Modeling the population dynamics of *Calanus finmarchicus* in the Gulf of St-Lawrence, Canada.

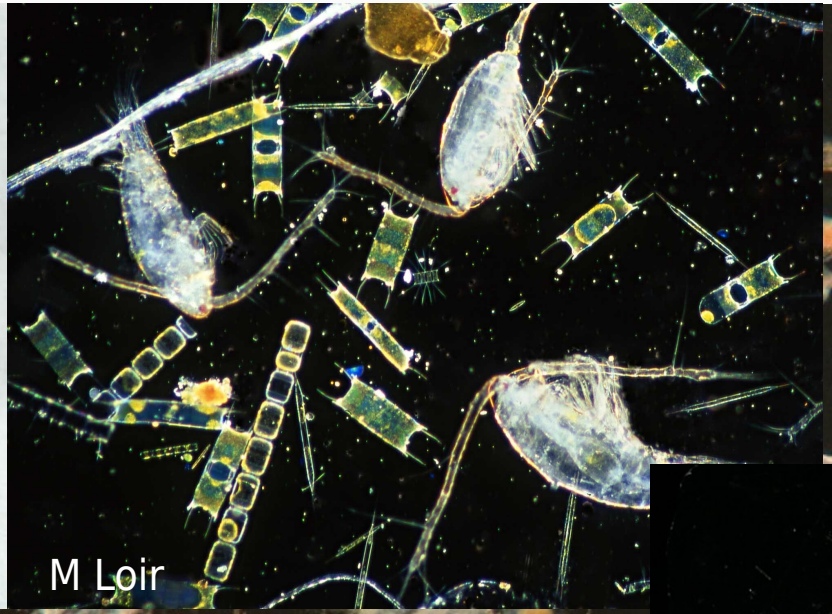
Frédéric Maps (GMRI, UMaine)

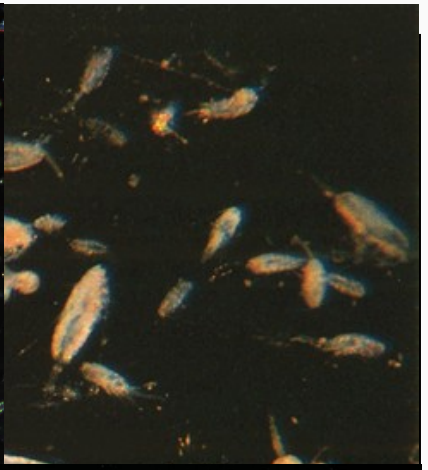
Stéphane Plourde (MLI, DFO)

Bruno Zakardjian (LSEET, USTV)

