A pan-regional comparison of the seasonal climatology in mortality and population dynamics of *Calanus finmarchicus* across the North Atlantic

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- **Mortality and survival: key parameter in *Calanus finmarchicus* population dynamics (i.e., Ohman & Hirche 2001, Plourde et al. 2009)**

- **Often used as a closure parameters in biological modeling or considered as a constant parameter**

- **Mortality in early stages (eggs, nauplii): important in the determination of overall recruitment success (i.e., Ohman et al. 2002, Plourde et al. 2009a, 2009b)**

- **Mortality responds to temperature, food availability and con-specific abundance (Ohman & Hirche 2001, Ohman et al. 2002, Heath et al. 2008, Plourde et al. 2009b)**

- **Varying mortality in response to environment: necessary to model region-specific *C. finmarchicus* population dynamics (Neuhiemer et al. 2010, Maps et al. 2010, Maps et al. in press)**

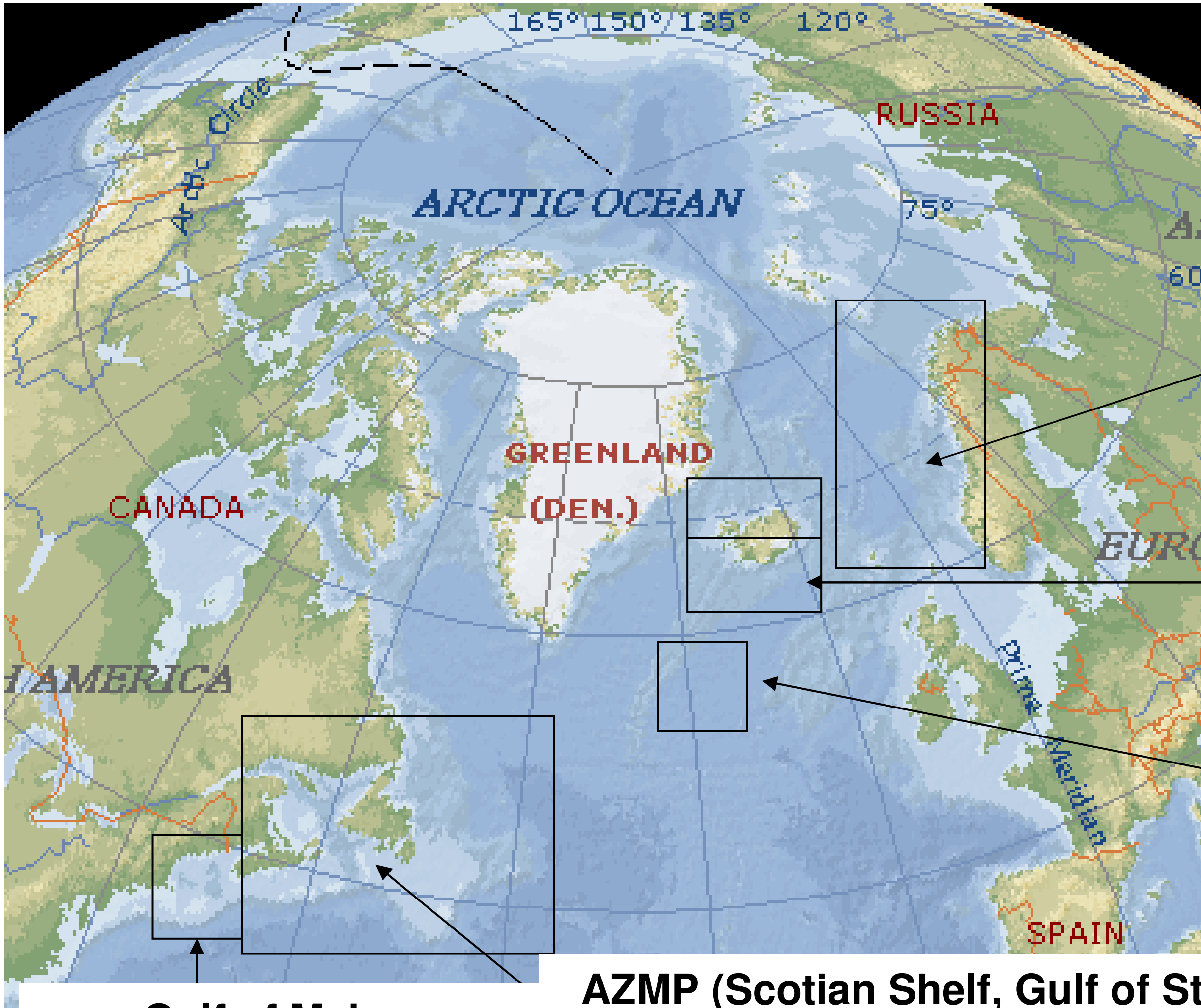
- **Survival trajectories: allowed to contrast population dynamics among regions/seasons in the AZMP region (Plourde et al. 2009b)**

- **Need for an pan-regional comparison using the same approach**

OBJECTIVES

1. To estimate stage-specific daily mortality rates in *Calanus finmarchicus* with the Vertical Life Table approach (VLT) in different regions across the North Atlantic using basic monitoring data
2. To compare long-term climatology in stage-specific mortality rate across regions in the North Atlantic
3. To describe relationships between stage-specific mortality and environment
4. To compare the population dynamics of *C. finmarchicus* in different regions in the North Atlantic by integrating mortality rates into survival trajectories from egg to C5

Data sets



Norwegian Sea:

Svinoy line 1991-2008

Iceland (Atlantic and Arctic regions): 1996-1998

Station India: 1971-1975

AZMP (Scotian Shelf, Gulf of St. Lawrence, Newfoundland Shelf): 1999-2009

Gulf of Maine:

2002-2008

- **Approach: similar to Plourde et al. 2009 using VLT for stage pairs Egg-C1, C1-C2, C3-C4, C4-C5, C5-C6**

