Oceanography and northern shrimp (*Pandalus borealis*, Krøyer 1838) recruitment variability in the Gulf of St. Lawrence and Northwest Atlantic

Patrick Ouellet[1] patrick.ouellet@dfo-mpo.gc.ca
Louise Savard[1], César Fuentes-Yaco[2], Peter Galbraith[1], Trevor Platt[3] and Alain Fréchet[1]

[1] Fisheries and Oceans Canada, Maurice Lamontagne Institute, 850 route de la Mer, Mont-Joli, QC, Canada, G5H 3Z4
[2] Fisheries and Oceans Canada, Bedford Institute of Oceanography, PO Box 1006, Dartmouth, NS, Canada, B2Y 4A2
[3] Plymouth Marine Laboratory, Prospect Place, PL1 3, Plymouth, UK


Credit : Thierry Gosselin

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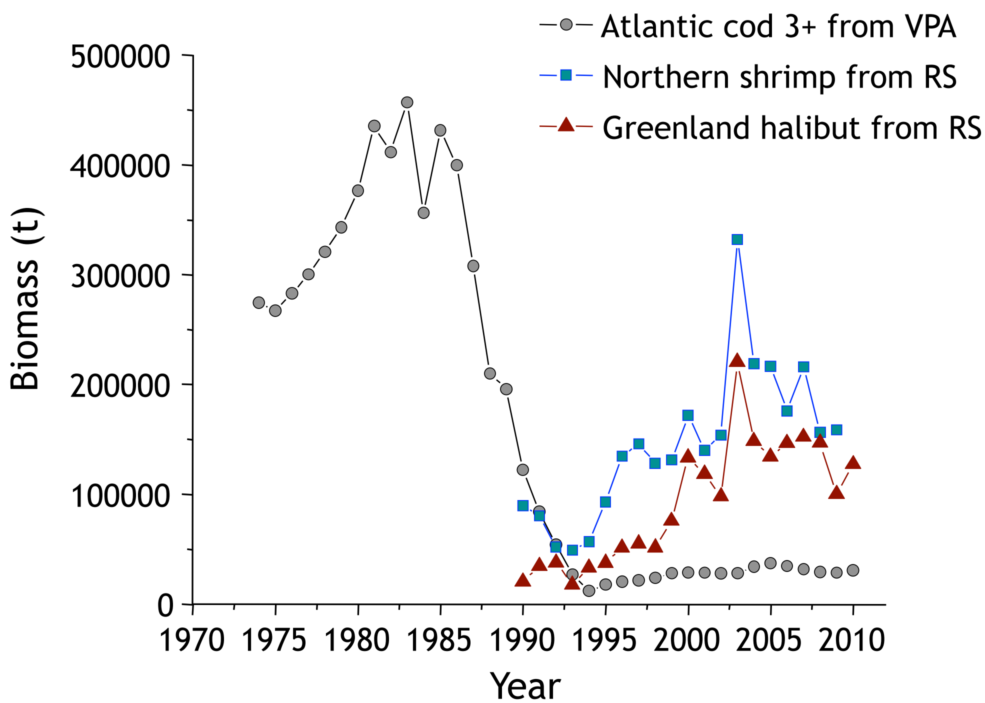
Plan

- The recent evolution of groundfish and northern shrimp abundances in the northern Gulf of St. Lawrence (GSL)
- Northern shrimp recruitment studies in the northern GSL:
  - Life cycle and larval ecology
  - Development of a larval survival index & ecosystem indicators
  - Northern shrimp and the match/mismatch hypothesis
  - Ocean surface characteristics and northern shrimp larval survival (recruitment variability) in the GSL and NW Atlantic
- Summary and Conclusions
- Future work: northern shrimp and climate change

Changes in northern shrimp, Atlantic cod, and Greenland halibut biomasses in the northern Gulf of St. Lawrence (GSL)



RS = summer (August) research survey
VPA = Virtual population analysis

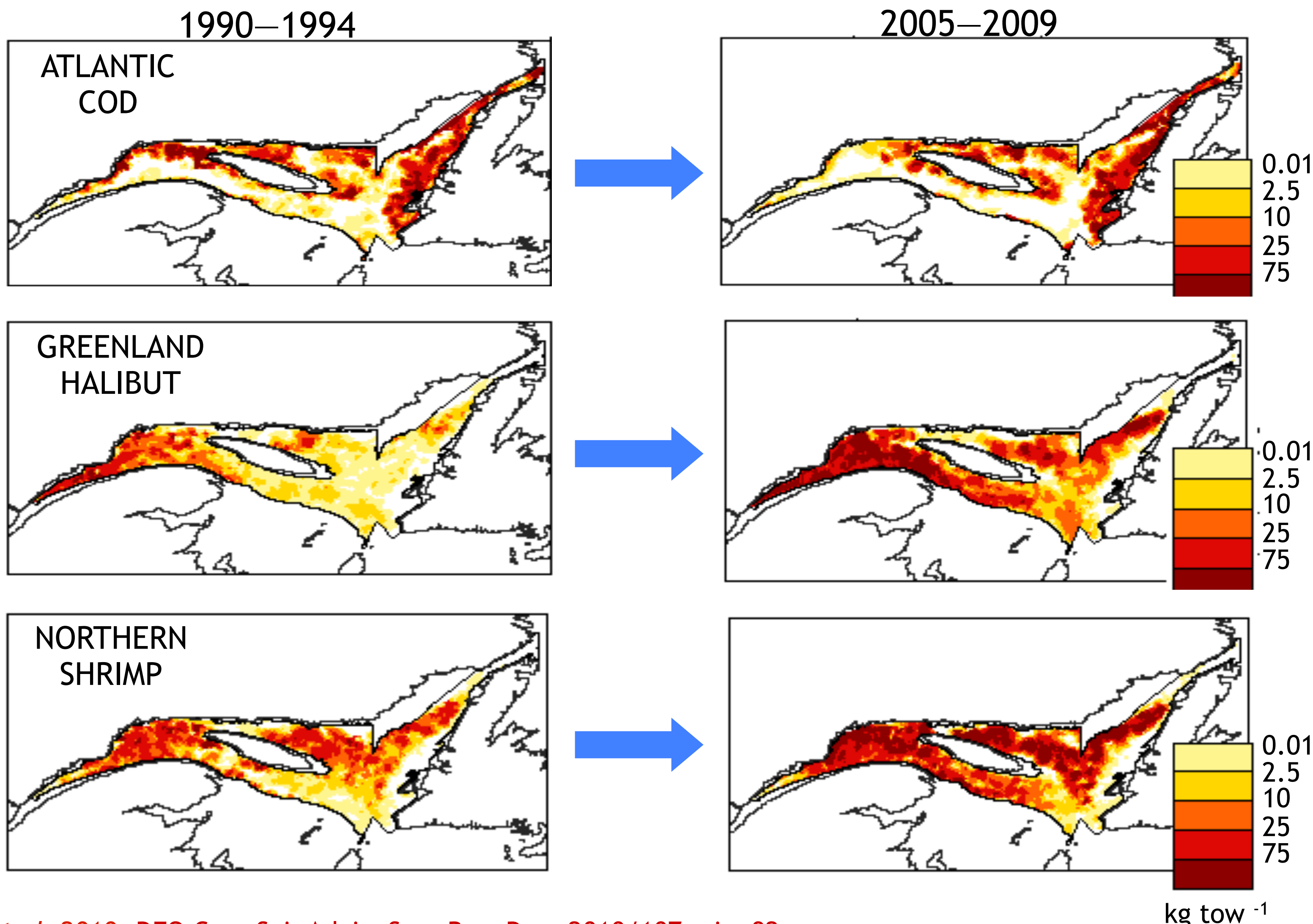
- Atlantic cod used to be the most important (in term of commercial value) and, along with redfish (*Sebastes* spp.), one of the major component of the northern GSL fishery

- Atlantic cod biomass peaked in the late 1980s in the northern GSL before declining to a historic low in 1994

- In comparison, both G. halibut and shrimp show an increasing trend beginning in the early 1990s but seem to have stabilized since the mid 2000s

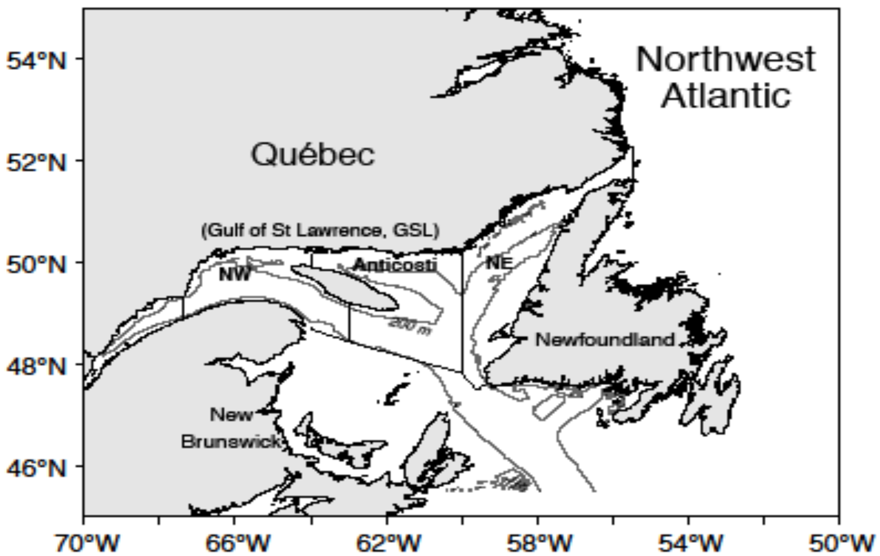
Shrimp, cod, and G. halibut abundance and distribution since 1990