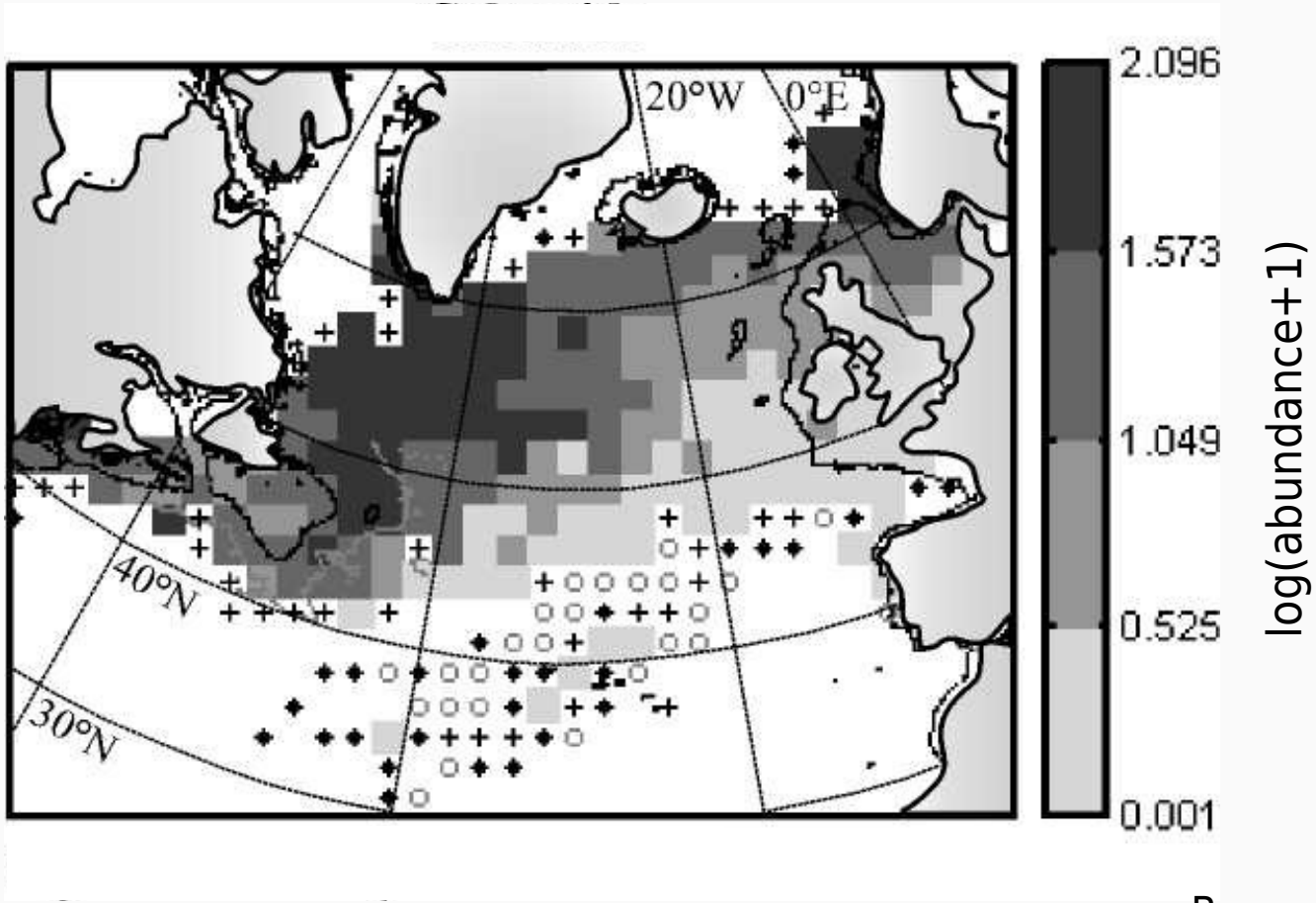
Copepods in pelagic ecosystems


C Linder, WHOI


M Loir

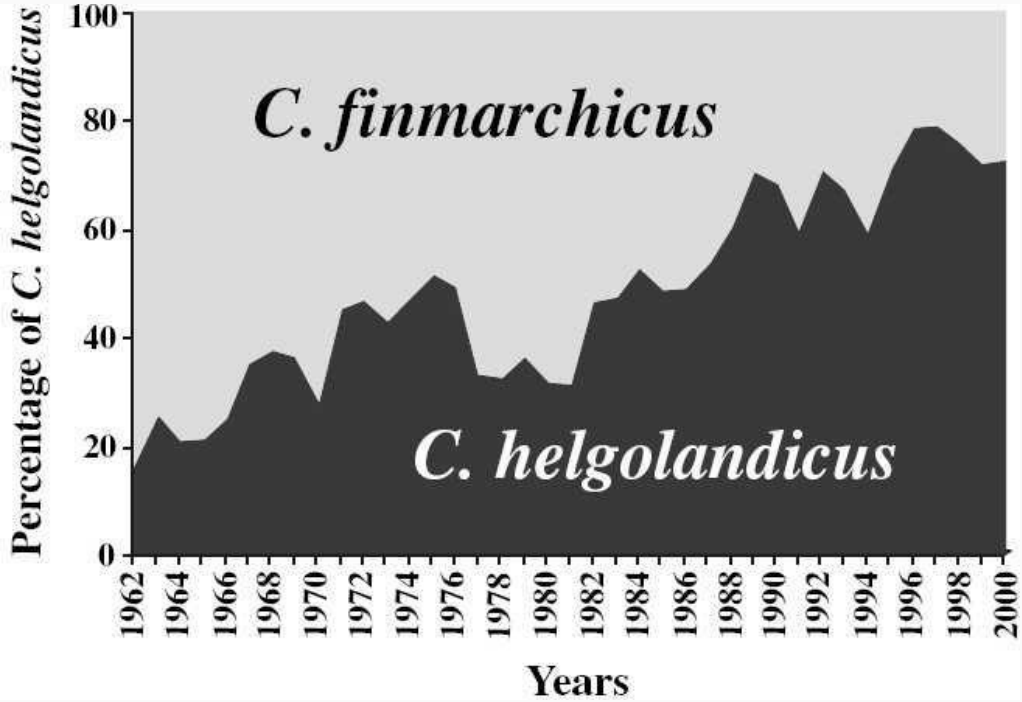


Calanus finmarchicus in the North Atlantic

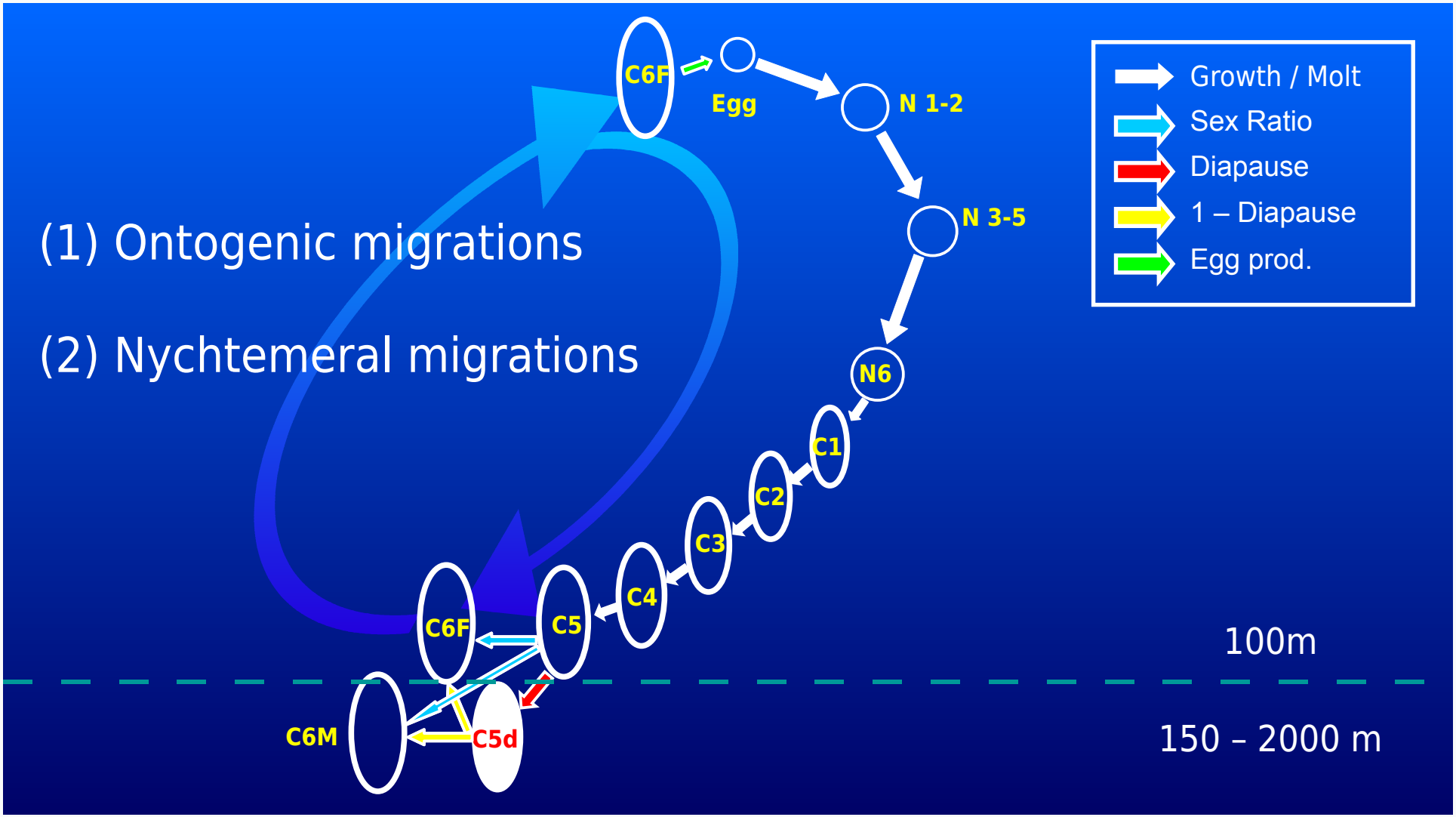


Barnard et al. 2002

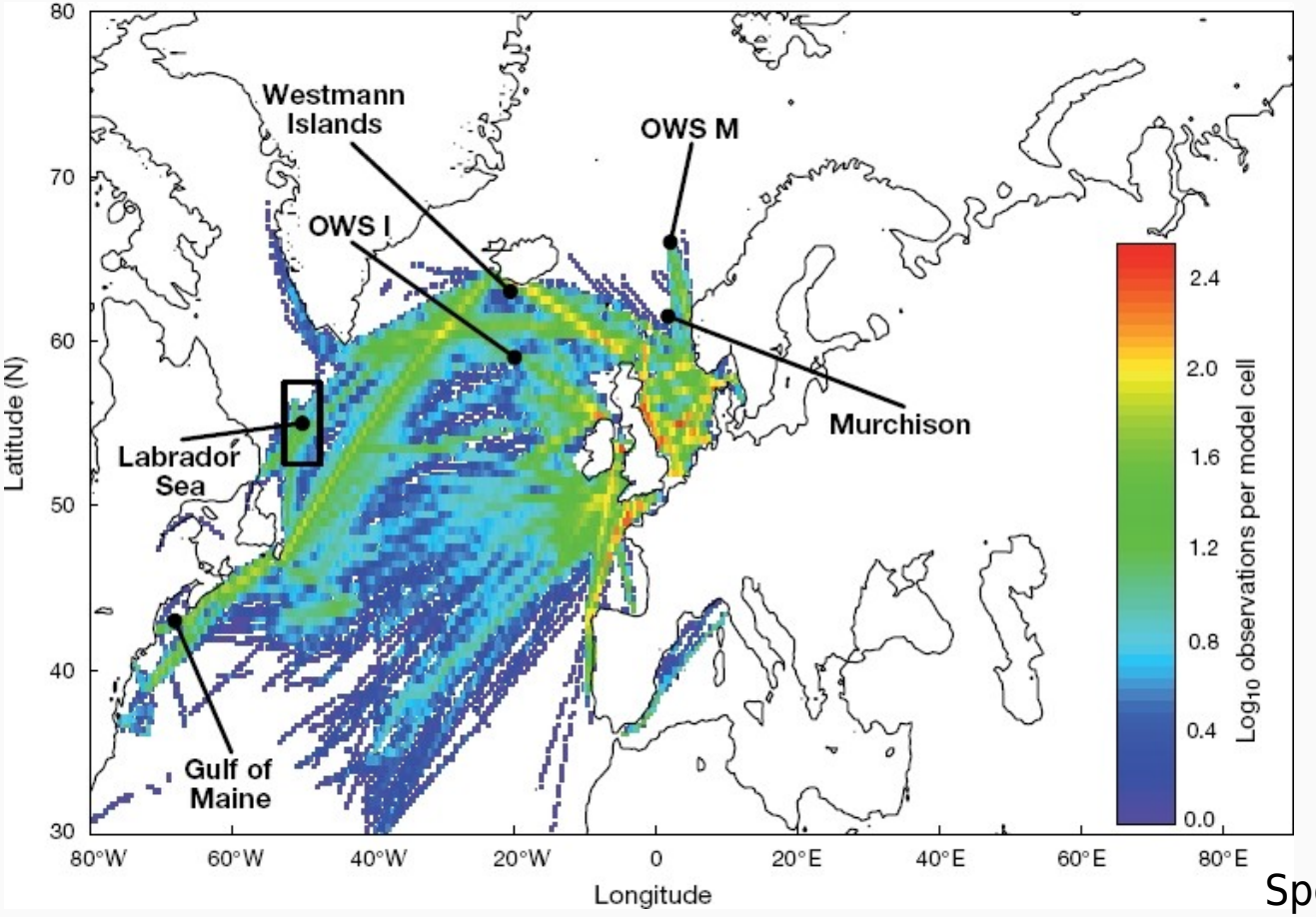
(Recent) changes



Reid et al. 2003


(1) Ontogenic migrations
(2) Nychtemeral migrations
C6F
Egg
N 1-2
N 3-5
N6
C1
C2
C3
C4
C5
C6F
C6M
C5d
Growth / Molt
Sex Ratio
Diapause
1 – Diapause
Egg prod.
100m
150 – 2000 m

Fragmented spatio-temporal sampling



Speirs et al. 2006

Interest for numerical methods

- Summarize the present knowledge of the system
- Fill the spatio-temporal gaps
- Different scales
- Quantify processes
- Develop / reject hypotheses

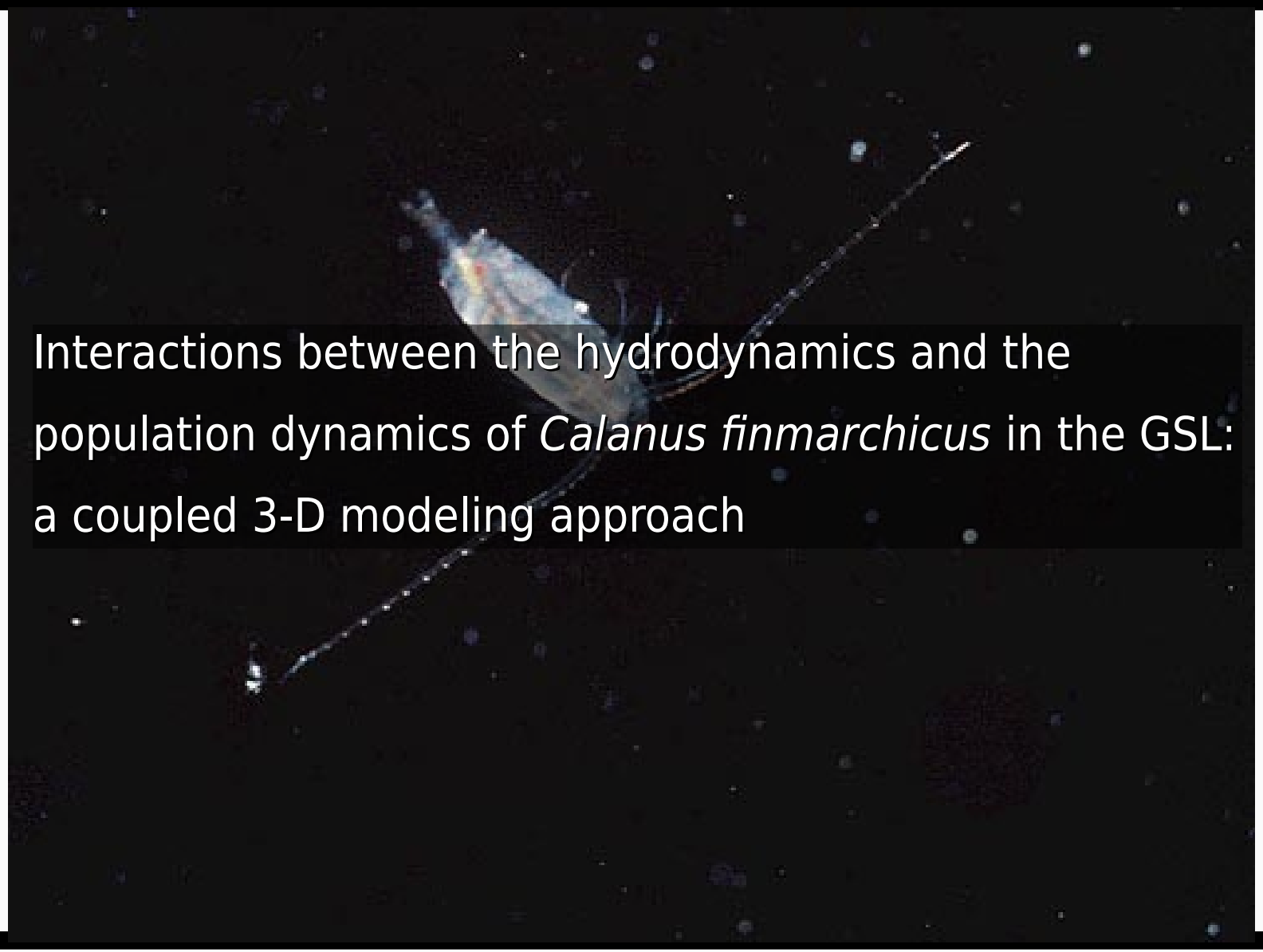
Understand and quantify the coupling between the variability of the physical processes and the population dynamics of *Calanus finmarchicus* in the GSL.

Numerous physical and biological processes involved

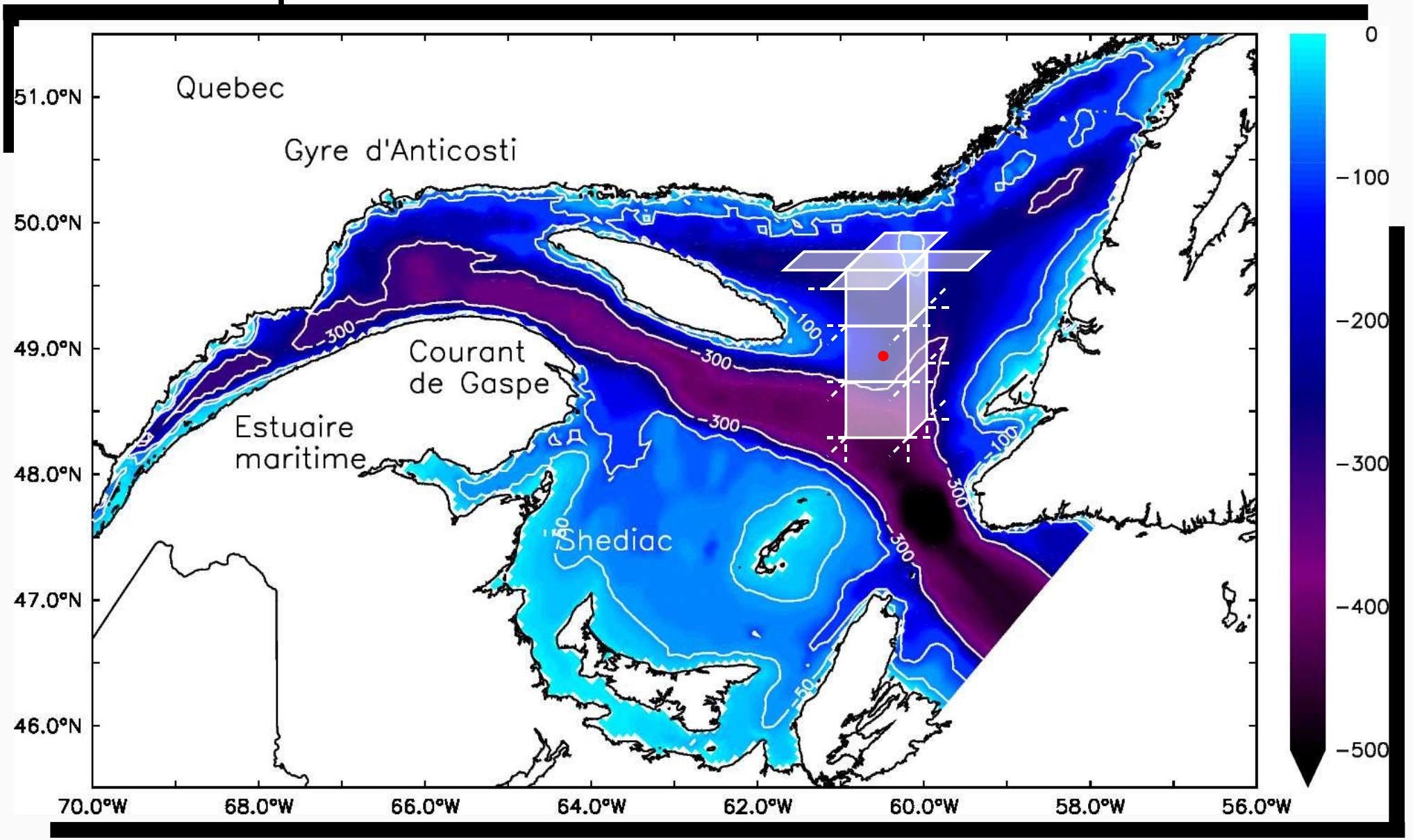
- Population : day → interannual = km(s) → oceanic basin
- Hydrodynamics = distribution, environment
- Vertical migrations = environment
- Diapause = interannual abundance variability / distribution

1. Impacts of nychtemeral and ontogenic **migrations** on the variability of the **distribution** and **abundance** of *C. finmarchicus* in the GSL

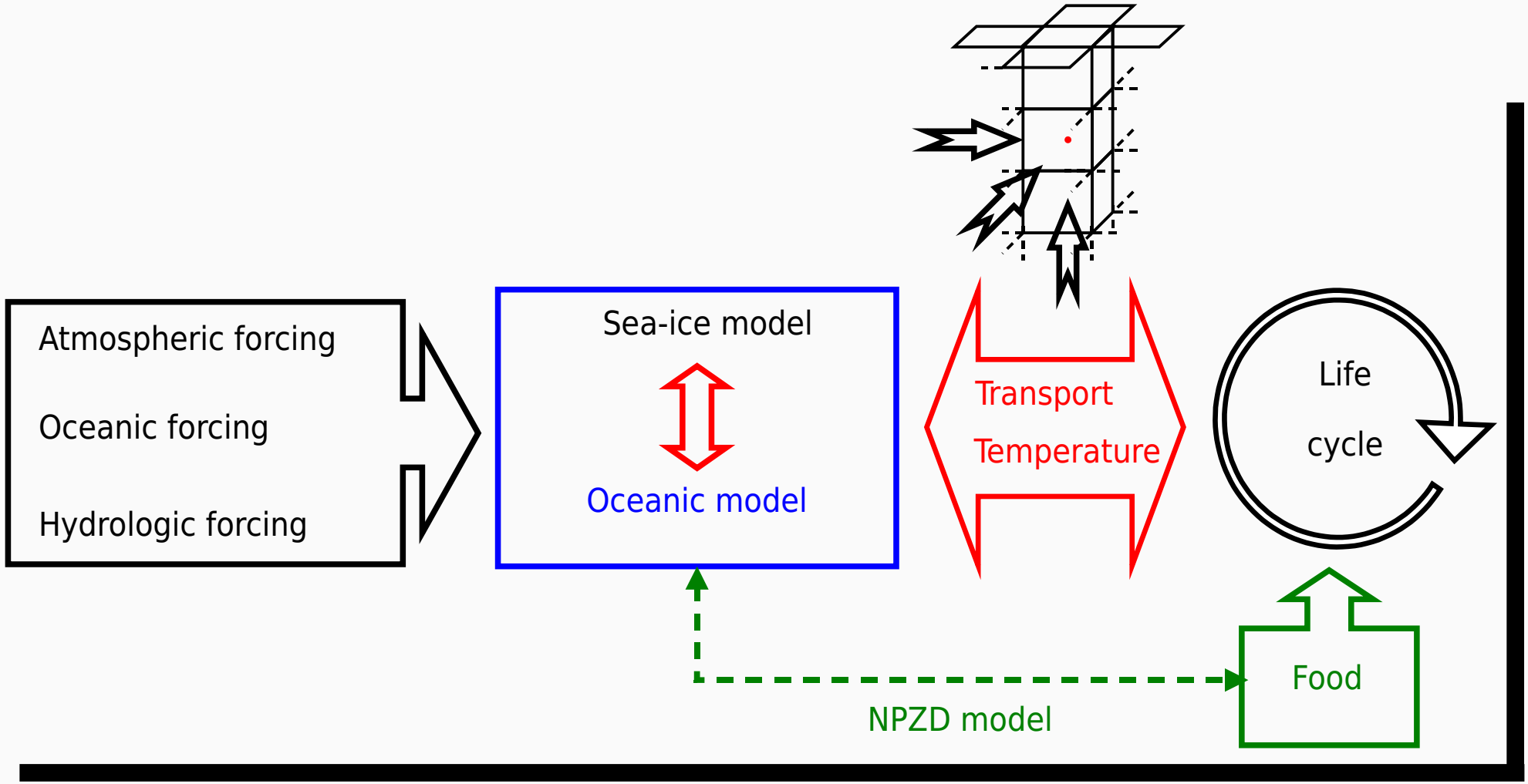
2. Control of entrance into and exit from **diapause** by the **lipid** metabolism in *C. finmarchicus*