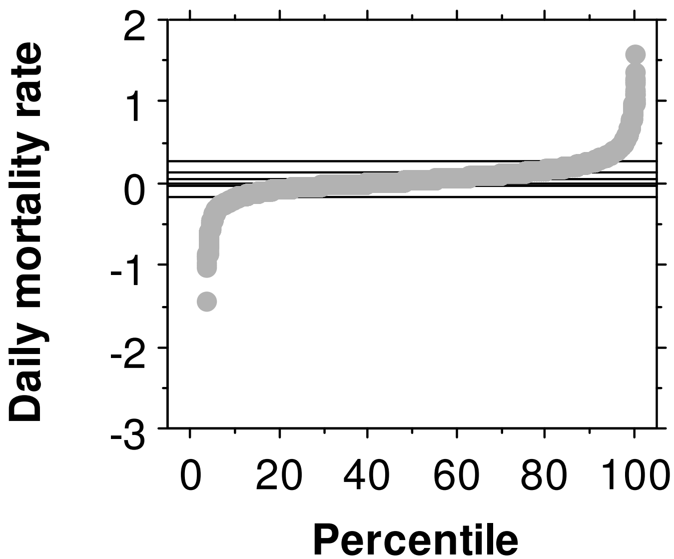
  - **PopEpr: Epr estimated with region-specific relationship with ambient chl *a***
  - **Temperature and chl *a*: surface layer most appropriate in each region (chl *a* normalised as mg m^{-3} for statistical analyses)**
  - **DT vs temp: Campbell et al (2001) or Corkett et al. (1985) depending on temperature regime**
  - **Monthly climatology: robust approach to minimize violation of VLT. Replication: Month*Year**
  - **Exception: Iceland (only few years), individual data (stations) considered as replicates**

	Region							
	GoMaine	GSL	Iceland	StnIndia	NFL	NwSea	SS	Total
n	70	156	158	35	145	146	196	906

Novelty for Pan-Regional Synthesis

1. Exclusion of mortality/survival values (obvious violation of VLT):

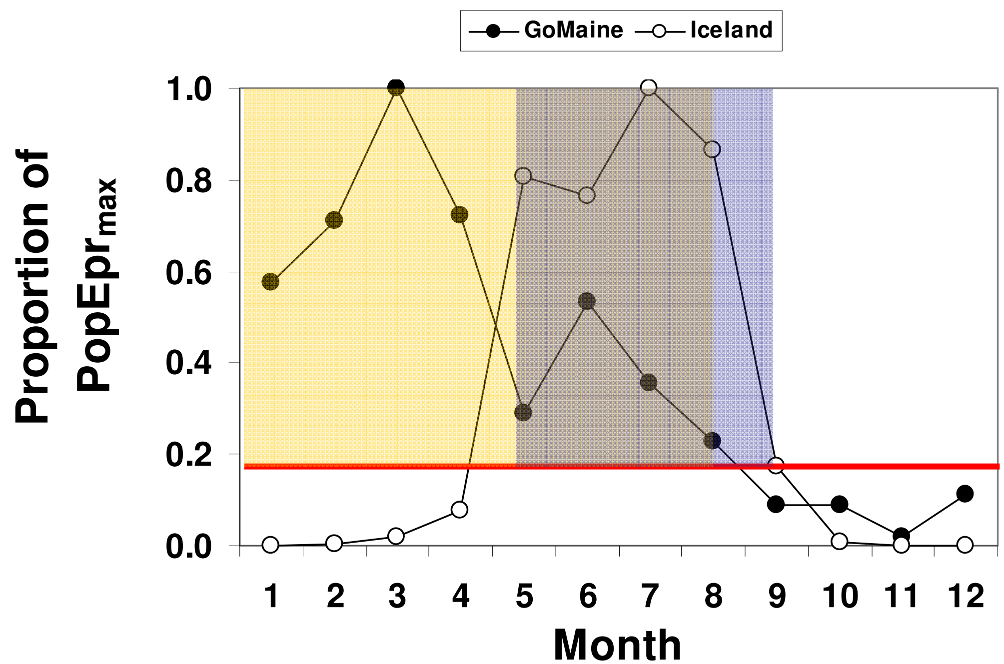
< 5th percentile, > 95th percentile



2. ID of periods for Pan-Regional comparisons:

-Population Growth Period: month = PopEpr > 0.15*$PopEpr_{max}$

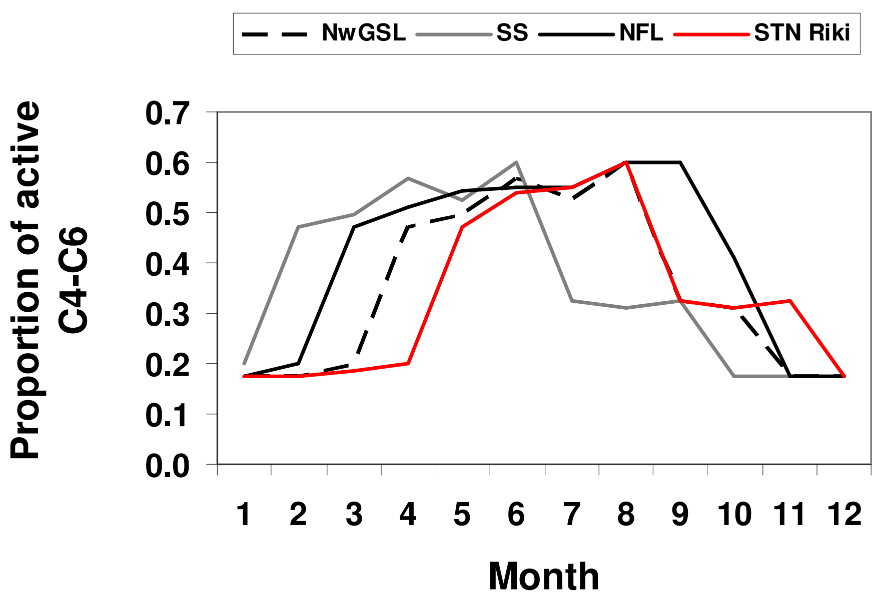
- DT Egg-N6 < 30 days to respect monthly scale



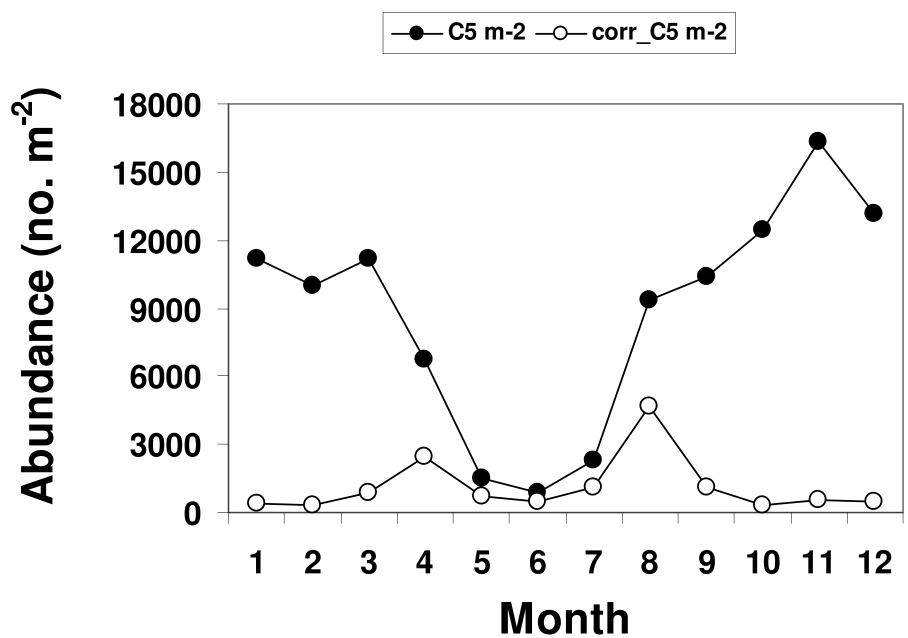
Novelty for Pan-Regional Synthesis

3. Abundance of late development stages C4-C5-C6: exclusion of overwintering components (NW Atlantic data) (Plourde et al. 2009b)