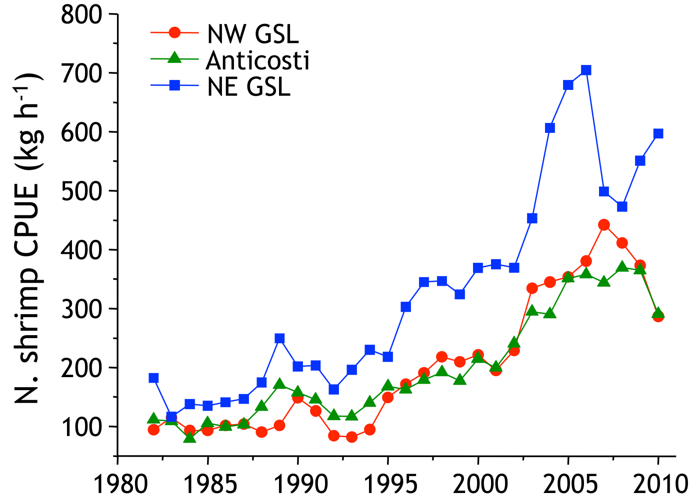
From August RS, five-year averages

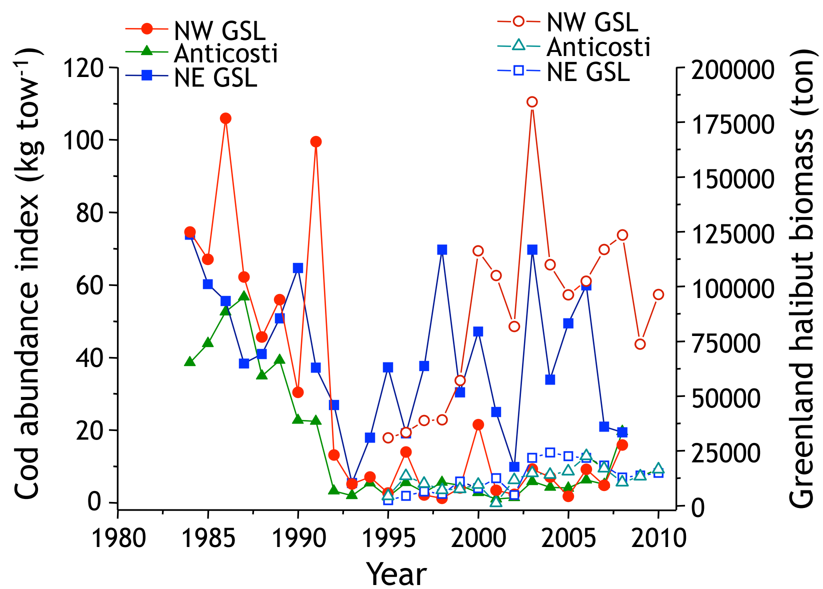


Bourdages *et al*. 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/107. vi + 92 p

Northern shrimp population structure in the northern GSL







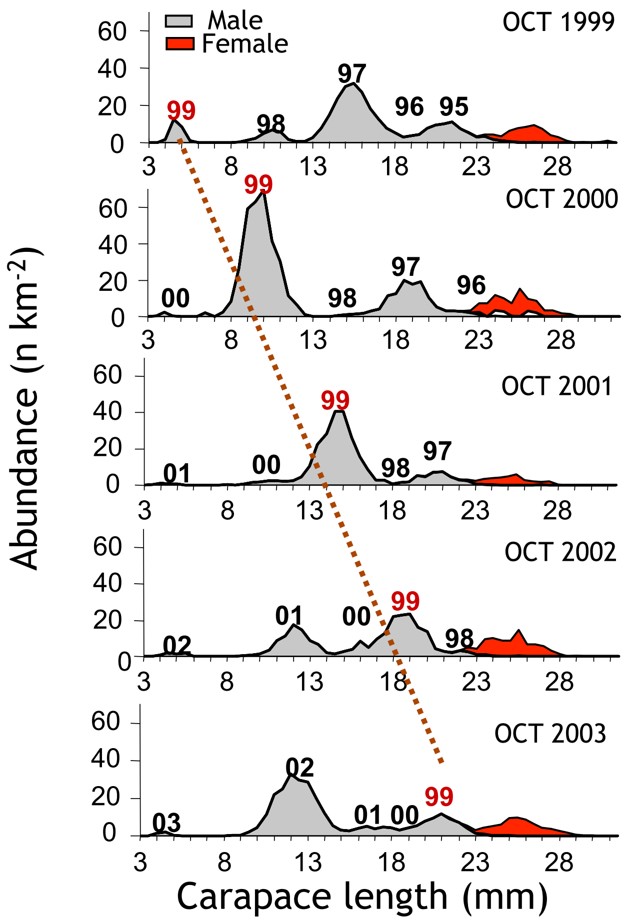
- Northern shrimp is subdivided into three populations in the northern GSL: NW GSL, Anticosti, and NE GSL. Standardized CPUE is a good proxy of biomass: R^2 = 0.533, 0.537 for NW and NE GSL, respectively

- Trends are similar among the populations. Beginning in early 1990s, at the historic low in cod in NW GSL and Anticosti but not in NE GSL, there are strong positive trends in the shrimp CPUE for all populations

- Also notable is the recent large increase in Greenland halibut biomass in the NW GSL

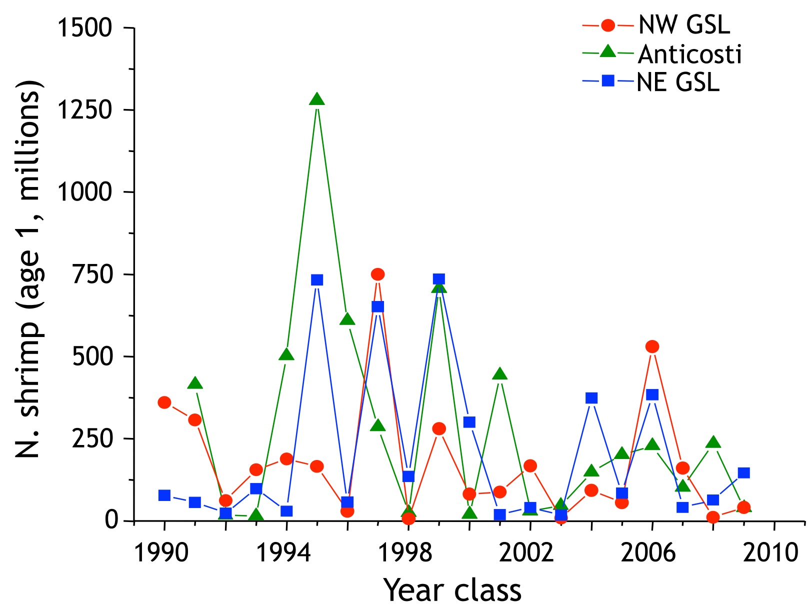
Northern shrimp recruitment variability since 1990

• Sampling with a specially design trawl showed the possibility to following cohorts. This led to the conclusion that year-class strength (recruitment to the fishery) is decided early, at the larval stages (L. Savard, pers. comm.)



• Since 1990, large interannual fluctuations, without apparent trends, have been observed in shrimp recruitment (number of age 1, from annual (August) research survey)

• There is also coherence among populations:
NE GSL and Anticosti, r = 0.551*
NW GSL and NE GSL, r = 0.514*
Anticosti and NW GSL, r = 0.166
(Cross-correlation lag 0, *$p < 0.05$)



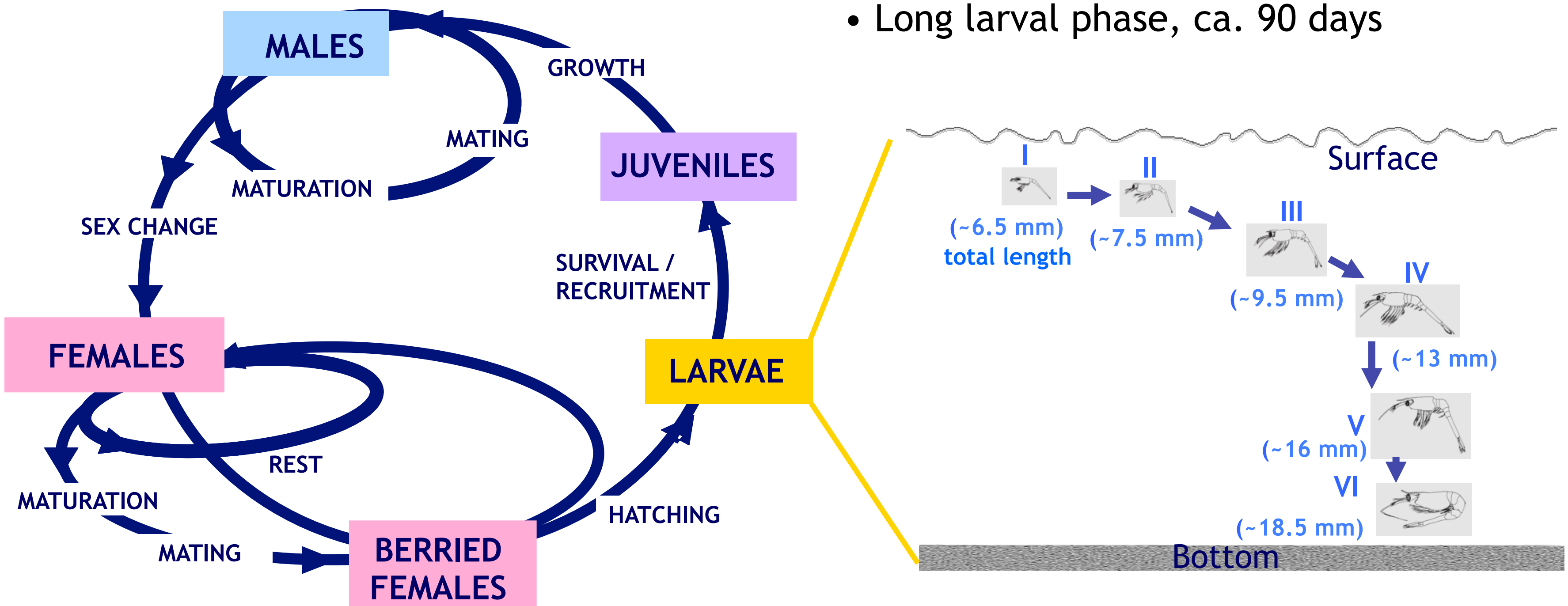
Understanding interannual recruitment variability (1)

- Northern shrimp recruitment studies in the northern GSL
  - Life cycle and larval ecology
  - Development of a larval survival index & ecosystem indicators