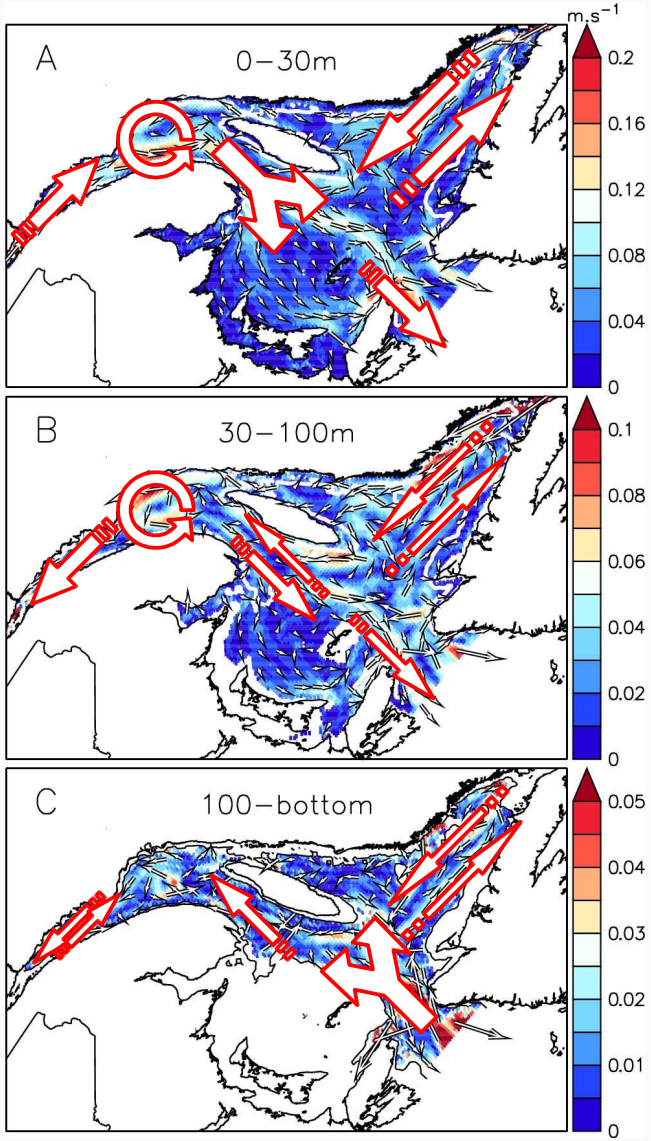


Interactions between the hydrodynamics and the population dynamics of *Calanus finmarchicus* in the GSL: a coupled 3-D modeling approach


Quebec
Gyre d'Anticosti
Courant
de Gaspe
Estuaire
maritime
Shediac
51.0°N
50.0°N
49.0°N
48.0°N
47.0°N
46.0°N
70.0°W
68.0°W
66.0°W
64.0°W
62.0°W
60.0°W
58.0°W
56.0°W
0
−100
−200
−300
−400
−500
100
300
50

