

Nine Years of Zooplankton Monitoring in the St. Lawrence Marine System (2001–2009)

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Sommaire

Ce document présente un aperçu de la variabilité saisonnière et interannuelle de la biomasse et de l'abondance du zooplancton récolté le long de sept sections situées sur l'ensemble du système marin du Saint-Laurent (SMSL) dans le cadre du Programme de monitoring de la zone Atlantique (PMZA) en juin et novembre de 2001 à 2009. Sur la période de neuf ans, il y a eu des changements importants sur une base saisonnière et interannuelle de l'abondance et de la composition spécifique du zooplancton. Ces variations saisonnières et interannuelles de la communauté de zooplancton peuvent avoir des impacts importants sur la production secondaire, le transfert d'énergie vers les niveaux supérieurs du réseau trophique et, conséquemment, sur le recrutement des espèces exploitées commercialement dans le SMSL.

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1998 (Therriault et al. 1998) with the aim of (1) increasing DFO's capacity to understand, describe, and forecast the state of the marine ecosystem and (2) quantifying changes in the ocean's physical, chemical, and biological properties and the predator-prey relationships of marine resources. From the beginning, AZMP developed an important observational program based on seasonal and annual surveys of the basic components of marine ecosystems in Eastern Canada. One particular success of AZMP is that it fills the gap in mesozooplankton sampling in this region and provides information on the natural variability of this important ecosystem component. Variations in the zooplankton community can have important impacts on secondary production and on the transfer of energy to upper trophic levels, and consequently on the recruitment of commercially important species in the St. Lawrence Marine System (SLMS). In this paper, we provide an overview of the interannual and seasonal variability of 15 zooplankton biomass and abundance indices for the Gulf of St. Lawrence.

Materials and Methods

Zooplankton samples were collected during surveys carried out in June and November 2001–2009 along six sections (St. Lawrence Estuary, Sept-Îles, southwest Anticosti, Cabot Strait, Bonne Bay, Îles-de-la-Madeleine); sampling along a seventh section, the central Gulf, began in November 2003 (Fig. 1). The collection and standard measurements of zooplankton abundance and biomass are based on AZMP protocols (Mitchell et al. 2002).

We analyzed June and November zooplankton samplings made at each station and developed different indices that characterize the state of the zooplankton community. These indices are the depth-integrated

- 1) *Calanus hyperboreus* biomass
- 2) mesozooplankton biomass (excluding *C. hyperboreus*)
- 3) copepod nauplius abundance
- 4) copepod abundance
- 5) small copepod abundance (smaller than *Metridia* spp.)
- 6) *Pseudocalanus* spp. abundance
- 7) large copepod abundance (*Metridia* spp. + *Calanus* spp. + *Paraeuchaeta norvegica*)
- 8) *Metridia* spp. abundance
- 9) *C. finmarchicus* abundance
- 10) *C. glacialis* abundance
- 11) *C. hyperboreus* abundance
- 12) meroplankton abundance (bivalve, echinoderm, polychaete, cirripedia, and decapod larvae)
- 13) carnivorous zooplankton abundance, including only the different chaetognath species, small cnidarian species (*Aglantha digitalis* and *Dimophyes arctica*), and the small hyperiid amphipod *Themisto abyssorum*
- 14) mesozooplankton abundance (excluding copepods), and
- 15) krill larva abundance (furcilia and calyptopis).

Each index was calculated for each station and then estimated for each section (mean of 5–10 stations) and for the whole SLMS (mean of seven sections) for June and November.

