the 2017 and the coloemtry data corresponded very well, the 2018 shell condition observations were very much at odds, leading tom very high recruitment estimates, and consequently very high mature mortality estimates.

**Model**

* Separate by year.
* 2017 time effect on both components, dropping out the second if it does not vary.
* Standard errors are constant.
* Proportions vary be shell condition
* Output should be [P|b\*,S] and [P|S]. Uncertainty should be accounted for.
* JAGS, Nimble or Stan.
* Separate immatures and matures.

Figure Y shows a scatterplot of the luminance L\* versus b\* showing that b\* separates observed shell conditions with shell conditions 1 and 2 tending towards the whiter end of the spectrum (i.e b\* is near 0) while shell conditions 3 and 4 become progressively yellower, with the few shell condition 5 observations having the similar colour characteristics as shell condition 4s.

For our purposes, the b\* measurement has the vast majority the power to discriminate between new and old-shelled crab. Changes in this value are associated with a progressive change from white to yellow of the chela as the carapace ages. While luminance L\* and a\* do vary between samples, they have little to no predictive power with respect to shell condition.

Figure Z shows three frequency histograms by measured b\* value for observations, divided by survey months from July 10th to September 22nd. We note that the prevalence of shell condition 1 crab diminishes with time and disappears completely by September. Carapaces of newly moulted crab age and then merge into the shell condition 2 group. One sampler was active during July and August while another was active during September only, thus seasonal and sampler effects are confounded. The proportions represented by shell condition along b\* are also shown. These histograms each show two distinct modes with values around the first mainly comprised of shell condition 1s and 2s while values around the second comprised of shell conditions 3s, 4s, and 5s, with a region of overlap between the two modes. We note that the first mode show a slight shift corresponding to a yellowing of new-shelled crab as the sampling season progresses.

The distribution of b\* values for the shell conditions 1 & 2 are generally symmetric with the exception of the August sample which exhibits a longer right-hand tail than either July or September. The b\* avlues for shell conditions 3, 4 and 5 tend much more towards the yellow part of the spectrum and show much more variability than shell conditions 1 and 2. Shell conditions 4 and 5 b\* values are higher still than shell condition 3 values.

**Analysis:**

We compared the sampler versus colorimeter-based methods of identifying new and old-shelled using the following statistical approach. Firstly, based on shell condition observations, we first modelled the proportions of new versus old-shelled as a function of b\* values via logistic regression by survey month. Secondly, profiting from the bimodality of the b\* values, we applied a two-component Gaussian mixture model, aiming to classify the observations into new and old-shelled components, using b\* values alone, done independently of shell condition observations. The former analysis also yielded an estimate of the proportion new-shelled crab which can then be compared to the logistic curve based on shell condition observations.

Formally, let be an indicator variable for new-shelled crab (i.e. shell conditions 1 or 2) for month and observation . For the logistic regression, we assume the observations to be i.i.d. where , where is the proportion of new-shelled crab as a function of b\* and and are estimated coefficients.

For the mixture analysis we assume these are unknown and assume rather that they are latent random variables where is the overall probability of observing a new-shelled sample in month . We assume the distributions over b\* within the new or old-shelled components to be Gaussian with means and standard deviations where indicates new and old-shelled components. The log-likelihood function for this mixture density is

where is a parameter vector regrouping the proportions, means and standard deviations to be estimated. Bootstrap estimates of these parameters were obtained by resampling the observations within each month 5000 times. For a given month , the proportion of estimated new-shelled crab based on this model is calculated as:

Confidence limits about this curve were calculated by using the bootstrap estimates for , and and calculating and taking the 2.5th and 97.5th percentiles of its values along b\*. We then examined whether the logistic curve calculated from the shell condition proportions lay within the confidence region of this curve.

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| Figure Y: Plot of the luminance b\* versus L\* colorimeter observations (n = 1143) from the 2017 snow crab survey, separated by shell condition. SAME GRAPH FOR 2018. ALSO HIGHLIGHT IMMATURES VERSUS MATURES. |

The mixture model fit is shown in **Figure Z2** showing that overall, the two Gaussian components of the mixture correspond very well to observed new and old-shelled shell condition-based groupings. The parameter estimates for the component proportions, means and standard deviations are shown in Table X.