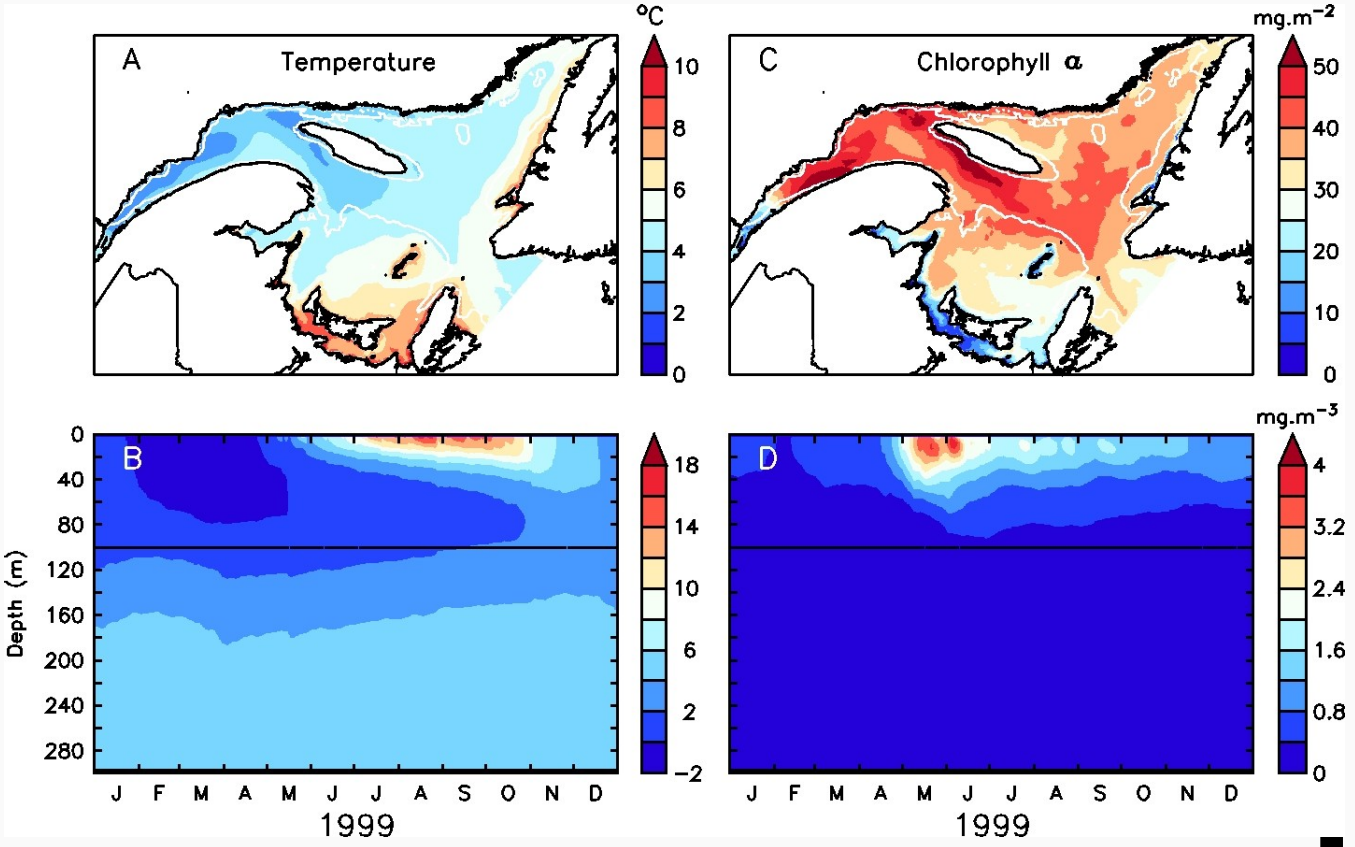
Coupled numerical model





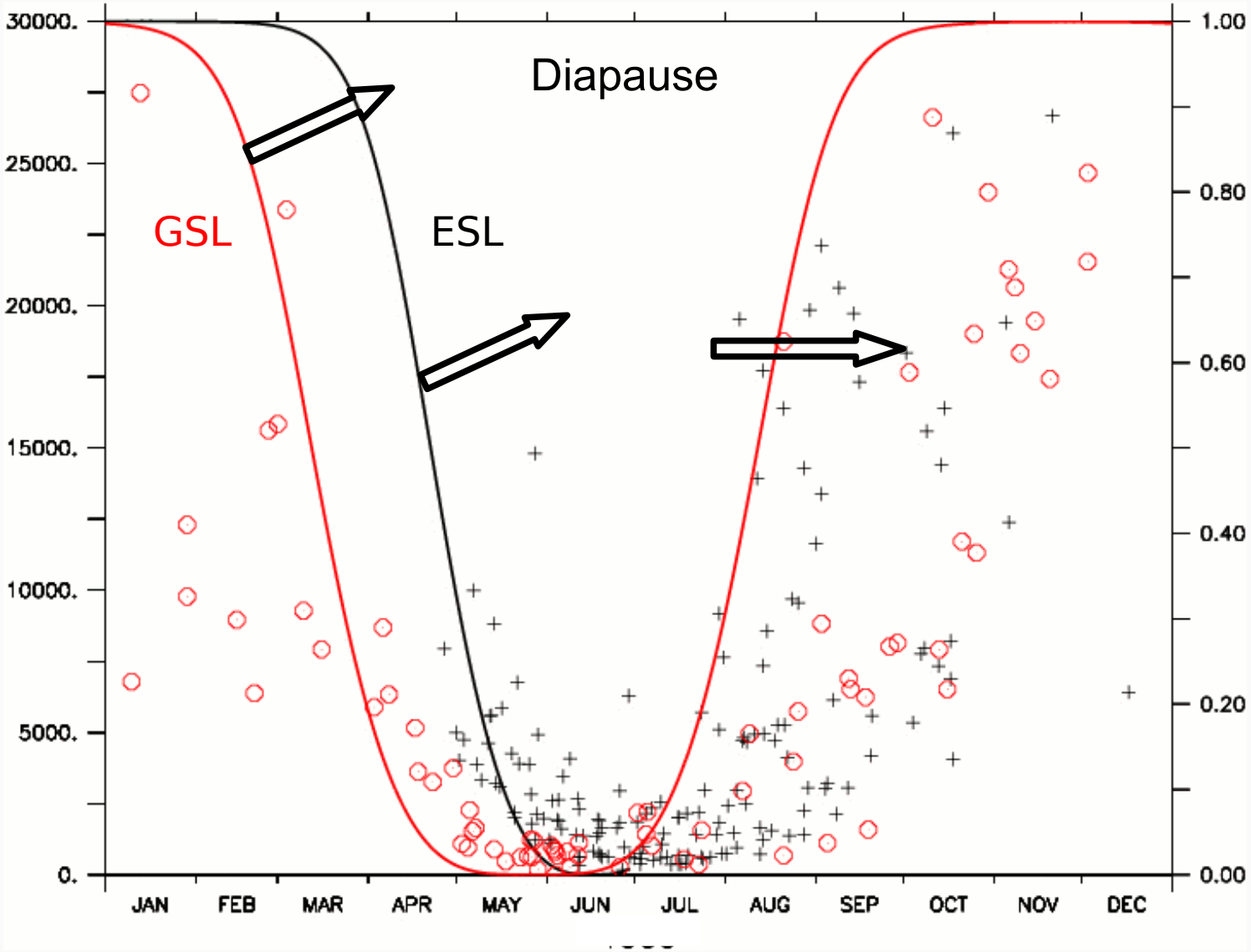
Development

Egg production

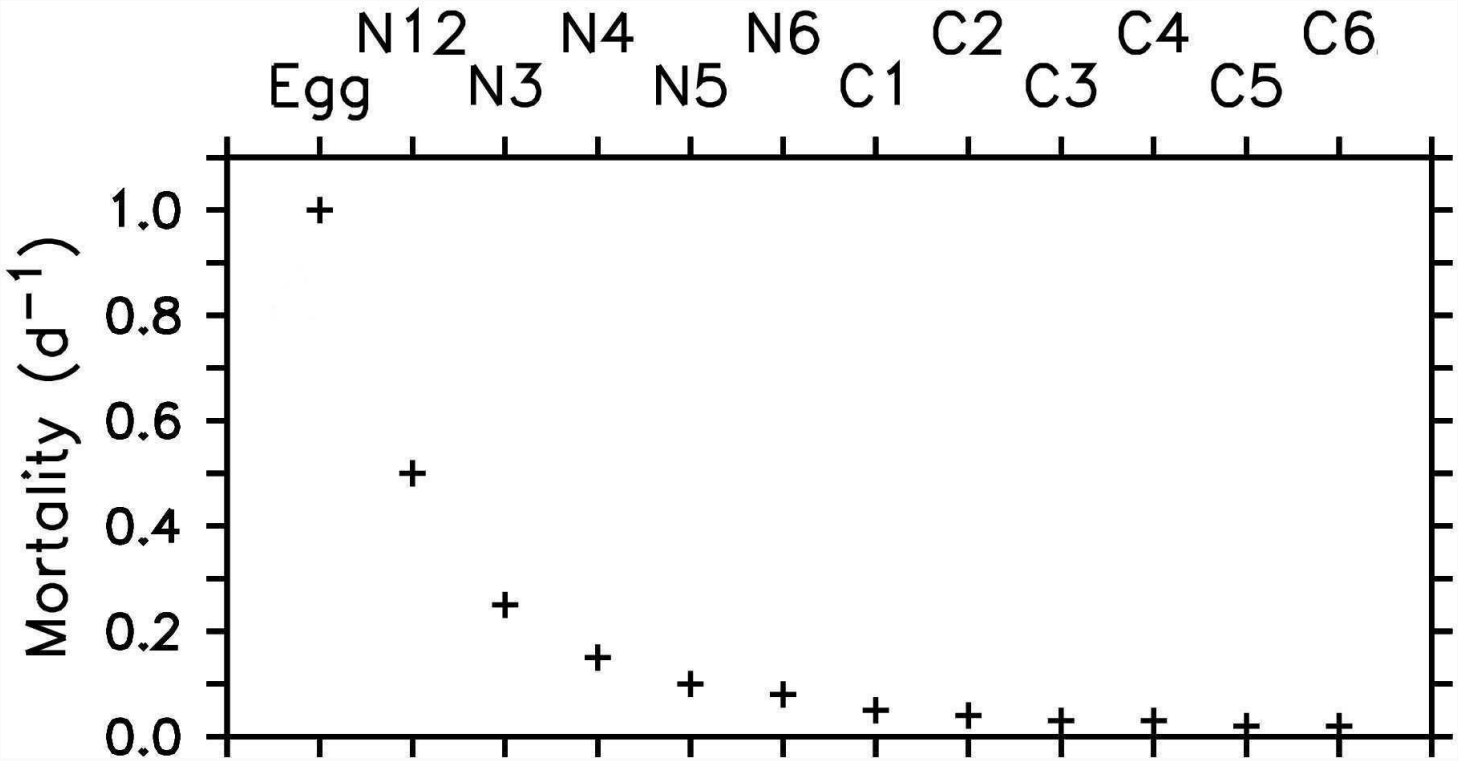


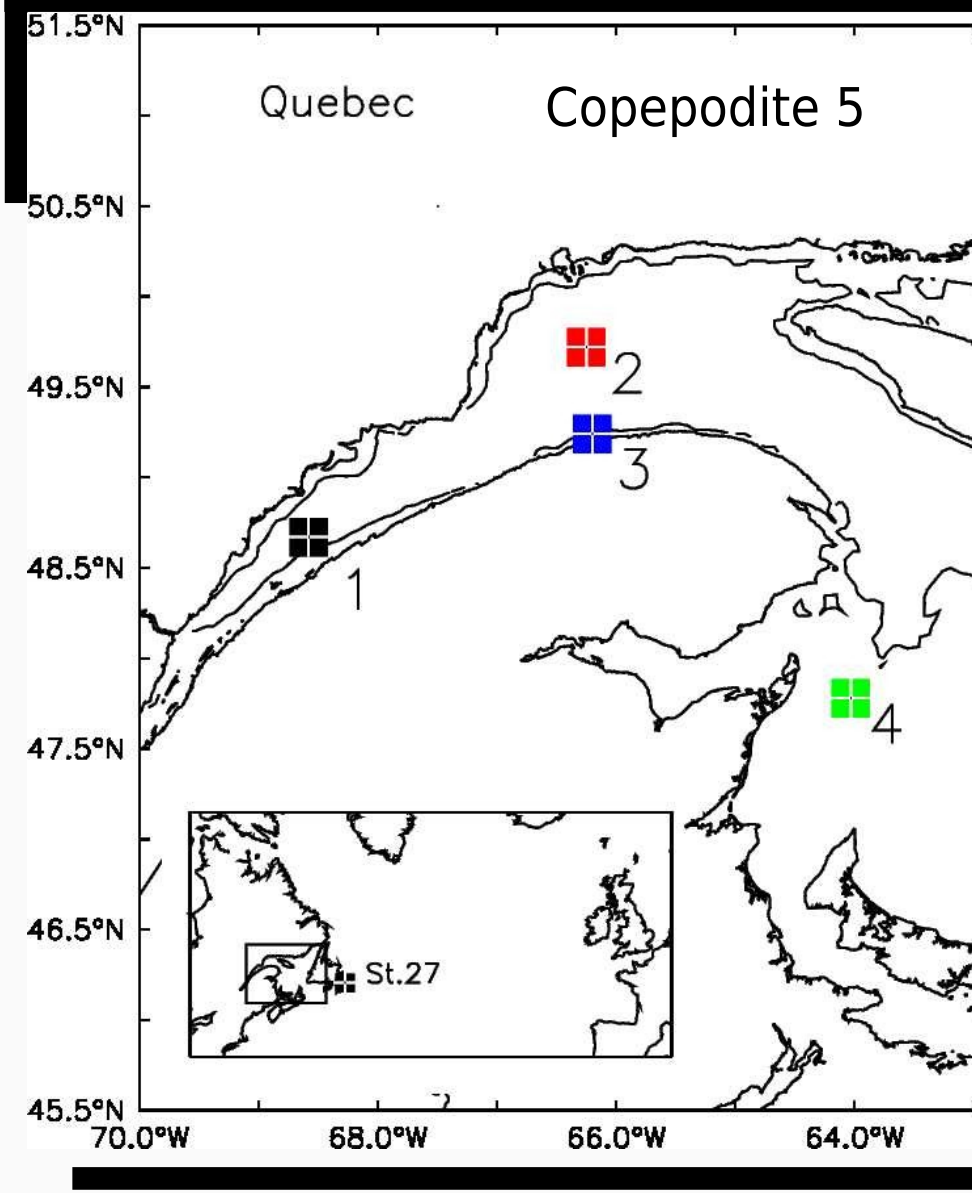
Migrations

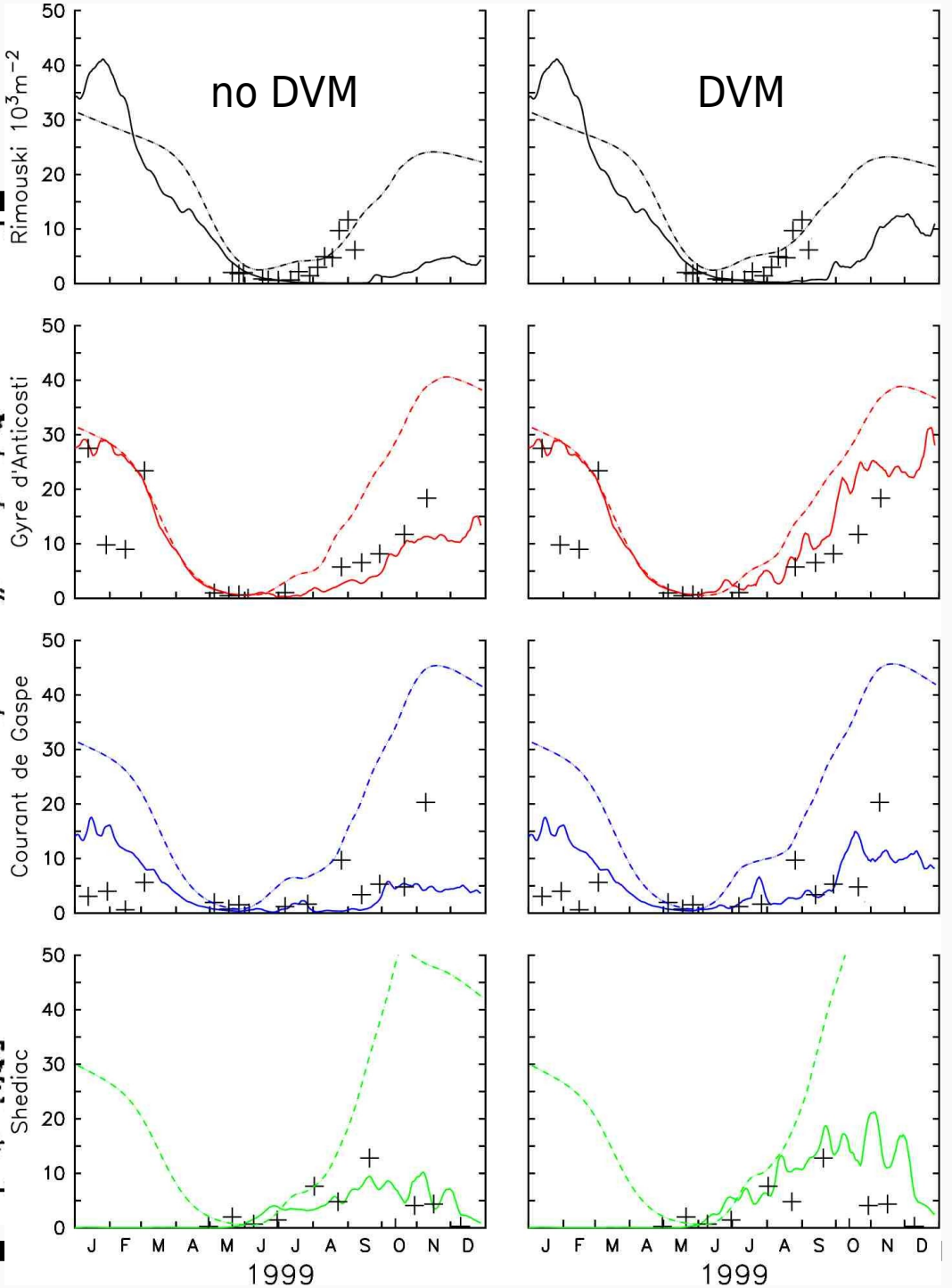
Stage	Ontogenic (no DVM)	Nychtemeral (DVM)
C4 / C5 / ♀	**5**	**0 - 100**
N1 - C3	5	-
C5d	150 - 250	150 - 250

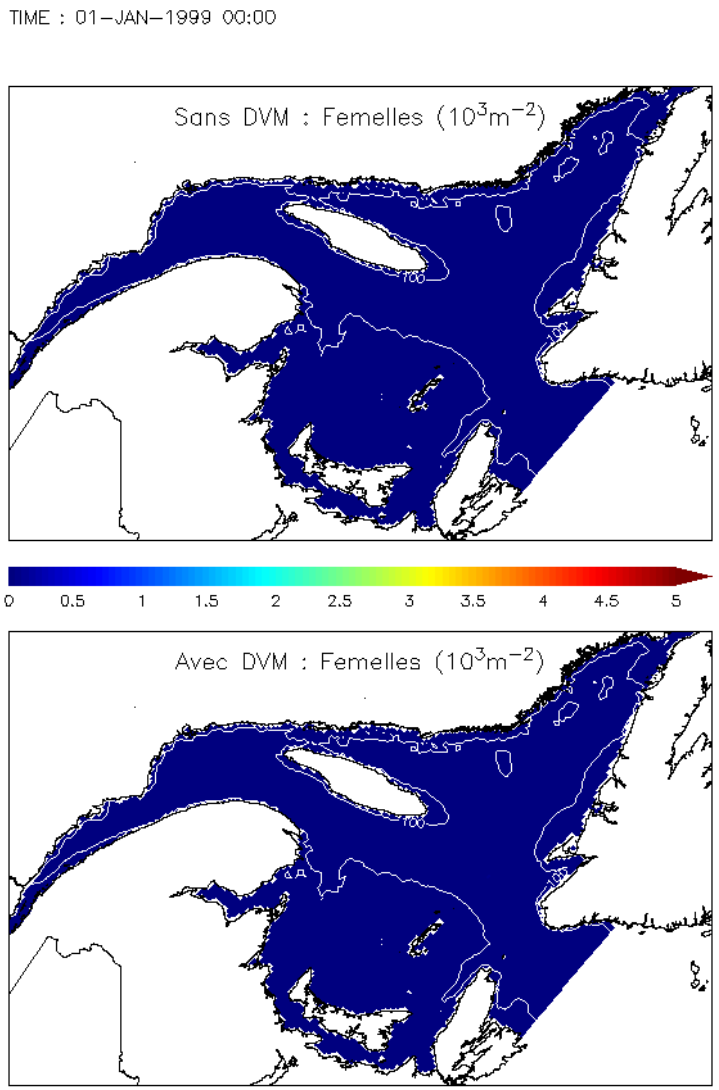

Diapause
GSL
ESL
30000.
25000.
20000.
15000.
10000.
5000.
0.
1.00
0.80
0.60
0.40
0.20
0.00
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Mortality




Quebec
Copepodite 5
51.5°N
50.5°N
49.5°N
48.5°N
47.5°N
46.5°N
45.5°N
70.0°W
68.0°W
66.0°W
64.0°W
1
2
3
4
St.27

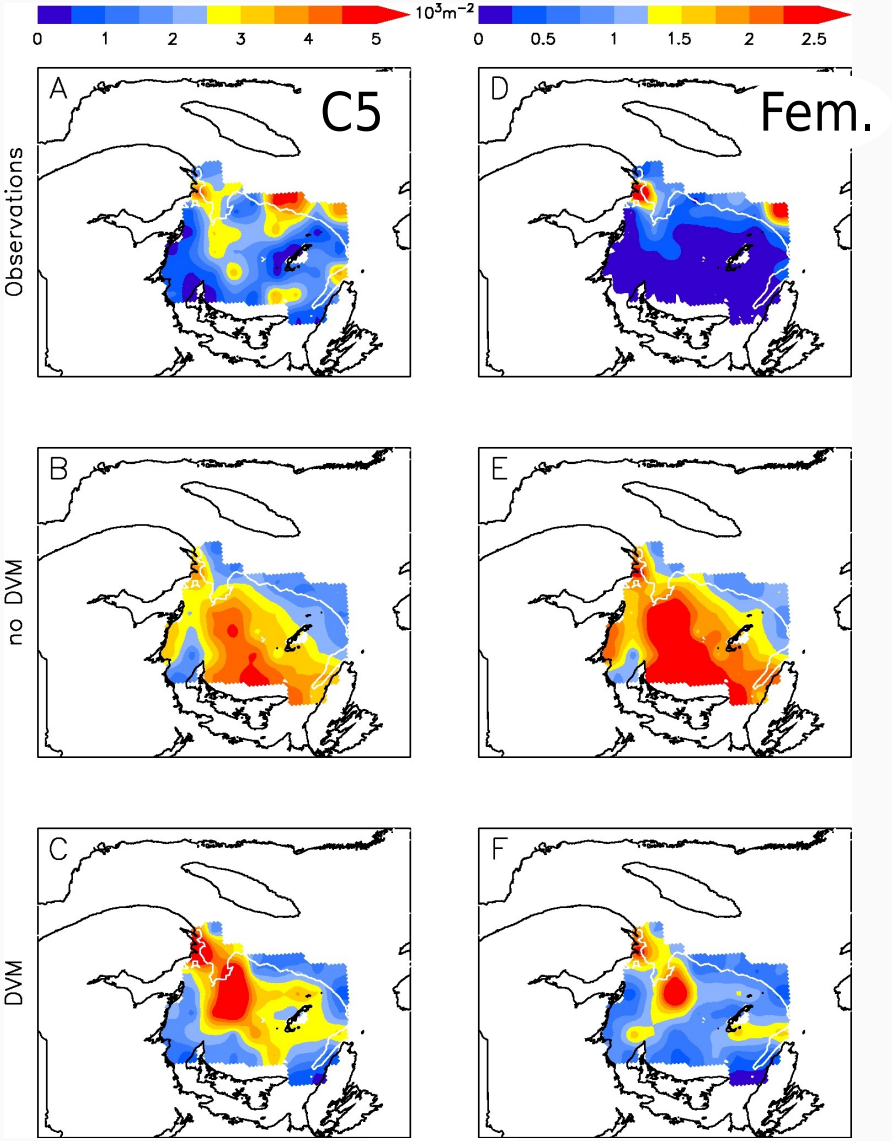

no DVM
DVM
Rimouski $10^3 m^{-2}$
Gyre d'Anticosti
Courant de Gaspe
Shediac
0
10
20
30
40
50
J F M A M J J A S O N D
1999


TIME : 01-JAN-1999 00:00
Sans DVM : Femelles ($10^3 m^{-2}$)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Avec DVM : Femelles ($10^3 m^{-2}$)