Anomaly time-series of the different zooplankton indices estimated for the SLMS were constructed by subtracting annual values from the mean computed over the standard period (2001–2006) (Fig. 2). June and November anomalies were nor-

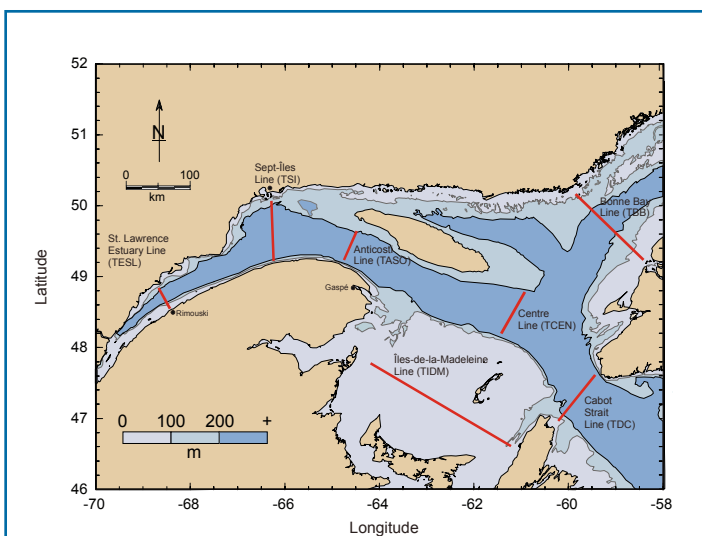


Fig. 1 Sections (red lines) sampled in June and November in the St. Lawrence Marine System.

Sections (lignes rouges) échantillonnées en juin et en novembre dans le système marin du Saint-Laurent.

malized by dividing the anomalies by the standard deviation of the data over the standard period. For example, a value of two indicates that the index was higher than the long-term average by twice the standard deviation.

Results

The interannual variations of the zooplankton indices obtained in June and November 2001–2009 are variable and complex (Figures 3 and 4). Variations were often characterized by large swings in zooplankton abundance

Index	June / juin									November / novembre								
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2001	2002	2003	2004	2005	2006	2007	2008	2009
<i>C. hyperboreus</i> biomass	-1.38	-1.19	0.77	0.45	0.68	0.67	0.55	0.22	0.27	0.56	-0.67	1.79	-0.84	-0.38	-0.45	0.14	0.78	-0.37
Mesozooplankton biomass	-0.16	-0.14	-0.02	0.03	-1.42	1.71	5.63	-2.81	-5.72	-1.44	0.75	0.81	-0.21	-0.86	0.95	0.98	-2.86	-0.72
Copepod nauplii	-1.05	0.06	0.45	1.66	-0.94	-0.17	3.35	1.25	-1.81	-1.14	0.82	1.54	-0.12	-0.61	-0.50	1.45	1.40	0.52
All copepods	-1.06	-0.70	-0.52	0.16	0.41	1.71	0.84	1.45	0.38	-1.31	1.30	0.35	0.74	-0.96	-0.11	0.15	1.32	1.66
Small copepods	-1.05	-0.71	-0.59	0.13	0.58	1.64	0.47	1.44	0.55	-1.24	1.34	0.09	0.86	-0.96	-0.08	0.10	1.57	1.93
- <i>Pseudocalanus</i> spp.	-1.16	-0.98	-0.54	0.96	0.76	0.95	0.38	1.44	0.94	-0.87	0.53	0.85	0.87	-1.57	0.19	-0.91	-0.42	2.01
Large copepods	-1.04	-0.65	-0.29	0.25	-0.09	1.83	1.85	1.10	-0.14	-1.08	0.42	1.79	-0.38	-0.52	-0.23	0.42	-1.11	-0.83
- <i>Metridia</i> spp.	-1.17	-0.04	-0.98	-0.12	1.09	1.22	1.13	0.37	-0.33	0.22	0.46	-0.95	-0.49	1.67	-0.90	-0.54	-2.06	-0.80
- <i>C. finmarchicus</i>	-0.84	-0.57	-0.32	0.31	-0.46	1.89	1.56	0.95	-0.64	-0.95	0.49	1.72	-0.30	-0.91	-0.06	0.23	-1.05	-1.12
- <i>C. glacialis</i>	-0.72	-0.57	-0.91	-0.11	1.73	0.58	4.15	2.10	2.76	0.94	-1.26	-0.57	1.31	-0.65	0.23	3.21	0.39	1.12
- <i>C. hyperboreus</i>	-1.43	-0.89	0.74	-0.08	1.18	0.48	1.47	1.01	2.25	-1.22	-0.66	1.73	-0.12	0.18	0.10	1.01	2.02	2.24
Mesozooplankton (no copepods)	-0.86	-0.66	-0.59	-0.44	1.15	1.40	2.42	-0.17	-0.14	-1.29	0.83	-0.70	-0.19	-0.10	1.45	4.14	7.62	3.25
Meroplankton	-0.49	-0.56	-0.51	-0.39	-0.05	2.01	0.14	-0.10	-0.08	-1.07	0.34	-0.40	0.22	-0.79	1.70	1.47	-0.22	-0.13
Carnivorous zooplankton	-0.80	-1.25	-0.47	0.31	1.00	1.21	0.98	1.10	0.58	-0.29	-1.50	-0.33	0.63	0.03	1.46	1.15	1.58	1.38
Krill larvae	-0.91	-0.25	-0.38	0.04	-0.44	1.94	4.27	0.97	-0.22	-0.75	-0.74	1.95	-0.24	-0.09	-0.14	0.90	2.16	-0.68