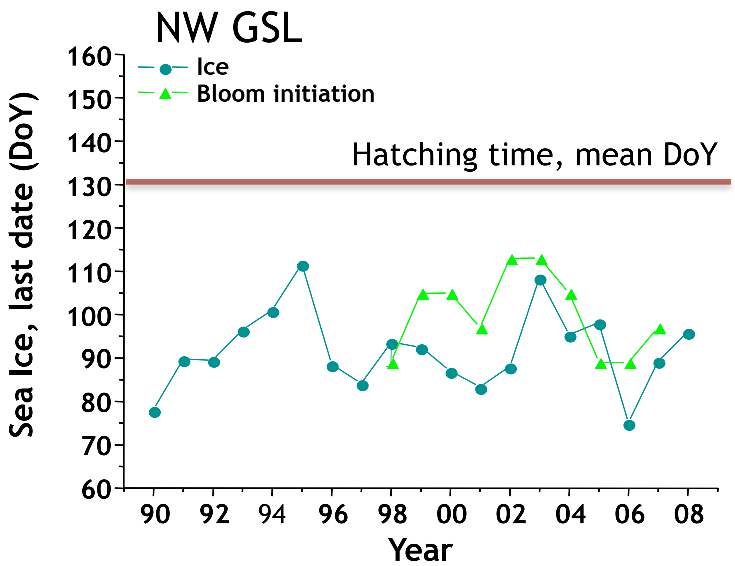
Pandalus borealis life cycle

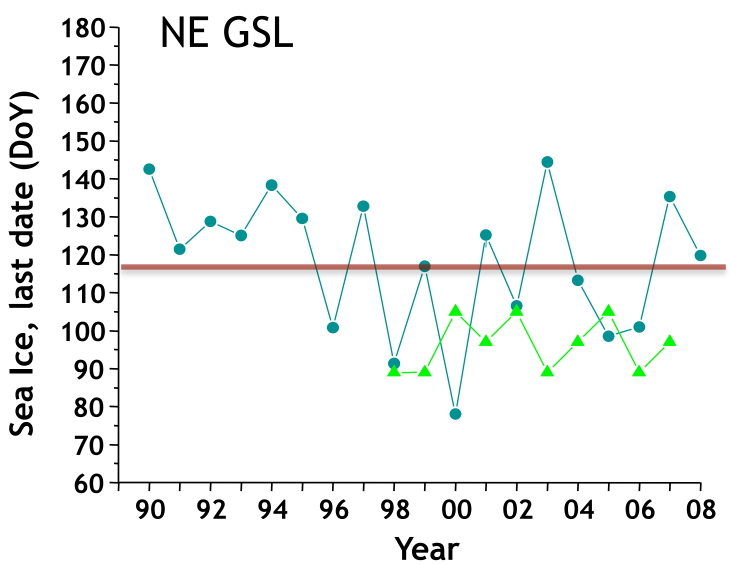
- Protandric hermaphroditism: born male, change to female at 4—5 years old
- Lives in deep water from juvenile to adult: growth, maturation, and reproduction influenced by deep-water temperatures

- Larvae hatch in early spring (end of April – May)
- Six larval stages, I to IV are truly pelagic
- Migration to deep water begins at stage V and VI
- Long larval phase, ca. 90 days



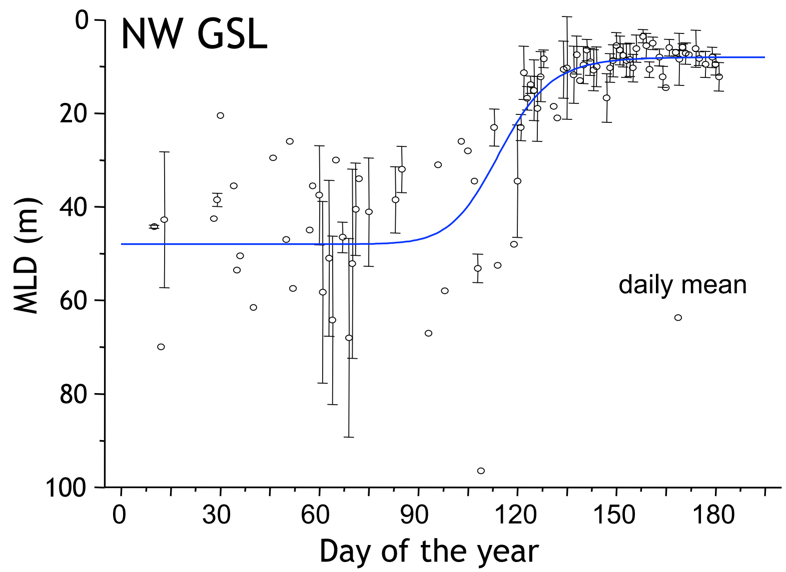
Conditions in spring in the northern GSL





- The NW GSL is totally free of ice at hatching time but not the NE GSL where hatching is earlier

- In winter and early spring, the upper water column is well mixed (deep mixed-layer-depth–MLD) but stratification follows quickly after the retreat of the ice, reducing MLD



Pêches et Océans Canada

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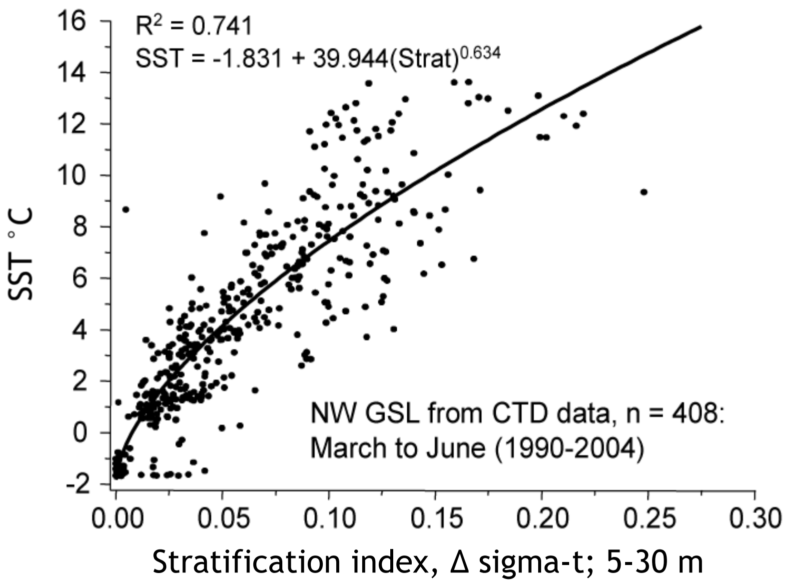
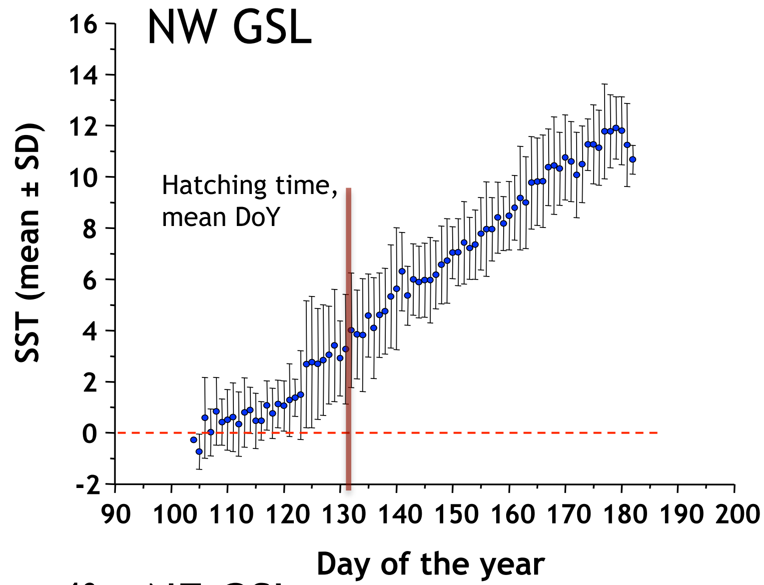
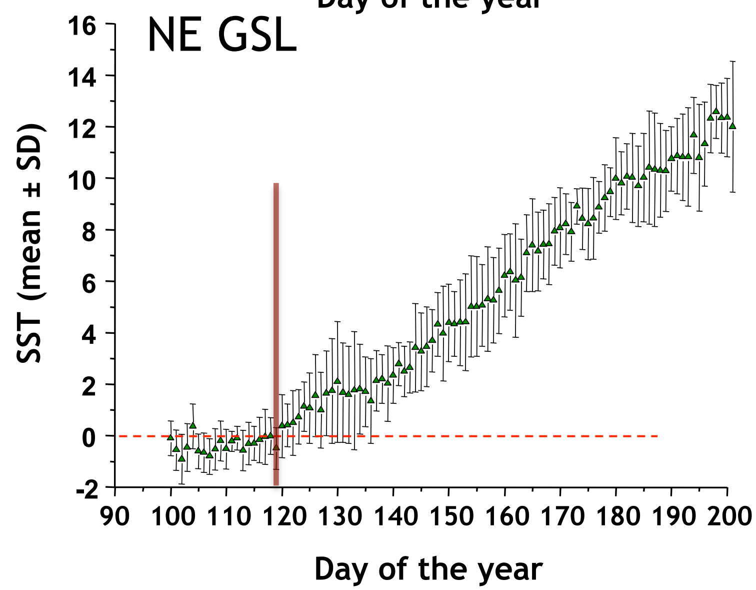
Conditions in spring in the northern GSL



A result of the stratification in the upper layer is a rapid increase in sea surface temperature (SST) in spring