Observation

No DVM

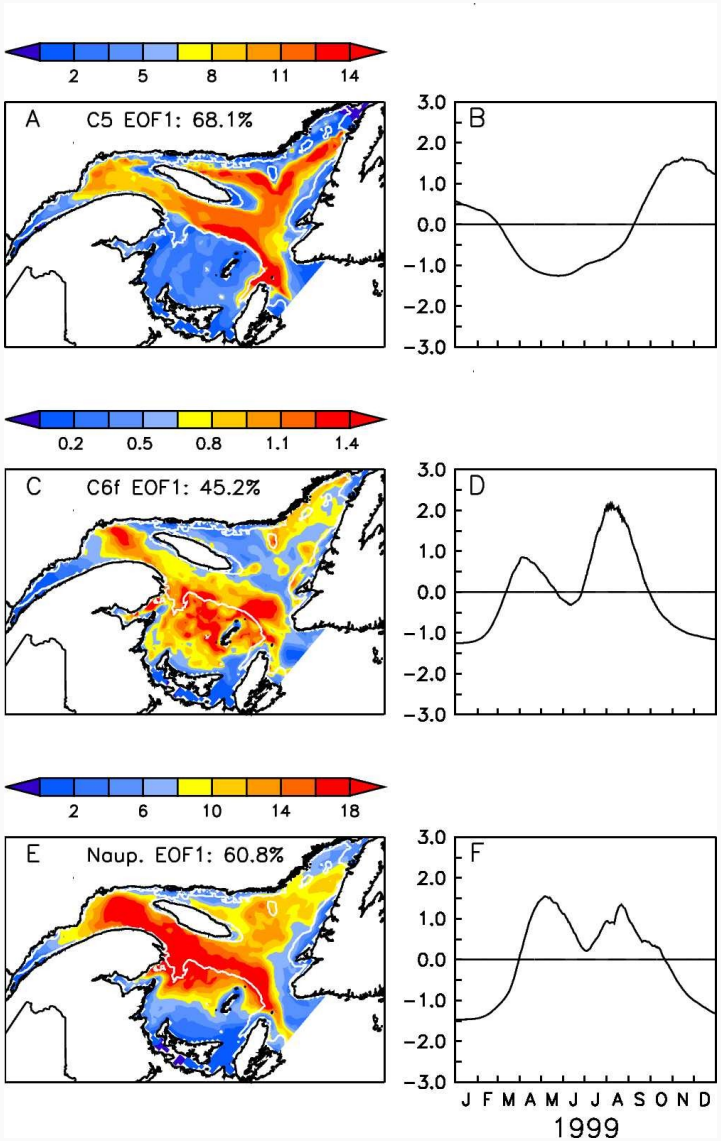
DVM



Cop. 5

Females

Nauplii

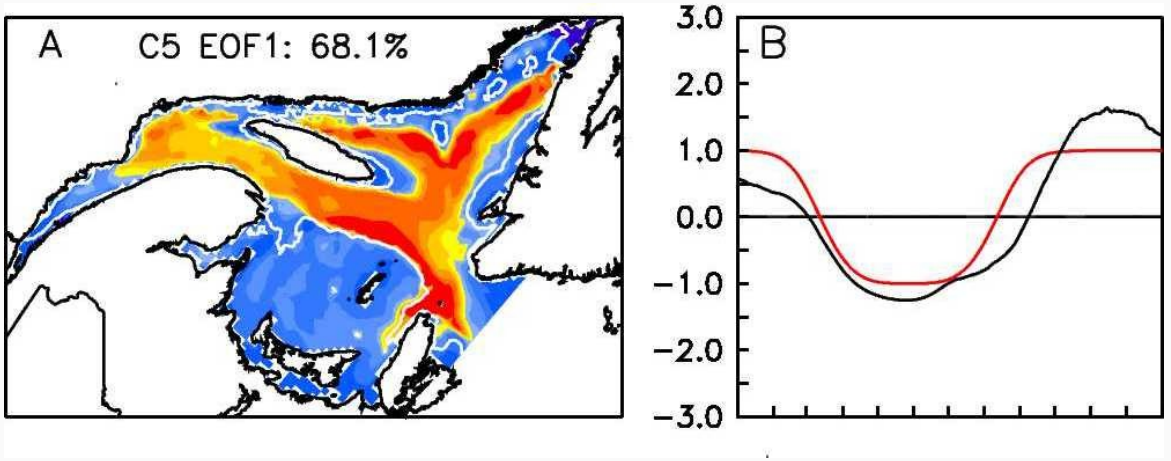


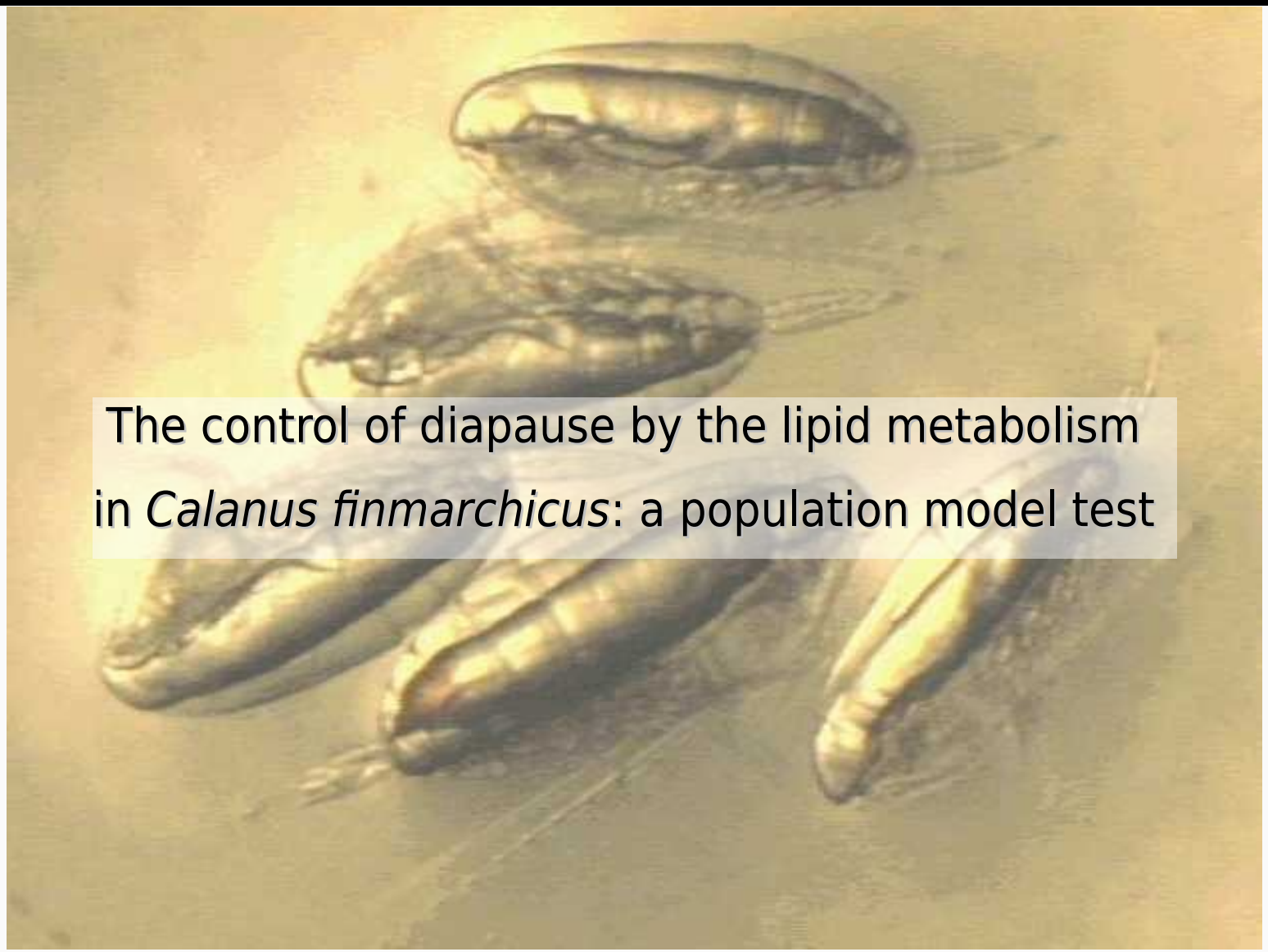
no DVM / DVM	EOF 1 **Life cycle** **~ 50%**	EOF 2 **Circ. / Topo.** **~ 20%**	EOF 3 **Misc.** **~ 5%**
C5-C5d	64.4 / 68.1	22.1 / 15.6	4.3 / 4.5
C6f	45.2 / 45.2	26.1 / 19.6	5.7 / 3.7
Nauplii	60.3 / 60.8	14.9 / 11.3	6.7 / 4.9

- More realistic with DVM

- **The *Calanus* circuit:** distinct hydrodynamic features linked together by both the life cycle and the behavior of *C. finmarchicus* in the GSL.

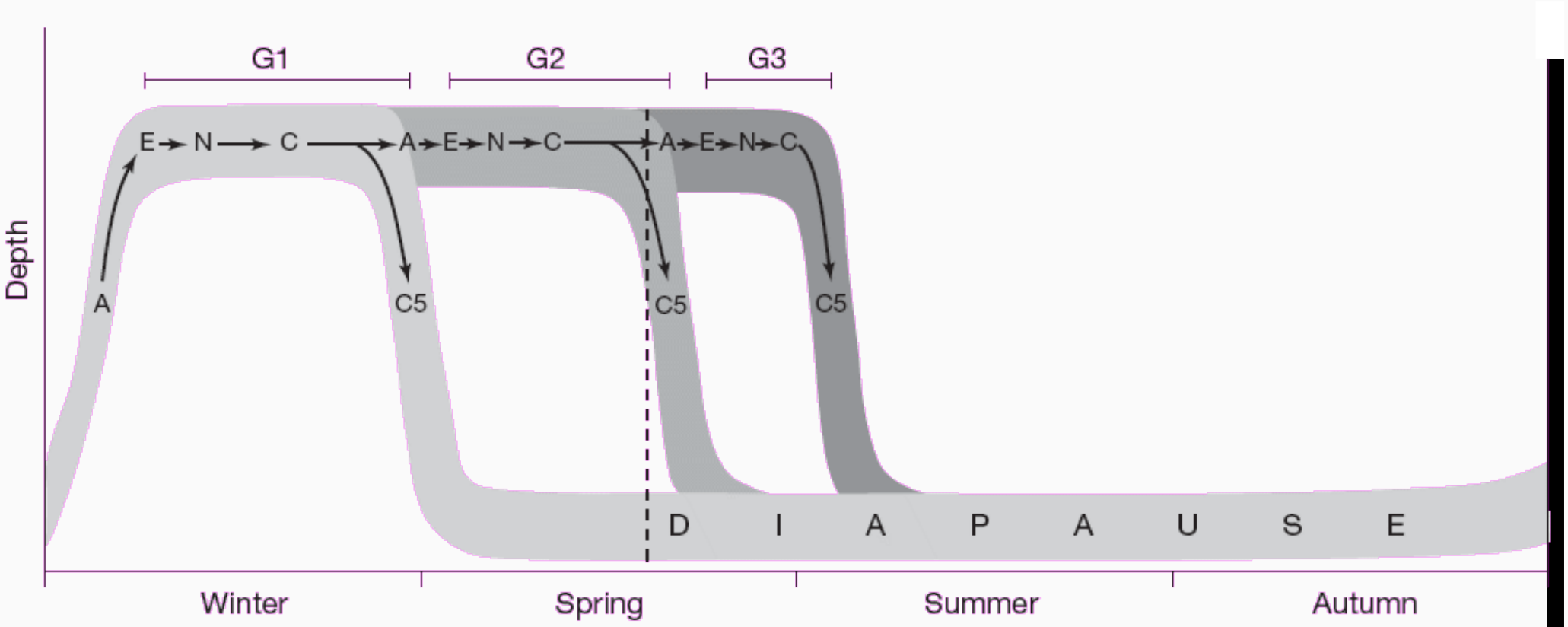
- **Limitations :** DVM & fixed diapause window





The control of diapause by the lipid metabolism in *Calanus finmarchicus*: a population model test

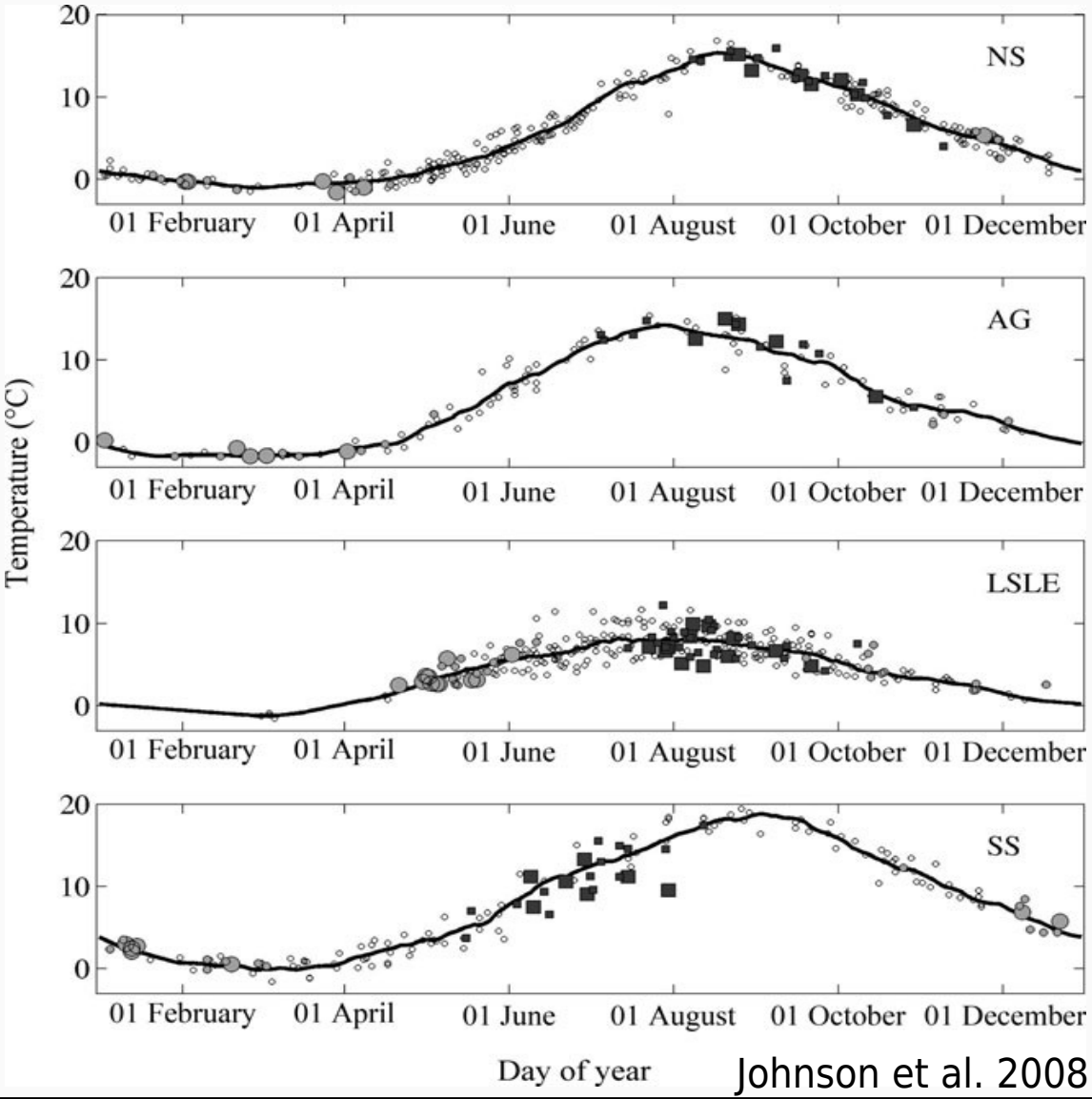
Diapause = phenology + adaptation to seasonality