Riki seasonal pattern of active component ajusted for regions (Johnson et al. 2008)



Impacts: NwGSL



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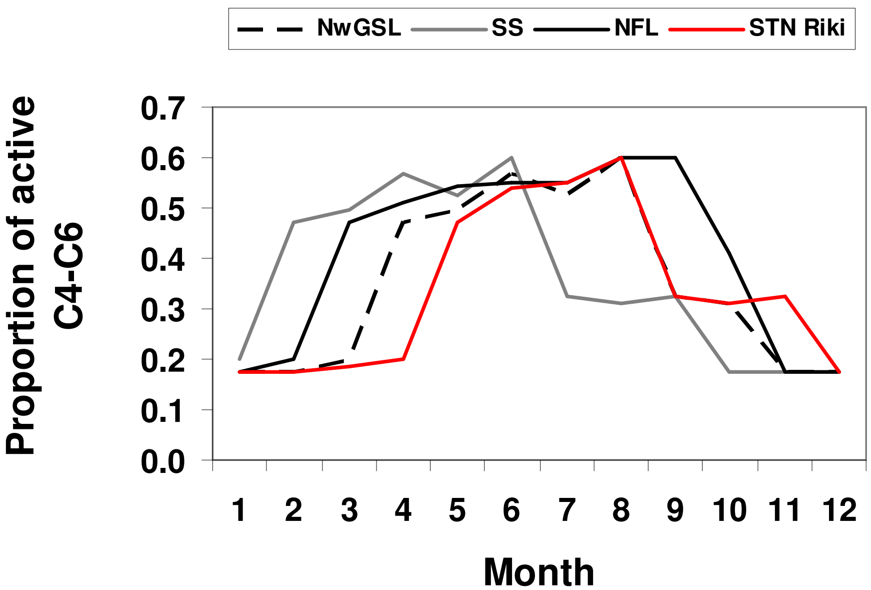