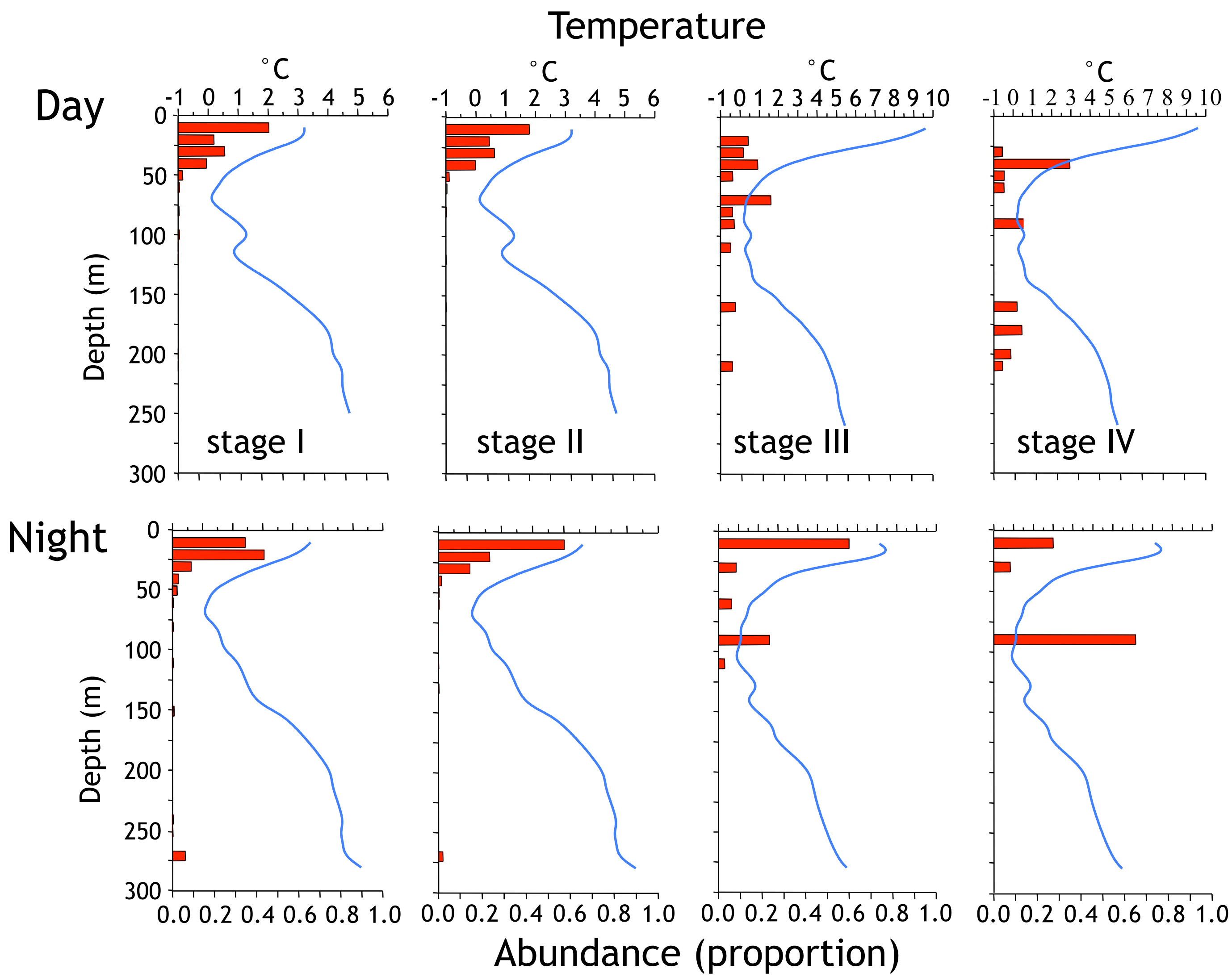
Shrimp larvae hatch earlier and in warmer surface water in the NW GSL compare to the NE GSL





Ouellet et al. 2007. Mar. Ecol. Prog. Ser. 339: 229-241

Vertical distribution, larval stage I to IV



- 95% of stage I & II shrimp larvae are found above 1°C and 50% above 3°C

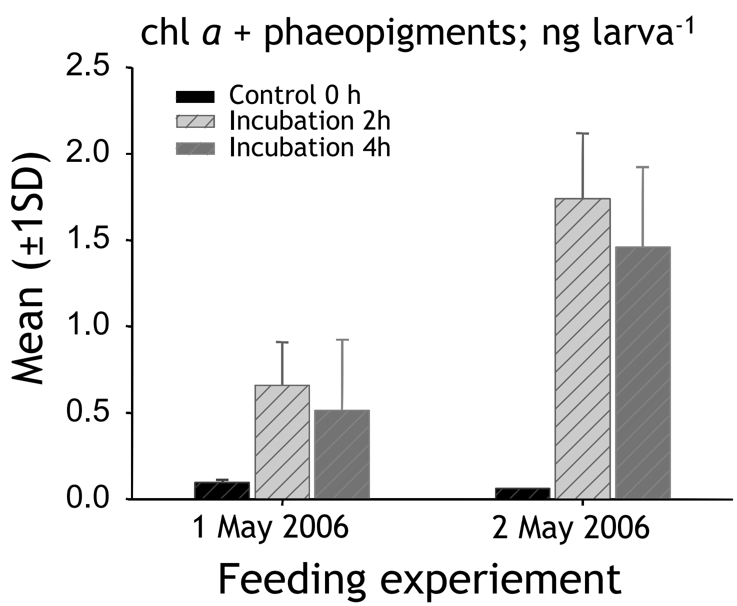
- Proportion of stage I & II larvae above 25 m;

day: ~60%
night: ~90%

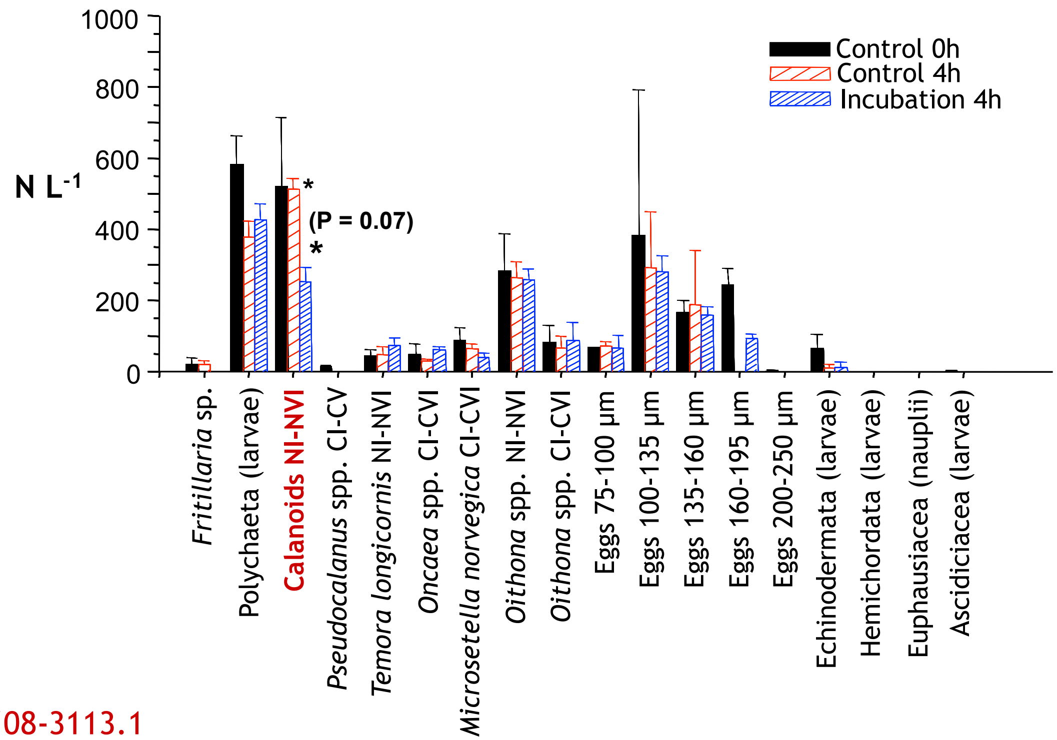
Ouellet & Allard. 2006. Fish. Oceanogr. 15. doi:10.1111/j.1365-2419.2005.00394

First stage larvae diet and trophic level

- Gut pigment examination by fluorescence shows that first stage shrimp larvae ingest phytoplankton cells
- Phytoplankton cells and diatom and zooplankton fragments were observed in larval guts

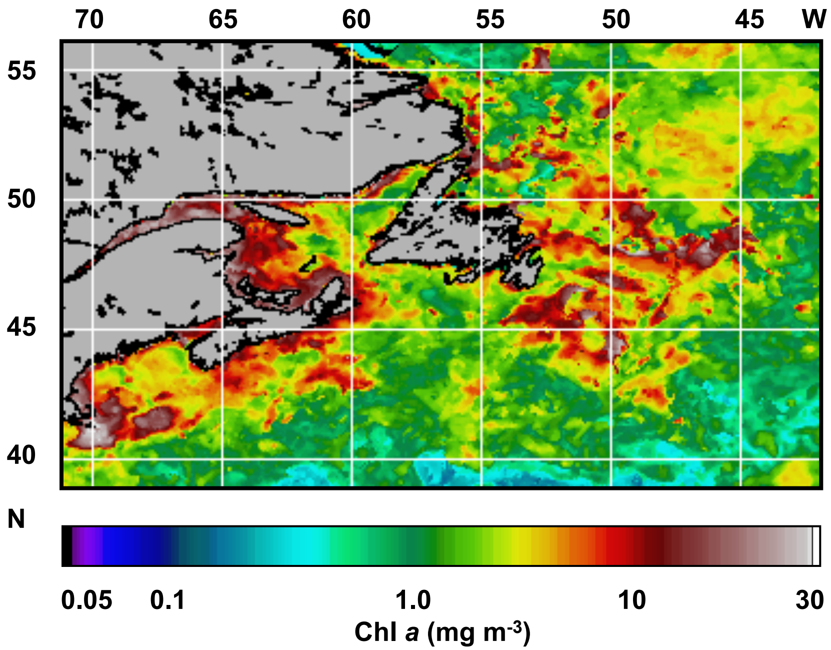


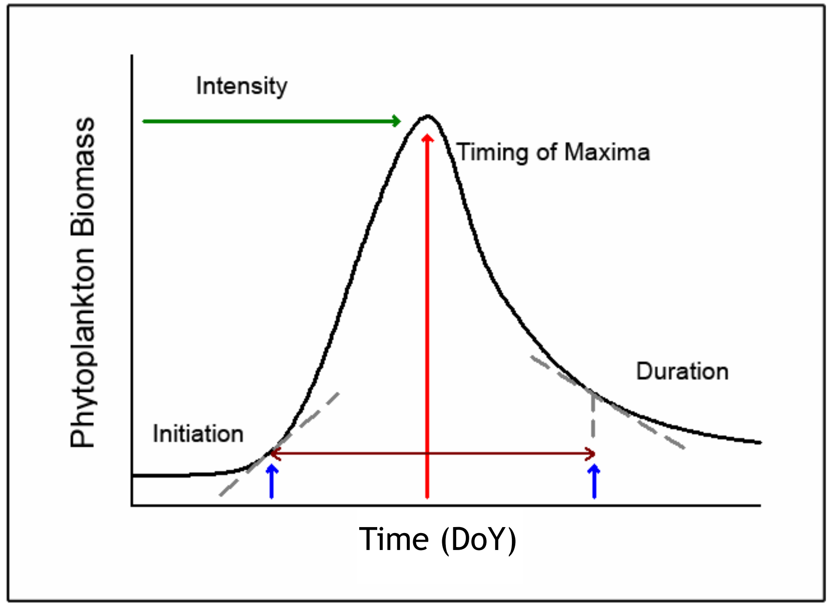
- Conversion of gut pigment concentrations to energy values suggests that phytoplankton alone is unlikely to provide the minimum calories required for the first stage larval development
- Controlled feeding experiments also showed that first stage larvae selected small zooplankton prey among the community



Ariza & Ouellet. 2009. J. Crust. Biol. 29. doi:10.1651/08-3113.1

Ecosystem indicators: spring bloom characteristics & SST





Bloom: SeaWiFS-MODIS spectral radiometric data, 9 km × 9 km spatial resolution, grouped into 8-d periods. Two curves (before and after the maximum) were fitted independently to concentrations (mg m^{-3}) over time and re-coupled to determine bloom characteristics: intensity, initiation, timing, and duration.

