# Environmental effects on recruitment of Northern shrimp (*Pandalus borealis*) in West Greenland waters: Impact of temperature and main predators

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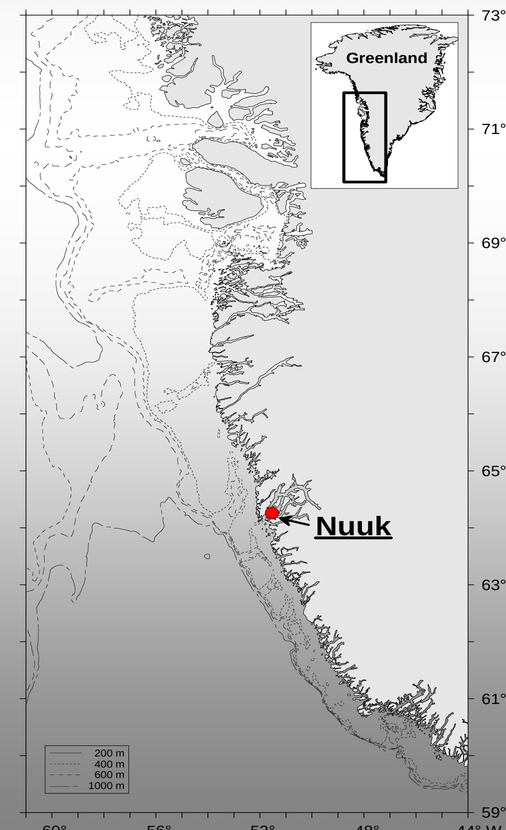



**ESSAS Open Science Metting, 22 – 26 May 2011, Seattle**

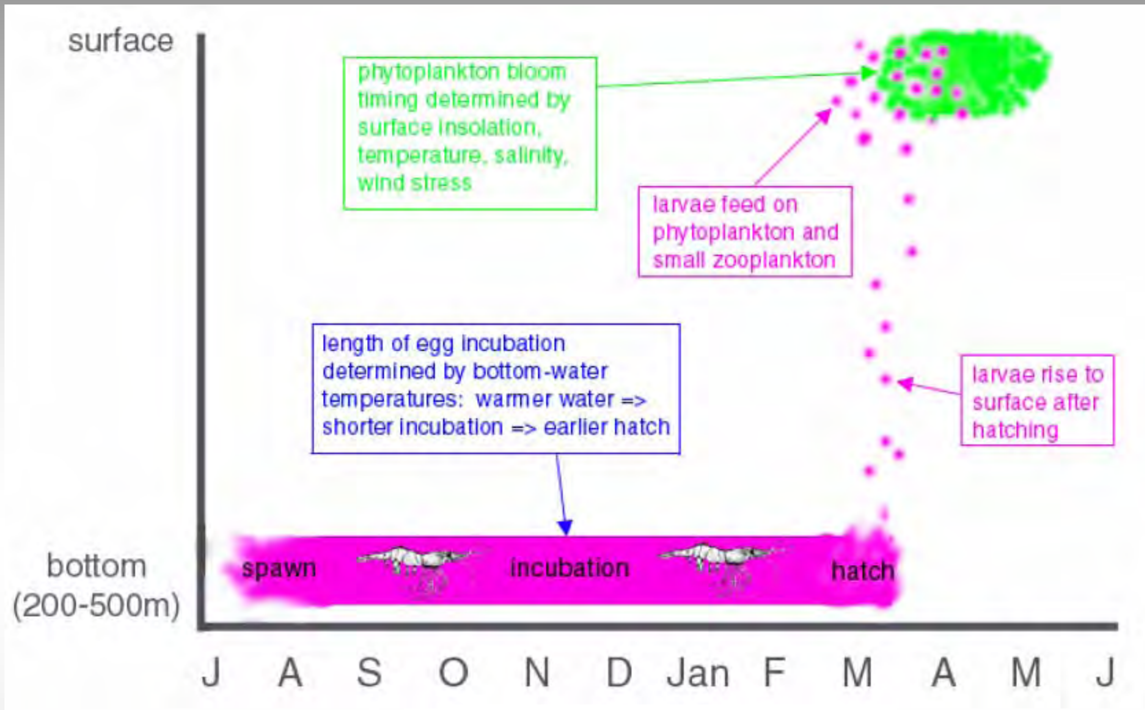
# Data sources and analyses


Time series of
- Temperature
  (Surface layer and bottom water)
- Biomass of Northern shrimp and its main predators
  (Atlantic cod, Greenland halibut)

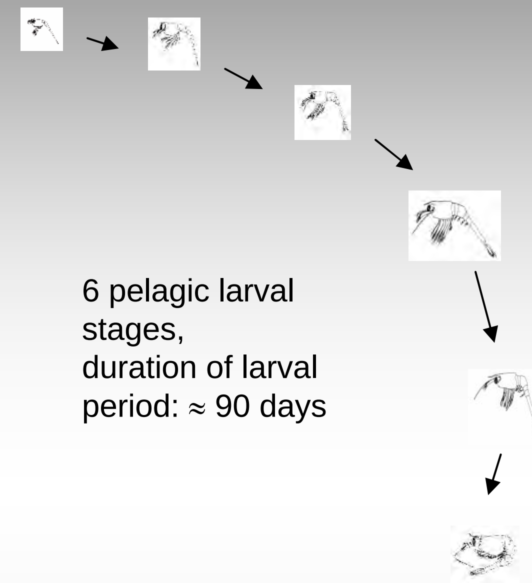
Stock-recruitment relationship for Northern shrimp
- without environmental variables
- with temperature and predator biomass


Data: Bottom Trawl Surveys (GINR and ISH)
Hydrographic investigations (DMI, GINR)

# Northern shrimp life cycle

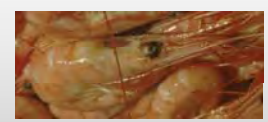


Koeller et al. (2009)



6 pelagic larval stages,
duration of larval period: ≈ 90 days

Juveniles



↓

Males

↓ Sex transition (after 4 – 6 years)

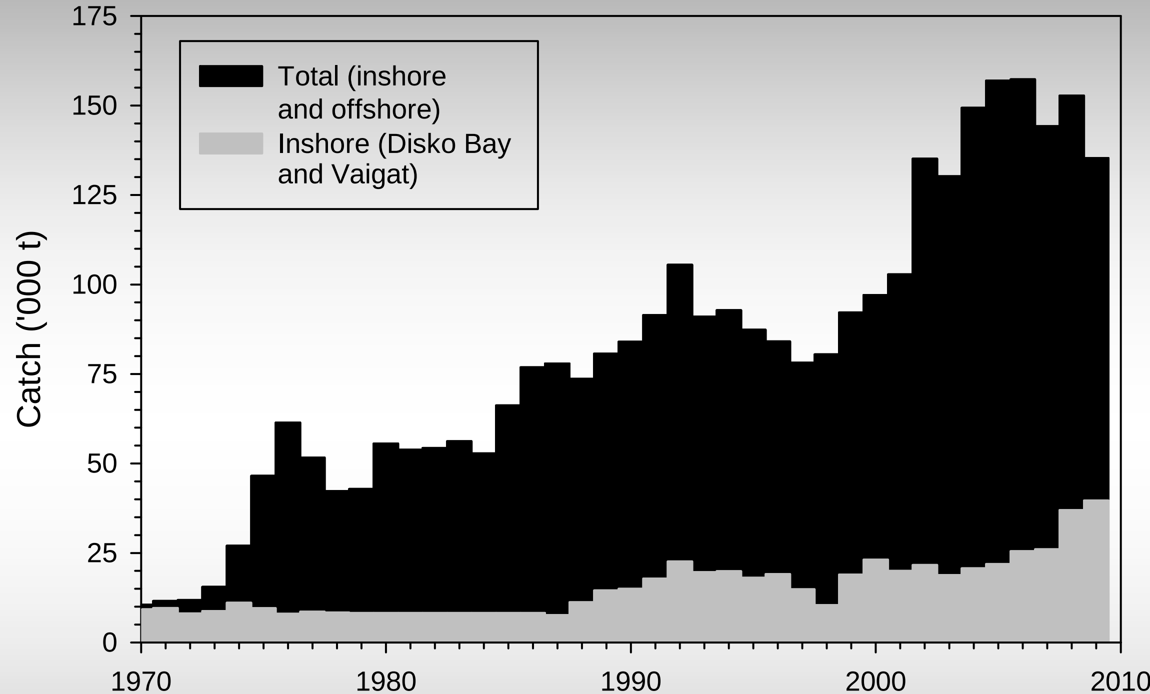
Females

(primiparous → multiparous)