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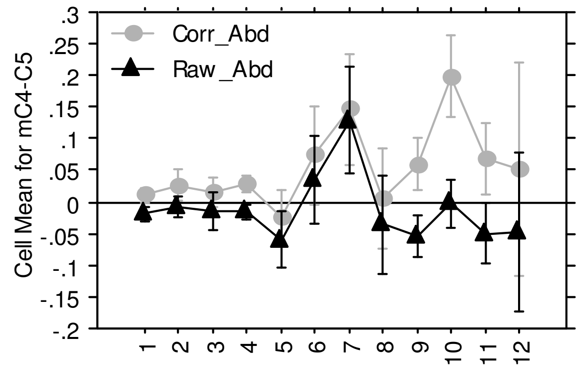
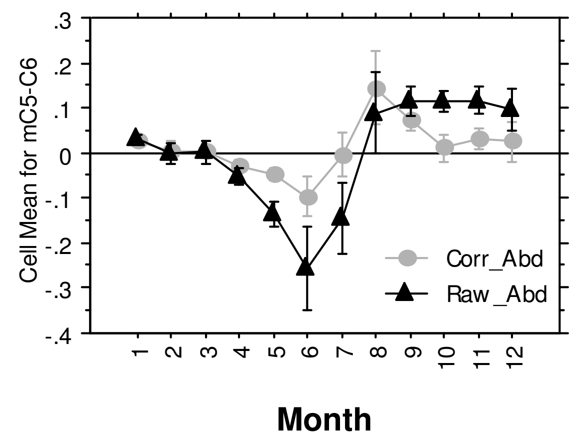
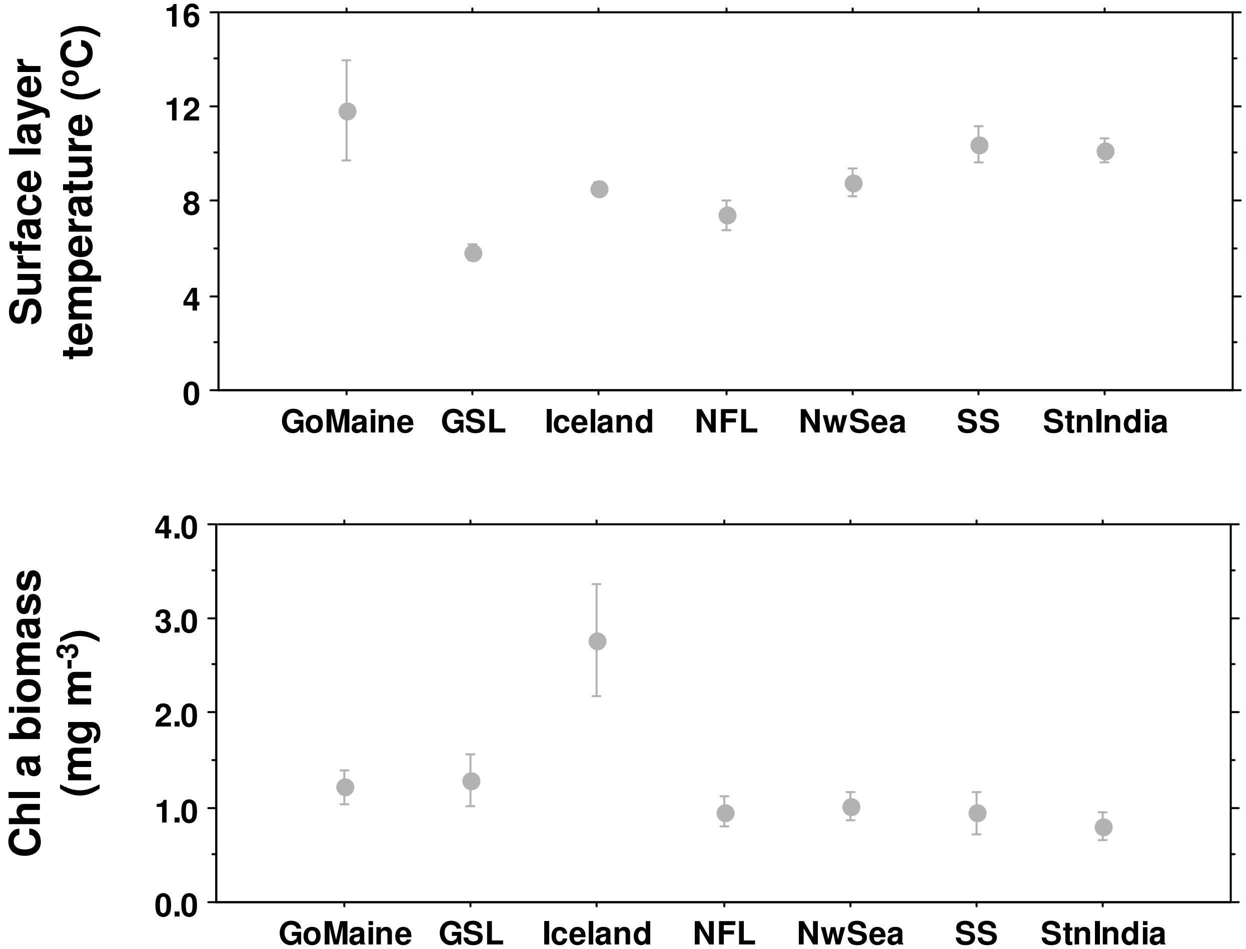
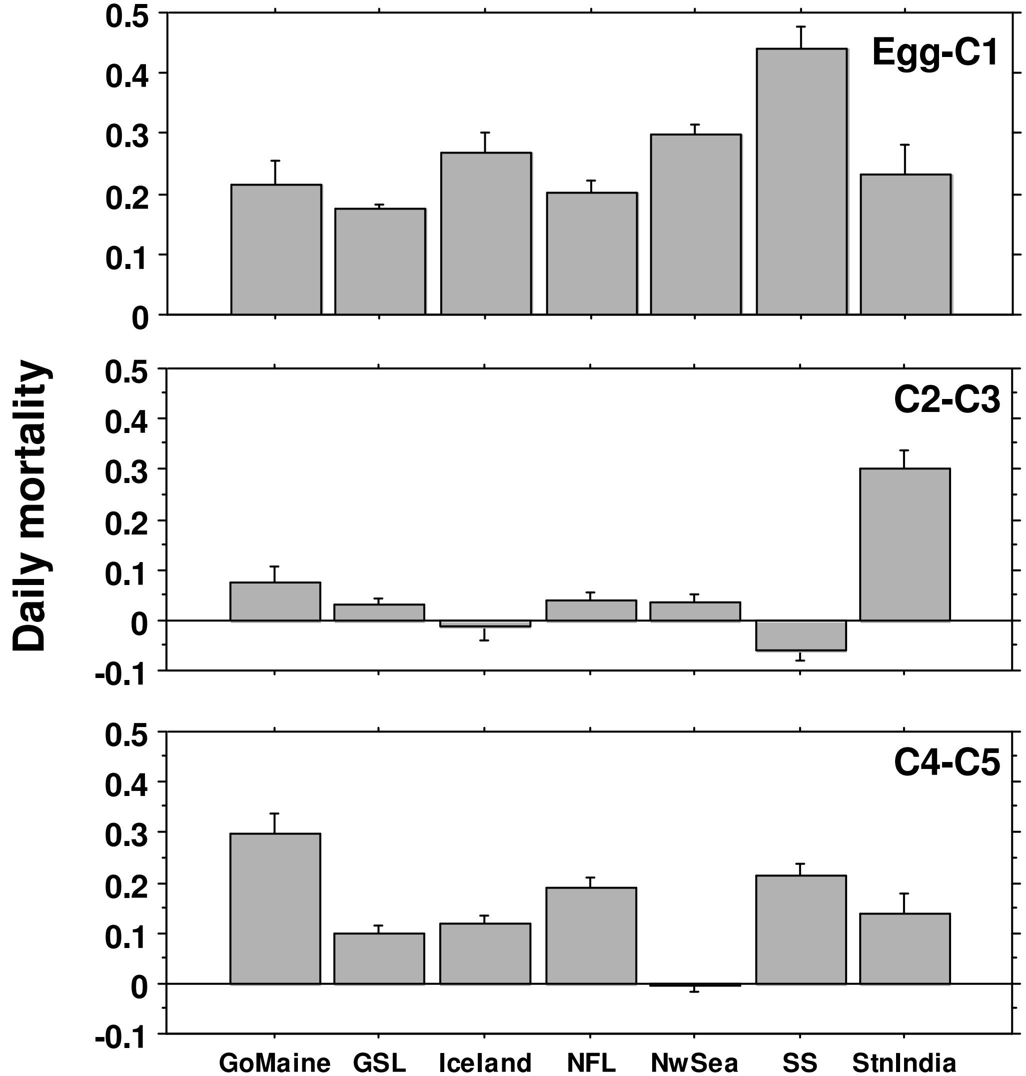




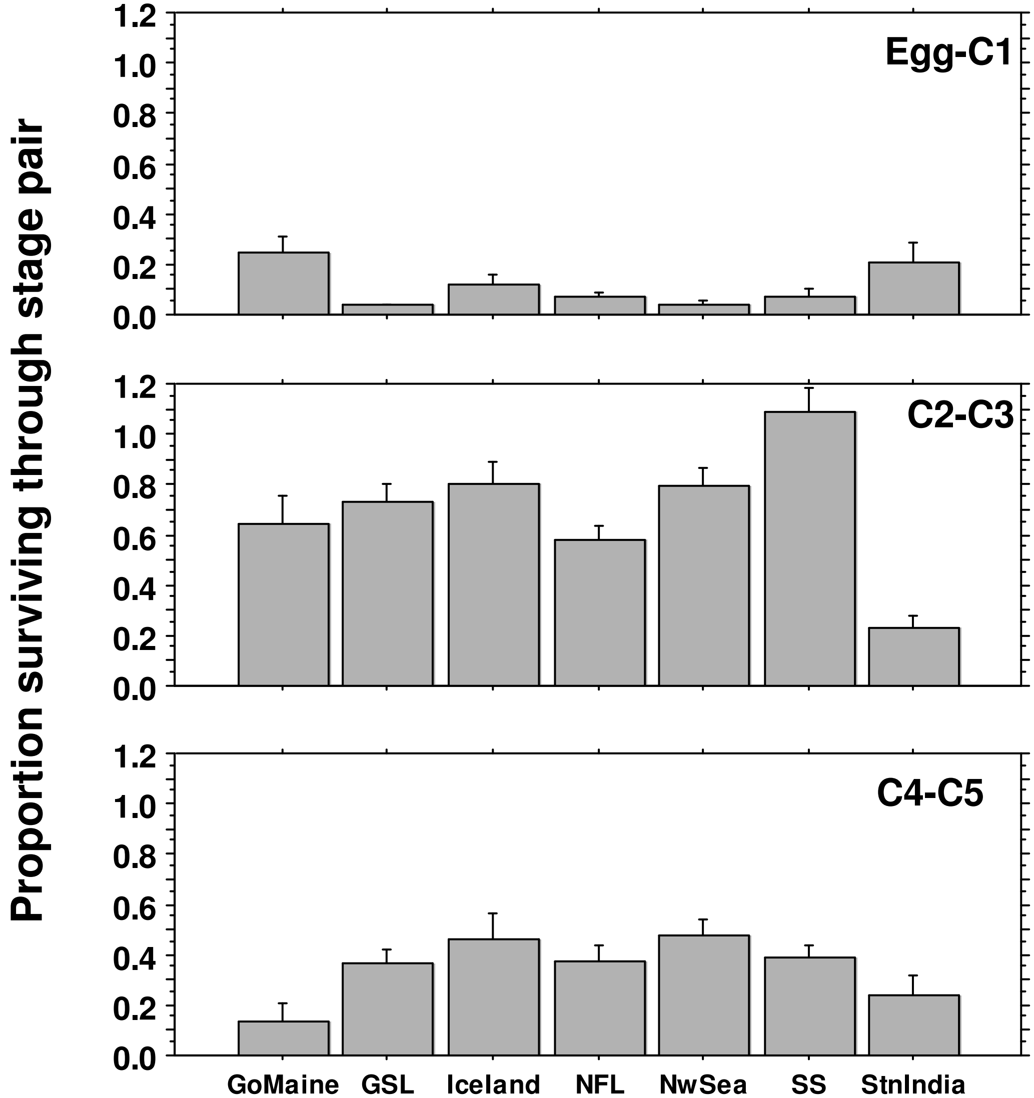
Environmental conditions in different regions during Pop Growth Period



