**Seasonal Changes in Carapace Condition, Hardness and Colour in Southern Gulf of Saint Lawrence Snow Crab**

**Context:**

* Like other crustaceans, the appearance of snow crab carapaces gradually change over time, associated with changes in hardness, colour, and texture.
* Some changes accompany the process of calcification of the carapace in the months immediately after moulting.
* Others changes occur over longer time periods, such as the accumulation of surface organisms that can gradually cover the carapace.
* The *condition* of a carapace refers to a categorical that is used to rank the relative age of a crab carapace since the last moult.
* For snow crab, this scale ranges from 1 to 5, with 1 corresponding to newly moulted crab and 5 corresponding to an old-shelled crab.
* The set of criteria used to identify carapace condition were chosen for their practicality and ease of application in the field, and that they could be easily taught and consistently applied by different samplers.
* The carapace condition scale has biological has commercial applications.
* Its main purpose is to separate newly-moulted crab, i.e. those that have moulted in the previous winter, from older crab that moulted in previous years.
* This allows, for example, for the estimation of fishery recruitment among commercialof This allows new fishery recruits from those leftover from the previous year’s fishery, allowing
* This application is important i
* Similarly, at-sea fishery observers use carapace condition in combination with carapace hardness measurements to monitor levels of soft-shelled crab in fishery catches. High observed levels of soft-shelled crab can bring about area closures, as part of an agreed-upon protocol to protect fishery recruitment, as these soft-shelled crab are not of commercial interest, yet they are vulnerable to handling mortality during regular fishing operations.
* The intended usage of the carapace condition scale was toThe utility of the condition scale
  + Scale: That the scale has
* However, for field observations to be useful, criteria used to classify shell condition must be practical, unambiguous, and relate to categories of interest. In practical terms, different observers should be able to be trained to quickly and consistently assign proper carapace condition categories.

*Conversely, very old shelled crabs are associated with a higher mortality rate and a resulting decrease in reproductive capacity. Commercially, older shelled crabs are less valuable as their carapace is often dirty, requiring a more involved treatment at the processing plant. Thus, crabs of intermediate shell condition are the favoured target of the fishery.*

**Carapace condition identification:**

The identification of these categories is based on tactile of visual assessments using a set of practical criteria, such as shell hardness (i.e. soft or hard), shell colour (white, yellowish), opacity of the carapace, iridescence of the carapace (newly moulted crab are iridescent), and the presence and coverage of epibiontic growth on the carapace. Table 1 describes the set of criteria used in the identification of carapace condition.

**Table 1**: Description of tactile and visual characters used to identify the condition of snow crab carapaces in the sGSL.

|  |  |
| --- | --- |
| **Character** | **Description** |
| *colour* | Newly moulted crab carapaces are white and progressively get yellower in the following months. This yellowing is also associated with a reduction in opacity. |
| *opacity* | Crab claws and appendages are more or less translucent after moulting. This is due to the carapace of a newly moulted crab being less calcified, and internal endoskeletal muscle and connective tissue layers have yet to expand and fill the interstitial space within. Over time, the carapace becomes more opaque and yellow. |
| *hardness* | As they calcify, crab carapaces will slowly harden following a moult. Crab hardness is determined from chelae hardness, either through manual (1988-1992) or using a durometer designed for the purpose (from 1993 to 2015). Carapace hardness was not evaluated from 2016 onwards. |
| *iridescence* | Multi-coloured light diffraction pattern observed within the carapace of newly moulted crab. This phenomenon is analogous to that observed in soap bubbles or thin oil films on water. Visibility of this trait is dependent on the both opacity and colour of the carapace as well as the epibiontic coverage. |

|  |  |
| --- | --- |
| *epibionts* | Epibionts are various types of sessile organisms, such as bryozoans, which grow on snow crab carapaces. They are also colloquially referred to as ‘moss’. Coverage in older-shelled can be extensive and be associated with a decalcification of the carapace. |

After moulting, these characters evolve in different ways, and different combinations of these characters form the basis of field identifications of carapace conditions. Carapace conditions follow a scale from 1, representing newly molted crab, to 5, representing very old-shelled crab. Carapace conditions are described in detail in Table 2.

