Monitoring the State of the ST. LAWRENCE RIVER

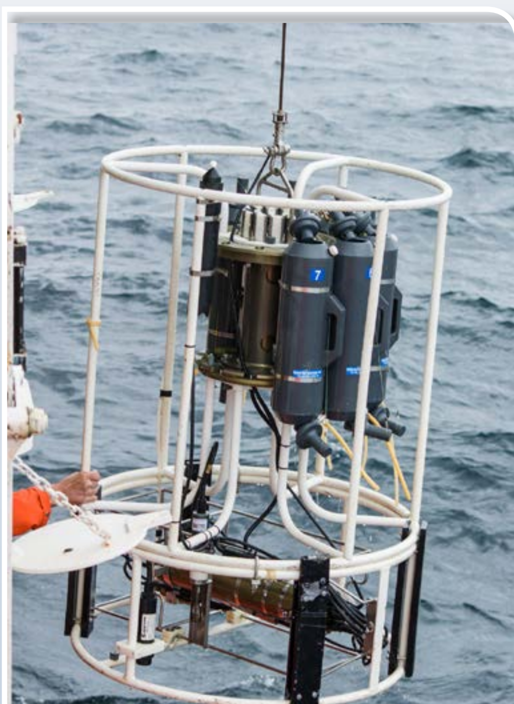
Oceanographic Processes in the Estuary and Gulf

3rd Edition

CCGS *Teleost*
photo: DFO, C. Nozères

Background

Human activities such as fishing, the introduction of non-indigenous species, and habitat alterations can cause significant changes in ecosystem functioning, while climate change and variability (e.g. warming waters, increased stratification, acidification) are also potential sources of disruption for the marine environment. In 1999, in order to better understand and monitor trends in oceanographic variables and support sustainable management of activities and resources, Fisheries and Oceans Canada (DFO) implemented the Atlantic Zone Monitoring Program (AZMP). Its purpose is to regularly collect data on biological (e.g. chlorophyll, zooplankton), chemical (e.g. dissolved oxygen, nutrients, pH) and physical variables (e.g. temperature, salinity, ice cover, freshwater runoff) in the maritime regions of eastern Canada. The goal is to build the necessary databases to describe, understand and eventually predict the seasonal, interannual and decennial phenomena that govern these ecosystems.



Water sampling rosette on CCGS *Teleost*
photo: DFO. C. Nozères

For the Quebec region, the area covered by the AZMP includes the Lower Estuary and the Gulf of St. Lawrence (Figure 1). The AZMP dealt with the challenge of accessing certain regions in terms of both time (e.g. ice in the winter) and space (e.g. seldom travelled regions north and northeast of the Gulf) by developing new sampling techniques. For example, helicopter surveys that cover the entire Lower Estuary and the Gulf have been conducted in March every year since 1996. Satellite remote sensing

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measurements also make it easier to collect data (e.g. sea surface temperature, phytoplankton biomass) in all regions. In addition, the AZMP uses related data, such as weather data, freshwater runoff data and water level data.

The weekly sampling activities performed since 1992 at the permanent station located off the coast of Rimouski are the primary source of data for monitoring the biological status of the Lower Estuary. Analyses have shown that the data collected at that station are generally representative of the conditions in the Gulf of St. Lawrence's northwestern regions.

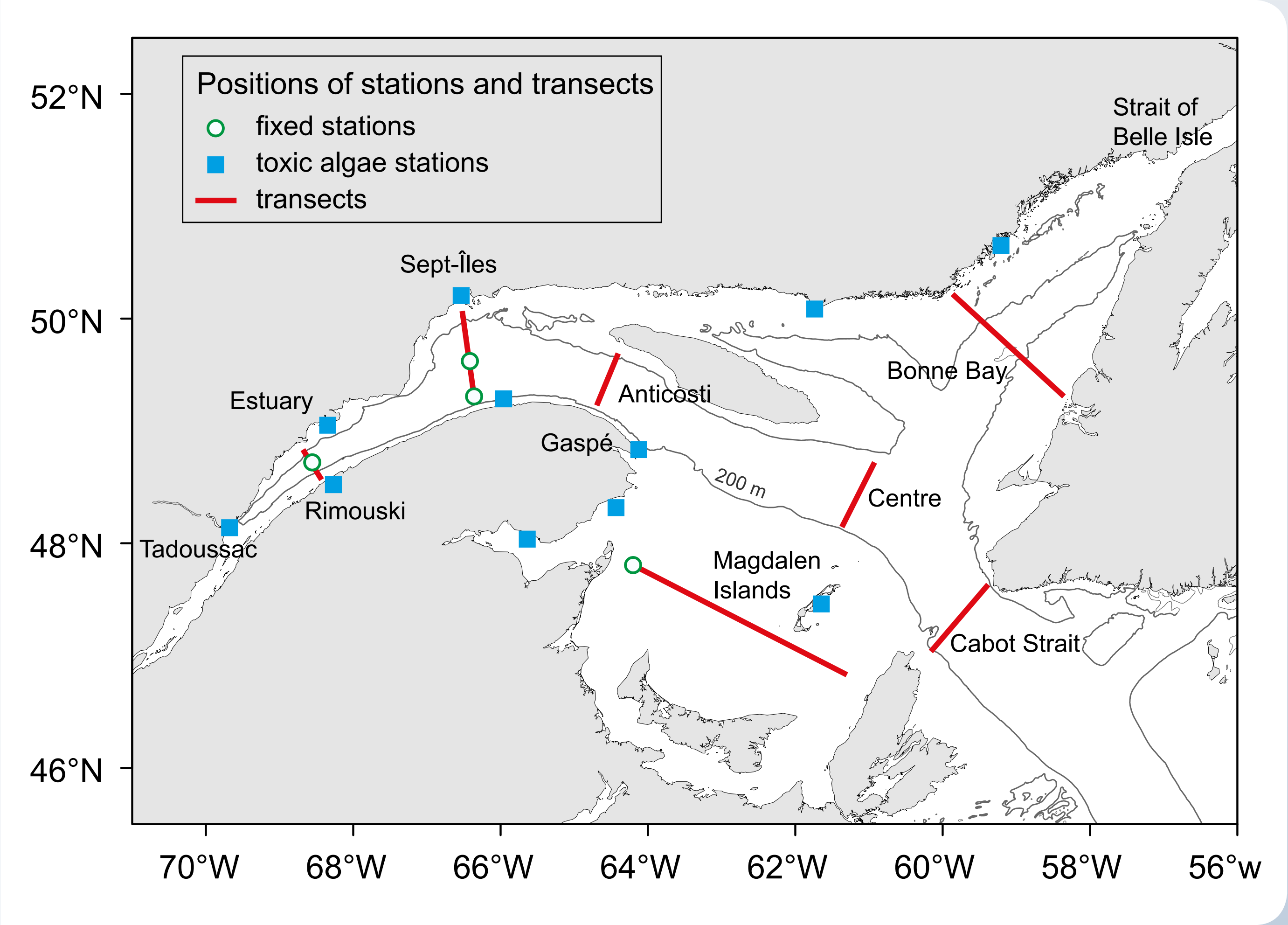
The AZMP acquires its data through sampling at stations located along transects twice a year, in June and November, and regular sampling every two weeks from April to November at fixed stations located in the most accessible regions. The program is also complemented by a network of coastal stations, where seasonal sampling is conducted to monitor the abundance of toxic algae in the Lower Estuary and the Gulf of St. Lawrence.