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| **Table X**: Mixture model parameter estimates by month for colorimeter data. *n* is the number of observations, (new) is the proportion of new-shelled crab in the sample, is the mean estimated b\* for the new and old-shelled components. In parentheses are the standard deviations of the component distributions. |
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| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Month** | ***n*** | **(new)** | **(old)** | **(new)** | **(old)** | | July | 307 | 59.8% | 40.2% | 0.34 (2.22) | 11.41 (4.68) | | August | 458 | 39.0% | 61.0% | 1.00 (1.47) | 11.38 (4.48) | | September | 378 | 37.4% | 62.6% | 3.15 (2.05) | * 1. (4.34) | |

The proportion of observations classified as new-shelled is 59.8% for July, compared with 39.0% and 37.4% for August and September. These proportions are not those of the underlying crab population, but may merely be a reflection the areas in which samples were taken. The mean values for the first component, corresponding to new-shelled crab, go from 0.34 to 1 to 3.15 for each month, replicating our visual assessment that chelipeds of new-shells get progressively yellower with time. The standard deviations of the new-shelled component were estimated to be 2.22, 1.47 and 2.05 for July, August and September respectively. In contrast the means for the old-shelled mixture component by month show little variation at 11.4, 11.4 and 12.3 and standard deviation which are more comparable. This supports the fact that carapace ageing for these more advanced shell categories should not display any great changes over a relatively small period.

The mixture probability densities can be used to calculate the probability of observing a new-shelled observation as b\* varies. This curve corresponds to the ratio of the density of the new-shelled component over the total mixture density. Figure Z3 shows this mixture probability curve along with a 95% confidence interval. Also shown is the logistic regression curve resulting from the proportion of new-shelled crab based on samplers’ empirical shell condition observations. This plot shows that empirical logistic curve is not statistically different from the mixture curves for either July or September, but that it is shifted significantly to the right hand side for the August sample.

This results from two issues: that the empirical sample has a heavier right-hand tail for August with respect to new-shelled crab, and also that the b\* values around the new-shelled peak are more tightly centered on the mode for this month, which translates into a sharper transition between the new and old-shelled components of the mixture. Comparing the intersection points of the two component densities in figure Z2, i.e. the point at which the mixture predicts there is an equal probability of being in the new or the old-shelled component, we see that the point is shifted to the left of either the July or the September sample. These structural differences in the b\* distribution may be due to some spatial effects as the samples for each month are not individually representative of the entire survey area. Care must be taken not to over-interpret these temporal patterns as they may be confounded with spatial patterns.

**Discussion:**

Using only color measurements for the chelipeds of larger male snow crab, we have shown that there are no significant differences between samplers’ assessment of new and old shelled males based on shell condition and a mixture model based classification method for the July and September samples, but there is a significant difference for the August sample.

Supposing that the mixture model results for August as true, this implies that there may be a possible classification bias favouring new versus old shelled crab.

Under this supposition, to what degree are these crab being misclassified? Given structural differents between the August mixture model and those of July or September, we advocate a more informal, conservative approach for this exercise. We suppose two b\* limits, one at 7 and the other at 10, beyond which any samples identified as new-shelled are treated as misidentified. Given the symmetry of the empirical values and the level of accordance between the mixture and logistic curves for September, we treat the misclassification probability for September as zero. Table Y shows the misclassification probabilities at these levels which were 1.1 % and 9.0% using a b\* = 7 threshold and 1.1% and 3.1% at the b\* = 10 threshold for the months of July and August, respectively. If we factor in the total number of males 90mm in the survey, the estimated misclassification probabilities for these males is 1.3% and 3.4% overall, percentages which are not expected to contribute in a major way to bias when inferring recruitment and residual abundances and biomasses in the 2017 stock assessment.

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| **Table Y**: Summary table of error rates by month of old-shelled classified as new-shelled supposing limits of b\* of 7 and 10 for the months of July and August. Also included are the numbers of males larger than 90mm observed in the 2017 snow crab survey. |
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| |  |  |  |  | | --- | --- | --- | --- | | **Month** | **Error rate (b\* 7)** | **Error rate (b\* 10)** | ***n* (survey)** | | July | 1.1% | 1.1% | 183 | | August | 9.0% | 3.1% | 341 | | September | 0 % | 0 % | 429 | |

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| Figure Z1: Histogram of observed b\* values in the samples along with observed shell conditions. |

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| **Figure Z2:** Mixture model fits to the b\* data values. Black and grey bars show the frequency histograms of new and old-shelled components of the sample based on shell condition observations, while the red lines show the estimated mixture probability densities as determined from the b\* values alone. |

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| Figure Z3: Proportion of new-shelled crab in the sample selected for the colorimeter study. Grey bars are the empirical proportions calculated from observed shell conditions while the black line is a logistic regression these observations. The red lines are the estimated proportions estimated from the mixture analysis of the b\* observations. Dashed lines show the 95% confidence intervals as estimated from a non-parametric bootstrap. |