Mortality (*m*) in different regions



Proportion surviving in different regions: *m* integrated over DT

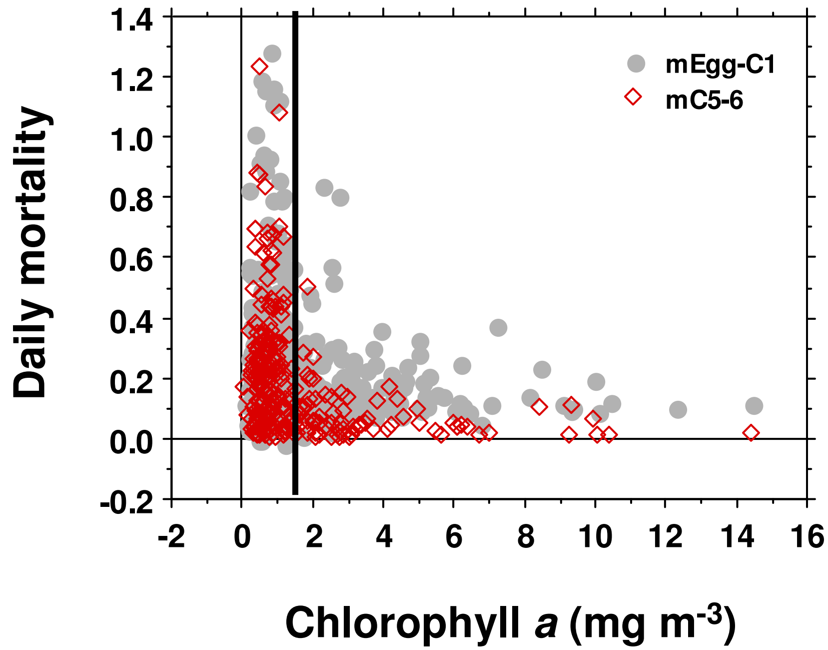


Mortality Egg-C1 vs environment

	GoMaine	SS	GSL	NFL	StnIndia	Iceland	NwSea
r^2	**0.51**	**0.58**	**0.24**	**0.12**	-	**0.60**	**0.31**
Coeffcient							
Intercept	**-1.63**	**-0.91**	**-0.18**	0.13	-0.82	**-3.11**	**-0.26**
LN Temp	**0.37**	**0.47**	**0.07**	**0.12**	0.35	**1.31**	**0.18**
LN Chla m^{-3}	0.32	0.09	0.02	0.04	0.24	-0.01	**-0.13**
LN C6f m^{-2}	**0.09**	**0.01**	**0.03**	0.01	0.0004	**0.03**	**0.02**

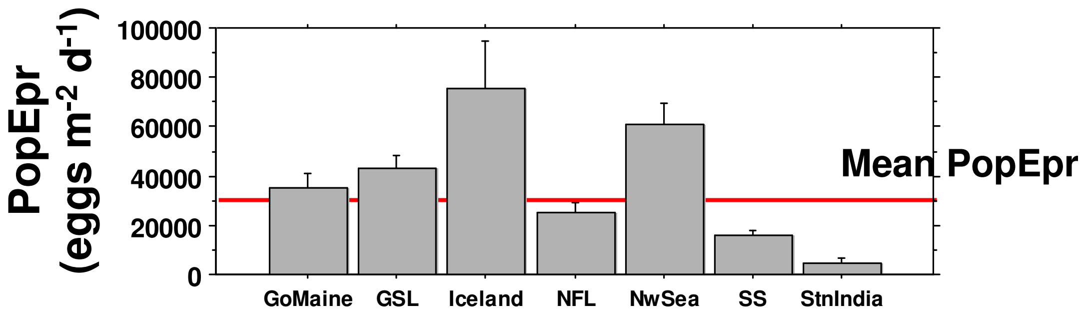
Overall positive effect of temperature on mortality…… (Plourde et al. 2009b)

Mortality vs food: mEgg-C1 and C5-C6 example (without negative values)

