**Background:**

The snow crab commercial biomass estimate is a central result of the sGSL’s annual stock assessments, being used to directly define quotas for the fishery in the following year. For the biomass estimates to play such a central role in the management of this fishery requires sound statistical sampling design, robust fishing protocols, catch standardization and analysis.

The statistical sampling design and the analysis of standardized catches have been the subject of public reviews, both during annual assessments processes and notably during the Framework Assessments of 2006 and 2010. These frameworks redefined the trawl survey bounds, the spatial sampling design, and cemented the set of analytical methods which are currently used to estimate snow crab biomass.

DFO Science’s commitment to the consistent application of these analytical methods is such that in 2019, when a switch from Matlab to the R statistical language was made, comparisons were made to ensure that results obtained on both platforms were nearly identical, insuring that results were within fractions of a percentage point. In contrast, most aspects of the fishing protocols used aboard the survey vessel and issues related to catch standardization have not been the subjects nearly the same degree of public scrutiny or review.

This has left the survey with important knowledge gaps about which factors can unknowingly influence catches. Being unaware or leaving these factors uncontrolled leaves the survey vulnerable to systematic biases, as the execution of some survey protocols have been inconsistent from year to year or from region to region. Failure to identify and control these factors led to serious biases in snow crab biomass estimates during the 2019 RAP and preliminary investigations hint at other important sources of bias in the historical times series.

**Comments on the January 2020 Snow Crab RAP:**

The 2019 snow crab survey introduced a new survey vessel and included a comparative fishing experiment with the previous survey vessel, in the hopes that any differences in fishing effects could be either ruled out or accounted for and corrected.

Early on in the survey, it became apparent that snow crab survey catches were abnormally large, raising concerns that some unknown mechanism was artificially inflating catches. A plethora of trawl probe observations, plus the inclusion of a comparative fishing experiment, made the 2019 survey very data rich, and it was hoped that any catch biases or underlying mechanisms could be elucidated. In this context, a number of analyses were performed, consisting of comparisons between survey vessel and trawl behaviour between different years, a formal analysis of data from the comparative fishing experiment, and indirect estimations of catch biases.

Unfortunately, results from the comparative experiment proved to be at odds with the aforementioned issues, and the analysis was hindered by weak swept area data, required for catch standardization, due to weak relaying of acoustic trawl acoustic mensuration signals. In the end, comparative experiment results were ambiguous, suggesting that whatever catch mechanisms were at play were particular to the locale where the experiment was performed, rather than being representative of the larger survey.

This led in turn to investigations into other survey data to identify the possible mechanism to explain why catches had systematically increased. It was shown that: 1) the new survey vessel had much poorer speed control than the previous vessel, 2) tows had a prolonged latent trawling phase during the trawl winching phase, which had up to this year been wholly ignored in the catch standardization (i.e. not included in the swept area estimation), and 3) rather than the survey vessel reversing its speed at the end of trawling, as was prescribed by protocol, it was shown that the vessel kept its heading, with only a moderate slowing of its speed progress, leading to a substantial portion of each tows’ swept area occurring during this latent trawling phase, representing about 30-50% of the total swept area.

It was shown further that the latent trawling phase in 2019 increased by ~12% with respect to 2018. During the 2019 RAP, this statistic was largely misconstrued as the best estimate of the actual bias in the catches, rather than an being estimate relating to this particular aspect of trawling.

However, direct comparisons of length-frequencies of female and sub-legal male snow crab showed a systematic increase across all sizes of ~30%. Such uniform increases across a broad range of sizes cannot be explained by any known natural process in the southern Gulf: recruitment leads to a spike in smaller sizes and overall migration is negligible (i.e. is a closed population). Further, snow crab survey by-catch levels of American Plaice, Atlantic Cod and Hyas crab, three widely distributed species in the southern Gulf, showed similar annual increases at about the same level of 30%. Corresponding increases were not observed for snow crab and these species in the September survey, raising further questions about their validity.