Overview of the situation

Changes in physical and chemical conditions

The Lower Estuary and the Gulf of St. Lawrence show significant vertical stratification based on temperature and salinity following a seasonal cycle. Freshwater runoff in the Estuary strongly influences the stratification and intensity of estuarine circulation. Since 1974, mean annual freshwater runoff has declined by 10%. While annual runoff fluctuated around the climatological mean during the last five years, the spring freshet occurred early in the season during the

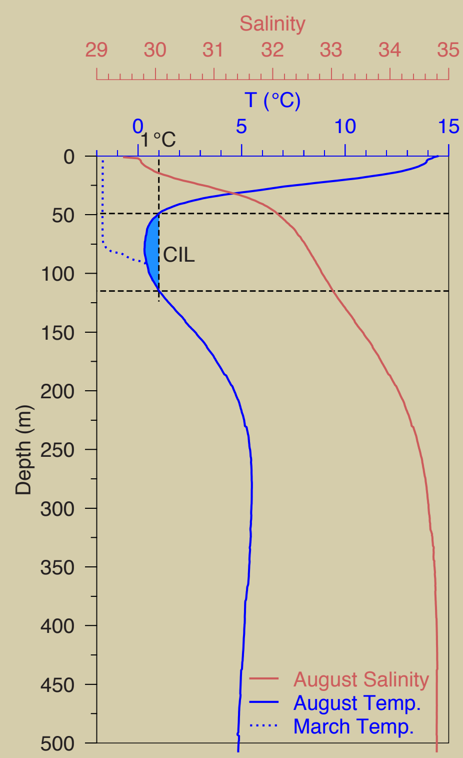
Figure 1 Position of AZMP transects and fixed stations and location of toxic algae sampling stations in the Estuary and Gulf of St. Lawrence



mild winters of 2010 and 2012, specifically in March rather than in April (Figure 2). However, the highest spring freshet since 1976 occurred in 2011 and late in the season, in May.

The summertime water column consists of three distinct layers: the surface layer, the cold intermediate layer (CIL) and the deeper water layer (Box 1). Surface temperatures reach maximum values between mid-July and mid-August with a climatological mean (1985–2010) that ranges from about 7°C at the head of the Lower Estuary (Tadoussac region - Figure 1) to over 17°C on the Magdalen Shallows. An analysis of historical data shows that summer surface waters are getting warmer as a result of rising air temperatures; it had risen at a rate of 0.9°C every 100 years since 1873, but has been rising at a faster rate in the last 20 years (Figure 3).

In the fall, surface cooling and wind-driven mixing lead to a progressively deeper and cooler mixed layer. As a result, the surface layer of the Gulf extends to an average depth of 75 m by the end of



Box 1

Vertical temperature and salinity profiles usually observed in summer in the Gulf of St. Lawrence (here in August 2007). The cold intermediate layer (CIL) is generally defined as the layer of water below 1°C. The dotted line on the left shows a typical winter temperature profile, with temperatures near the freezing point for the layer of water from 0 to 75 m in depth.

Figure 2 Mean monthly flow of the St. Lawrence measured in Québec City (in black). The blue represents the 1981–2010 monthly climatologies plus and minus one-half standard deviation of the monthly variability.