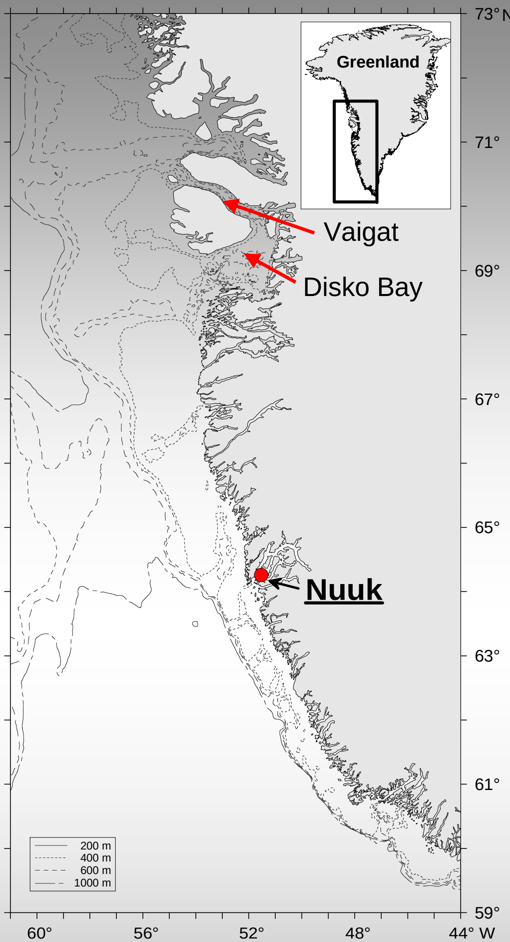
- Reproduction cycle adapted to bloom timing through egg incubation time at long-term average bottom temperatures
- Mismatch when changes in surface layer conditions (→ bloom timing) are not in phase with changes in bottom temperature (→ duration of egg period)

Duration of egg-bearing period: 9 months at 1.5°C
7.5 months at 3.5°C)

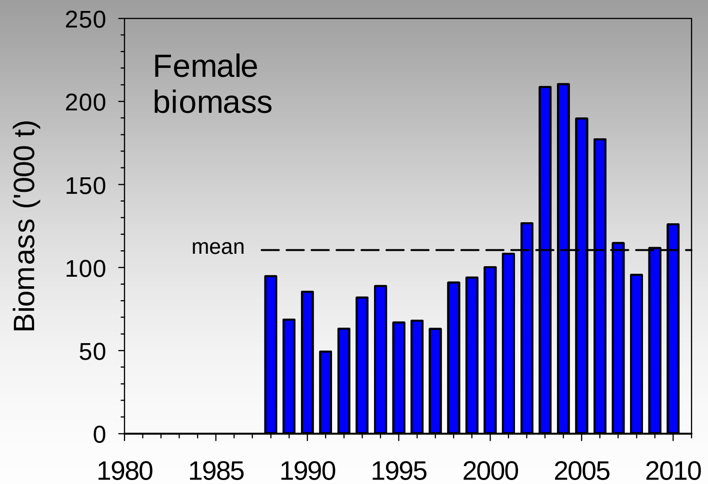
# The fishery for Northern shrimp at West Greenland

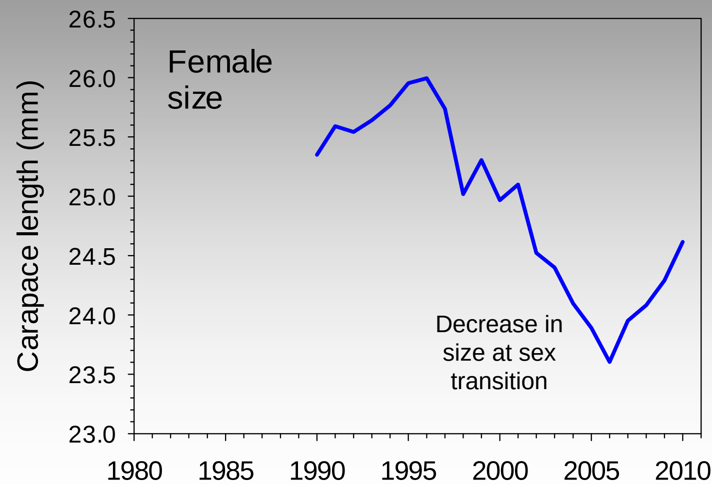


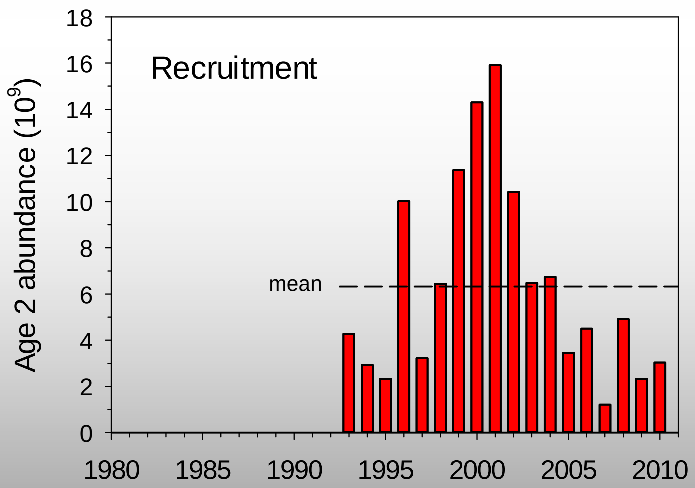

Arboe and Kingsley (2010)

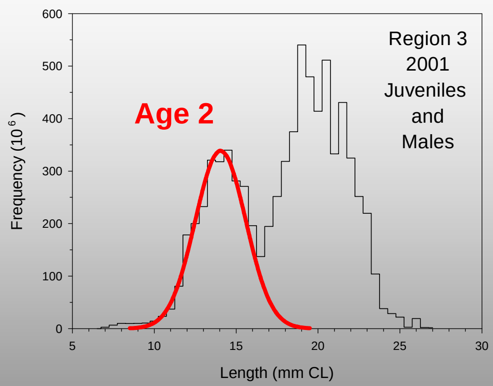



# Northern shrimp female biomass and recruitment





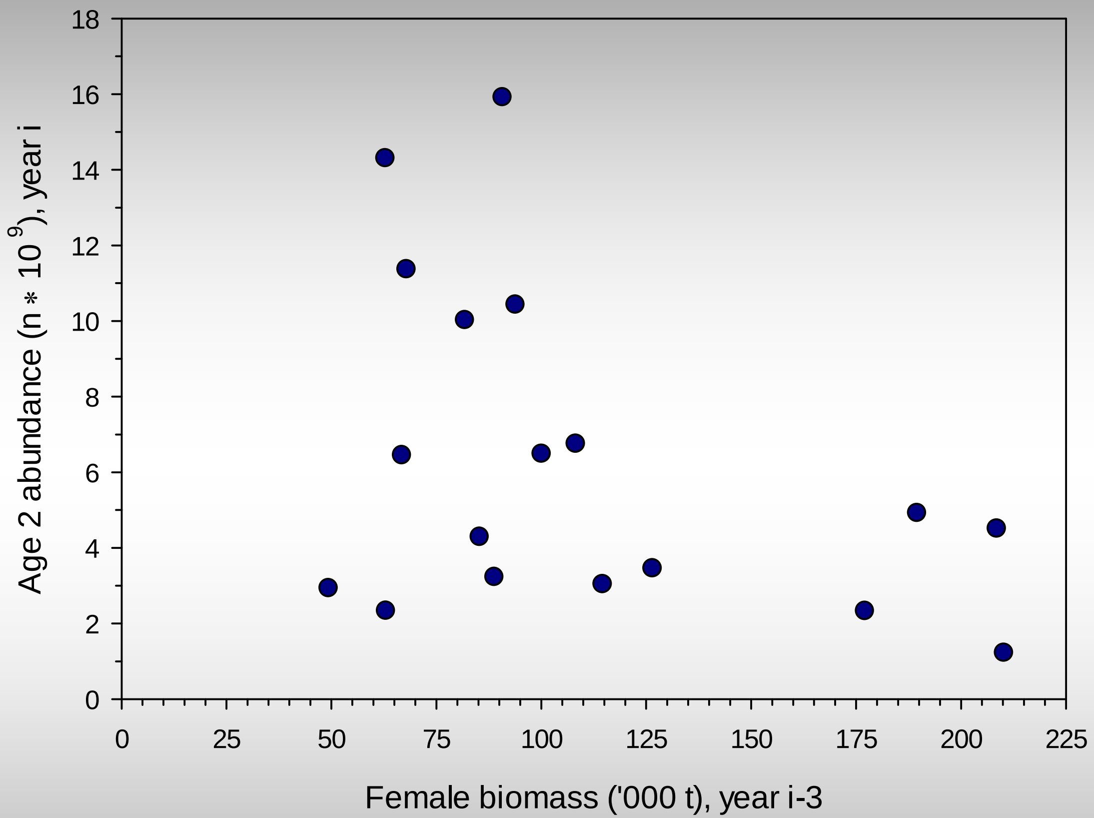
Extracted from length frequencies using modal analysis (MIX, CMIX)