The picture for commercial male abundance added to the confusion. In contrast to smaller snow crab and the by-catch species mentioned above, levels of commercial snow crab were oddly comparable to those of 2018. This led to the hopeful supposition that the commercial portion was somehow exempt of whatever process seemed to be inflating those of smaller crab. This supposition was bolstered by the observation that the 2019 commercial biomass estimate seemed to be in reasonable agreement with the predicted value stemming from fishery recruitment model in 2018. However, this special interpretation of the 2019 commercial snow crab biomass is problematic:

1. ***Catchability***: This interpretation necessarily leads to the idea that the catchability for commercial-sized males in 2019 is somehow different, indeed less, than that smaller sized male and female snow crab. Given the nature of the trawl being used, it is hard to imagine a mechanism whereby larger males should somehow be less apt to being caught than smaller individuals. I am not aware of such a mechanism being suggested in any past assessments.
2. ***Variability***: The dynamics of female and non-commercial male snow crab are driven by the natural processes of recruitment, natural mortality and migration. In addition to these, commercial snow crab highly is highly impacted by fishing activity, both directly via declared landings (known) and indirectly through fishery by-catch mortality (unknown). This latter process makes the commercial component dynamics more difficult to predict than non-commercial crab. This variability may even be more pronounced in recent years, given the known large-scale redistribution and local concentration of fishing effort brought about by Northern Atlantic Right Whale area closures in recent years.
3. ***Consistency with the recruitment model***: Whatever the mechanism, mortality for commercial males is known to be highly variable and the consistency of the biomass estimate with the predictive recruitment model, which is highly uncertain, should not be used as a basis for justifying its validity. Indeed, a spike in commercial mortality is a more likely explanation for the commercial crabs’ consistency with prior prediction.
4. **September survey index**: In contrast to the snow crab survey, the September survey index showed a decrease in commercial biomass with respect to 2018. Though this estimate is more uncertain due to its lower sampling intensity, it is consistent with a significant overestimation in commercial biomass.

**Consistency of the survey time series:**

* Survey **vessel speed** and **end-of-tow manoeuvres** varied significantly impact the duration and extent of the latent trawling phase. This aspect of trawling was largely uncontrolled in past surveys and thus represents, through their unaccounted contribution to the trawl swept area, a significant source of regional and annual bias in snow crab survey catches.
* **Winch hauling speed** was not controlled in past surveys and is expected to vary from vessel to vessel and may even vary according to the inclinations of the winch operator. Winch speed has a direct impact on the duration and extent of the latent trawling phase.
* Investigations into swept area statistics showed large swings in annual swept area. If we assume that the analytical method has been consistently applied (and to my knowledge it has), this implies to annual **differences** either with **measurement of the trawl** net or **trawl geometry**. This may reflect changes in the placement or performance of trawl acoustic sensors, or changes in the configuration of the trawl through time. In particular, studies have highlighted the importance of controlling and monitoring trawl symmetry in fishing survey protocols. Such controls are implemented in many ICES bottom trawl survey protocols, as in NOAA bottom trawl surveys. The Gulf’s own September multispecies survey has such controls in place.