**Table 2**: Detailed description of snow crab carapace conditions.

|  |  |
| --- | --- |
| **Condition** | **Description** |
| **1 (New soft)** | The crab has moulted within approximately three months. The carapace that is soft or firm but flexible, the claw deforms under thumb pressure. The dorsal surface is light brown and the ventral surface is pink or white and translucent. Iridescence is apparent at different spots on the carapace. Neither wear nor scars are shown on the carapace, spines and dactyls are very sharp. The carapace is very clean with no visible epibionts. The meat yield is low at this stage. |
| **2 (New hard)** | The crab moulted in the past 3 to 12 months. The carapace is more rigid and the claw is resistant under thumb pressure. The dorsal surface of the carapace is light brown and the ventral surface is white and opaque. Iridescence is still visible at multiple locations on the carapace. No appearance of wear or scratches, spines are still very sharp. The crab is clean and the carapace may have a few epibionts (i.e. moss, Balanus, Spiroide and leech eggs). Meat yield is medium at this stage. |
| **3 (Intermediate)** | The crab moulted more than a year ago. The carapace is hard and firm. The claws are unbreakable under thumb pressure. The dorsal surface of the carapace is light brown and the ventral surface is yellow-beige. Iridescence only appears at a few spots on the carapace. Spines and dactyls are still sharp but signs of wear are visible. Scars are visible on the ventral surface. The meat yield is at its maximum level at this stage. This crab has very few or no moss spot (bryozoans) on the carapace. Other epibionts (Balanus and / or Spiroide) are generally present. |
| **4 (Old)** | The carapace is hard and firm and the claws are unbreakable by simple thumb pressure. The dorsal surface is dark brown and the ventral surface is yellowish brown with no iridescence. Signs of wear and ageing are evident; with many scars and scratches on the carapace. Spines and dactyls are rounded. The organisms (moss, Balanus and / or Spiroide) are always present. |
| **5 (Very old)** | The carapace is dirty and claws and articulations are softening due to decalcification. The dorsal and ventral surfaces are dark brown with no iridescence. Scars are everywhere on the carapace. Carapace wear is widespread, with spines and dactyls well rounded and often damaged. Epibionts (Bryozoa, Balanus and Spiroide) are always present. |

**Table 3:** Summary of characteristics and diagnostic criteria used to identify carapace condition in the sGSL.

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| --- | --- | --- | --- | --- | --- |
|  | **Carapace condition** | | | | |
| **Characteristic** | **1** | **2** | **3** | **4** | **5** |
| Description | new soft | new hard | intermediate | old | very old |
| Relative age | <3 months | 3-12 months | > 1 year | > 1 year | > 1 year |
| Dorsal colour | light brown | light brown | light brown | dark brown | dark brown |
| Ventral colour | translucent | white opaque | yellow-beige | yellow-brown | dark brown |
| Iridescence | yes | some | none/traces | - | - |
| Wear / scars | - | - | traces | yes | yes |
| Spines / dactyls | sharp | sharp | slight wear | rounded | rounded |
| Balanus/Spiroide | - | some | some | yes | yes |
| Bryozoans | - | - | none / few | yes | yes |
| Meat yield | low | medium | high | high | high |

**2. Sampling**

**2.1. Shell condition**

**2.1.1. Description:**

Most of these criteria are evaluated by visual inspection by a trained observer. However, shell hardness was manually evaluated from 1988 to 1992 by squeezing the chelae of each sample. This subjective technique was subsequently replaced in 1993 by a specialized instrument called a *durometer*, which measures shell hardness and returns a value from 0 to 100, with 68 being the threshold value at which samples were designated soft- or hard-shelled (Foyle et al. 1989). Newly moulted crabs as well as very old shelled crab have softer carapaces than those of intermediate categories.

**Evolution in the snow crab survey:**

The number of shell condition categories has generally increased since the inception of the trawl survey in order to address industry demands or reach new research goals.

From 1988 to 1991, there were three shell condition categories, corresponding to newly moulted crab (shell condition 1), hard-shelled crab (shell condition 2) and old-shelled crab (shell condition 3). In 1992, the newly moulted crab category was split into its soft-shelled (relabeled shelled condition 1) and hard-shelled (relabeled shell condition 2) components. Both these categories are colloquially referred to as ‘white’ crab (referring to the shell colour) while the term ‘soft’ crab specifically refers to the shell condition 1 category. Categories previously labeled shell condition 2 and 3 were subsequently relabeled as 3 and 4, respectively.

In 1993, the previous shell condition 3 category was split into two categories according to whether iridescence was detectable or not, and relabeled as shell conditions 3 and 4, respectively. The previous shell condition 4 was relabeled as shell condition 5. This five-category system forms the basis of scale in use today, although some sub-categories were added, mainly to address industry demands. Specifically, an ‘*m*’ suffix was added to crab to indicate the light presence of epibionts (i.e. *m*oss) on the carapaces of both shell condition 3 (from 2002 onward) and shell condition 2 (from 2005 onward) categories, though in the latter case, the suffix was dropped the following year. However, the *m* suffix is ignored in all stock assessment analyses and summary statistics.