by region (to account for geographical differences in growth)

GINR survey, Ziemer et al. (2010)

Cod end mesh size
1988-1992: 40 mm
Since 1993: 20 mm

# Stock recruitment relationship



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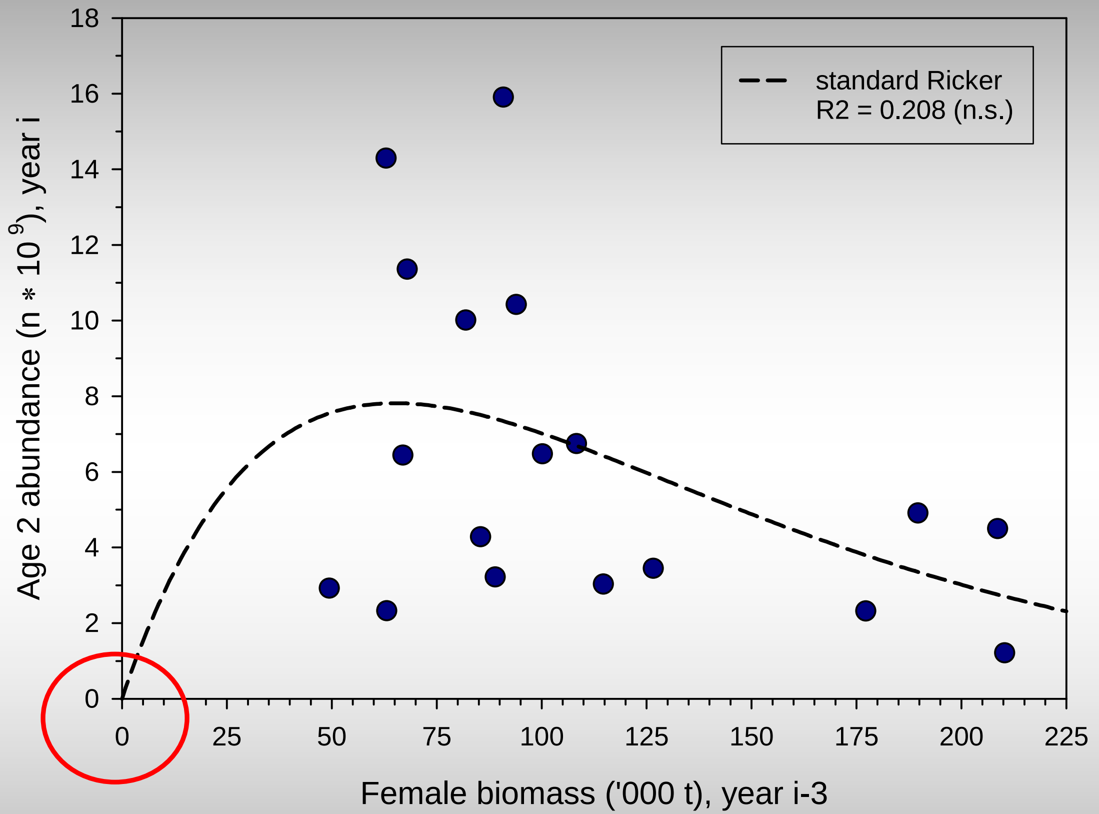


$R = \alpha * P * \exp(-\beta * P)$

α: density independent

β: density dependent

Ricker (1954)

Intercept > 0:

- Female biomass not a good measure for reproductive potential
- High (≈ 40 %) egg mortality during egg bearing period
- Removal of egg bearing females by the fishery

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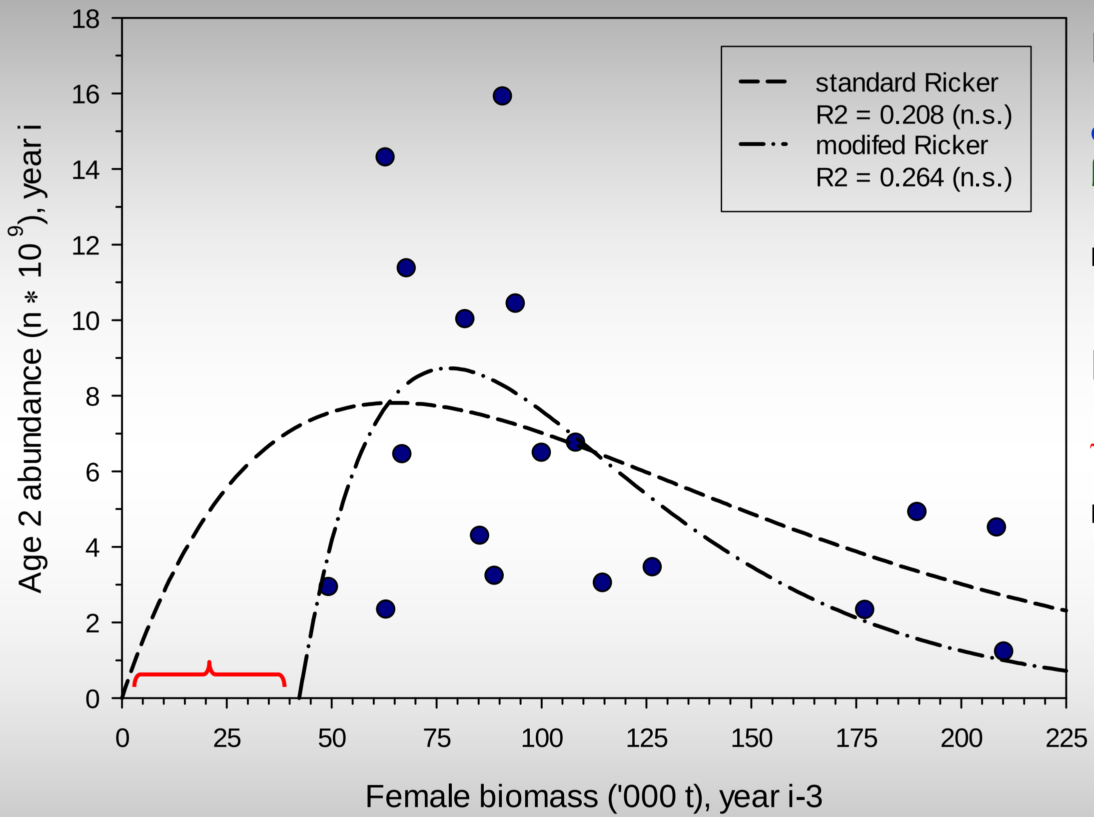


$R = \alpha * P * \exp(-\beta * P)$

$\alpha$: density independent

$\beta$: density dependent

Ricker (1954)

$R = \alpha * (P - \gamma) * \exp(-\beta * (P - \gamma))$

$\gamma$: depensation for $\gamma > 0$

Frank and Brickman (2000)