Fig. 2 Anomalies of the 15 zooplankton biomass and abundance indices obtained for the St. Lawrence Marine System in June and November 2001–2009. The anomalies are normalized with respect to their standard deviations over the 2001–2006 period. Blue, white, and red represent negative, normal, and positive zooplankton conditions, respectively.

Anomalies calculées pour les 15 indices de biomasse et d'abondance de zooplancton du système marin du Saint-Laurent, en juin et en novembre, entre 2001 et 2009. Les anomalies sont réduites en divisant par les écarts-types calculés sur la période de 2001 à 2006. Le bleu, le blanc et le rouge représentent respectivement des valeurs négatives, normales et positives de la condition du zooplancton.

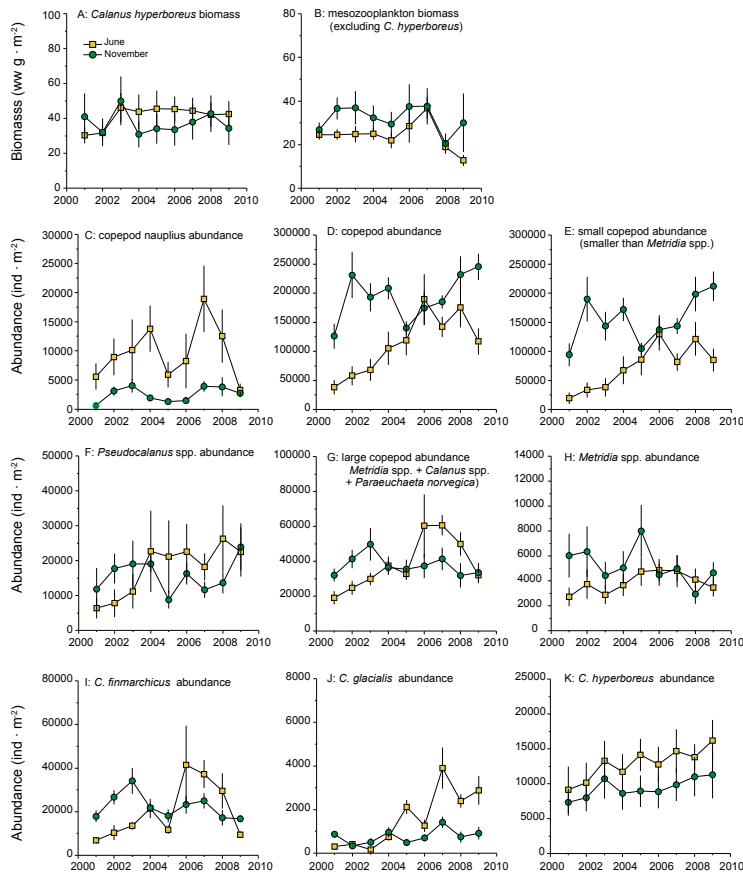


Fig. 3 Mean (\pm SD) zooplankton wet weight biomass (*C. hyperboreus*, mesozooplankton excluding *C. hyperboreus*) and abundance (copepod nauplii, copepods, small copepods, *Pseudocalanus* spp., large copepods, *Metridia* spp., *C. finmarchicus*, *C. glacialis*, *C. hyperboreus*) in the St. Lawrence Marine System in June and November 2001–2009.

Moyenne (\pm l'écart-type) de la biomasse humide de zooplancton (*C. hyperboreus* et de mésozooplancton sans *C. hyperboreus*) et de l'abondance (nauplii de copépodes, copépodes, petits copépodes, *Pseudocalanus* spp., grands copépodes, *Metridia* spp., *C. finmarchicus*, *C. glacialis*, *C. hyperboreus*) en juin et en novembre dans le système marin du Saint-Laurent entre 2001 et 2009.

between consecutive years while trends sometimes persisted for a number of years. There were no marked interannual (2001–2009) or seasonal (June, November) changes in the biomasses of *C. hyperboreus* or mesozooplankton (excluding *C. hyperboreus*) (Fig. 3A, 3B).