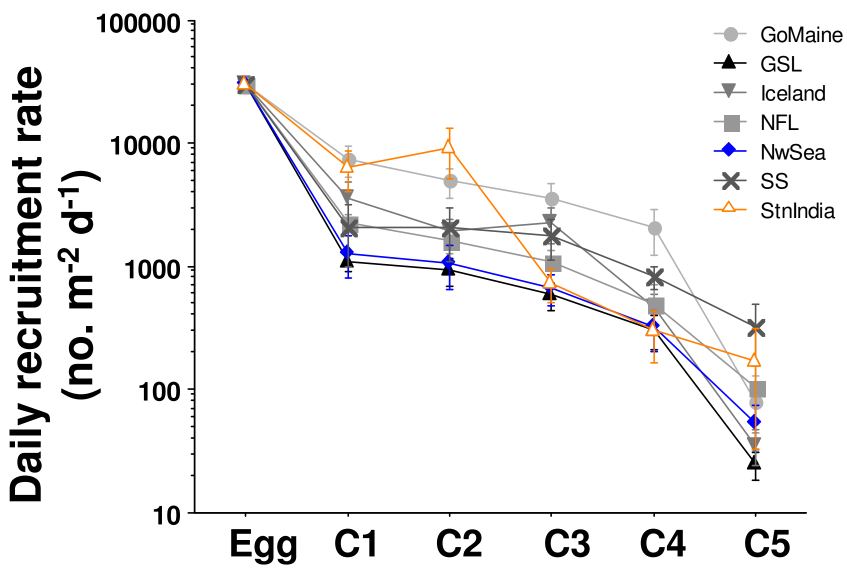


Higher mortality rate at chl a < 1.5 mg m^{-3}

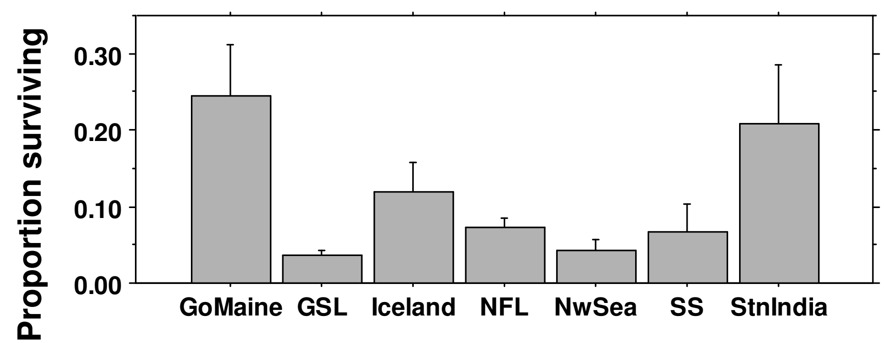
Survival trajectory in different regions: daily recruitment rate



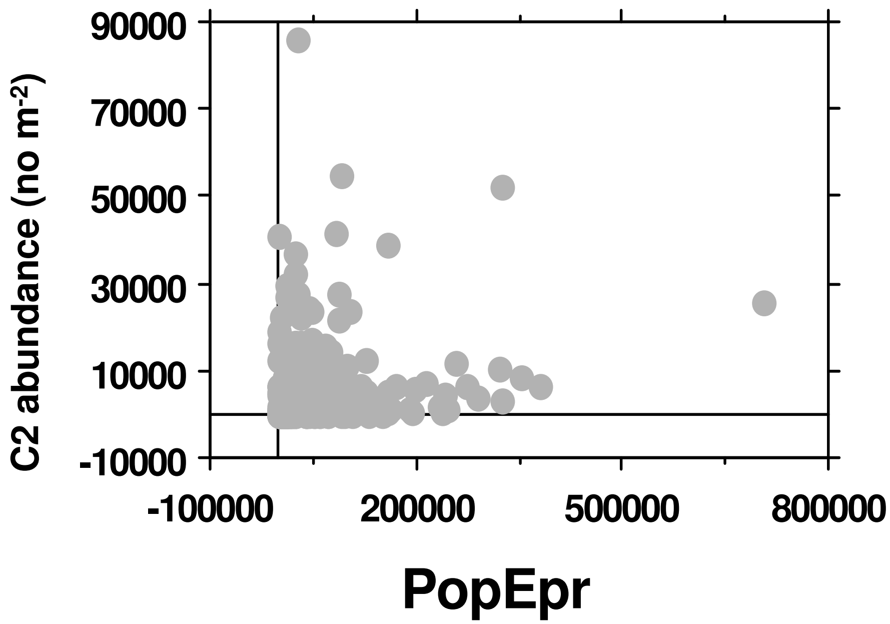
- Normalised with mean PopEpr
- Significant differences in C1 recruitment (survival from Egg-C1)
- Survival from C1 to C4 similar in most regions (exception: StnIndia)



- Proportion surviving from Egg to C1 : 0.04 (GSL) to 0.24 (GoMaine)