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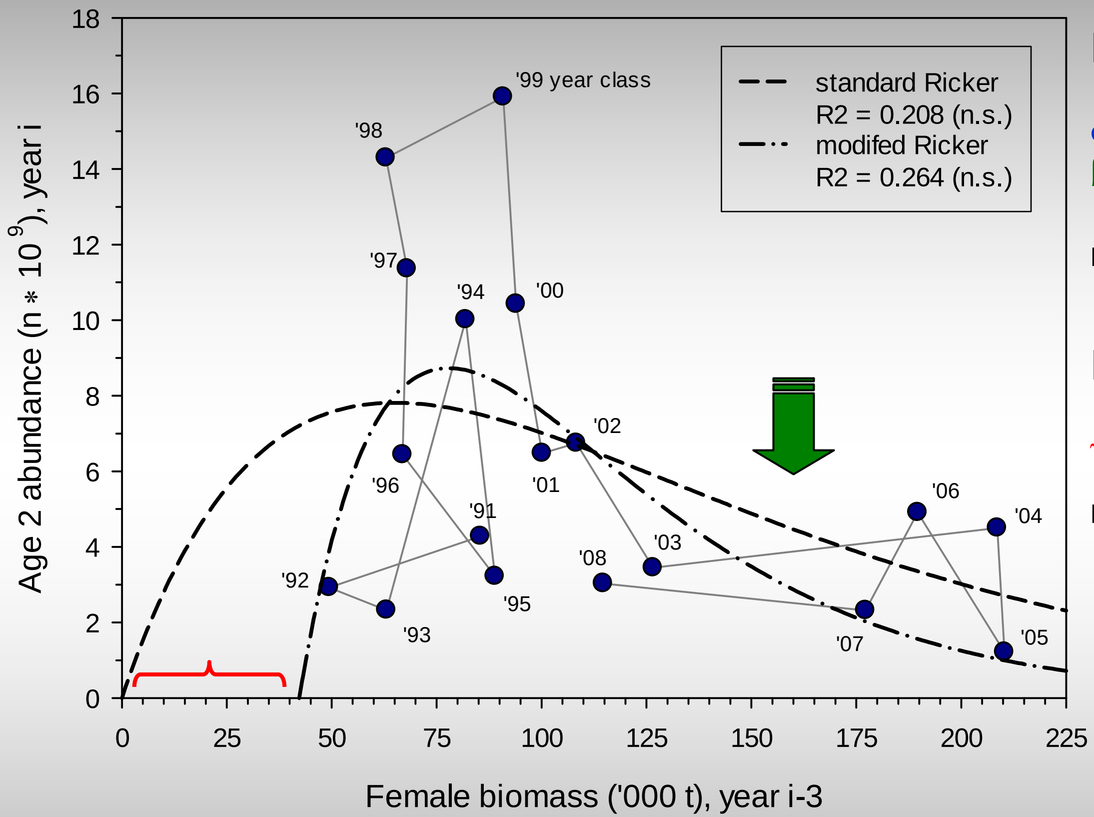


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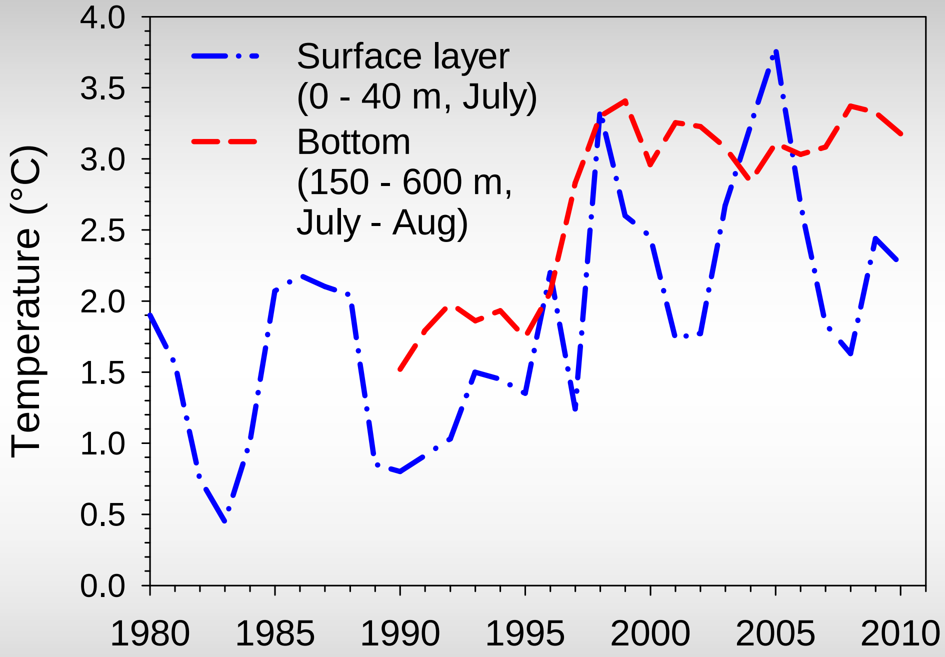
'Density-dependence':

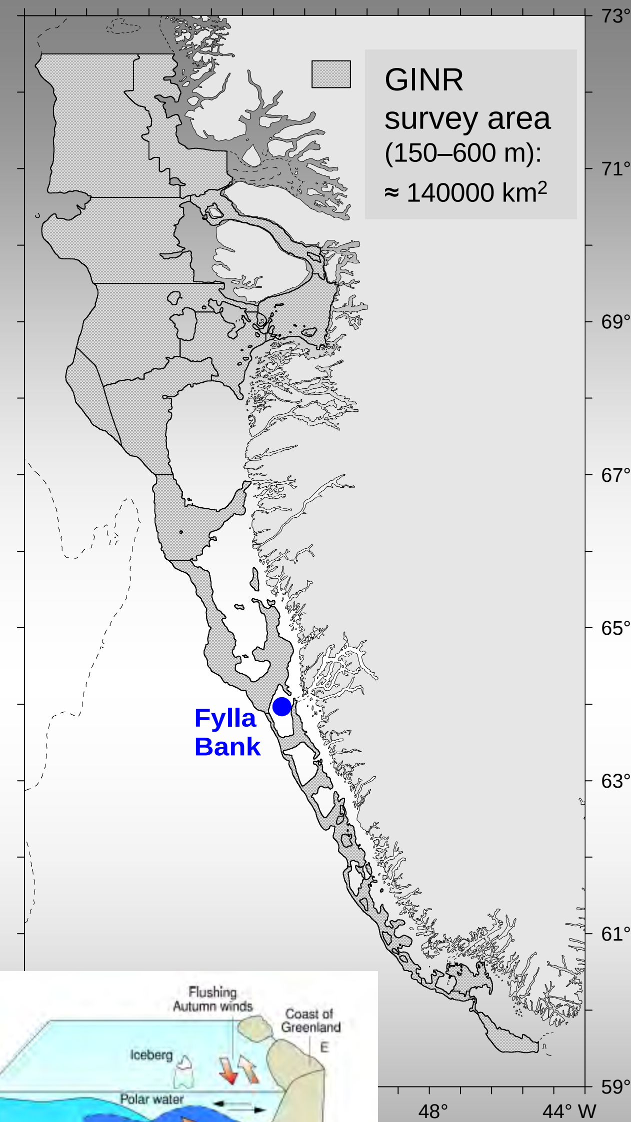
- •Lower carrying capacity
- •Mismatch of larval hatch
- •Higher predation

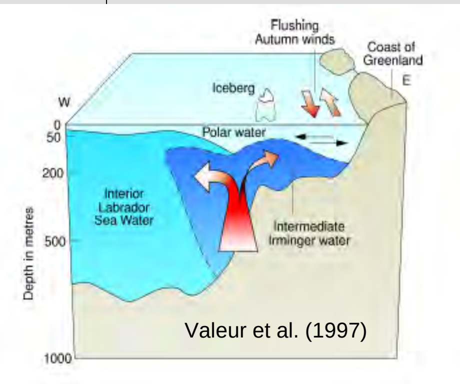
?