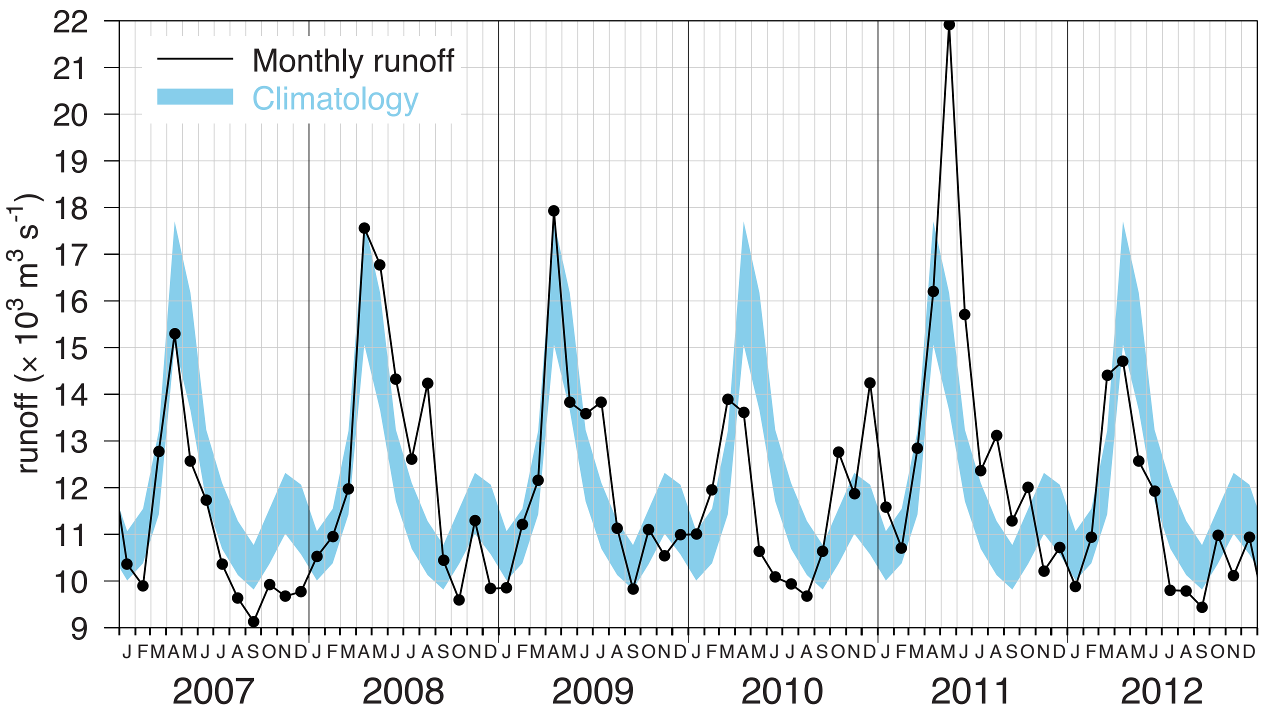
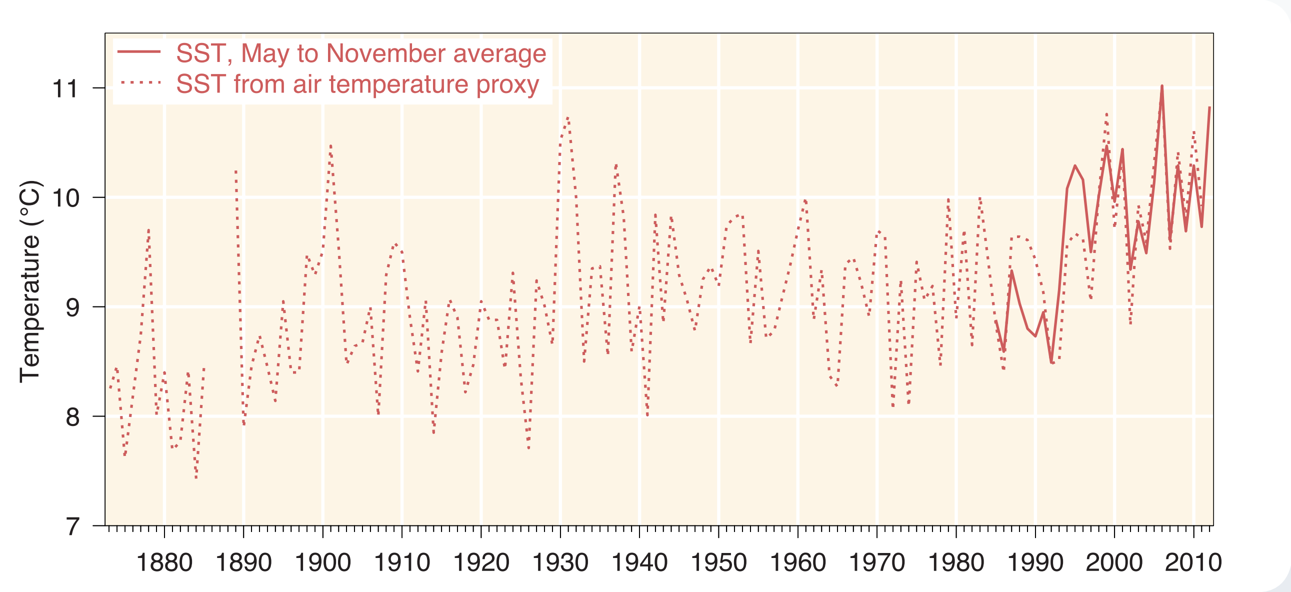


Figure 3 Mean sea surface temperature (SST) in the Gulf of St. Lawrence from May to November (1985–2012: full line) and estimate of historical temperatures based on air temperature since 1873 (dotted line).



March when temperatures drop to near freezing (-1.8 to 0ºC). The maximum extent and volume of sea ice reached in winter, as well as the duration of the ice season, have been declining in the Gulf since 1990. Since 1969, three winters have seen a near complete absence of ice (1969, 2010 and 2011), the only winters with air temperatures 2–3°C higher than normal. This may be a taste of conditions we will be seeing 50 years from now, based on climate change scenarios.

During spring, surface warming, sea-ice melt waters and continental runoff produce a lower-salinity and higher-temperature surface layer, below which cold waters are partly isolated from the atmosphere and form the summer CIL. This layer makes up a large proportion of the Gulf's summer waters and influences physical, chemical and biological processes. The mean summer temperature in the CIL has experienced large interannual variations, with a long period of intense cold between 1986 and 1998 (Figure 4). Since

Figure 4 Minimum temperature in the summer in the cold intermediate layer (mean across the Gulf of St. Lawrence) on July 15 of each year.