Control of recruitment in *C. finmarchicus*: survival from Egg to C1



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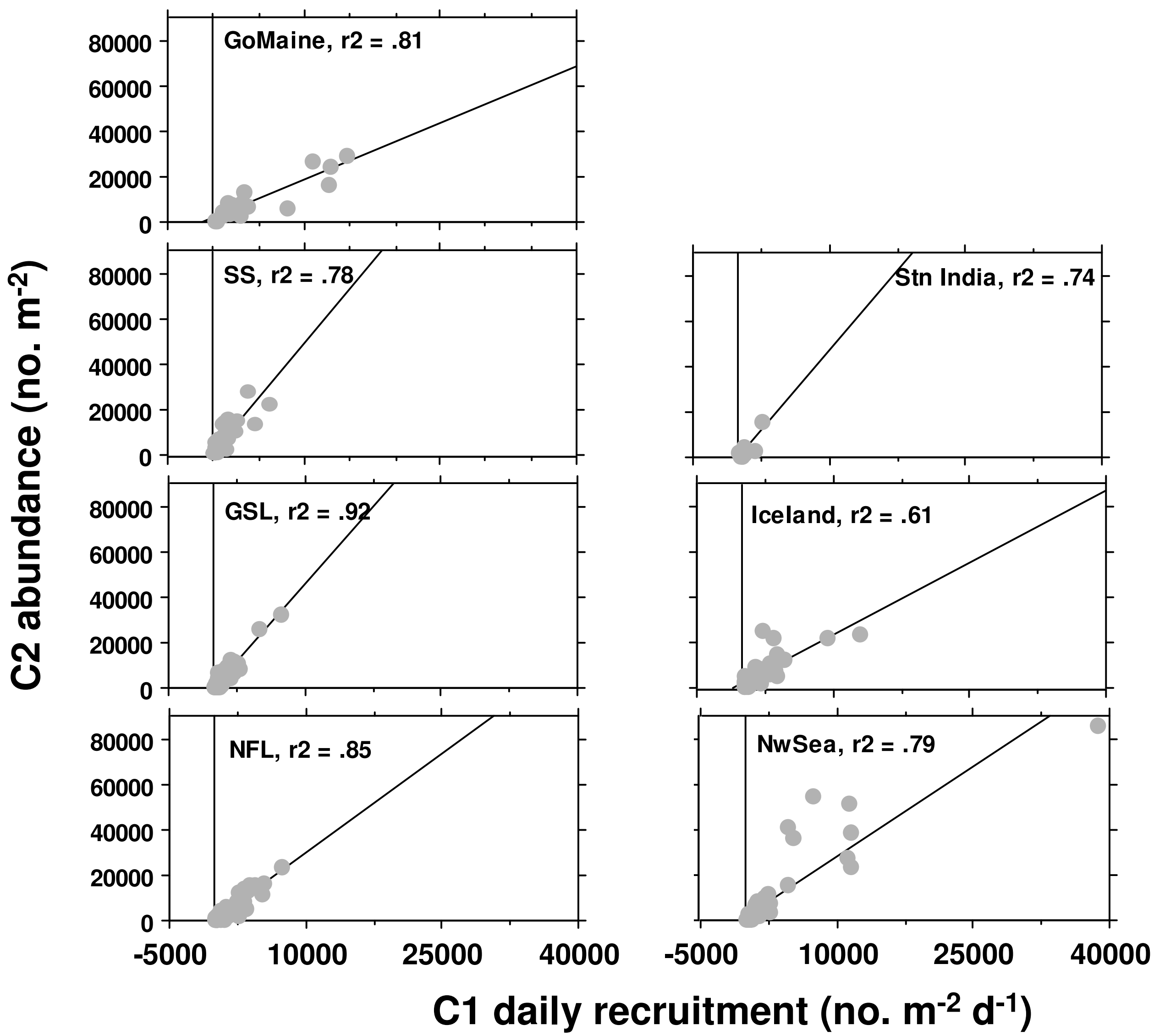
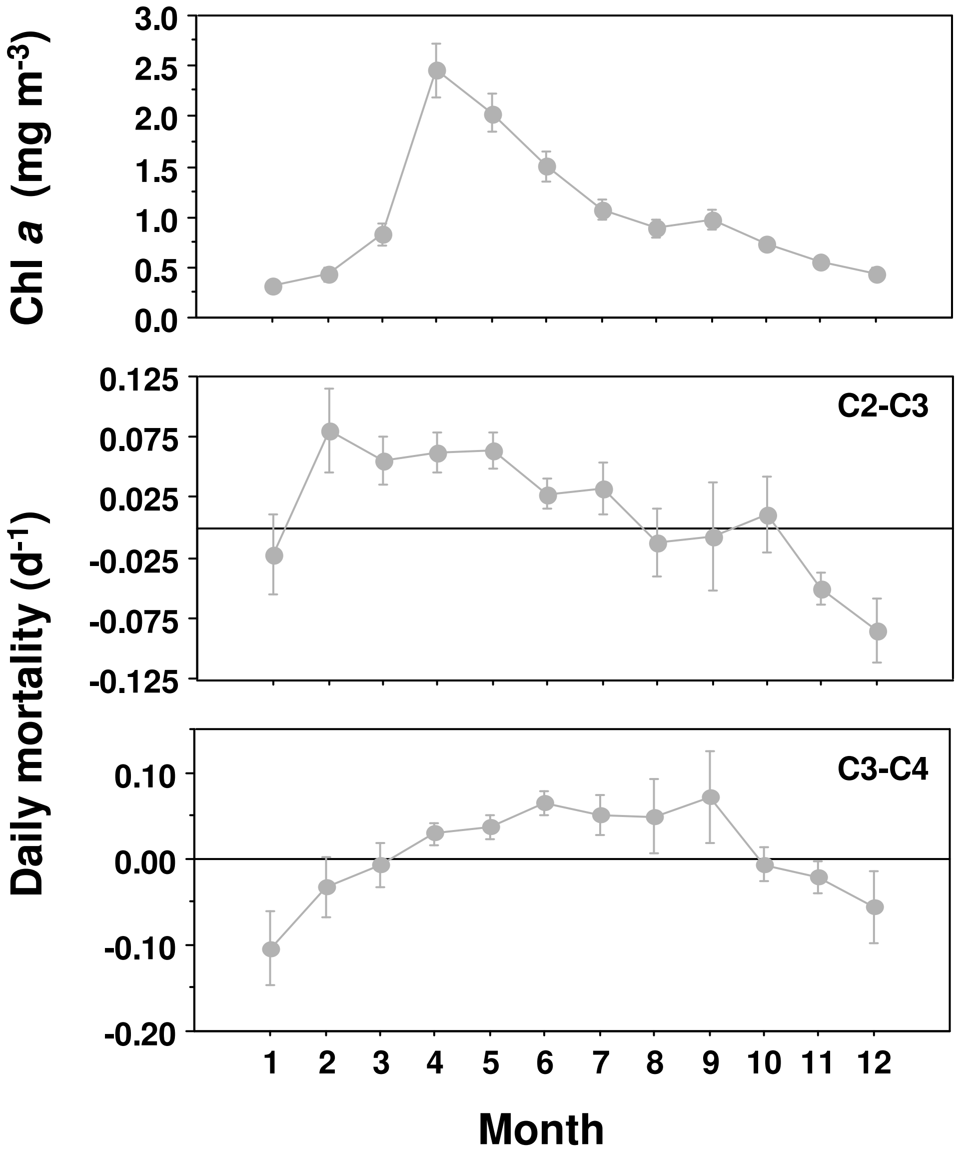


Negative mortality values: problem with estimate of DT?

