Hi Stephanie,

This message is to give more momentum to the EAFM snow crab project and see how we can move forward together this fall and next year. I am hoping we can have a planning meeting in the not-too-distant future.

I have attached the proof of my ICES J Mar Sci article and supplementary material on the temperature-size rule in snow crab. This article contains parts of the presentation I gave at the 2019 Norway ICES symposium. This is the uncorrected proof. I was hoping to be able to send you the final corrected version, with only some rather minor changes, but I understand that it may be another few weeks before it appears online. This article explains my view on why/how snow crab size at terminal molt (SaTM) changes in relation to temperature and posits that most of the change is due to thermal history of early life history stages (juveniles hereafter).

Key to predicting temperature effects on SaTM is an understanding of instar structure, which I provide in the article for the north Gulf of St Lawrence (nGSL). Instar structure is important information because in conjunction with temperature-dependent juvenile growth rates (also documented in the attached article), it allows to establish reasonable time lags for projected effects of juvenile thermal history on SaTM and age at recruitment to the fishery (here, by recruitment I mean any male – adolescent or adult). I deliberately did not cite in my article Hébert et al.’s (2002) interpretation of instar structure in the south Gulf of St Lawrence (sGSL) because it is not at all based on modal analysis of size frequency distributions of wild snow crab and was discordant with other observations in the nGSL (and sGSL, the Robichaud *et al*. 1989 study) – I simply did not want to discuss the possible reasons for this disparity in an already long article. However, this did lead me to examine the sGSL bottom trawl survey data which Hugues Benoît provided to me. I guess Amélie may have passed on to you the French working document I produced based on a cursory examination of those data (in any case, I have attached it again here). This examination strongly suggests that juvenile and pre-recruit instar structure in the south GSL may not be different from elsewhere in the Gulf, not a terribly surprising finding given what appears to be a very conservative growth format across the snow crab’s world distribution.

Right now, I am finishing up an experiment-based manuscript looking at the additional (complementary) role of sociosexual context in the variability of male SaTM, essentially testing Elner & Beninger’s (1995) hypothesis that male mating success or failure can modulate onset of terminal molt. The assumption is that sociosexual context can modify the distribution of males among the terminal molt instar options set by thermal history of early juveniles.

Writing up these two manuscripts got me thinking about the sGSL and a few things you might want to look at or consider:

* In the nGSL, the ≈1000-km long north shore has a narrow shelf with a clear longitudinal temperature gradient. Since snow crab seasonal and ontogenetic movement is mostly across-shelf, local temperature effects are clear for all life history stages. I see the situation in the sGSL being more complex, as later life history stages may converge and mix toward the center of the Magdalen Shallows. So, although juvenile thermal histories may differ from north to south around the sGSL, the resulting adult phenotypes may mix on the deeper shelf, obfuscating temperature effects.
* Investigating instar size structure in the sGSL using the snow crab survey data would seem to be a logical thing to do, unless this has already been done and I am unaware (might even be useful for Tobie’s population model). If you do this, and for juvenile instar structure in particular, you might want to consider some spatial discretization of data to reflect juvenile hotspots in possibly different thermal habitats. It seems to me that such juvenile hotspots existed in the Baie des Chaleurs (‘cold’ habitat?) and along the Cape Breton west coast (‘warm’ habitat?)… juveniles in these two sites might have different growth rates and maturity schedules. There may be other juvenile concentrations or maybe the hotspots have shifted geographically (thermally) in time?
* There seems to have been in recent years a growing difference between the nGSL snow crab stocks and the sGSL snow crab stock in terms of interannual fluctuation of abundance/biomass (or proxies thereof). Stocks in the nGSL continue to exhibit strong cyclic variability of pre-recruits and commercial biomass but the sGSL stock seems to have become more ‘stable’. Part of the explanation for this difference may reside in the fact that fluctuations in larval supply have become more attenuated in the sGSL (Émond *et al*., 2020), but I also wonder if the thermal landscape of the sGSL juveniles is as uniform now as it was decades ago (question for Joël Chassé, I guess)? A less uniform thermal landscape would be conducive to juveniles of the same year class growing at different rates (see my ICES JMS article) in different parts of the sGSL and recruiting to legal size in different proportions and possibly at different ages, which would contribute to dampen biomass oscillations.

For the next steps in the EAFM snow crab project, I suggest we should have a virtual meeting to discuss where to go. The following are some points that I personally would like to dig into more deeply , and which could form a foundation for discussion and collaboration (with anything else you would like to add on):

1) In cohorts that have settled and grown in a given temperature regime, females distribute themselves between mainly 2 consecutive adult instars and males among 4-5 consecutive adult instars. All studies so far that have considered temperature effects on SaTM have invoked time constraints or time invariance in the terminal molt schedule (see my attached article). For males, this does not mean that recruitment to legal size occurs at a constant age. Rather, it is the age at first transition from adolescent to adult (first instar for terminal molt) that may be fixed, with regular (=non-skip) molters from a cohort subsequently distributing themselves progressively and on an annual basis across the remaining 3-4 consecutive instars for terminal molt. For example, in a cold regime these 4-5 adult instars could be instars VIII-XI/XII recruiting over the post-settlement ages of 6-9/10 years (with very few crabs reaching legal size and only at age 10) while in a relatively ‘warmer’ regime these 4-5 instars could be adult instars IX-XII/XIII recruiting also at ages 6-9/10 (but with many crabs reaching legal size at age 9). More evidence for time invariance of terminal molt schedule is needed, and importantly we also need to better understand what additional role skip-molting plays in the temporal and instar distribution of terminal molt for a cohort (see discussion in my attached article).

2) What is the evidence that early juvenile thermal history influences SaTM in female and male snow crab? I showed in my Norway presentation evidence for this in nGSL snow crab, and it was apparently stronger in females than in males probably due to terminal molt occurring over a lesser number of consecutive instars in females compared to males. What is the magnitude of change in terms of size and instar structure/composition? For reasons given above, I would expect the effect to be clearer in data from spatially-thermally segregated nGSL populations than in the spatially aggregated sGSL data (although spatial discretization of sGSL might yield a different answer). In this sense, these two parts of the GSL potentially offer interesting contrasts for comparing temperature effects and management implications.

3) How invariable are the maturation schedules of individual “cohorts”? Is the proportion of males from terminally-molting into each of the adult instars the same from cohort-to-cohort (year-to-year) or are commercial losses due to molting to a sublegal adult size more important in some cohorts (years) than in others? Preliminary analyses in the nGSL suggest the latter occurs. What are the factors involved in interannual variability – density and/or sociosexual context are two possibilities?

4) When these three first questions are answered, we could move onto ecosystem and management implications considering for instance changing proportions of males recruiting to legal size among cohorts and changes in female per capita fecundity and reproductive tempo (hence lifetime sperm needs). This would be amenable to simple population modeling under various climate change scenarios with the additional consideration of changing snow crab habitat area (and presumably mortality rate). What would be the ecosystem consequences and what might be the threshold change in SaTM needed for management to take action?

Anyway these are just some thoughts in line with the project’s description and goals. Please feel free to share this information with the snow crab team members in your region (I have cc’d Cédric Juillet as he may want to become involved or will at least want to track progress closely). I look forward to hearing back from you. When you feel ready to have a meeting, let me know and we can decide on the format together, dates and extent of participation. I am in “office” this and next week (but pretty busy) and then on vacation for 2 weeks (but I could fit a meeting in during that vacation, no problem).

Cheers,

Bernard