**2.1.2. Discussion:**

Criteria presented in Table X are used as dichotomic classifiers (i.e. they place samples within one of two states). However, closer examination reveals that each trait that they are applied to may be considered as continuous rather than binary. For instance, there is in fact a spectrum of intermediate forms between white and yellow coloured crab, rather than simply two colour states. Similar points may be made with regards to opacity, iridescence, epibiontic growth and senility. And so, the application of the criteria requires an *a priori* definition of a threshold value to which each observed state will be first compared and then classified.

There are two types of threshold values, depending on the nature of each specific trait. The first type is based upon the notion of detectability or upon the ability of an observer to simply detect a specific trait. In this group we find the epibiont growth criterion used to separate shell conditions 3 and 3m as well as the iridescence criterion used to separate shell conditions 3m and 4. The second type of threshold value is intermediate between the two given states. These include the colour, opacity, senility and hardness criteria. Only in the case of shell hardness, with its fixed threshold value and instrument-based observation, would we qualify the threshold value as being objective.

For both types of threshold values, we expect some level of subjectivity and thus some variation in the classification systems used by different observers. For instance, some observers may more easily detect a given trait than others. More problematically, some observers may be more conservative or liberal when applying intermediate threshold values. This is especially true given the greater subjectivity of selecting an intermediate threshold value when faced with a range of similar adjacent states. These are necessarily more difficult to teach to new observers, given that no clear-cut transition is apparent.

In addition, the senile criterion, used to identify the shell condition 5 category, is in fact a composite of multiple criteria, namely epibiontic growth, shell hardness and overall appearance, all of which are rather more or less subjectively used to identify kinship.

Given the issues raised above and the long time period covered (almost twenty years), there is some question as to the consistency of individual observers through time as well as between observers. We may also ask whether the splitting of various categories throughout the years resulted in some portion of adjacent shell condition categories being incorporated into the split category. For example did some portion of crab previously classified as shell condition 4 end up as shell condition 3m crab when the changes in protocol were implemented? Since systematic comparisons between the various classification systems and observers were performed, the following discussion will necessarily be centered on the adequacy of the classification criteria and their threshold values.

We will address the previous points must be weighed by the following counterpoints. Firstly, the core group of scientific observers has remained largely unchanged since the inception of the trawl survey. In cases where new observers were hired, these were always under the direct supervision of experienced observers. In general, the above points regarding the constancy and consistency of classification criteria and threshold values care were kept in mind for each trawl survey, the necessary subjectivity associated with observer-based classification will always lead to some level of classification bias and error. Secondly, in terms of stock assessment, proper identification of certain groups is much more important than for others. In particular, a large part of setting quotas and determining stock abundance trends relies in quantifying fisheries recruitment and exploitable abundance. Separate analysis of these two groups requires the separation of shell condition 1 and 2 commercial crab from shell condition 3, 4 and 5 crab. This proper discrimination between these two groups relies on shell colour, a criterion with an intermediate-type threshold value. What greatly increases the discriminatory power of this criterion is that as a result of the specific timing of the moulting period and the trawl survey, the absolute age difference of shell condition 2 crabs and shell condition 3 crabs since their last moult is at least one year. Thus, in practice there is generally little uncertainty when identifying the colour state as there is generally good contrast between the two. More often, other demographic groups used in stock assessment are used in a more informal way. For instance, shell condition 5 individuals are used qualitatively as an index of exploitation rate, and so despite its somewhat ambiguous classification criteria, as long as its strict quantitative interpretation is not overly relied upon, there is little danger of overinterpretation of the data. Although summary statistics tables showing the proportions of each shell category are often presented, these have only been informally used for assessing certain commercially-centered dynamics trends of the stock. Any future quantitative analyses based on the proper identification of shell condition categories (e.g. shell condition-structured population models) must keep the above points in mind when interpreting results.

Overall, the same three shell conditions used originally still serve as the focus of the stock assessment today, where today’s multiple shell conditions are combined prior to analysis.

Explain why back calculations, estimating proportions using back-calculations is difficult.

We note that our comments are restricted to data gathered on trawl survey expeditions and that the criteria used by at-sea observers, while very similar, may differ somewhat for practical reasons.

Goal of the report: to qualify the uncertainty associated with shell condition identification.

Add Marcel’s comments – references to literature and other groups using similar shell condition classification systems.

* Meat yield is not a diagnostic criterion, it is related to carapace condition.

Foyle, Timothy P., Hurley, Geoffrey V., Taylor, David M. 1989. Field testing shell hardness gauges for the snow crab fishery. Canadian industry report of fisheries and aquatic sciences, 193:viii-38