SST: NOAA-AVHRR images, 1 km × 1 km spatial resolution, grouped into 7-d periods:

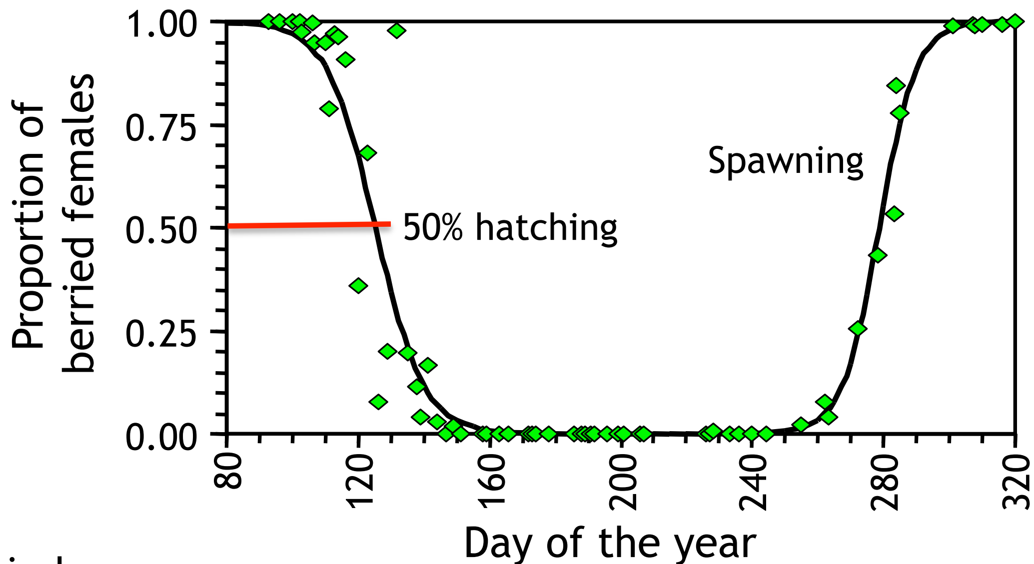
1) SST_H(°C) for the week coinciding with the date of 50% egg hatching
2) SST warming rate (°C d^{-1}): $(SST_{H+4week} - SST_H)/28d$

Ecosystem indicators: Hatching time and larval survival index

Hatching date:

Shrimp samples were collected (since 1992) from commercial fisheries within each study area

Proportions of egg-carrying females plotted against the catch date; a curve is fitted to estimate the day of the year on which the half the eggs have hatched (50% of females without eggs)



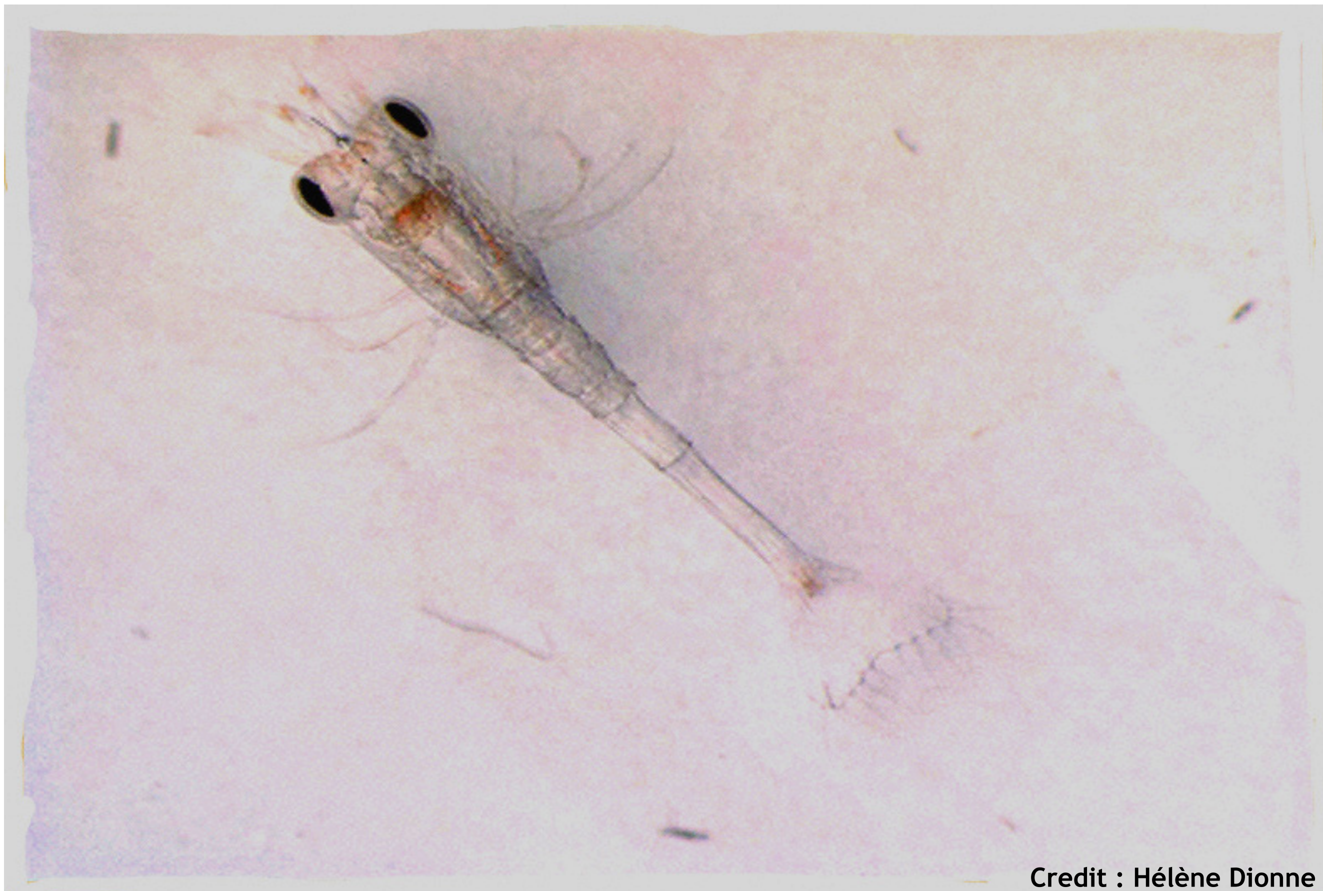
Larval survival index:

Spawning stock biomass index (SSB) estimated from the catch rate of multiparous females in the fishery (April and May) (i.e., females that are responsible for the production of larvae during the same year)

Larval survival index estimated by dividing the recruitment index (age 1 abundance from RS) by the SSB index

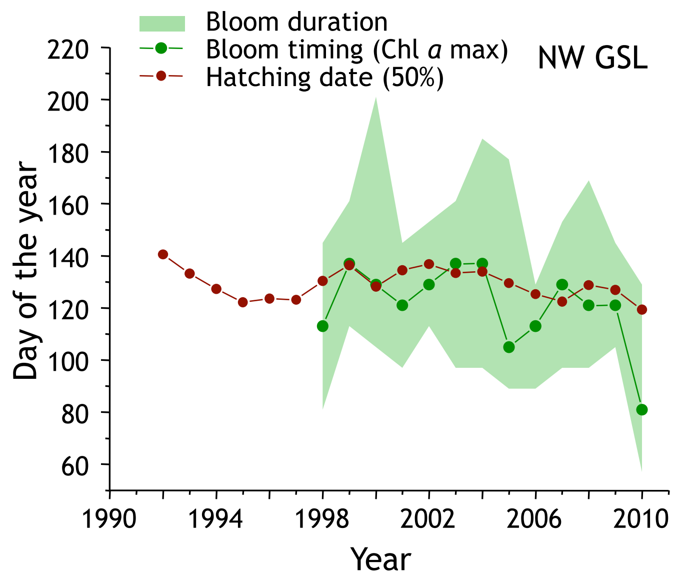
Understanding interannual recruitment variability (2)

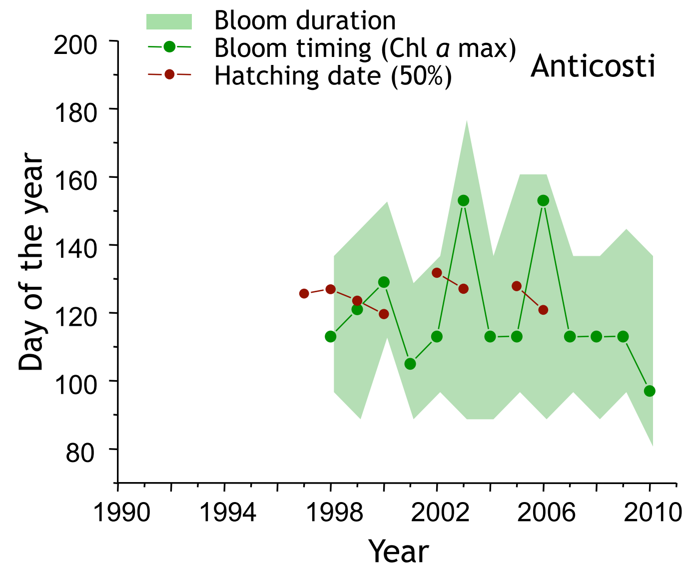
- Northern shrimp and the match/mismatch hypothesis
- Ocean surface characteristics and northern shrimp larval survival (recruitment variability) in the GSL and NW Atlantic