Copepod nauplii were typically much more abundant in June than in November for each year except 2009, although there were interannual variations (Fig. 3C). The higher June abundance is likely driven by nauplii of *C. finmarchicus*, which is the dominant large copepod in the SLMS at this time of year (Fig. 3I). The interannual variations in copepod nauplii and *C. finmarchicus* abundance are highly correlated in June only ($R^2=0.82$, $p<0.001$, excluding data from 2006).

There were twice as many copepods during November compared to June (except in 2005–2006). Overall, there is a long-term increasing trend from 2001 until 2008 in the June copepod abundance (Fig. 3D). The seasonal and interannual patterns in total copepod abundance are largely due to small copepods (including *Pseudocalanus* spp.) (total and small copepod abundances are highly correlated; $R^2=0.97$, $p<0.001$), confirming that this group largely dominated the whole copepod assemblage in abundance (Fig. 3E, 3F).

The total abundance of large copepods in June shows an increasing trend from 2001 to 2007 followed by a decrease in 2008 and 2009 (Fig. 3G). This was not the case in November, when we observed an increase from 2001 to 2003 and a slight decrease in 2004 followed by no change until 2009. Prior to 2004, large copepods were more numerous in November than in June, while the reverse

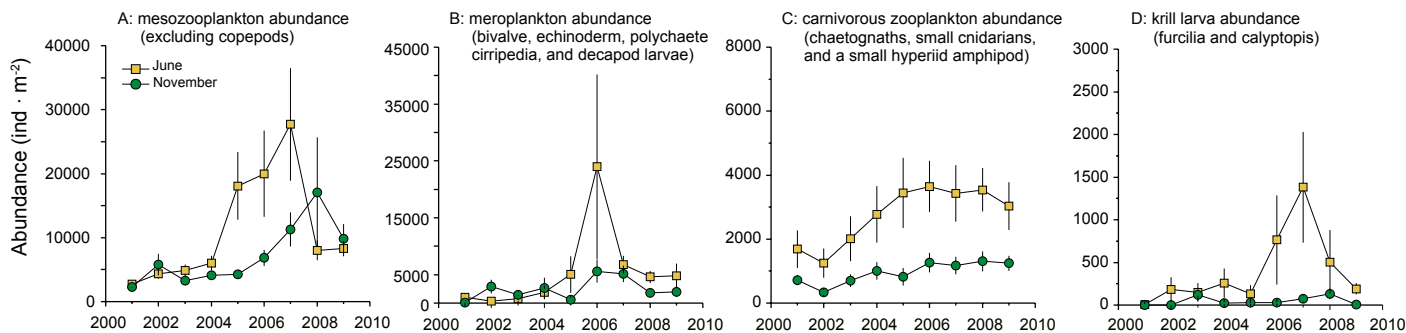


Fig. 4 Mean (\pm SD) abundance of mesozooplankton, meroplankton, carnivorous zooplankton, and krill larvae in the St. Lawrence Marine System in June and November 2001–2009.