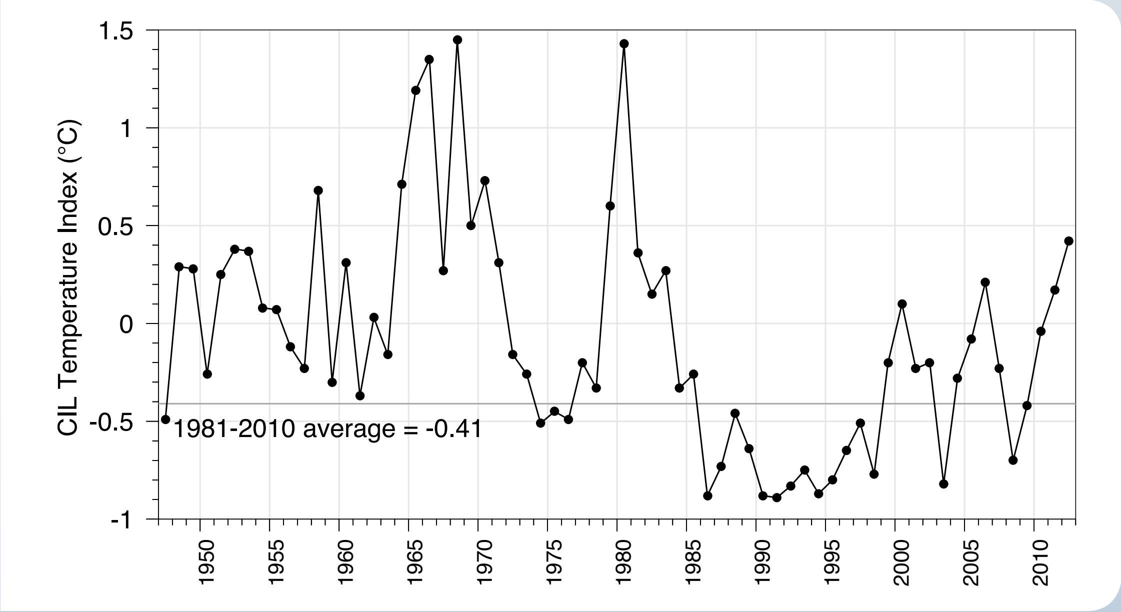
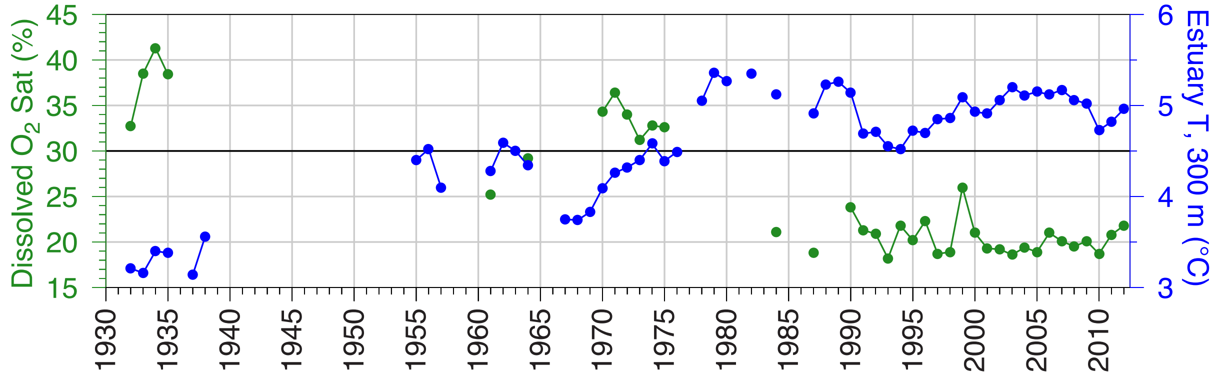


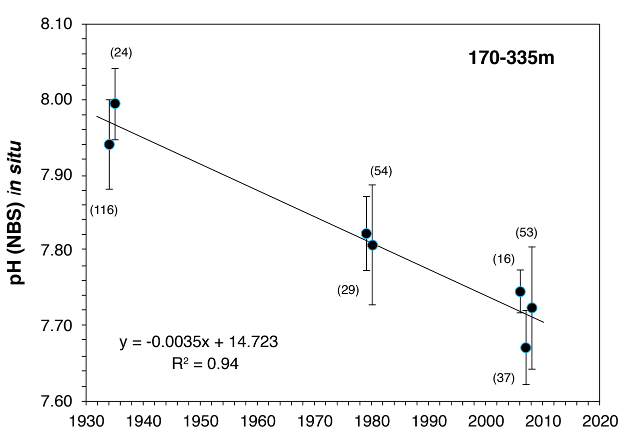
Figure 5 Temperature (blue) and dissolved oxygen concentrations (green) at a depth of 300 m in the St. Lawrence Lower Estuary.



then, temperatures have risen, but the mean in 2003 was as low as those observed during the cold period; 2003 was also the year with the highest volume of ice observed in the Gulf since 1969. In summer 2012, the mean temperature in the CIL was the highest since 1980.

The deep water layer of the Lower Estuary, located below the CIL (>150 m), begins at the continental shelf. Waters entering the Cabot Strait move upstream, mixing little with shallower waters. These waters take approximately three to four years to reach the head of the Lower Estuary. Along the way, dissolved oxygen concentrations decrease because of the respiration of organisms in the water column and on the bottom. The lowest dissolved oxygen concentrations are found in the deep waters of the Lower Estuary, which were briefly hypoxic in the early 1960s and have consistently been hypoxic at approximately 19 to 22% saturation since 1984 (Figure 5).

Figure 6 pH trends in the deep waters (> 170 m) of the St. Lawrence Lower Estuary from 1934 to 2010*.