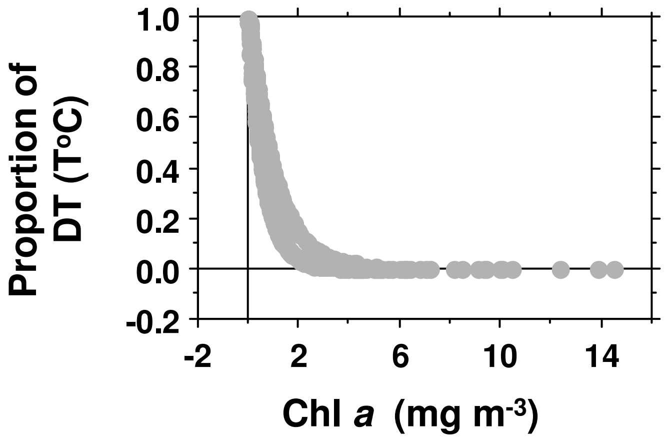


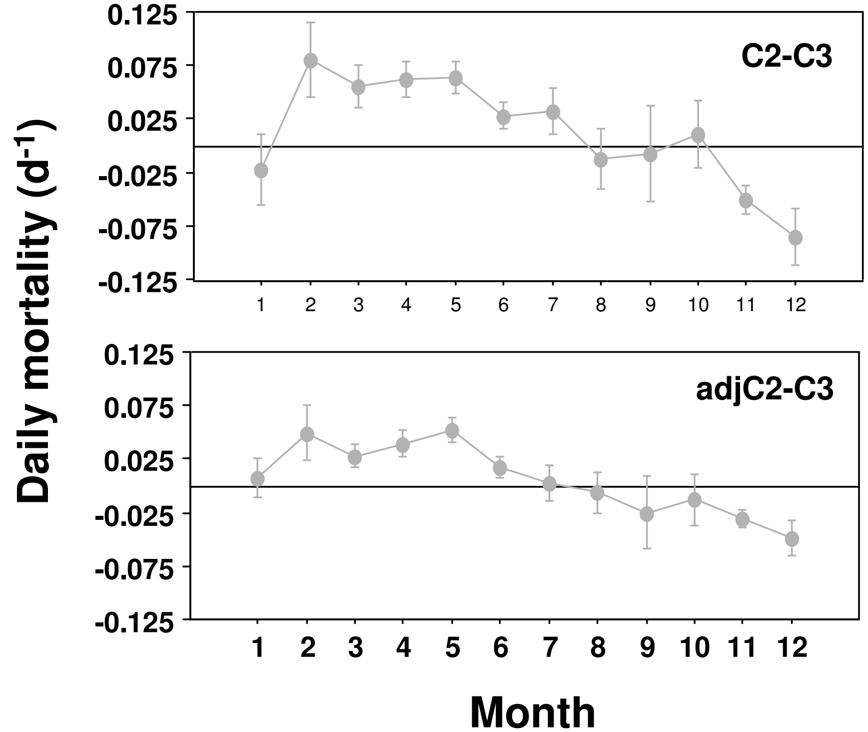
- Relatively high % of negative *m* values (30-40%), even in early copepodid stages
- Likely not because of 'local' violation of VLT: correction for diapause, high n of replicates (monthly values) over several years
- Region-specific recurrent advective patterns could cause violation of VLT for some stage pairs with distinct DVM behaviours
- Phenomena also observed in stage pairs (C2, C3) with very similar DVM behaviour (similar advective influence)
- On a broader scale, appears associated to low ambiant chl *a*
- Potential candidate: delayed DT due to food shortage (Campbel et al. 2001)

Negative mortality values: problem with estimate of DT?

- **Food and DT: prolonged DT at low food**

DT= 1-e$^{(-1.64*chla)}$ (Campbell et al. 2001)





- **DT estimated from Temp and chl *a* (adj C2-C3)**
- **adj mC2-C3 less 'negative', but with a similar seasonal pattern (single effect of food limitation applied to all stages…)**
- **Food limitation likely stage-specific and greater in late stages (Basedow & Tande 2008): <u>need for stage-specific DT vs food limitation</u>**
- **Late stages in surface layer in fall-winter: potential for delayed (food) or arrested (diapause) development (Pedersen et al. 1995, Campbell et al. 2001)**

Conclusions

- **Stage-specific mortality and proportion surviving through stage pairs varied among regions in the North Atlantic**

- **Mortality in Egg-C1 was significantly associated to temperature and density-dependent processes in almost all regions…..**

- **… while there was also a significant negative effect of chl *a* biomass on mortality in Egg-C1 in the Norwegian Sea (Svinoy Line)**

- **The highest mortality in Egg-C1 and C5-C6 were generally associated with low chl a biomass, suggesting a detrimental effect of food limitation on mortality and survival during cohort development**

- **Survival to stage C1 varied among regions, which mostly determined the region-specific recruitment to early copepodite stages**

- **While correcting data (removing) for the presence of deep owerwintering animals improved mortality estimates in late stages, the relatively high occurrence of negative mortality in early copepodite stage pairs from late Summer to late Winter suggested a much longer DT due to low food availability, indicating that DT under such conditions would poorly parametised**

Conclusions

- **Future work to improve interpretation: assessment of the potential impact of advection in different region**

- **Future work (long-term): obtain a better understanding of the region-specific physiology**

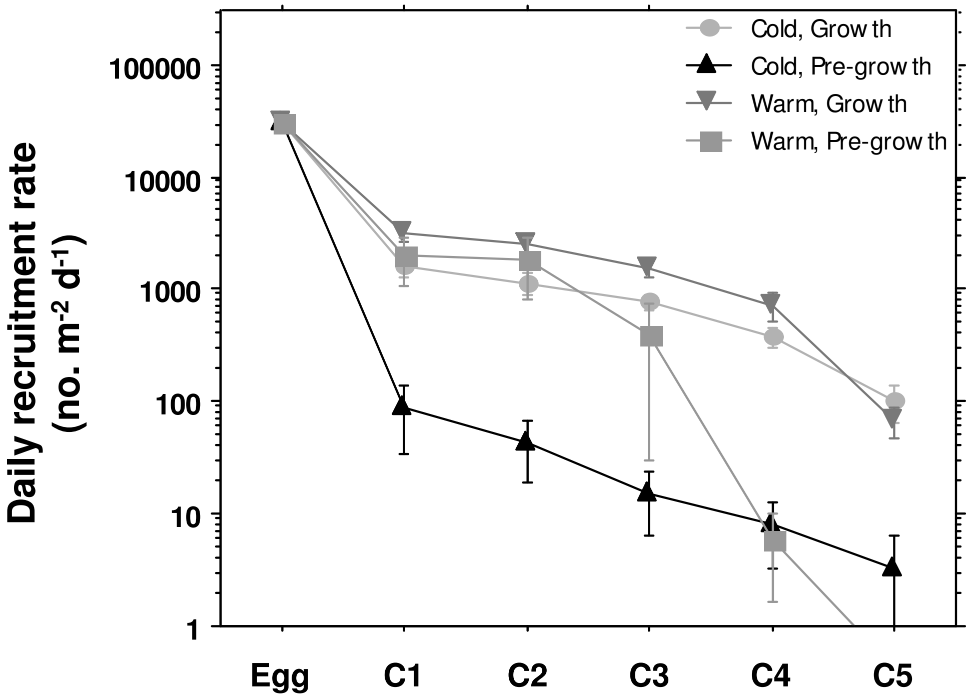
  - **Campbell et al. (2001): appropriate for the genetically different *C. finmarchicus* in the Northeast Atlantic? (Bucklin et al. 2000)**
  - **Corkett et al. (1986): potential for contamination by *C. glacialis* (Lindeque et al. 2006, Parent et al. in review) ?**

Acknowlegments

All the scientists, technicians, officers and crew who contributed to the efforts of these different sampling programs.

Funding in support of these projects and sampling programs in their respective country

Supplement…..



- Cold regions: regions under the influence of Arctic water, high abundance of *Chyp* and *Cglac*
- *Chyp-Cglac*: earlier arousal from diapause and ontogenetic migration to deep overwintering depth
- Survival Egg-C1: much lower in 'cold regions' early in the season (*Cfin* pre-growth period)
- Early is the better (Varpe et al. 2007)? Not necessarily in cases when other large *Calanus* abundant (i.e. considering intra-guild predation)
- Caution: this could be partly explained by 'violation' to VLT early in the season (DT> 30 days..)
- … but this an average over several months in winter-spring in AZMP and Arctic waters north of Iceland