Abondance moyenne (\pm l'écart-type) de mésoplancton, de méroplancton, de zooplancton carnivore et des larves de «krill» en juin et en novembre dans le système marin du Saint-Laurent entre 2001 et 2009.

was observed after 2003. The increasing June and decreasing November trends in large copepod abundance are also apparent in the interannual abundance variations for both *Metridia* spp. in June ($R^2=0.60$, $p=0.014$) and *C. finmarchicus* in June and November (respectively $R^2=0.95$, $p<0.001$ and $R^2=0.96$, $p<0.001$) (Fig. 3H, 3I). However, this pattern is not evident in the interannual variations of the two large arctic species *C. glacialis* and *C. hyperboreus*, which showed gradual increases in abundance from 2001 to 2009 (*C. glacialis*, June: $R^2=0.71$, $p=0.005$, November: $R^2=0.49$, $p=0.133$, excluding 2001; *C. hyperboreus*, June: $R^2=0.78$, $p=0.00$, November: $R^2=0.59$, $p=0.01$) (Fig. 3J, 3K).

Since *C. hyperboreus* biomass is relatively invariant over time (Fig. 3A), does the increase in abundance of this species (Fig. 3K) imply a gradual decrease in body size for individual animals, especially in June? According to interannual June variations in the proportions of two categories of *C. hyperboreus* individuals (adult female CVI and juvenile CIV), there was a significant decrease (from 10% to 5%) in the proportion of adult female CVI between 2001 and 2009 ($R^2=0.68$, $p=0.008$; Fig. 5A) and a significant increase (from 50% to 70%) in the proportion of the smaller CIV ($R^2=0.59$, $p=0.016$; Fig. 5B). Considering that both the wet and dry weights of female CVI individuals are between five and nine times higher than those of CIV (unpublished data), the small decrease in the abun-

dance of female CVI vs. the large increase in abundance of CIV explains the relatively stable *C. hyperboreus* biomass over time that we see in Figure 3A. This could be a consequence of changes in food availability (e.g., amount, timing, palatability).

For the last four indices—mesozooplankton other than copepods, meroplankton, carnivorous zooplankton, and krill larvae—their total abundances were usually higher in June than in November (Fig. 4A–D); this is the opposite of what was observed for the mesozooplankton biomass (excluding *C. hyperboreus*) and the total abundance of copepods, which were usually higher in November than in June. Mesozooplankton abundance (excluding copepods) displays an increasing trend from 2001 until June 2009; the high values in June 2005–2007 are due to high numbers of the appendicularia *Fritillaria borealis* (Fig. 4A). There are no notable tendencies in meroplankton abundance, but there was a record peak in echinoderm larvae in June 2006 (Fig. 4B). For carnivorous zooplankton, there was a gradual increase in abundance in both June and November 2001–2005 after which numbers became stable (June: $R^2=0.67$, $p=0.007$, November: $R^2=0.73$, $p=0.003$) (Fig. 4C). This increase in carnivorous zooplankton abundance, particularly in June, is highly correlated with the strong increase in numbers of small copepods (2001–2009; $R^2=0.84$, $p<0.001$; Fig. 6), which probably represent their main prey. Finally, there was a long-term increasing trend in krill larva abundance between June 2001 and 2007 followed by decreases in 2008 and 2009 (Fig. 4D), resembling the interannual change in mesozooplankton abundance. These two indices are significantly correlated ($R^2=0.69$, $p=0.006$), suggesting that both were influenced by the same physical and/or biological factors.