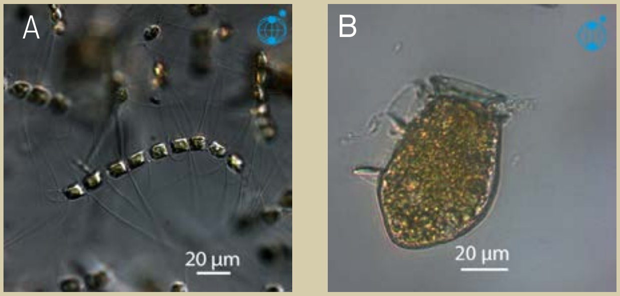


* The dots represent the annual mean of historical measurements taken between May and September with confidence intervals at 95%. Numbers in parentheses correspond to the number of measurements taken in a given year.

In addition to the oxygen decrease, pH in deep waters (>170 m) decreased by 0.2 to 0.3 units between 1934 and 2010 (Figure 6) — about a 100% increase in acidity. This acidification results in a decrease in calcium carbonate, which is vital in building the shells and skeletons of several organisms, including molluscs, crustaceans and coral. The uptake of anthropogenic CO_2 from the atmosphere, the origin of water masses, and organic matter decomposition in deep waters are responsible for the acidification of the St. Lawrence.

Changes in biological conditions (phytoplankton and zooplankton)

The phytoplankton in the Lower Estuary is a diverse community dominated by different taxonomic groups, depending on the season. Monitoring the abundance of phytoplankton groups at the Rimouski station gives us an overview of recent trends in the community. The diatom/dinoflagellate or diatom/flagellate ratios are good indicators of environmental change, as these groups respond distinctly to the environment, particularly to nutrient input and water column stratification. Therefore, warming



Example of the diversity of phytoplankton communities in the St. Lawrence. A) the diatom *Chaetoceros socialis*, B) the dinoflagellate *Dinophysis acuta*. Photo: Plankton Net

waters, increased runoff and eutrophication tend to favour dinoflagellates and flagellates. In the Lower Estuary, we have seen changes in the diatom/dinoflagellate and diatom/flagellate ratios since 1997, with a tipping point around 2003 (Figure 7), associated with a recent increase in dinoflagellates and flagellates.

Phytoplankton production in the Gulf follows an annual cycle characteristic of temperate regions with two typical blooms, a significant one in the spring and a second, less significant one in the fall. An analysis of sea surface colour images captured by the MODIS (*Moderate Resolution Imaging Spectroradiometer*, NASA) satellite, converted into an indicator of phytoplankton biomass, provides an overall picture of primary productivity in the ecosystem. For Gulf of St. Lawrence regions, excluding the Lower Estuary, data since 2003 show very strong negative anomalies (much earlier than usual) for all regions for the beginning and peak of the phytoplankton bloom in 2010 and 2012, two warm years when the ice disappeared early (Figure 8).

The mesozooplankton in the Lower Estuary and Gulf of St. Lawrence is dominated by species of calanoid copepods. Significant variations in zooplankton composition have been observed across the Gulf since 1999. While the abundance of small calanoids saw negative anomalies from 1999 to 2005, these species were generally more abundant

Figure 7 Diatom/flagellate and diatom/dinoflagellate ratios, mean from May to August, at the Rimouski station, Lower Estuary.

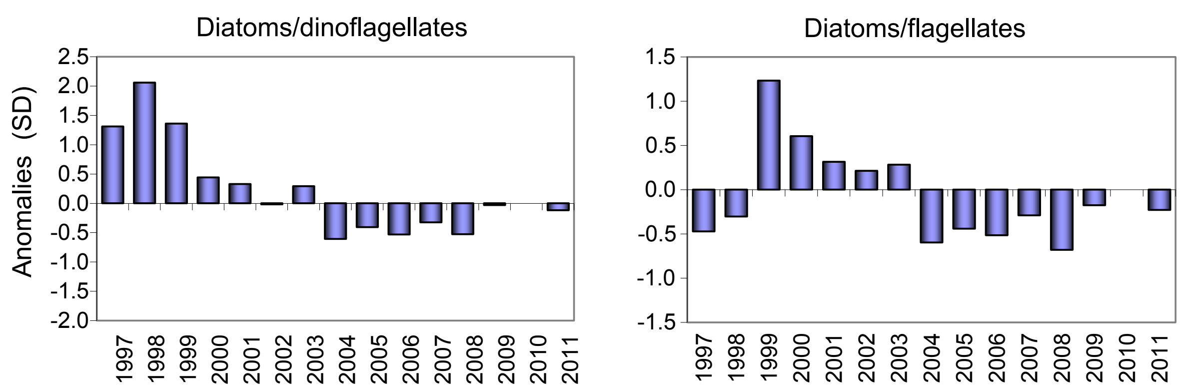
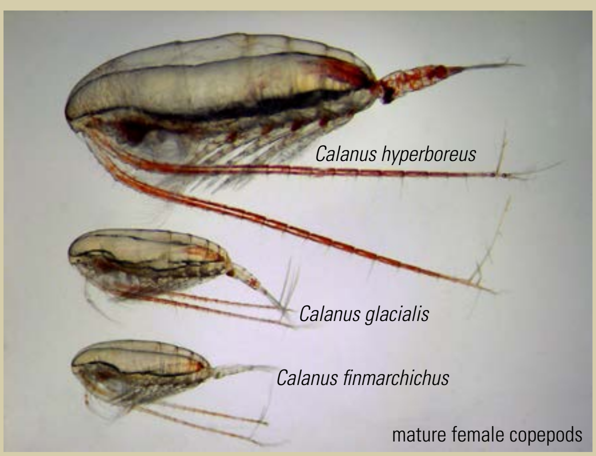


Figure 8 Anomaly from the time of phytoplankton bloom in four distinct regions of the Gulf of St. Lawrence. Blue was used to show progressively earlier blooms (light to dark), while red was used to show an opposite effect.