Tarrant et al. 2008

Synchronization required

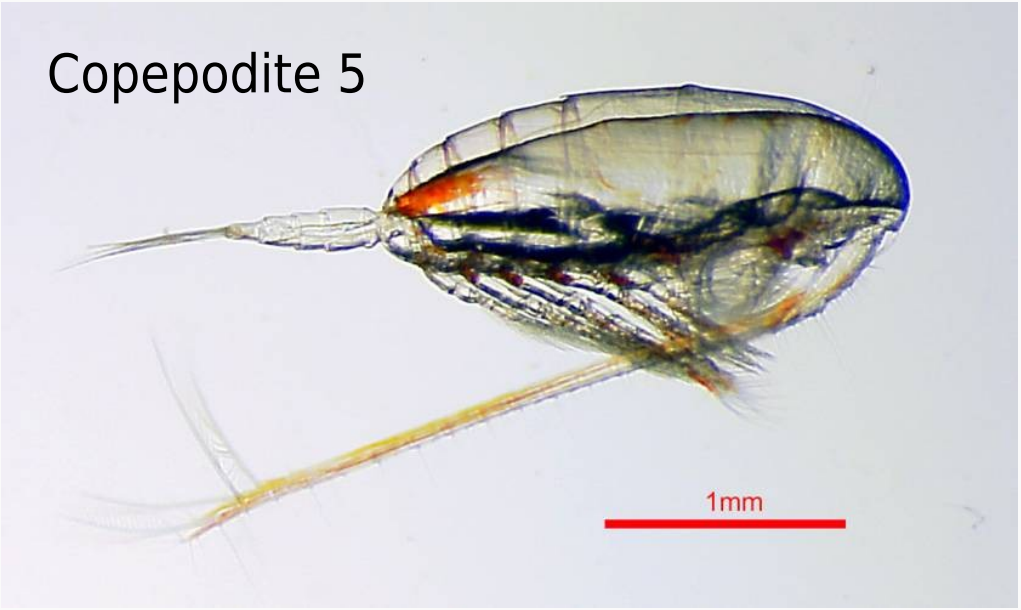
- ~~Photoperiod ?~~
- ~~Primary production ?~~
- ~~Temperature ?~~
- **Endogenous control ?**



Johnson et al. 2008

Lipids

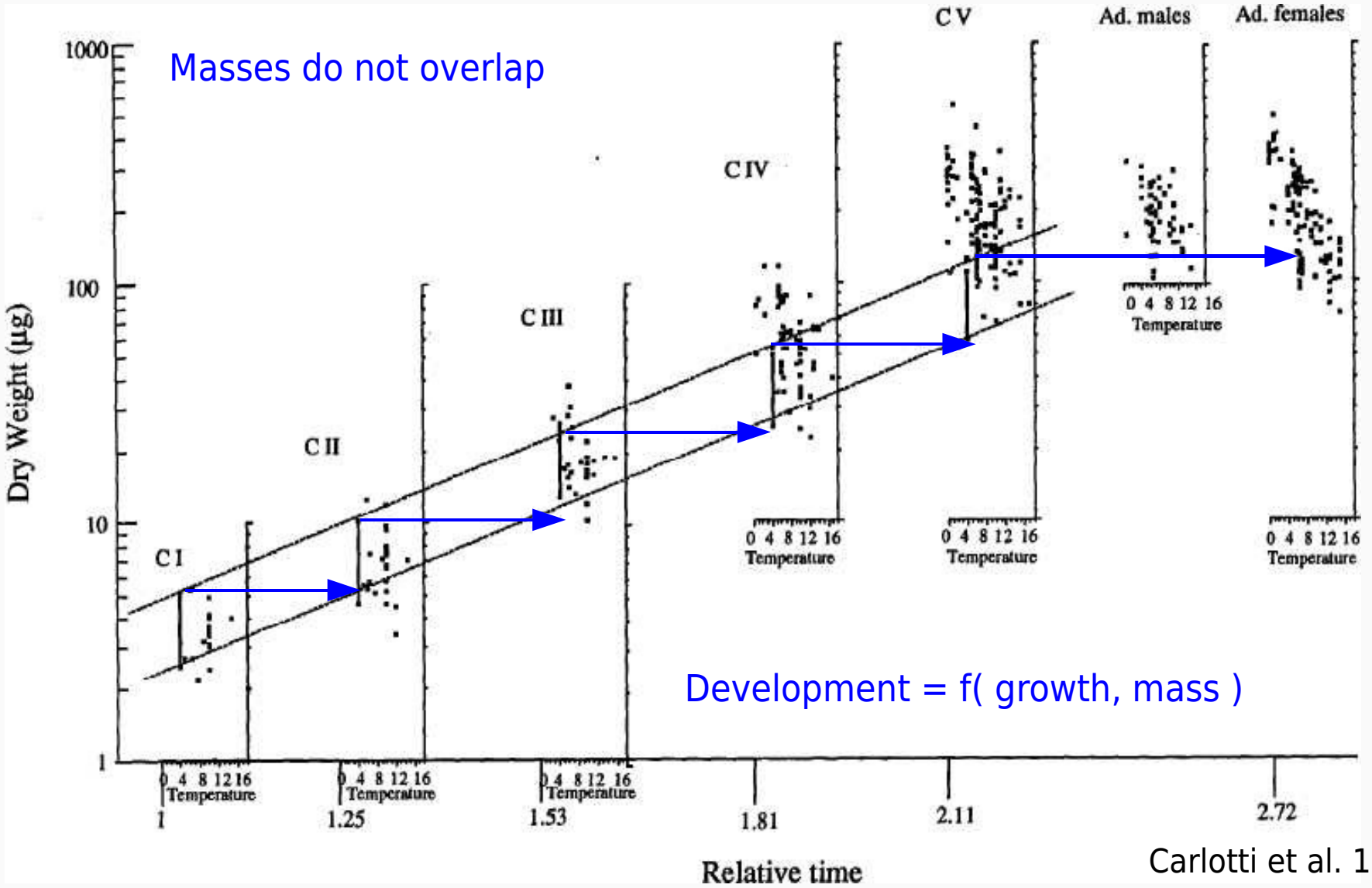
- ~ 70% of C5's body C but ~ 30% of female's body C
- Integrative variable



An individual entering diapause without enough lipid storage would be lost for the population : starvation / detrimental environmental conditions

(1) C5 enter diapause when the lipid / total C ratio > threshold

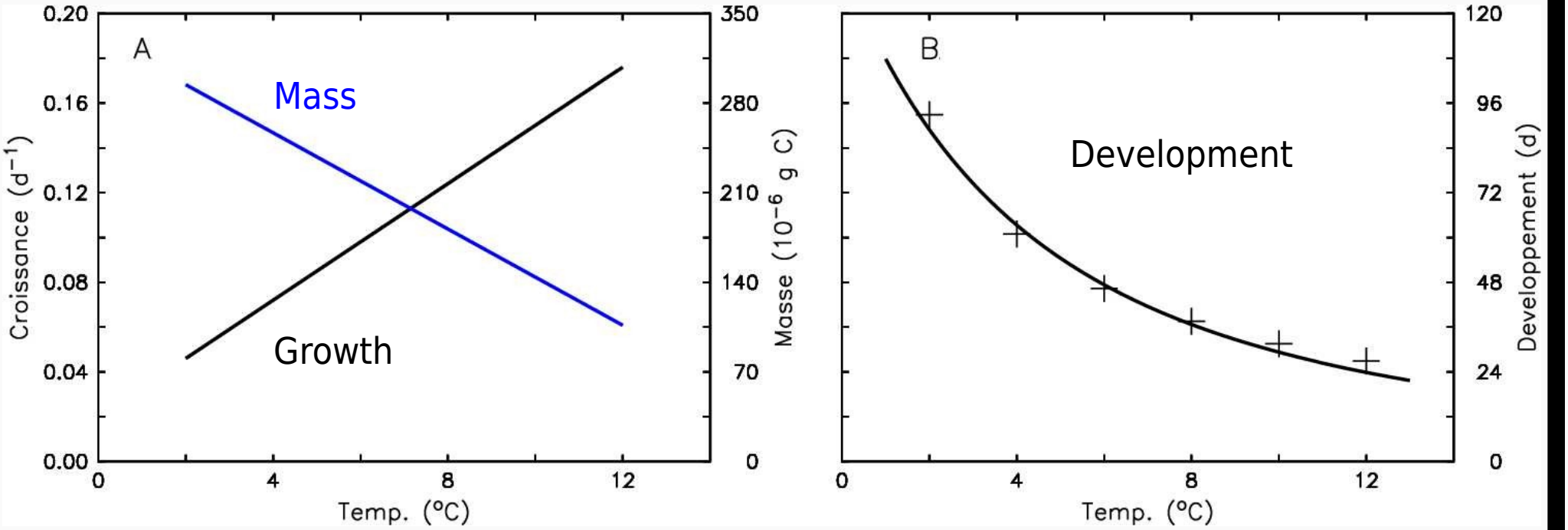
(2) C5 terminate diapause when lipids ~ threshold