**Recommendations:**

* Internal or external review to clearly identify weaknesses in the trawl survey fishing protocol, with the aim of clarifying and formalizing fishing protocols to address any issues.
* Present a summary draft of this survey protocol to stakeholders during the 2020 RAP.
* Allot some time during future snow crab RAPs to present and openly discuss issues with fishing protocols, survey index standardization and survey index validation. Addressing these issues is critical to improving the consistency of abundance and biomass indices, as well as the credibility of DFO Science in delivering these central survey results.
* While some aspects of fishing protocols are generally well controlled, such as fishing gear (Nephrops trawl), the warp cable length (~3:1 depth ratio), the target fishing speed (~2 knots) and the target tow duration (5 minutes), other important aspects which have potentially important scaling effects (i.e. bias) on catches had not been considered in years prior.
* The issue of these scaling effects was brought to the fore by 2019 snow crab survey, where the introduction of a new vessel was accompanied by an unprecedented increase in snow crab catch levels, being a full 30% above any previously observed in the 30-plus year history of the survey.
* This increase was found to be oddly uniform across a broad swathe of snow crab sizes and was present in both sexes in equal measure. This structural increase cannot be explained by any known natural process, as recruitment would lead to a large spike in smaller individuals only, and mass migration on such a scale is untenable as a hypothesis due to the closed nature of the snow crab population in the sGSL.
* Also, investigations into other species caught during the snow crab survey revealed similar increases in species with wide spatial distributions in the sGSL, such as American Plaice, Atlantic Cod, and Toad Crab.
* In the September multispecies survey, no such increases were observed in the indices for any of these species, including snow crab.

In an effort to elucidate the driving mechanism behind these increases, and possibly correct for them, a thorough investigation was made using auxiliary data gathered during the survey, including trawl acoustic probes, touchdown sensors and water pressure probes.

* While many aspects of the trawling process were shown to be consistent with those from recent years, there were some notable differences.
* The first notable difference, was that vessel speeds were much more variable than in previous years, indicating poorer speed control of the survey vessel due the lack of a variable pitch speed control which was present in the previous survey vessel.
* The second notable difference was a large increase in duration of a latent trawling phase, a period of unaccounted trawling between the stop signal and the lifting off by the trawl from the bottom. This was shown to be largely the result of slower winch operation during hauling.

This brought to light both the existence and significance of this hitherto unconsidered aspect of trawling, which is driven not only by winch speed, but also by end-of-tow manoeuvres by the survey vessel.

This then led into investigations into the consistency of these manoeuvres between survey years and showed that they have not been consistent, neither in orientation nor speed.

Investigations into swept area estimates through the years also showed surprising differences between the average values of survey years, strongly suggesting systematic differences in placement of trawl probes, trawl mensuration or trawl configuration between survey years.

**Commercial biomass:**

Conclusions:

* As analysts, we are only permitted to ignore factors inasmuch as we are able to defend their spatio-temporal invariability, i.e. that they show no trends in different regions of the survey and between years.
* Otherwise we can and do fail in our duty as a Science department to ensure that the integrity of the biomass is maintained.
* It is not sufficient to lump such factors into a box labelled ‘unknown’ and assume that statistical methods will somehow correct for these failings. Biases in the sampling do carry through fully in the estimates.
* Controlling these and other variables is often difficult in the field, with vessel being subject to mechanical issues and less than ideal fishing conditions.
* That there is doubt in the consistency of the time series is not new. The earliest portion of the time series was dropped from the assessment because of worries that the fishing techniques being used, i.e. side-trawling, was not comparable with current stern trawlers.
* Comparisons between September survey and snow crab survey indices raised concerns that vessel changes in the latter were accompanied by significant changes in catchability, most notably the recent vessel change in 2013. Since vessel changes in the snow crab survey, of which there have been five, were not accompanied by a comparative fishing experiments, this raised serious doubts with regards to the temporal consistency of the biomass estimates.
* With these issues in mind, the 2019 snow crab survey included 40 regular stations off in western Cape Breton 2019 at which the previous survey vessel the CFV Jean Mathieu, fished alongside the new survey vessel the Avalon Voyager II.
* Some identifiable factors fall under the heading of vessel effects are:
  + the vessel’s horsepower, which can effect the interplay between the trawl and the vessel’s inertia when bottom obstacles are encountered,
  + the vessel’s movements under different sea conditions, which largely depend on its centre of gravity
  + speed control of the vessel (i.e. presence of a variable-pitch control)
* Some factors can be grouped under gear effects, these include:
  + Unequal warp cable lengths.
  + Differential twisting of cables on either side of the trawl.
  + Gear entanglement.
* Other factors fall under the heading of fishing operations, including:
  + net deployment and hauling procedures, start and end of tow vessel manoeuvres.