# Temperature



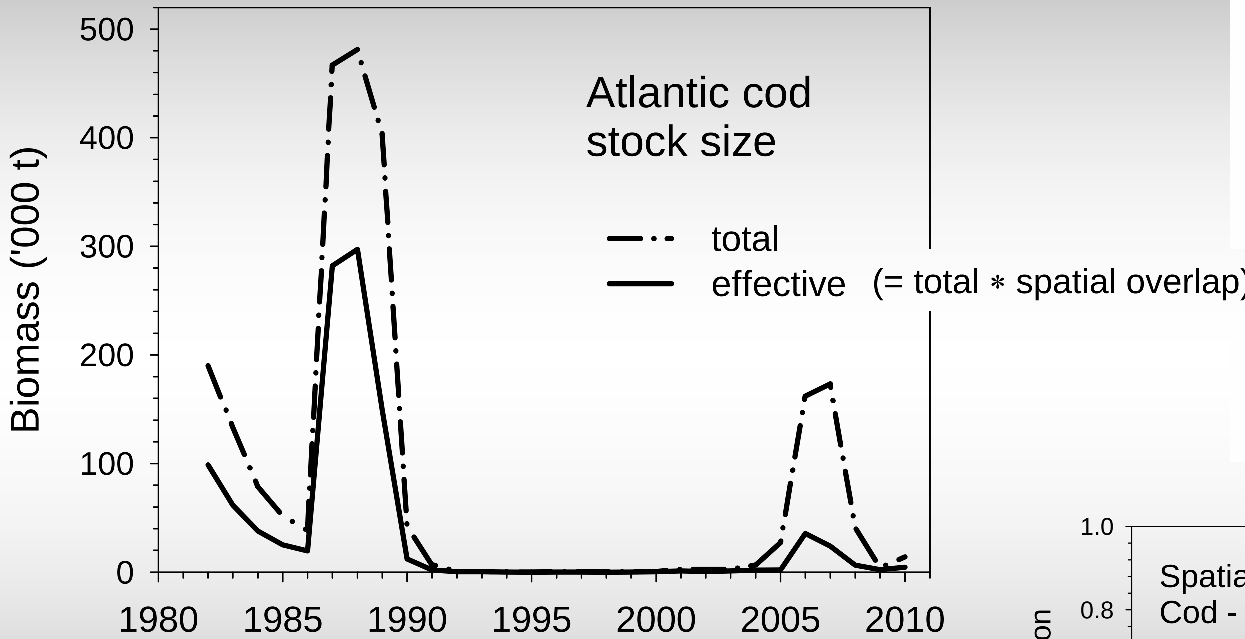

Shrimp recruitment above average:

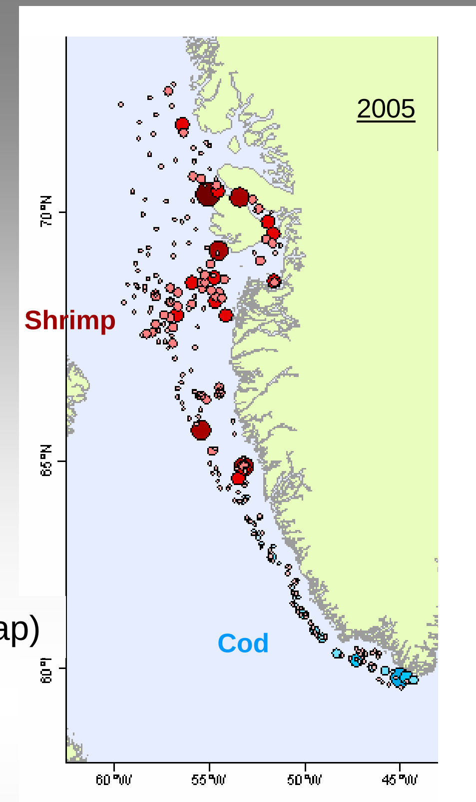


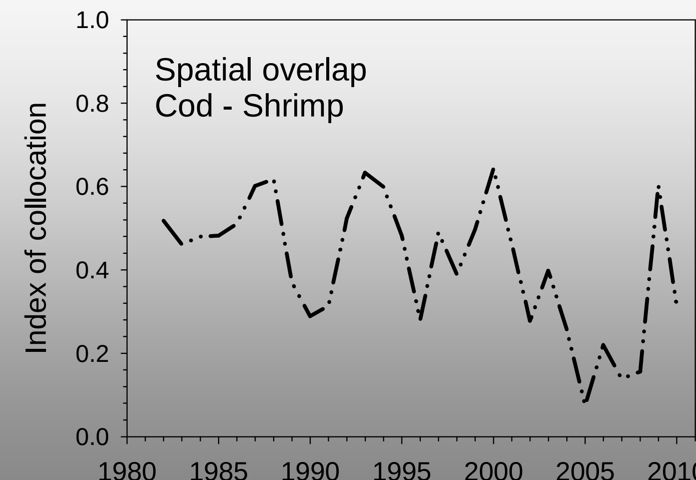
# Atlantic cod biomass

4 mio t in 1950 !



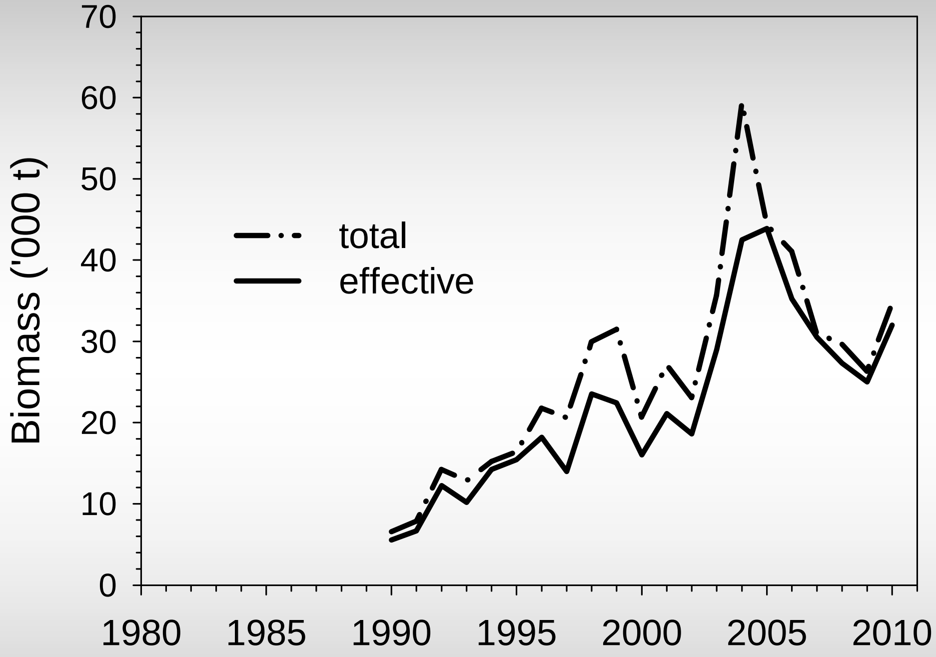

Shrimp recruitment above average:



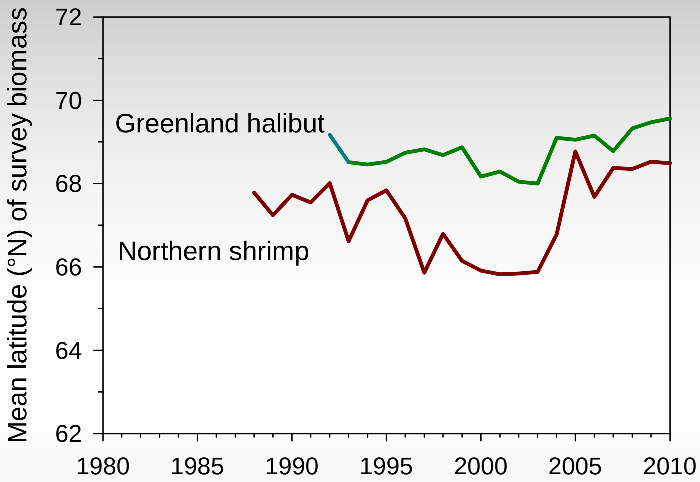

Cod biomass based on ISH and GINR surveys

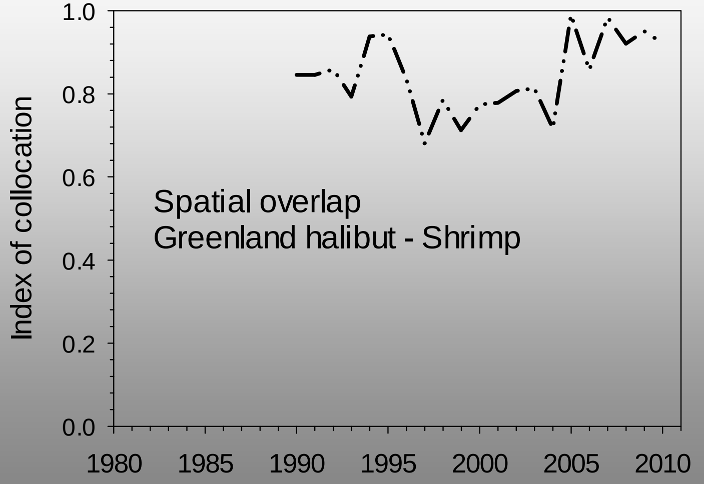
# Greenland halibut biomass

Index from GINR trawl survey (150 - 600 m) includes mainly juveniles




Shrimp recruitment above average:

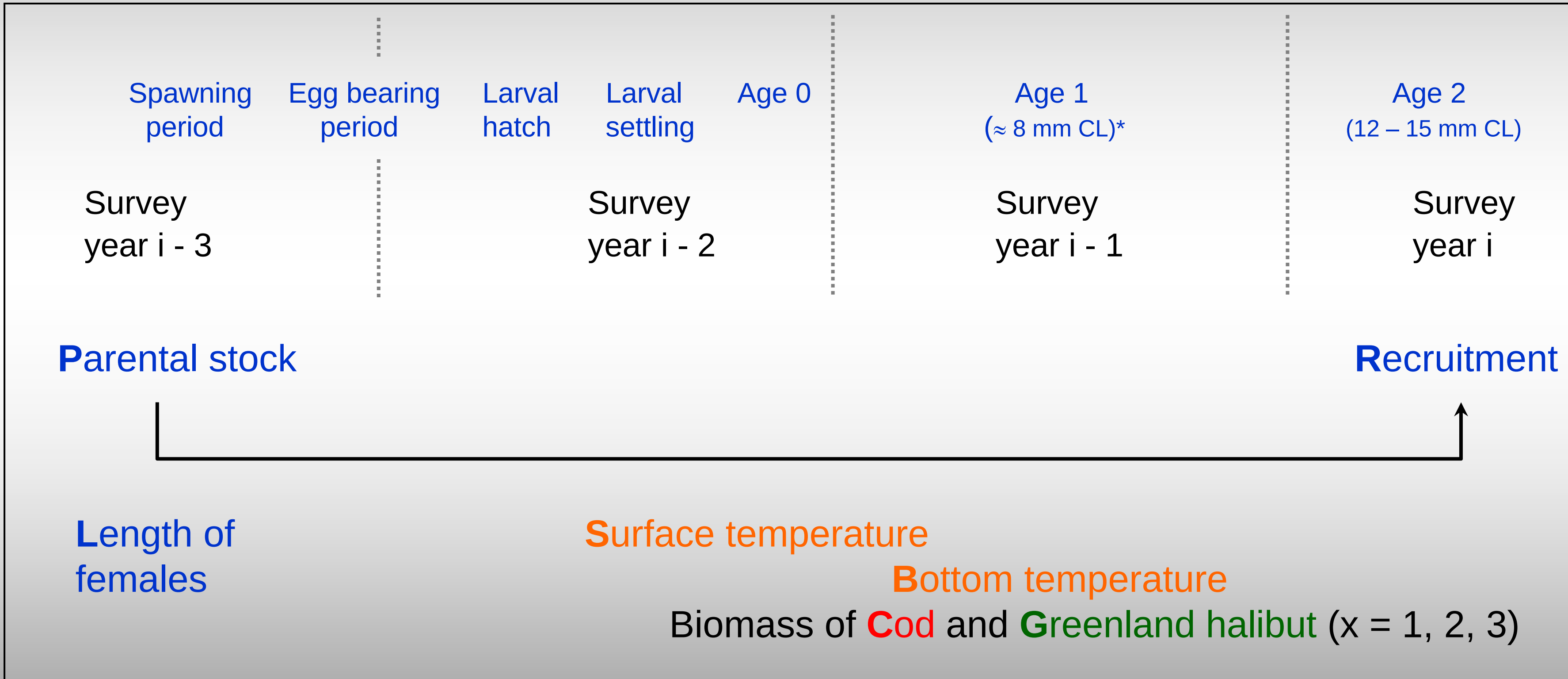


# Environmental variables and time lags (full model)

$$\underbrace{\ln(R_i/P_{i-3}) = \ln(\alpha) - \beta * P_{i-3}}_{\text{Ricker model (linearized form)}} + \underbrace{\chi * L_{i-3} + \delta * S_{i-2} + \eta * (S-B)_{i-2} + \lambda * B_{i-1} + \mu * C_{i-x} + \nu * G_{i-x}}_{\text{Environmental variables}}$$

**Ricker model (linearized form)** **+** **Environmental variables**




CL: carapace length
*: not well retained in survey trawl

- Non significant variables were removed by stepwise linear regression

# Stock-recruitment relationship
## - with environment (final model)

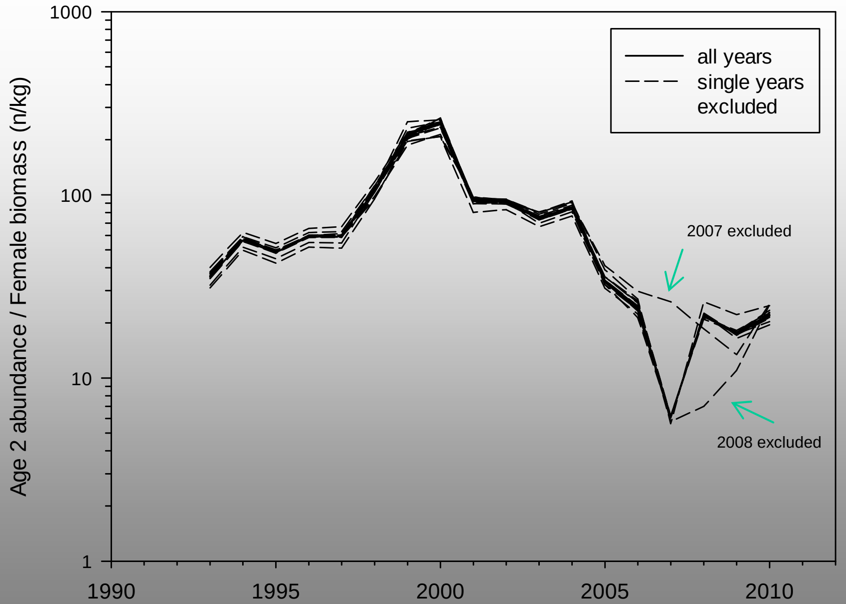
| Final model: Variable | Coefficent | P | |
|---|---|---|---|
| (Intercept) | -34.2470 | < 0.001 | |
| Surface layer temperature, 2 year lag | 0.9230 | < 0.001 | Increase → enhanced plankton production (food for shrimp larvae) |
| Difference between surface layer and bottom temperature, 2 year lag | -0.8750 | 0.002 | Decrease → better match between plankton bloom and timing of larval hatch |
| Northern shrimp female size, 3 year lag | 1.4260 | < 0.001 | Larger females produce more (and large/better ?) eggs |
| Cod biomass, 1 year lag | -0.0358 | 0.033 | Predation on juvenile shrimp |
| Cod biomass, 2 year lag | 0.0377 | 0.020 | (Predation on competitors of shrimp ?) |
| 18 years $R^2$: | 0.8860 | < 0.001 | |

- explains 89% of the variability in the recruit per female biomass index
- selected variables and sign of most of the coefficients are biologically plausible
- but positive coefficient for Cod biomass lagged by 2 years difficult to explain