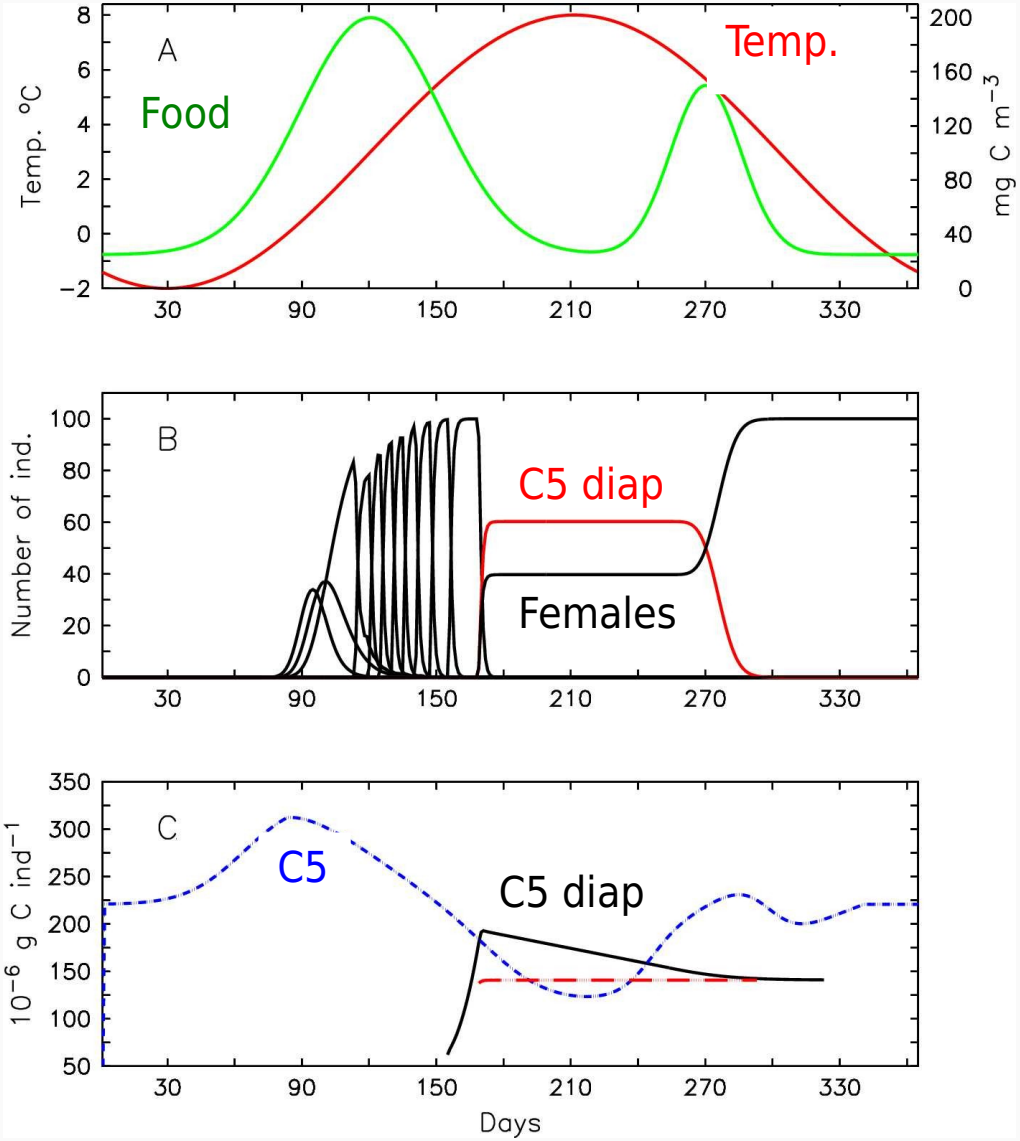


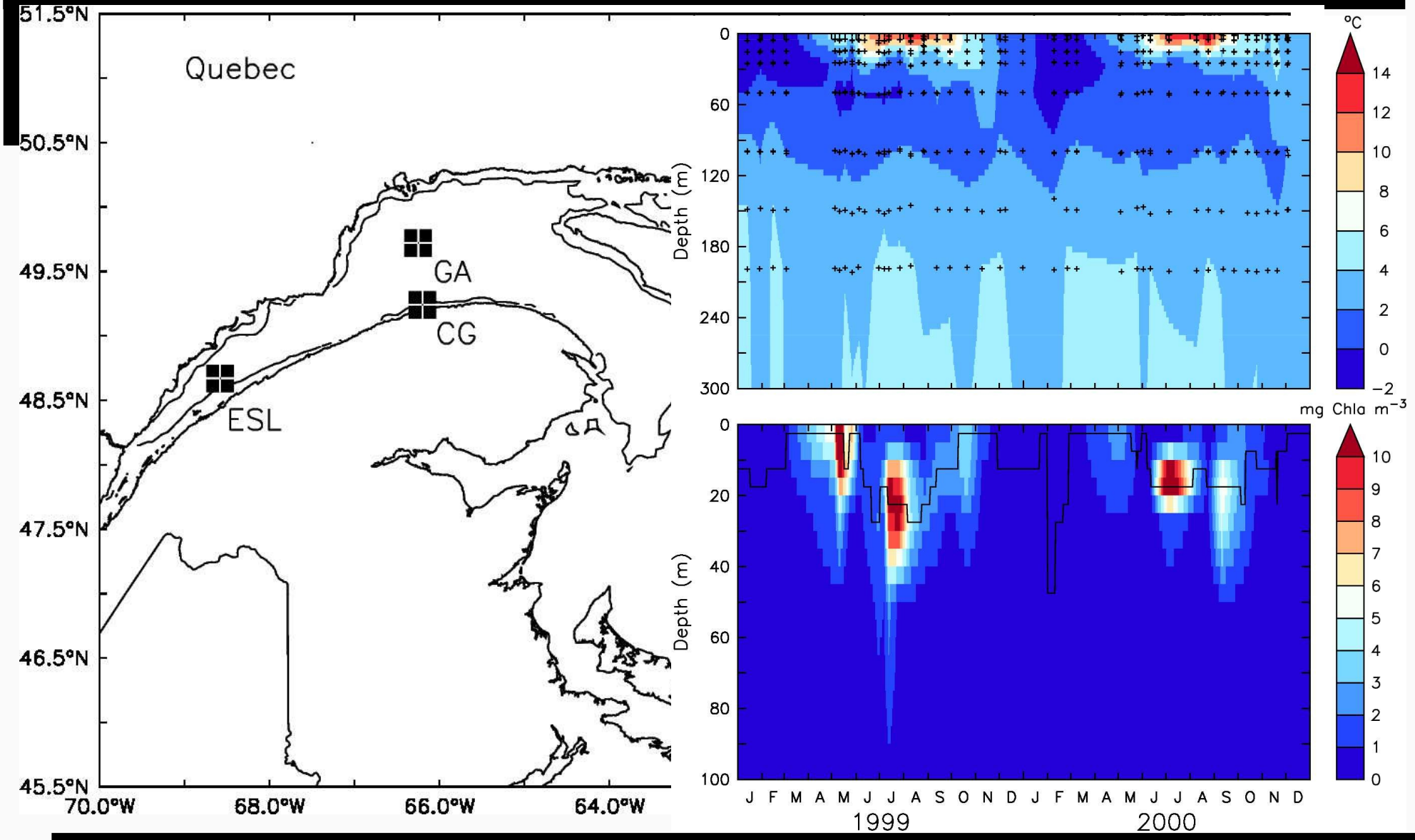
Carlotti et al. 1993

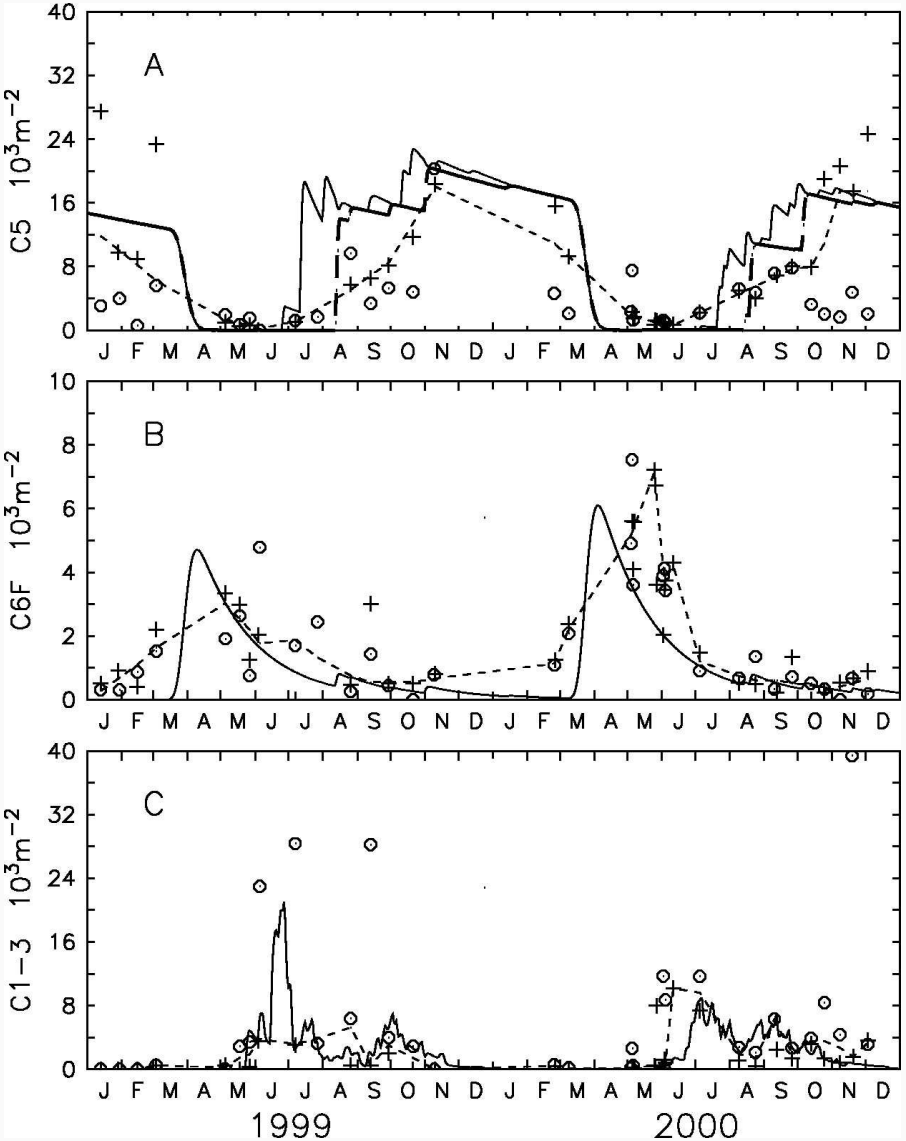
Growth and critical molting mass fonctions of the environment

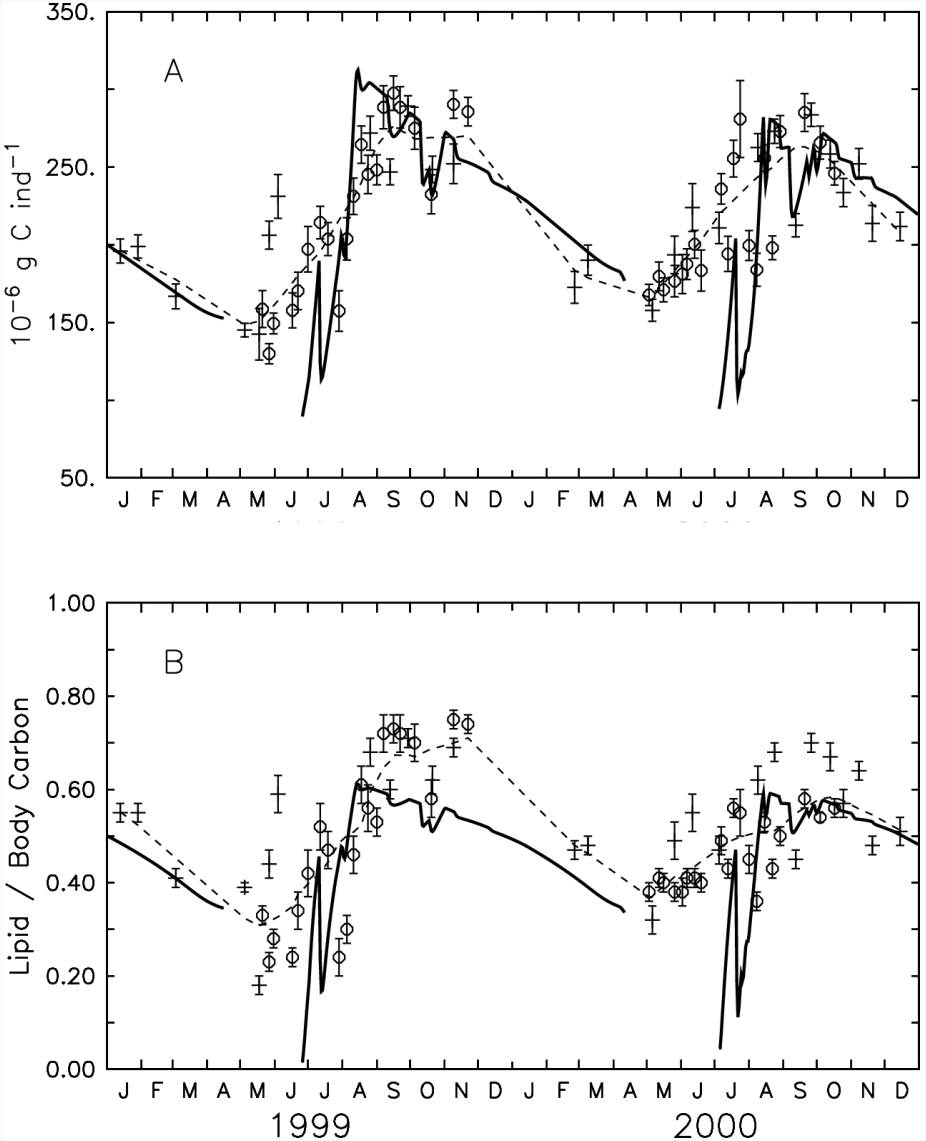
Example: C5

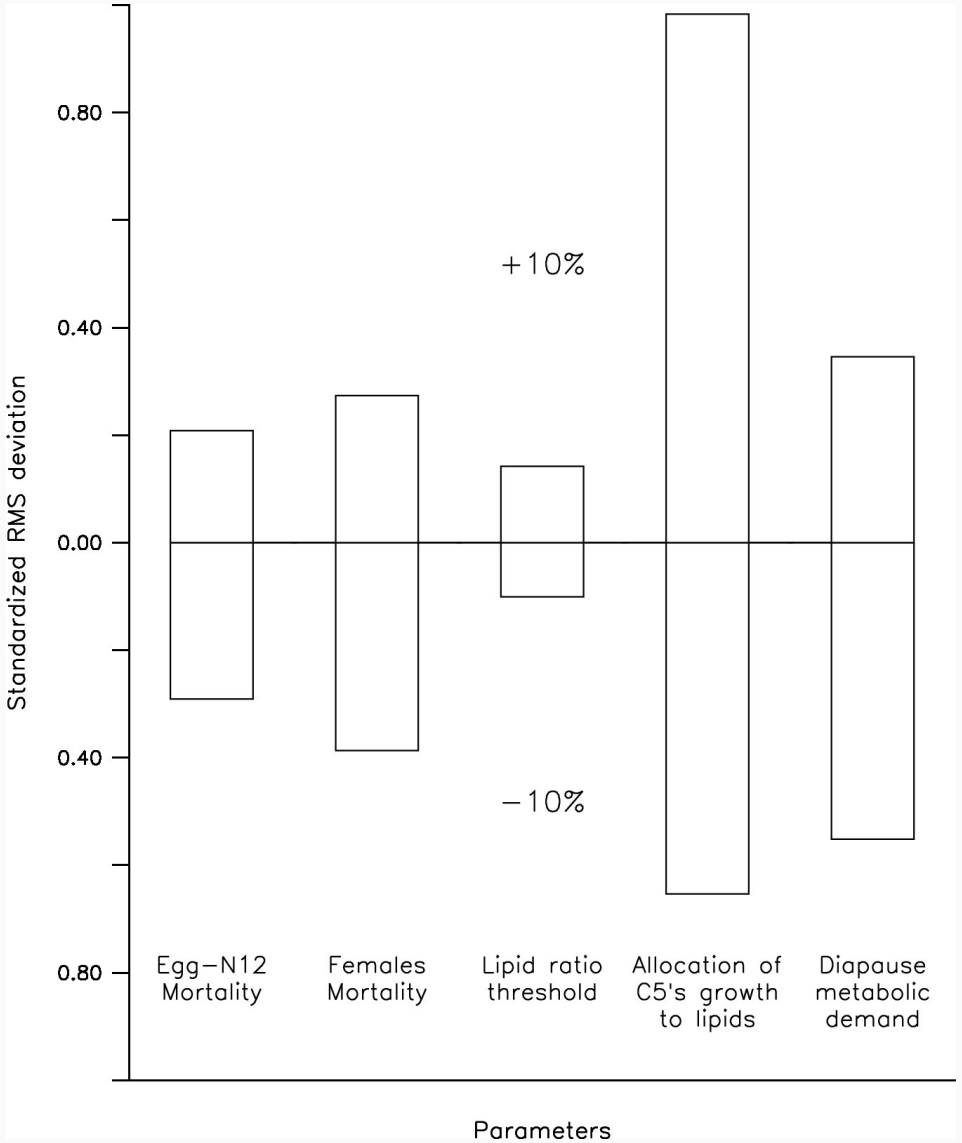



A
Food
Temp.
Temp. °C
mg C m^{-3}
B
C5 diap
Females
Number of ind.
C
C5
C5 diap
10^{-6} g C ind^{-1}
Days


51.5°N
50.5°N
49.5°N
48.5°N
47.5°N
46.5°N
45.5°N
70.0°W
68.0°W
66.0°W
64.0°W
Quebec
GA
CG
ESL
Depth (m)
0
60
120
180
240
300
°C
14
12
10
8
6
4
2
0
−2
mg Chla m^{-3}
10
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
J F M A M J J A S O N D J F M A M J J A S O N D
1999
2000


A
B
C
C5 $10^3 m^{-2}$
C6F $10^3 m^{-2}$
C1−3 $10^3 m^{-2}$
J F M A M J J A S O N D J F M A M J J A S O N D
1999
2000


A
B
350.
250.
150.
50.
10^{-6} g C ind^{-1}
1.00
0.80
0.60
0.40
0.20
0.00
Lipid / Body Carbon
J F M A M J J A S O N D J F M A M J J A S O N D
1999
2000