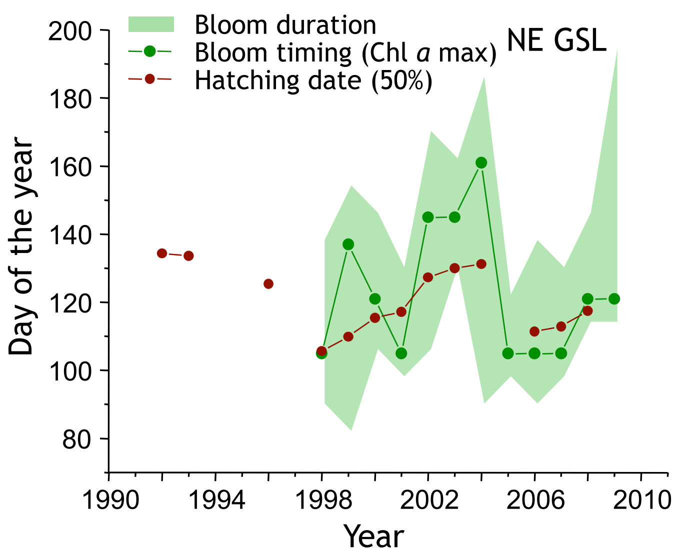


Credit : Hélène Dionne

Hatching time and phytoplankton spring bloom in northern GSL…



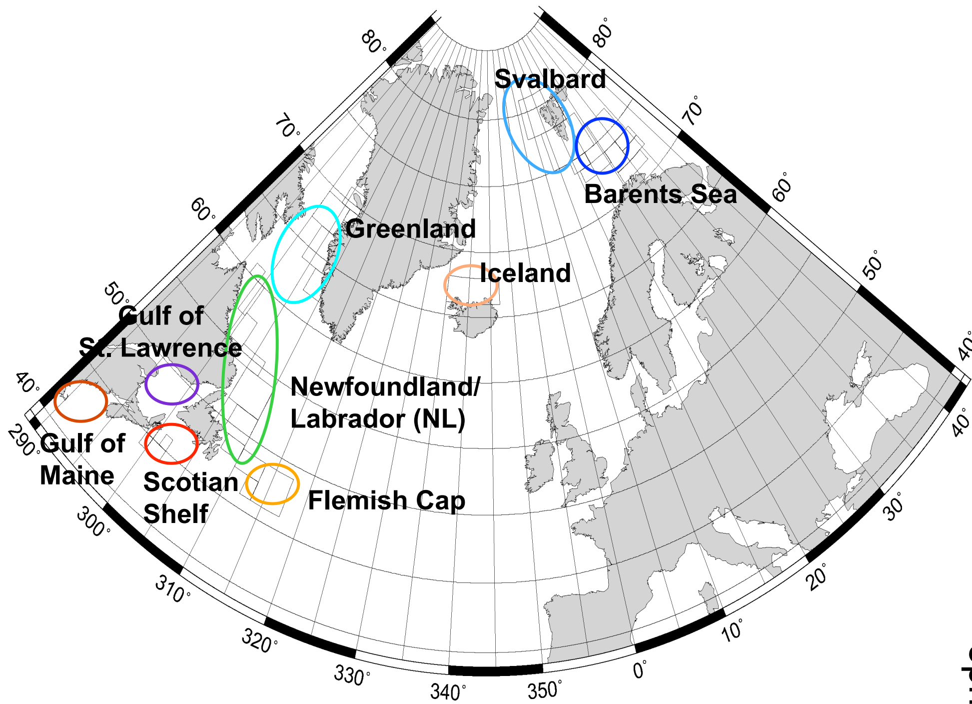




- Timing, duration, and intensity (not represented on these graphs) of the spring phytoplankton bloom vary among years for each region of the GSL

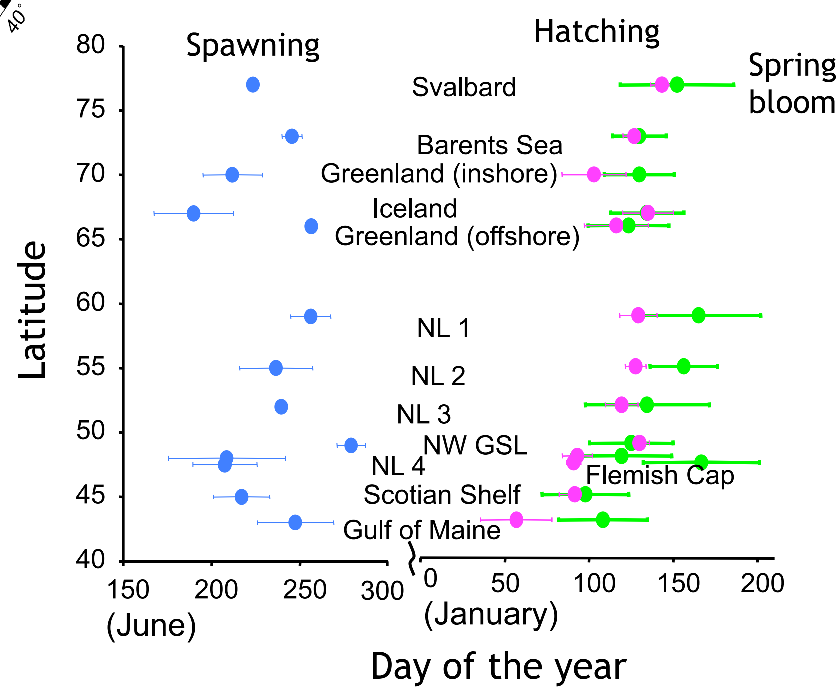
- However, northern shrimp hatching always happens after bloom initiation and close to the bloom maximum (except for 2010 in the NW GSL where the bloom was much earlier)

… and throughout the North Atlantic



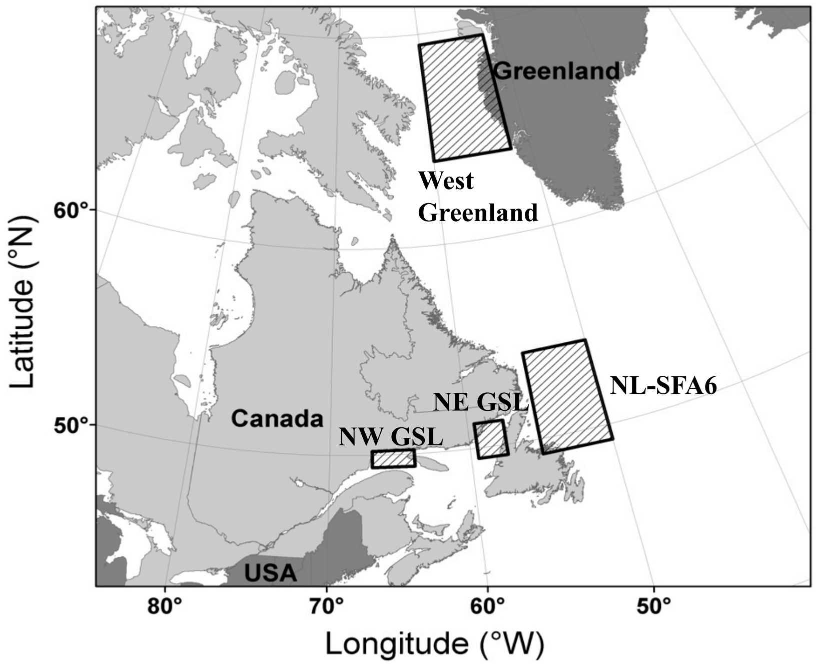
- Using the same methodology as for the GSL study: Comparing shrimp hatching times and the timing of the spring phytoplankton bloom from the Gulf of Maine to the Barents Sea

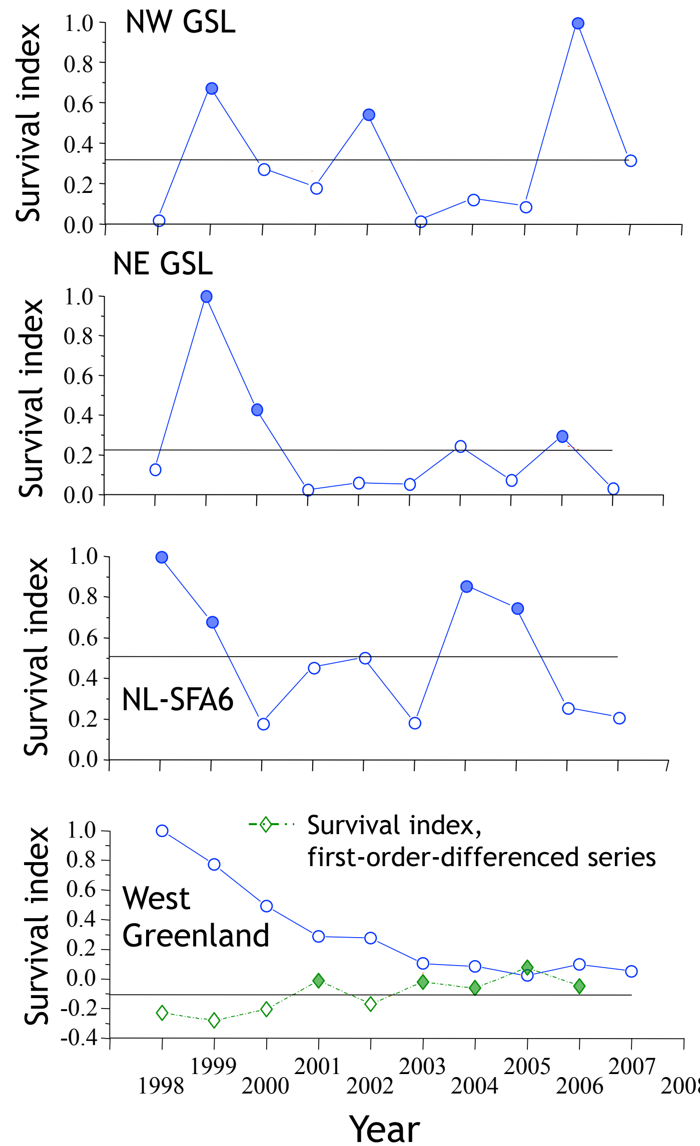
- Duration of egg development depends on bottom temperature, hence reproduction and spawning time must have adapted to local temperature for hatching to coincide with bloom time



Koeller *et al*. 2009. Science. 324. doi:10.1126/science.1170987

Ocean surface characteristics and larval survival & recruitment variability





Approach:

- For four populations but a period limited by the availability of bloom data (SeaWiFs, 1998 to 2008)
- Comparing mean values of the selected indicators (i.e., SST; SST warming rate; bloom initiation, duration, intensity) between years of below (empty symbols) and above (filled symbols) mean (horizontal line) larval survival

Ouellet *et al*. 2011. ICES J. Mar. Sci. 68. doi: 10.1093/icesjms/fsq174

Ocean surface characteristics and larval survival & recruitment variability

For all regions, larval survival was consistently positively associated with the duration of the bloom but stronger relationships between larval survival and SST-derived indices:

In addition to a good match between larval hatching and the biological production cycle (spring bloom), favourable temperature conditions are critical; a rapid warming of the upper water column following hatching or higher temperature at hatching in colder environments (e.g., NE GSL) seems essential for the larvae to benefit from hatching during a period of (potentially) high primary and secondary production

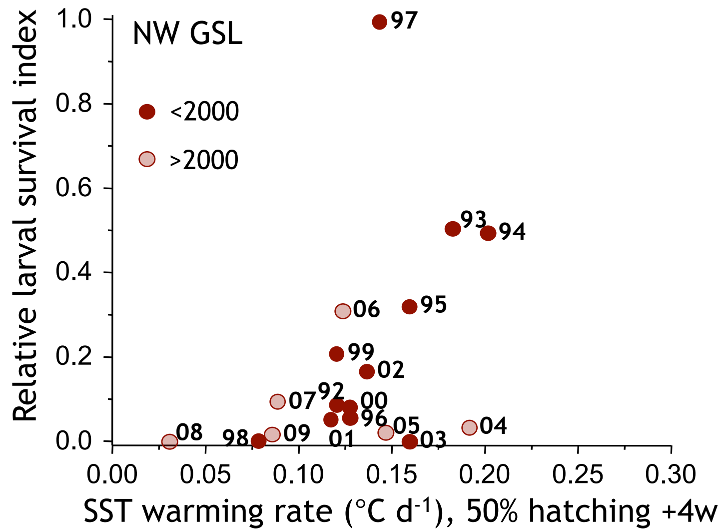
Comparison of ocean surface characteristics between years with below-average (B) and above-average (A) larval survival indexes (SurInd) in each region. Note: Only the marginally significant (p < 0.1) differences in the original Ouellet et al. table are shown.

Region	Group	Dependent variable	ANOVA F, *p*	Kruskal-Wallis χ^2, *p*	*t*-test t, *p*	Conclusion B(avg) vs. A(avg)
NWGSL	SurInd	Wrate (°C d^{-1})	**3.499, *0.098***	**3.365**, *0.066*	1.870, *0.098*	B (0.154) < A (0.178)
NEGSL	SurInd	SST (°C)	**5.186**, *0.057*		2.277, *0.057*	B (-0.411) < A (0.081)
SFA6	SurInd	Wrate (°C d^{-1})	**4.693**, *0.062*		-2.166, *0.062*	B (0.052) < A (0.082)
		Init (DoY)	***5.957, *0.041***		***2.441, *0.041***	B (103.6) > A (89)
WG[1]	SurInd	SST (°C)	**4.026**, *0.085*		2.007, *0.085*	B (0.152) < A (0.626)

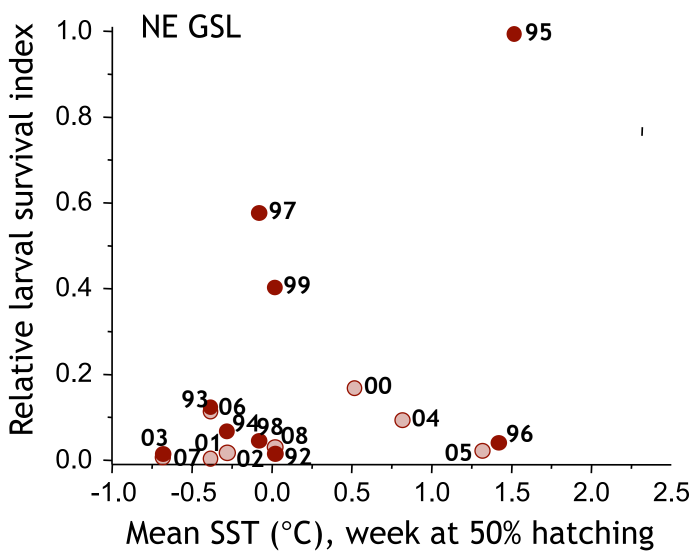
[1]Trend removed by first-order difference

Ouellet *et al*. 2011. ICES J. Mar. Sci. 68. doi: 10.1093/icesjms/fsq174

In detail: SST and larval survival in the GSL, 1990 to 2009



SST warming & Survival index	Pearson r, *p*	Spearman r_s, *p*
All years	0.417, *0.085*	**0.437, *0.070***
Before 2000	0.561, *0.148*	**0.755, *0.031***
After 2000	0.081, *0.824*	0.043, *0.907*



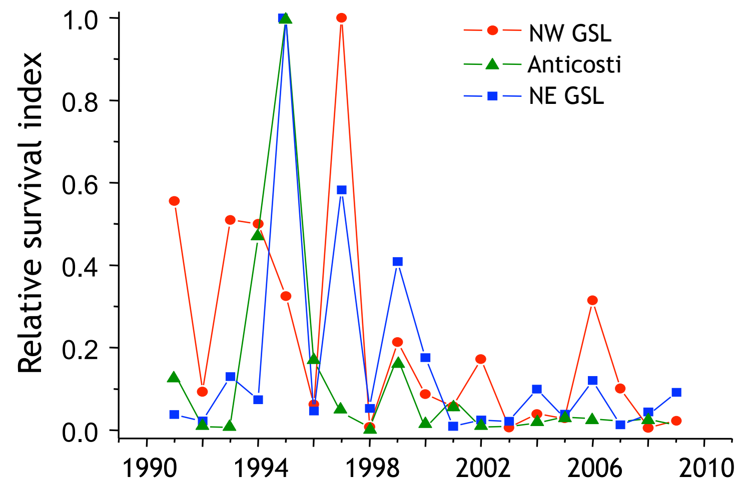
Mean SST & Survival index	Pearson r, *p*	Spearman r_s, *p*
All years	0.396, *0.115*	**0.428, *0.086***
Before 2000	0.458, *0.254*	0.060, *0.887*
After 2000	0.353, *0.352*	0.571, *0.108*

Why is larval shrimp survival lower since 2000?

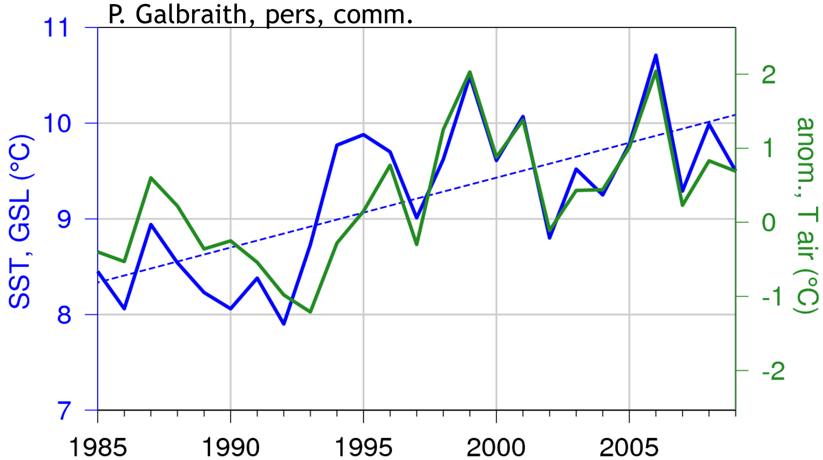
• Northern shrimp larval survival indices have been generally low since 2000

• Conditions are changing in the GSL: Warmer SST have been recently observed and there is a declining trend in the warming of the surface water mass in the NW GSL

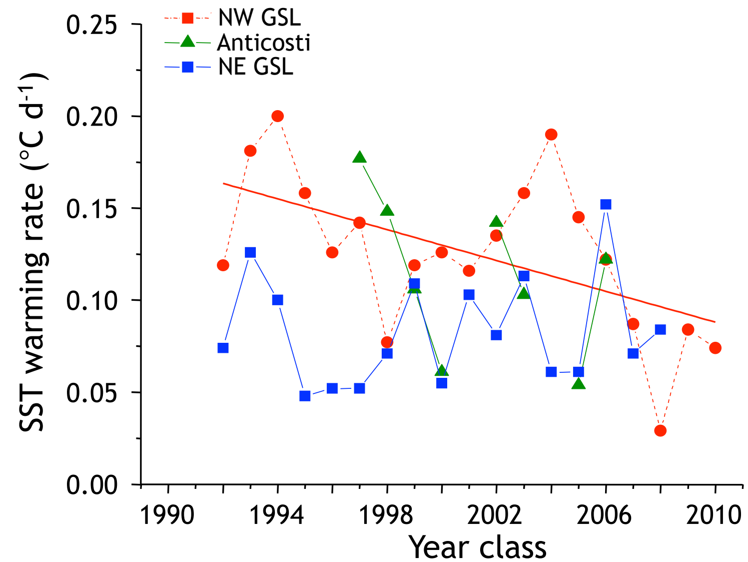
• Has the warming begun to affect the northern shrimp populations?



P. Galbraith, pers, comm.



SST average from May to November (blue line) and average annual air temperature anomaly at nine weather stations around the GSL (green line).



Summary and Conclusions

- In the northern GSL, northern shrimp and Greenland halibut biomasses increased after the dramatic decline in Atlantic cod abundance

- However, since the collapse of the cod population we found no evidence of top-down control (from Greenland halibut or Atlantic cod) of northern shrimp biomass. Environmental (bottom-up) factors must explain the large interannual fluctuations in shrimp recruitment (i.e., larval survival and abundance of age 1)

- A major international effort revealed that the reproductive cycle and spawning time of northern shrimp populations are adapted to local deep-water temperature such that hatching occurs during the spring phytoplankton bloom and potentially high biological production

- A direct relationship between varying spring bloom conditions and larval survival is less clear. However, stronger relationships with SST-derived indices suggest that favourable conditions for development of secondary production—hence an abundance of food for the successive pelagic larval stages—are critical

- In recent years, lower levels of larval survival have been more frequent in the GSL

- With global climate change, local temperature conditions are likely to change in northern shrimp habitats. What will the impacts be on abundance and distribution?