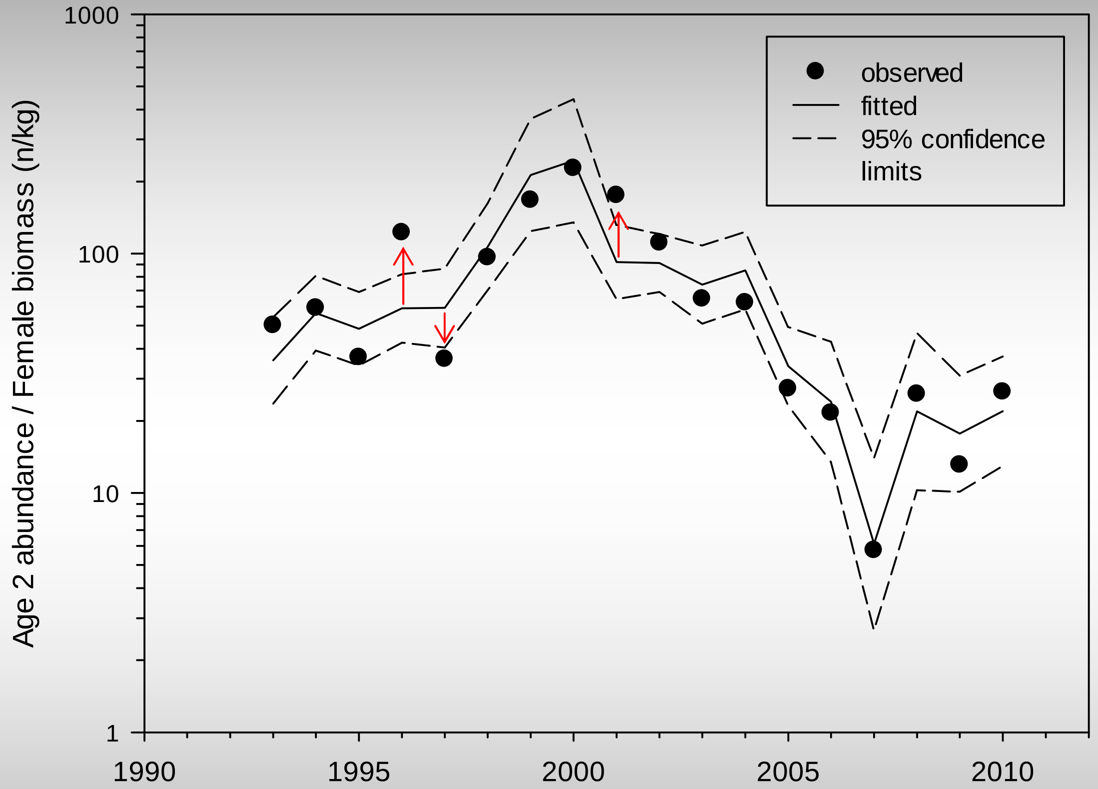
# Model robustness

## Sequential exclusion of single years:

| Variable | Result |
|---|---|
| Surface layer temperature, 2 year lag | significant in all cases |
| Difference between surface layer and bottom temperature, 2 year lag | significant in all cases |
| Northern shrimp female size, 3 year lag | significant in all cases |
| Cod biomass, 1 year lag | not significant in two cases (2006, 2007) |
| Cod biomass, 2 year lag | not significant in two case (2007, 2008) |
| | |
| Other variables (Greenland halibut biomass, 1 year lag) | significant in two cases (1996, 2008) |



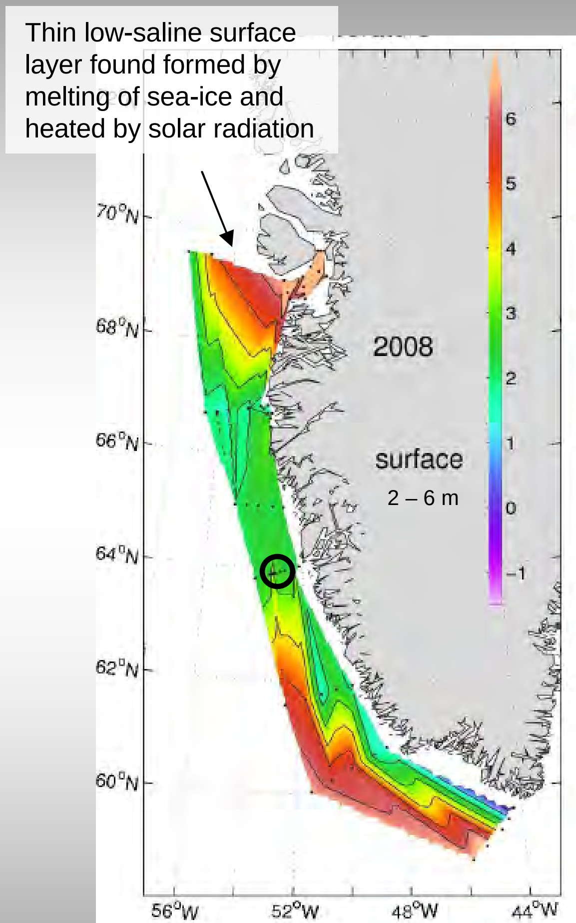
# Model comparison with observations

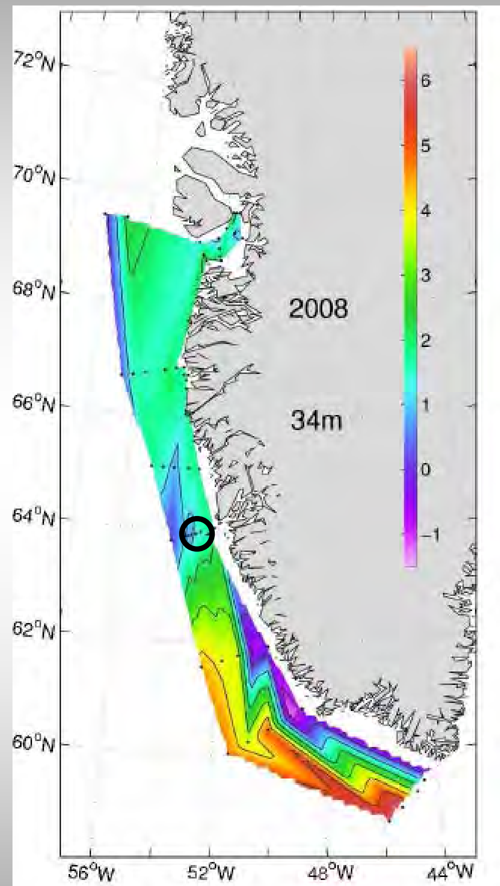


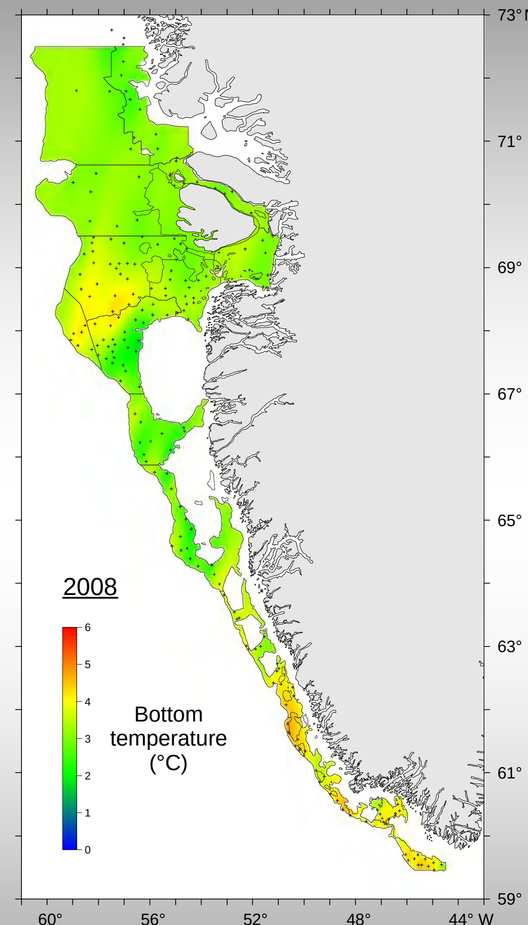

- Estimates outside 95 % confidence limit for 3 years (1996, 1997, 2001)