In addition to changes in the spatial sampling designs mentioned above, there have been multiple vessel changes during the 30+ year history. This has been underlined in previous RAPs as a key source of uncertainty, as changes in vessel manoeuvring or fishing operations can affect catches and possibly bias any derived abundance or biomass estimates.

**Comparative fishing experiment:**

* The reliance on the results, or rather the lack thereof, of conclusions from the comparative fishing experiment had the effect of further muddying the waters, since it seemed liked a reasonable attempt of estimating the relative catchability between the vessels had been made. I would agree that the effort, both financially, experimentally and analytically, certainly justified a thourough analysis of its results. However, it largely failed, in that it explained none of the discrepancies which were observed in the remainder of the 2019 survey. Whatever the mechanisms in play during the survey, these seemed to be absent during the comparative component.
* This lack of corresponding increases among commercial sizes and supposed consistency with the predictive model was used to justify that the commercial categories were not subject to the same level of bias than sub-legal sizes.
* However, inferring the bias on commercial sizes is more problematic than inferring that of sublegal sizes, due to large variations in annual mortality rates, portions of which are driven by unquantified by-catch mortality from fishery activities and intra-specific competition.
* Unfortunately, I feel these efforts at elucidating the swept area scale and mechanism, rather than bringing a proper focus on the scale of the possible bias, rather detracted from the original assessment of the scale of the bias as was evident through simple comparisons of the fish and toad crab by-catches, snow crab length-frequencies and the population mechanisms.
* Commercial categories

Biases can be addressed analytically or controlled using a properly researched and implemented survey protocol.

While a survey protocol exists for the snow crab survey, aspects of fishing have never been formalized and described in detail for review. I have certainly never been privy to its contents and proposed amendments to this protocol have met with indifference on the part of the survey’s

Biases can sometimes be corrected analytically, though accounting for the various underlying unobserved mechanisms is laborious a require the formulation of assumptions….

* I would describe suggested validation procedures
* Reactions to formalize and update the fishing protocol were tepid. As yet, there is still no formal protocol. While certain aspects of the protocol are described in the literature, e.g. tows of 5-minutes at trawling speeds of 2 knots, inter-annual variability have been shown for a number of
* There are further issues with trawl swept areas show abnormal interannual oscillations, suggesting underlying issues in trawl behaviour, trawl mensuration, and/or its calculation.
* Differences in trawl configuration and/or asymmetry may driving these oscillations and additional sensors are required to measure/control for these, which are standard components of other surveys, such as the September multispecies survey, which includes a trawl symmetry measure.
* Given these issues, I find the differences between the analytical rigor and experiment rigor to be at odds, and the onus falls largely on the analyst to correct for numerous experimental issues which crop up on in the snow crab biomass time series.
* Positive biases as were observed in 2019 exposed the fishery to severe local exploitation pressures and embarrassment for DFO if the stock prediction is not borne out and fishers are unable to attain their quotas.
* In cases where the biomass would be underestimated, the quality of the work at DFO Science would rightly be the target of a harsh review under the public eye and would expose the Department to calls of financial compensation by the industry.
* I believe that the collaborations and interactions between DFO Science and snow crab industry, though fractious at times, have been largely fruitful and currently shows a level of confidence which was largely absent through much of our shared history.
* I believe that most of the issues raised above can be addressed in a timely and cost effective manner, though I suggest that there is a lack of understanding within DFO Science regarding the importance of the biomass index and the issues within the gathering of its data, their analysis and interpretation of their results.
* I recognize that the sheer number of disparate results may have frustrated a proper synthesis,
* The inability of to quantify the commercial bias directly, should not have
* These points were brought to my manager and CSAS representative prior and were
* I recognize my own culpability in the communication of the results during the past year, though I would refrain from entering another assessment cycle if these Science’s management were subject to apparent censoring in front of the fishing industry representatives and reviewers.