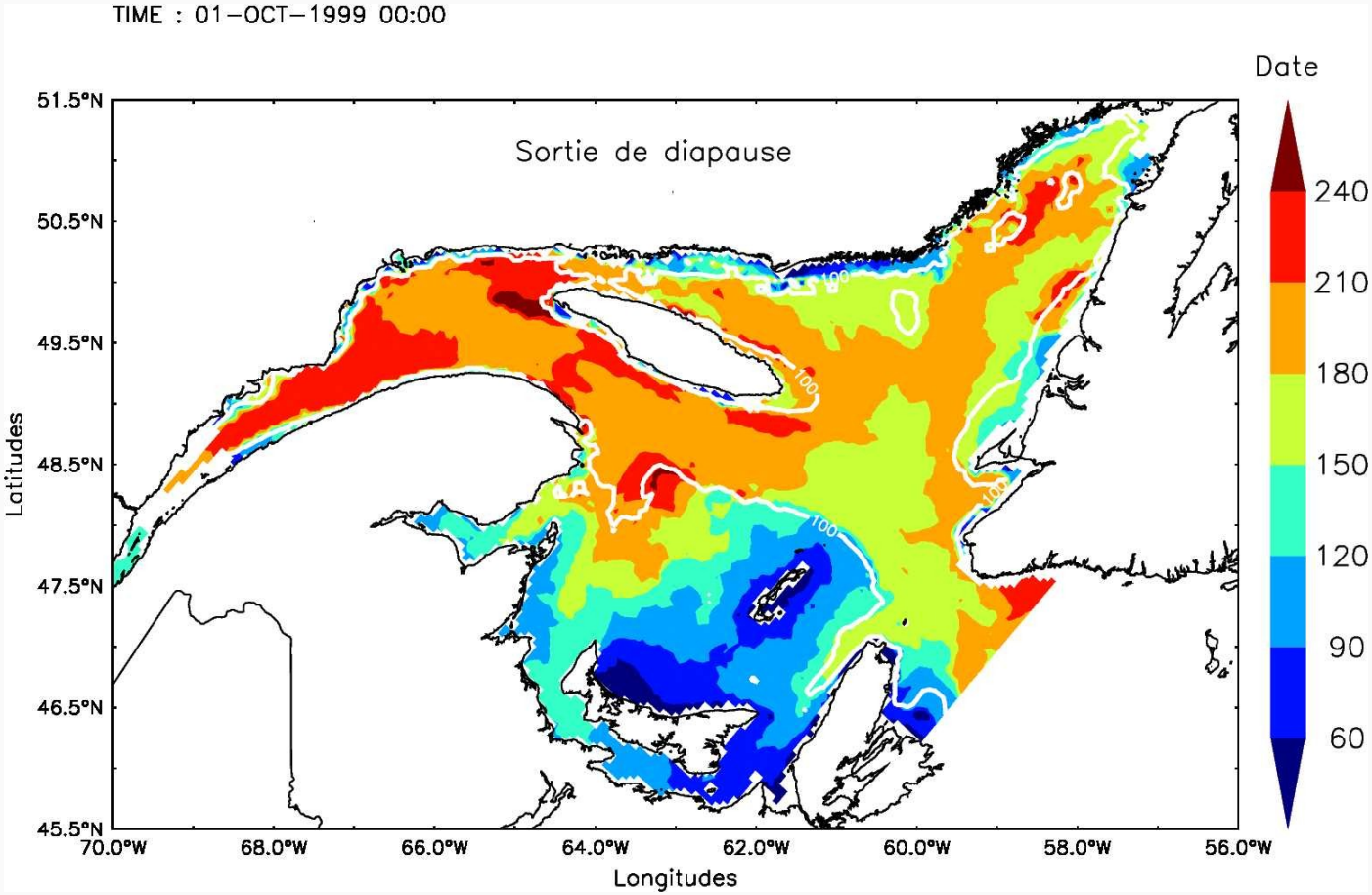

0.80
0.40
0.00
0.40
0.80
+10%
−10%
Standardized RMS deviation
Egg−N12 Mortality
Females Mortality
Lipid ratio threshold
Allocation of C5's growth to lipids
Diapause metabolic demand
Parameters

1999	13 August	30 September	1st November
Proportion (%)	69	8	23
2000	19 August	6 October	19 November
Proportion (%)	57	38	5

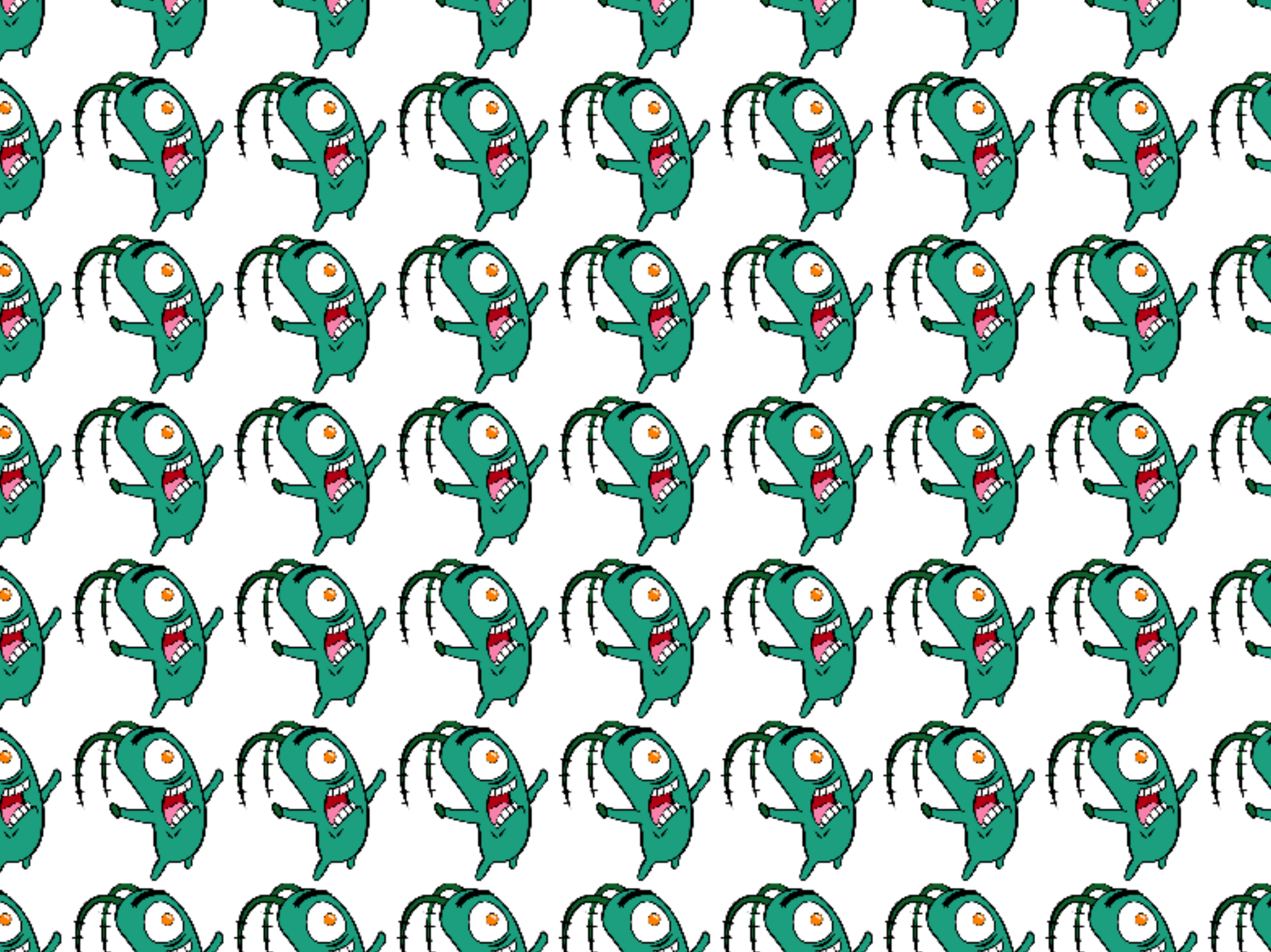
- Realistic phenology
- Realistic seasonal cycle of lipids (C5)
- Realistic abundances & amount of lipids
- Diapause : control by the lipids plausible

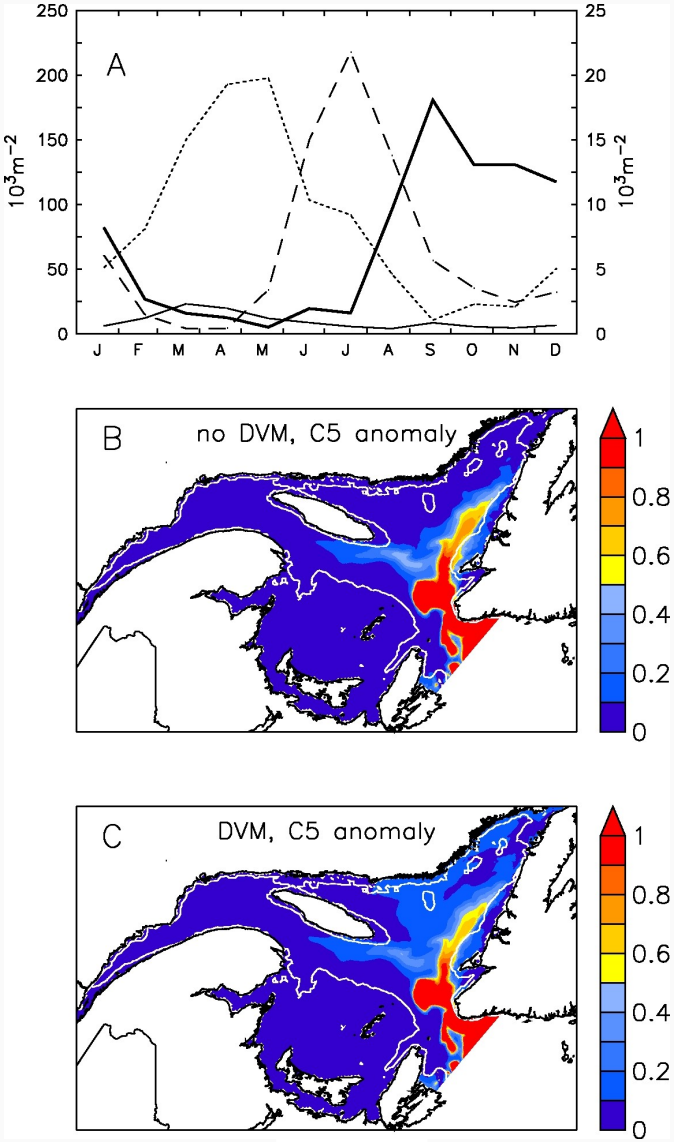
➔ Response to environmental variability,

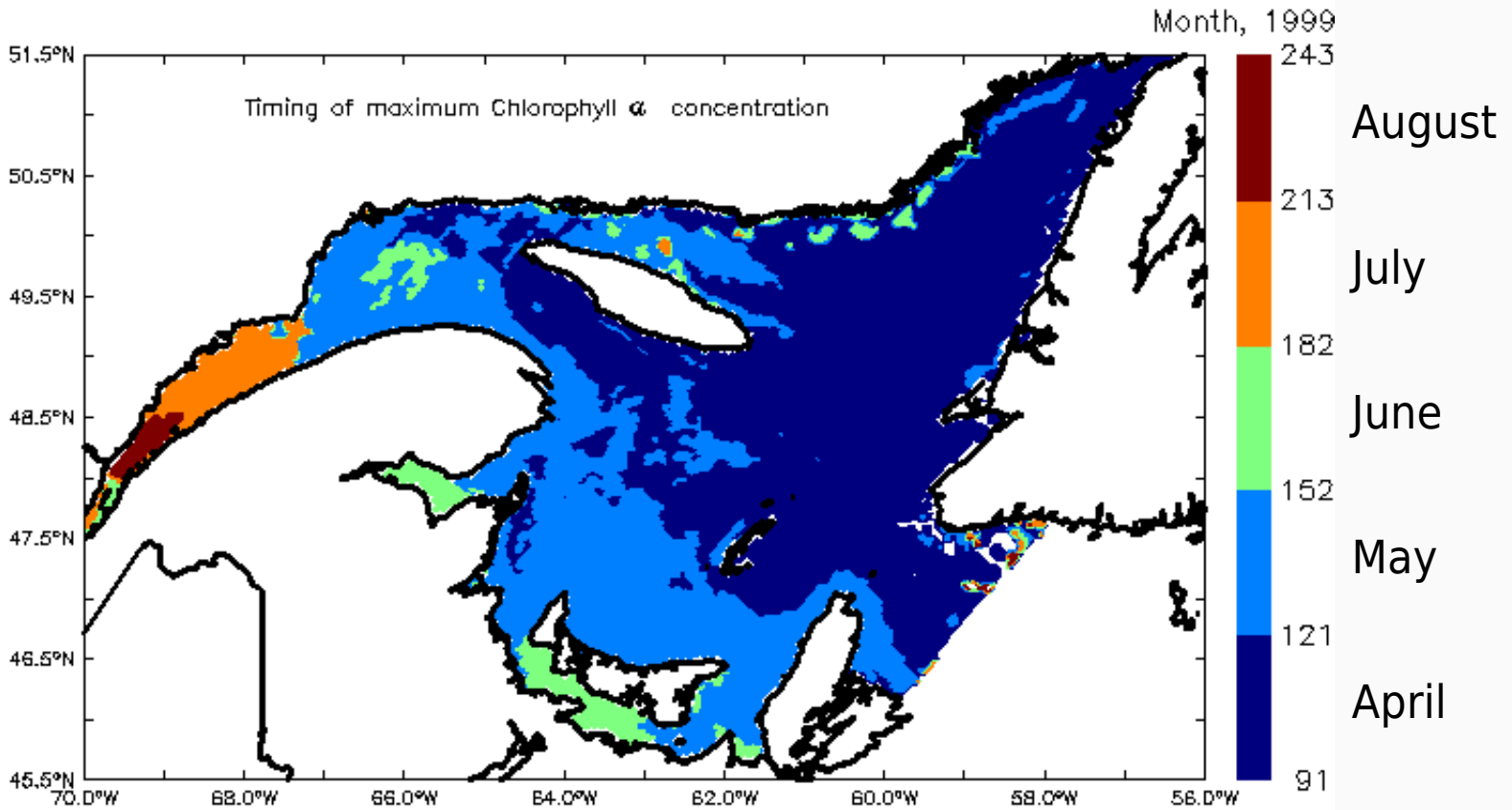
potential for regional variability


TIME : 01-OCT-1999 00:00
Sortie de diapause
Date
240
210
180
150
120
90
60
May
April
March
Feb.
Jan.
Dec.
51.5°N
50.5°N
49.5°N
48.5°N
47.5°N
46.5°N
45.5°N
Latitudes
70.0°W
68.0°W
66.0°W
64.0°W
62.0°W
60.0°W
58.0°W
56.0°W
Longitudes

- Better understanding of migration behavior
- Test phenotypic variability of diapause
- Implement mortality as a fonction of the environnement in models
- + flexibility → climatic changes scenarios
- Need for individual variability
- Integrative (hierarchical) approach : IBM + population, distributions ...




A
250
200
150
100
50
0
25
20
15
10
5
0
$10^3 m^{-2}$
$10^3 m^{-2}$
J F M A M J J A S O N D
B
no DVM, C5 anomaly
1
0.8
0.6
0.4
0.2
0
C
DVM, C5 anomaly
1
0.8
0.6
0.4
0.2
0


Timing of maximum Chlorophyll a concentration
Month, 1999
243
213
182
152
121
91
August
July
June
May
April
51.5°N
50.5°N
49.5°N
48.5°N
47.5°N
46.5°N
45.5°N
70.0°W
68.0°W
66.0°W
64.0°W
62.0°W
60.0°W
58.0°W
56.0°W