➢ Future work: northern shrimp and climate change

Assessing the response of northern shrimp (*Pandalus borealis*) populations to climate change and variability

Patrick Ouellet & Denis Chabot
Fisheries and Oceans Canada
Maurice Lamontagne Institute (MLI)
850 route de la mer,
Mont-Joli, QC, Canada G5H3Z4

David Orr
Fisheries and Oceans Canada
Northwest Atlantic Fisheries Centre
PO Box 5667
St John's, NL, Canada A1C 5X1

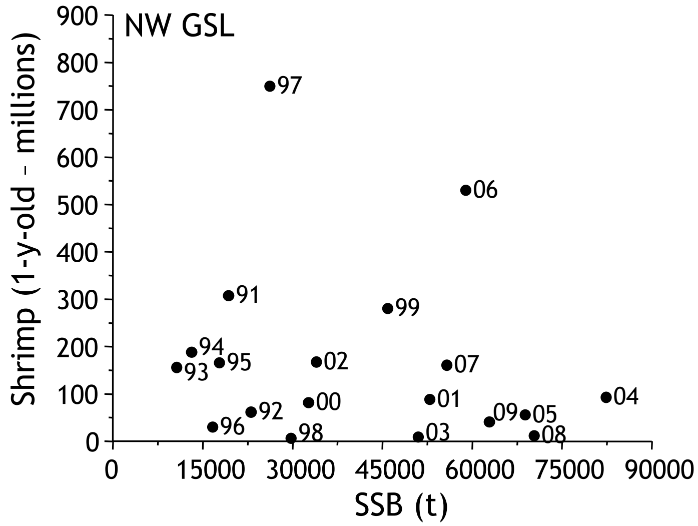
Piero Calosi
RCUK Research Fellow, Marine Biology and Ecology Research Centre
University of Plymouth
622 Davy Building, Drake Circus, Plymouth - PL4 8AA, UK

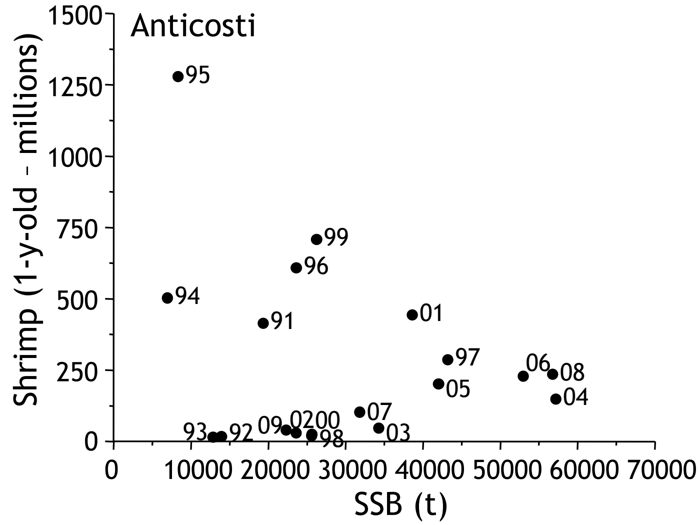
Objective: To assess the ability of northern shrimp populations to adjust to changes in mean temperature

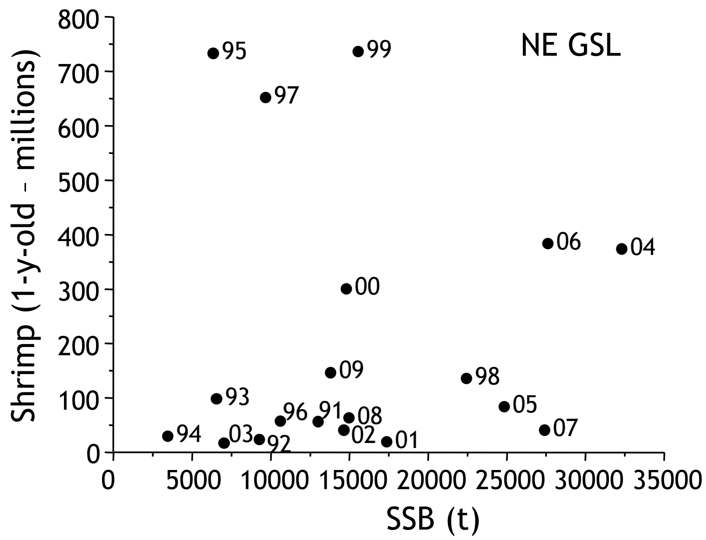
Approach (2011–2014): Determine the thermal tolerance limits (temperature dependence of aerobic metabolism) for optimal function and also the lethal temperatures for different phases of the life cycle (larvae and males and females) for different populations along a thermo-latitudinal gradient of distribution

This information coupled with climate scenarios produced by atmosphere–ocean models will allow an assessment of the impacts of climate change and variability on the productivity, distribution, and resilience of these populations in the Northwest Atlantic

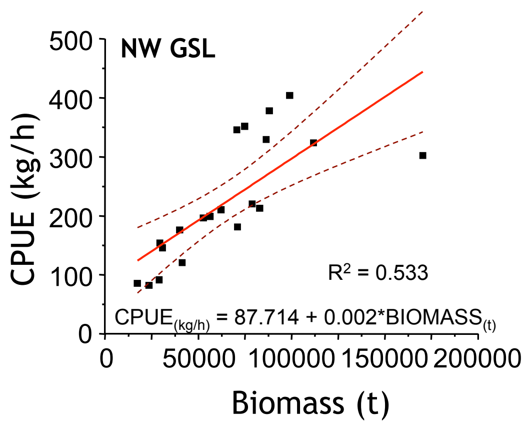
(No) Stock-recruitment relationships

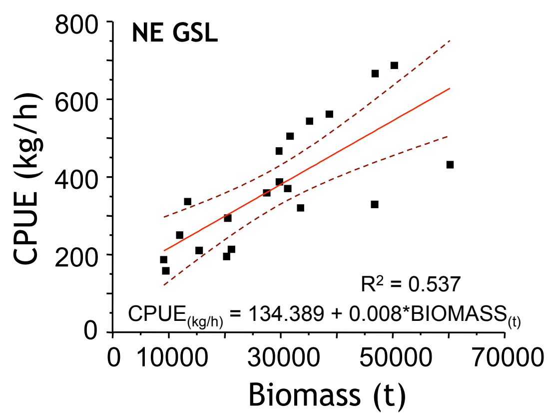




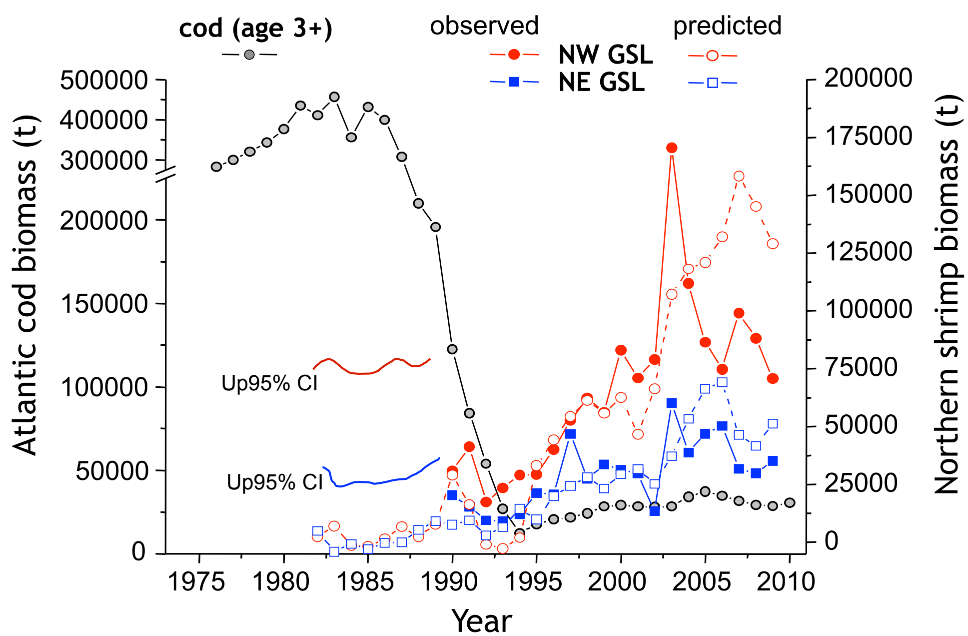


Northern shrimp abundance at the peak of cod biomass in northern GSL?





Relationships between standardized CPUE (standardized for season, gears, vessels, etc.) and biomass in the NW and NE GSL might be used in an attempt to estimate northern shrimp abundance before 1990…

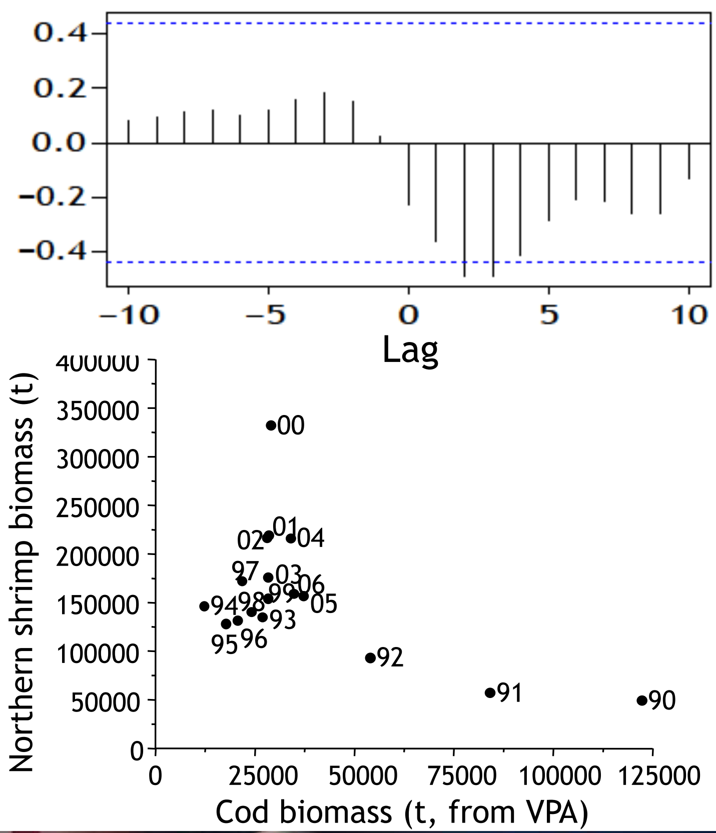


If the regressions are used to go back in time (even though it is not recommended to interpolate outside the range of X), despite large uncertainties illustrated by the upper 95% confidence intervals, it seems unlikely that northern shrimp biomass in the 1980s was higher than what is observed since 2000…

Interactions between shrimp and G. halibut and cod

- No significant stock—recruitment relationships have been observed for the northern shrimp populations of the GSL
- No evidence of “top-down” control on northern shrimp biomass in the GSL

Cross-correlation between Atlantic cod and northern shrimp biomasses for the entire GSL



Cross-correlation between Greenland halibut and northern shrimp biomasses for the entire GSL