Indicator	Region	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Beginning of spring phytoplankton bloom	Northwest Gulf	0.76	0.76	0.00	0.00	0.00	0.76	0.00	-2.29	0.00	-0.76
	Shediac Valley	0.70	0.70	-0.90	0.70	-0.90	0.70	0.70	-1.70	-0.90	-0.90
	Magdalen Islands	0.20	-1.37	-0.59	0.98	0.20	0.98	0.98	-1.37	0.20	-0.59
	Northeast Gulf	1.58	0.00	0.00	-1.58	0.00	0.00	-1.58	-3.16	0.00	-1.58
	Cabot Strait	0.98	0.20	0.20	-0.59	0.20	0.98	0.20	-2.15	-3.71	-1.37
Peak phytoplankton abundance	Northwest Gulf	1.21	1.21	-0.72	-0.72	0.24	0.24	0.24	-1.69	0.24	-0.72
	Shediac Valley	0.78	-0.11	-1.89	-0.11	0.78	0.78	0.78	-1.00	-0.11	-1.89
	Magdalen Islands	0.47	0.47	-2.34	0.47	0.47	0.47	0.47	-0.47	1.40	-0.47
	Northeast Gulf	2.31	-0.10	-0.10	-0.10	-0.10	-0.10	-0.90	-0.90	0.70	-0.10
	Cabot Strait	0.28	0.28	0.28	-0.85	0.28	1.41	0.28	-1.97	0.28	-1.97

Figure 9. Annual standardized anomalies in the abundance of small and large calanoids (mesozooplankton) at the fixed stations and transects of the AZMP from 1999 to 2012. Red was used to show positive anomalies (and higher abundances) and blue was used to show negative anomalies (and lower abundances) relative to the mean.

	Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Small calanoids	Gaspé Current	-0.91	-0.91	-0.84	-0.85	-0.84	0.16	0.38	-0.16	-0.13	0.43	1.59	2.07	4.80	8.45
	Anticosti Gyre	-0.67	-0.68	-0.96	-0.93	-0.84	-0.45	-0.45	0.33	0.11	1.93	1.21	1.38	2.21	-0.54
	Shediac	-0.76	-0.66	-0.75	-0.94	-0.80	-0.25	-0.03	-0.09	0.10	2.54	0.76	0.89	0.93	-0.16
	Estuary		-0.56	-1.28	-1.34	-0.97	0.42	-0.57	1.14	0.97	-0.06	1.04	1.21	1.00	0.36
	Sept-Iles		-0.78	-1.08	-0.97	-1.10	-0.51	-0.50	1.03	0.34	1.22	0.96	1.40	0.65	-0.49
	Anticosti		-0.67	-1.22	-0.95	-1.06	-0.23	-0.65	1.39	0.92	1.51	0.36	0.62	1.11	-0.33
	Magdalen Islands		-1.16	-1.42	-0.47	0.19	-0.59	-0.51	1.07	-0.61	0.88	1.22	1.40	1.84	0.68
	Bonne Bay		-1.22	-1.40	-1.14	-0.56	1.31	0.05	0.09	-0.08	1.09	1.29	0.59	1.95	0.68
	Centre					1.58	-1.05	-1.23	-0.02	-0.42	-0.25	0.11	1.28	4.30	0.97
	Cabot Strait		-0.68	-2.11	-0.55	0.36	0.36	0.68	0.48	-0.87	0.72	0.00	1.60	1.75	-0.40
Large calanoids	Gaspé Current	-0.49	0.07	-0.46	-0.92	2.58	0.82	0.37	0.43	-0.14	-0.27	-1.10	-0.89	-1.47	5.46
	Anticosti Gyre	-0.29	-0.49	-1.33	-0.11	1.95	-0.08	-0.98	0.09	0.91	0.32	1.27	-1.25	-1.03	0.21
	Shediac	-0.92	-0.77	1.12	-1.53	1.78	1.37	0.31	0.21	-0.28	-0.63	-0.55	-0.11	-1.81	0.59
	Estuary		0.26	-0.70	-0.02	-0.03	0.02	0.90	-0.21	2.28	0.09	-1.15	-1.44	-1.12	-0.73
	Sept-Iles		-0.31	0.15	-0.88	1.38	-0.34	-0.84	1.76	1.26	-0.62	-1.04	-0.51	-0.49	0.18
	Anticosti		-0.39	-0.47	-0.61	-0.18	-0.57	-0.21	2.64	1.14	-0.36	-0.50	-0.47	-0.81	0.11
	Magdalen Islands		-1.61	0.14	0.61	0.63	0.05	-1.00	0.91	0.62	1.52	-0.49	-1.37	-1.36	1.53
	Bonne Bay		-0.92	-0.56	-0.11	-0.40	1.61	-0.23	-1.65	0.96	1.54	-0.04	-0.19	-0.49	1.12
	Centre					2.08	-0.40	-0.56	-0.51	0.55	-0.02	0.12	-1.26	-1.21	0.16
	Cabot Strait		1.64	-0.98	0.48	0.15	0.83	-1.05	0.35	0.79	-0.22	-0.13	-1.86	-0.84	0.07



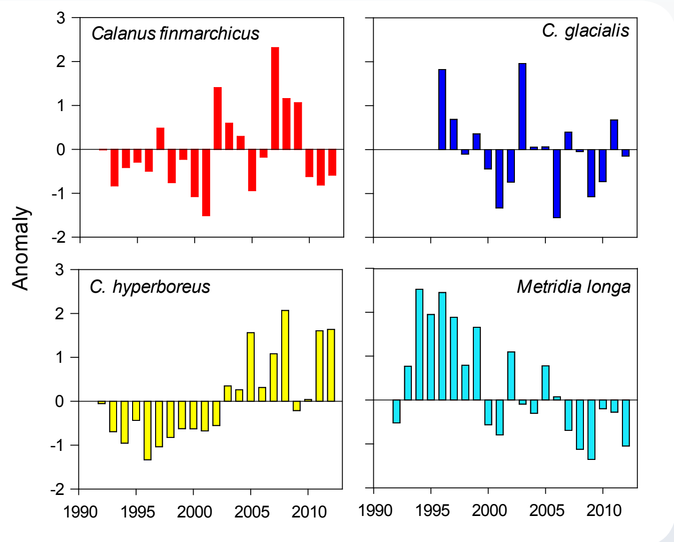
Several species of *Calanus* copepods make up most of the mesozooplankton biomass in the Estuary and Gulf of St. Lawrence. These species differ in their life cycle and adult size. As a result, fluctuations in the relative abundance of all species may affect the ecosystem's productivity and its very functioning.