# Spatial aspects

## - Temperature

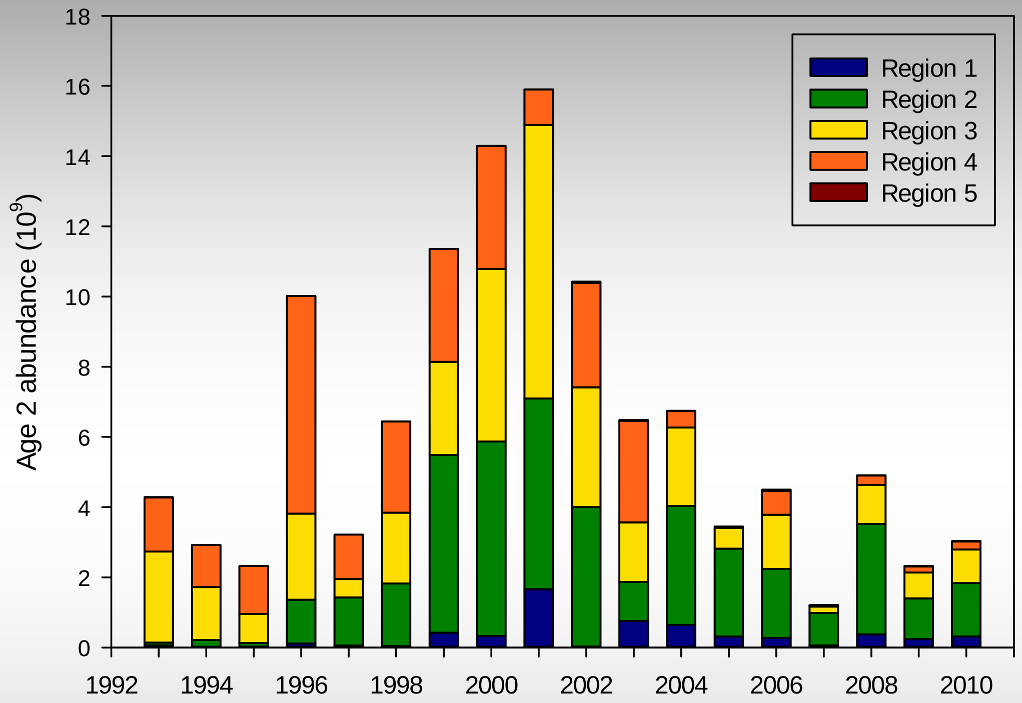


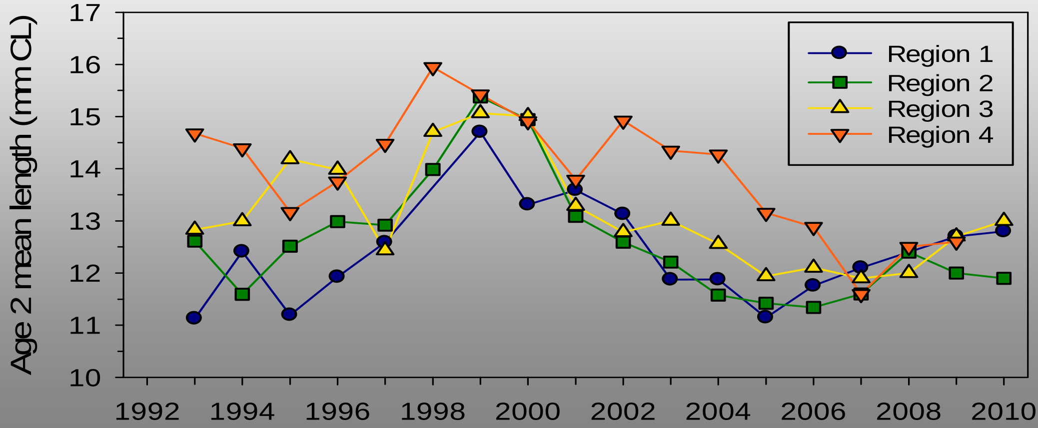



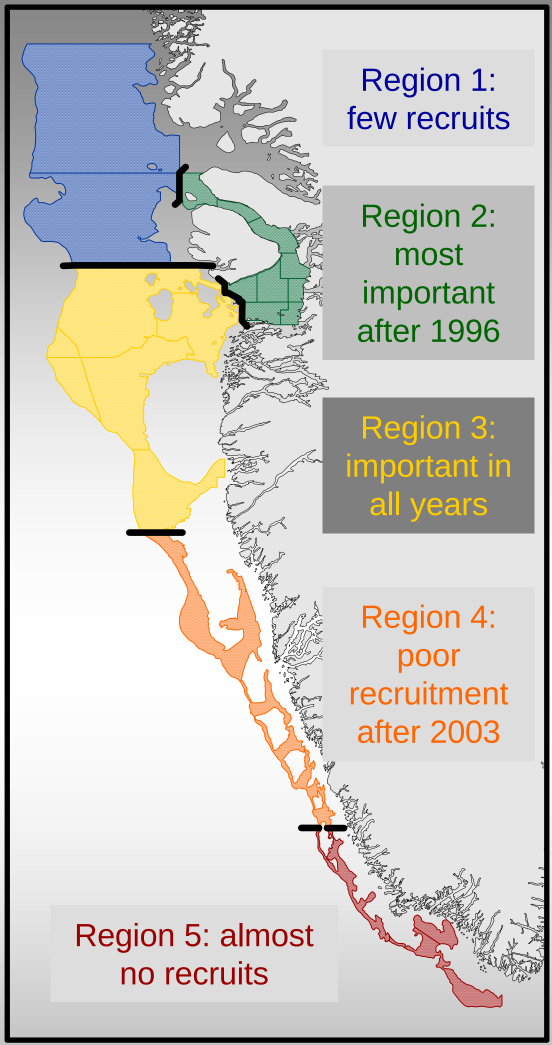




○ : Fylla Bank standard oceanographic station

# Spatial aspects
## - Recruitment



# Conclusions

- Reasons for poor recruitment since 2005 (and for ‘density-dependence’) not well defined

- Size of SSB not the most important factor (although survey biomass of females should not fall below 75000 t to maintain chance for recruitment at or above average)

- Variability in recruitment can neither be explained by changes in temperature or predator biomass alone

- Bottom-up and top-down processes important

- Spatial aspects (on minor scales) needs to be considered to improve:
  - selection of relevant data series
  - selection of appropriate model for forecast

## Acknowledgements

Jörg Appel (Institute for Sea Fisheries Hamburg, ISH) provided the geo-referenced data for Atlantic cod and bottom temperatures from the German groundfish survey, and we would like to thank him and his colleagues Dr. Manfred Stein, Dr. Hans-Joachim Rätz and Dr. Heino Fock involved in the German groundfish survey for their cooperation.

Photos: GINR archive (C. Egevang, R. Frandsen, L. Heilmann, A. Jarre, P. Lund, J. Sethsen, M. Storr-Paulsen, E. Smidt)


**Comparison of spatial distributions**

Geo-referenced survey data (biomass density per tow) for Atlantic cod from the German groundfish survey and for Northern shrimp and Greenland halibut from the Greenland survey for shrimp and fish were used to examine the spatial overlap between the two species. A geostatistical tool, the global index of collocation (*GIC*) developed by Bez and Rivoirard ( 2000) for pelagic species and used by Hendrickson and Vázquez (2005) for demersal fish, was applied for this purpose. The *GIC* is based on computing both the centre of gravity (*CG*) and the inertia (*I*) of a population. The coordinates of the centre of gravity are computed as:

$$CG = \begin{cases} \dfrac{\sum_i u_i z_i}{\sum_i z_i} \\[2ex] \dfrac{\sum_i v_i z_i}{\sum_i z_i} \end{cases}$$

where $u_i$ is the longitude, $v_i$ is the latitude and $z_i$ is the observed density at each sampling location *i*. The inertia is a measure of the horizontal dispersion of the population and is calculated as the mean squared distance between an individual sample and the centre of gravity in surface area units:

$$I = \frac{\sum_i (x_i - CG)^2 z_i}{\sum_i z_i}$$

where $x_i$ is the position of an individual sample. An annual *GIC* value is then computed as:

$$GIC = 1 - \frac{\Delta CG^2}{\Delta CG^2 + I_1 + I_2}$$

where $\Delta CG^2$ is the distance between the centres of gravity of the two populations and $I_1$ and $I_2$ represents the respective inertias.

The *GIC* is a spatial statistic ranging from 0, where each population is concentrated on a single but different location, to 1, when the two centres of gravity are coincident. It is not influenced by the occurrence of zero catches and does not assume a specific geometrical shape of the species distribution, but requires that the distributional range of the two species is sampled with a comparable level of spatial integration (Bez and Rivoirard, 2000). Ellipses of the inertia, which would represent the main directions of the dispersion but not the spatial distribution in itself as suggested in Hendrickson and Vázquez (2005), were not estimated in the present study.