In conclusion, Atlantic Zone Monitoring Program zooplankton data obtained in June and November 2001–2009 in the SLMS display significant variations in species composition and abundance. These changes may be related to the recent shift in the spring phytoplankton community (Dufour et al. 2010) and/or to physical factors during the summer and fall. The seasonal and interannual changes in the zooplankton community may have major impacts on secondary production and energy transfer to higher

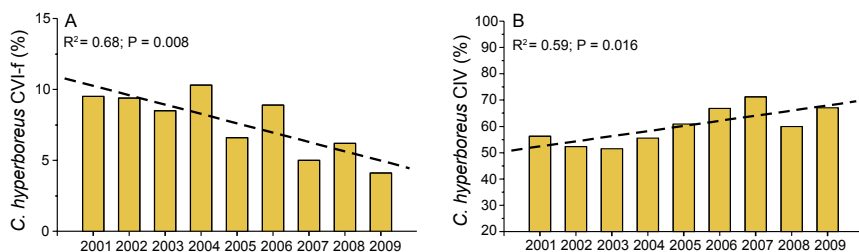


Fig. 5 Significant Pearson's correlations between the mean proportion (%) in abundance of *Calanus hyperboreus* adult female CVI (A) and juvenile CIV (B) and the sampling year for June 2001–2009 in the St. Lawrence Marine System.

Corrélations de Pearson significatives entre la proportion (%) moyenne en abondance de *Calanus hyperboreus* femelle adulte CVI (A) et juvénile CIV (B) et l'année d'échantillonnage pour juin et novembre dans le système marin du Saint-Laurent entre 2001 et 2009.

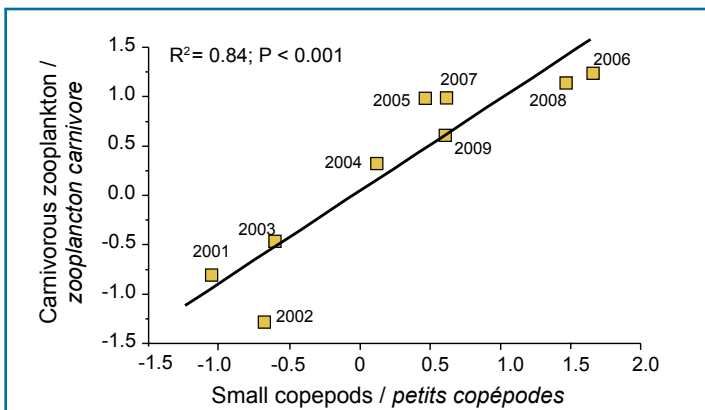


Fig. 6 Significant Pearson's correlation between the mean abundance anomalies of carnivorous zooplankton (different chaetognath species, small cnidarian species [*Aglantha digital* and *Dimophyes arctica*], and the small hyperiid amphipod *Themisto abyssorum*) and small copepods (smaller than *Metridia* spp.) estimated for June 2001–2009 in the St. Lawrence Marine System.

*Corrélations de Pearson significatives entre les anomalies de l'abondance moyenne de zooplancton carnivore (diverses espèces de chaetognathes, petites espèces de cnidaires [*Aglantha digital* et *Dimophyes arctica*], et le petit amphipode hyperide *Themisto abyssorum*) et les petits copépodes (plus petits que *Metridia* sp.) calculées pour juin dans le système marin du Saint-Laurent entre 2001 et 2009.*

levels of the food web, and consequently on the recruitment of commercially exploited species in the SLMS. By continuing its integrated sampling of the basic physical, chemical, and biological properties of the ecosystems, the AZMP provides the essential information at appropriate temporal and spatial scales to further

investigate these relationships and contribute to our increasing understanding of the natural variability of this ecosystem.

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