Photo: Ida Beathe Øverjordet and Dag Altin, 2012, *Journal of Plankton Research*, 34(3). Reprinted with permissions.

than normal (positive anomalies) from 2008 to 2011 (Figure 9). As for the large calanoids, their numbers were generally lower than normal from 2008 to 2011. The opposite variations of these major classes of zooplankton probably reflect their different environmental preferences.

The monitoring done at the Rimouski station since 1992 has made it possible to describe zooplankton composition during the cold period mentioned earlier. *Calanus finmarchicus* and *C. hyperboreus*, two species abundant in Northwest Atlantic waters, generally saw negative abundance anomalies from 1992 to 2002 (Figure 10). That cold period was followed by a warmer period from 2003 to 2012, during which the abundance of *C. finmarchicus* fluctuated between positive and negative values, while that of *C. hyperboreus* was generally above normal. Two species typical of the continental shelves under the influence of Arctic waters, *C. glacialis* and *Metridia longa*, showed a different interannual pattern of abundance with highly positive anomalies from 1993 to 1999 (Figure 10), years with generally colder temperatures in the Lower Estuary. As the years that followed were generally warmer, these

Figure 10 Annual standardized anomalies in the abundance of the calanoid copepods *Calanus finmarchicus*, *C. hyperboreus*, *C. glacialis* and *Metridia longa* at the Rimouski station from 1992 to 2012.

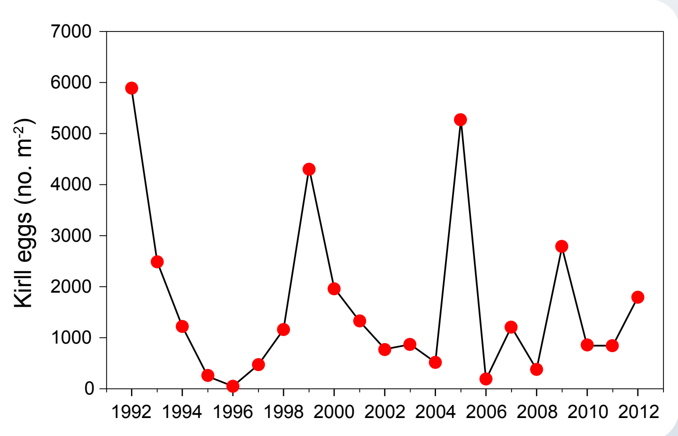


Arctic species on average have shown below-normal abundances since 2000. Note the strong positive anomaly in the abundance of *C. glacialis* in 2003, a year characterized by very low temperatures in the region.

Changes in zooplankton seasonality have been observed at the Rimouski station since 1992. Reproduction monitoring for the indicator species *C. finmarchicus* has revealed a significant reduction in female body size (prosome length) from 1993 to 2009, correlating with a 25% decrease in the number of eggs produced per spawning event. This decrease in female fecundity was accompanied by a change in the seasonality of *C. finmarchicus* population dynamics. While the main recruitment period was observed between mid-July and early August from 1993 to 2003, the peak abundance of young stages was observed between mid-June and early July from 2003 to 2012, indicating earlier recruitment in the region. Moreover, we have been seeing an increase in the importance of secondary recruitment, a second generation, later in the season (September) at the Rimouski station since 2003.

Krill, which consists of several species of euphausiids, is both an important component of the large zooplankton and an important prey of several species of fish and marine mammals that feed in the Lower Estuary. It is practically impossible to make a reliable assessment of krill abundance using conventional plankton nets. However, a relative index of interannual variations in abundance based on the abundance of krill eggs at the Rimouski station between May and October was developed. This index shows strong interannual variations with maximums observed every 3 or 5 years (Figure 11). These variations in population abundance are likely caused by fluctuations in recruitment success in response to environmental conditions.

Figure 11 Annual (May to October) abundance index of krill eggs at the Rimouski station, Lower Estuary, from 1992 to 2012.

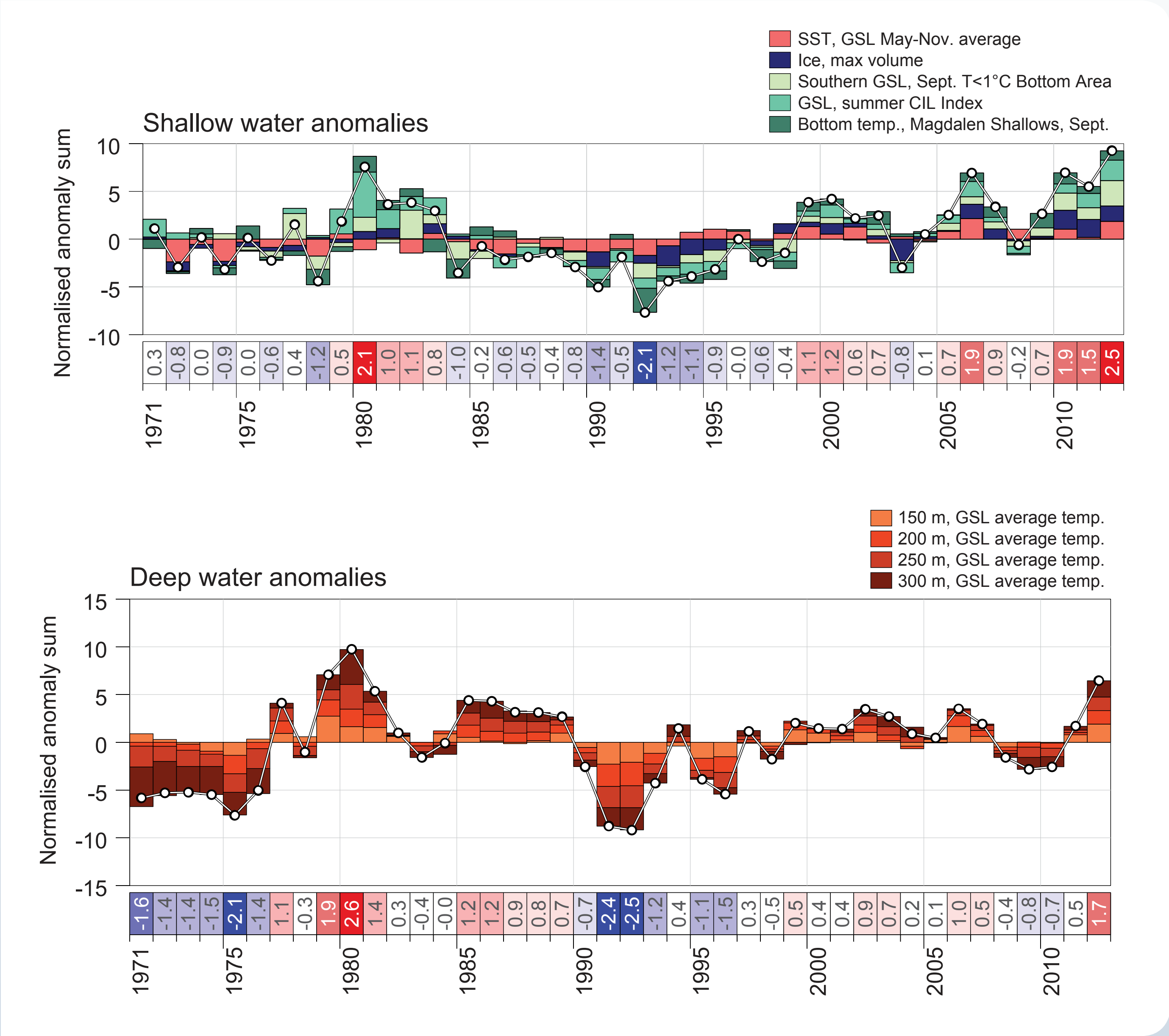


Outlook

The incorporation of several temperature indicators for the shallow and deep waters of the Estuary and Gulf of St. Lawrence shows a recent upward trend. Particularly warm conditions near the surface in 2010 and a record in 2012, and above-normal temperatures in deeper waters for the same year were observed (Figure 12).

Changes have been observed in the phytoplankton (e.g. increase in flagellates and dinoflagellates) and zooplankton communities (e.g. increase in abundance of small calanoid species, change in seasonality). They indicate that biological conditions respond to environmental variation. These changes in plankton production can affect productivity and recruitment processes of higher trophic levels, including commercial species. Therefore, these variations

Figure 12 Combination of different indicators of physical conditions for the Lower Estuary and the Gulf of St. Lawrence (GSL).



in production dynamics are among the direct impacts of conditions such as hypoxia and acidification on organisms.

The mild winters of 2010 and 2012 resulted in lower and early-season freshwater runoff. Very low concentrations of sea ice observed in relation to high air temperatures contributed to a much earlier than normal spring bloom in the Gulf of St. Lawrence in 2010 and 2012.

The unusual conditions recently observed in the Estuary and Gulf of St. Lawrence might become the new norm, based on projections from global climate change scenarios for the next 50 years. The Monitoring the State of the St. Lawrence River Program remains an essential tool to monitor ecosystem response and prepare for expected changes.

Key Measures

The Atlantic Zone Monitoring Program delivers multidisciplinary monitoring of oceanographic conditions in the Lower Estuary and Gulf of St. Lawrence. The annual status assessment is based on the review of several physical and biological parameters and variables. Sea ice conditions, sea surface temperature, and mean water layer temperature are indicators of conditions for biological community development. Hypoxic conditions and water pH are indicators of environmental stressors that could affect community productivity.

The timing and intensity of the spring phytoplankton bloom are critical to the production of zooplankton in these ecosystems. Phenology and the relative abundance of zooplankton species respond to physical conditions and are indicators of potential conditions for the success of higher trophic levels.

To learn more

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http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html
http://slgo.ca/

Oceanographic buoys equipped with communication systems to send and transmit data in real time. Photo: DFO

photo: DFO, D. Chamard

State of the St. Lawrence Monitoring Program

Four government partners – Environment Canada, Fisheries and Oceans Canada, Parks Canada, and the Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques du Québec – and Stratégies Saint-Laurent, a nongovernmental organization that works actively with riverside communities, are pooling their expertise and efforts to provide Canadians with information on the state of the St. Lawrence and its long-term evolution.

To this end, environmental indicators have been developed on the basis of data collected as part of each organization's ongoing environmental monitoring activities. These activities cover the main components of the environment, namely water, sediments, biological resources, uses and shorelines.

For more information on the State of the St. Lawrence Monitoring Program, please visit our Web site at:
http://www.planstlaurent.qc.ca/.

Written by: Peter Galbraith
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Michel Starr

Fisheries and Oceans Canada
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Aussi disponible en français sous le titre :
Les processus océanographiques dans l'estuaire et le golfe