Marine Biological Hotspots: Ecosystem Services and Susceptibility to Climate Change

Project Leader
Jean-Eric Tremblay (Université Laval), Philippe Archambault, Michel Gosselin (Université du Québec à Rimouski)

Network Investigators
Yves Gratton (Institut national de la recherche scientifique - Eau, Terre et Environnement); Simon Bélanger (Université du Québec à Rimouski); Pierre Larouche, Christian Nozais, Michel Poulin, Yvan Simard, (Université du Québec à Rimouski); Connie Lovejoy (Université Laval); Kim Juniper (University of Victoria)

Collaborators and Research Associates
Derek Mueller (Carleton University); Nicolas Cassar (Duke University); Leah Braithwaite (Environment Canada - Canadian Ice Service); Peter Galbraith, Michel Starr (Fisheries and Oceans Canada - Maurice Lamontagne Institute); Daniel Bourgault (Institut des sciences de la mer de Rimouski); Frédéric Olivier (National Museum of Natural History of France); Steve Blasco (Natural Resources Canada - Geological Survey of Canada (Atlantic)); Maurice Levasseur, Karen Scarcella (Québec-Océan); Kevin Arrigo (Stanford University); Cindy Grant, Mike Hammill, CJ (Christopher John) Mundy (Université du Québec à Rimouski); Jacques Gagné, Pierre Galand, Warwick Vincent (Université Laval); Andrew Hamilton, Bernard Laval (University of British Columbia); David G. Barber, Steven Ferguson, Gary A. Stern (University of Manitoba); John Hughes Clarke (University of New Brunswick); Simon T. Belt, Guillaume Massé (University of Plymouth); Jody Deming (University of Washington)

Post-Doctoral Fellows
Hongyan Xi, Post-Doctoral Fellow (Fisheries and Oceans Canada - Maurice Lamontagne Institute); Adéline Piot, Post-Doctoral Fellow (Université du Québec à Rimouski); Delphine Benoit, André Comeau, Pierre Coupel, Amandine Lapoussière, Adam Monier, Chiaki Motegi, Ramon Terrado (Université Laval)

PhD Students
Sélima Ben Mustapha (Fisheries and Oceans Canada - Maurice Lamontagne Institute); Heike Link, Virginie Roy (Institut des sciences de la mer de Rimouski); Caroline Sévigny (Institut national de la recherche scientifique - Eau, Terre et Environnement); Blandine Gaillard, Christian Marchese, Armelle Simo, Nassim Taalba (Université du Québec à Rimouski); Nathalie Jolie, Johannie Martin, Emmanuelle Medrinal, Deo Florence Onda, Nicolas Schiffrrine, Mary Thaler (Université Laval)

MSc Students
Gabrièle Deslongchamps (Institut national de la recherche scientifique - Institut Armand-Frappier); Pierrick Barbier, Mariève Bouchard Marmen, Katrine Chalut, Julien Laliberté, Maxime Samacoïts (Université du Québec à Rimouski); Myriam Bergeron, Jean-Sébastien Côté, Robyn Edgar (Université Laval)

Undergraduate Students
Joannie Charette, Sophia Elvire Thompson (Université du Québec à Rimouski)

Technical Staff
Laure de Montety, Sylvie Lessard, Lisa Treau de Coeli (Institut des sciences de la mer de Rimouski); Pascal Guillot (Québec-Océan); Marjolaine Blais, Jonathan Gagnon (Université Laval); Jessica Nephin (University of Victoria)
Abstract

Living, harvestable resources in the upper Arctic Ocean ultimately depend on the production of marine microalgae. Microalgal production also mitigates global warming by fixing the greenhouse gas CO₂ into biomass, of which a portion sinks to the seafloor. This process, called the “biological CO₂ pump”, supplies food to the benthic organisms living at the bottom. Ongoing alterations of the physical environment will have profound impacts on the growth conditions of primary producers, affecting the timing, productivity and spatial extent of biological hotspots (i.e., areas of elevated food web productivity against the low background typical of the Canadian Arctic). This project investigates how changes in the dynamics of sea-ice and glacial ice (icebergs and ice islands), water temperature, ocean circulation and wind forcing affect primary production in the upper water column and the benthic ecosystem underneath. Specific objectives are to 1) locate biological hotspots (and coldspots) of pelagic and benthic activity, 2) assess how they function and interact, and 3) assess how their productivity and biodiversity is likely to respond to further perturbations of the environment. To do so, we are and have been developing and implementing cutting-edge observational and experimental approaches that exploit remote sensing from space, autonomous underwater vehicles as well as the sampling and laboratory facilities of the CCGS Amundsen. Our work is done in very close collaboration with several ArcticNet projects, collaborators and partners from government and the industry.

Key Messages

- Colored dissolved organic matter (CDOM) contributes up to 70% of total light absorption in the Arctic and has been mostly responsible for the overestimation of chlorophyll by satellites (remote sensing).
- The melting of multi-year releases significant amount of non-algal particulates (NAP) near the sea surface, which creates a “biofilm” and alters optical properties.
- The use of regional relationships for the retrieval of chlorophyll a is expected to improve the quantification of phytoplankton biomass in the Canadian Arctic.
- Incident PAR above the sea surface has significantly decreased over the Arctic and subarctic seas due to increasing cloudiness, partly counteracting the positive influence of reduced sea-ice on biological productivity.
- Significant surface warming has occurred in Hudson Bay in the last decade, which is expected to force plankton to adapt towards strategies compatible with a warmer and more oligotrophic marine environment.
- Many high latitude ribotypes are specifically adapted to colder waters, and are likely to be vulnerable to the ongoing effects of Arctic climate warming.
- Some phytoplankton groups can acclimate to the changing environment by altering their cellular content and/or pigment composition.
- In opaque, high-CDOM coastal waters, some phytoplankton acclimate to the low availability of light by synthesizing accessory pigments that absorb light at longer wavelengths (UV).
- The magnitude of the phytoplankton bloom in terms of biomass is particularly high in the Bering Sea, Baffin Bay and Canadian Archipelago (6-18 mg m⁻³) and lower in the Beaufort Sea, the central Arctic Ocean and Hudson Bay (1-2 mg m⁻³).
- The heterotrophic nanoflagellate Cryothecomonas could be a sensitive indicator of recent ice melt in the water column.
- Specific taxa of sympagic dinoflagellates and diatoms may be useful indicators of the presence of land-fast versus drift ice.
- Nematodes are the most numerous group of
the Canadian Arctic meiofauna followed by copepods, nauplii larvae and polychaetes.

• Factors structuring the meiofaunal community are mainly the amount of phytodetritus in the sediment, oxygen, temperature at the water/sediment interface and sediment type.

• Interannual variability in benthic remineralization and food supply is larger at hotspots than at coldspots.

• Meiofauna mediates the flow of organic matter between muddy deposits and higher trophic levels.

• Autoxidation, photooxidation and biodegradation processes act much more intense challenges for bacteria than for phytoplankton due a lack of adapted antioxidant system in these microorganisms.

• Arctic cod in the eastern Beaufort Sea is distributed into 2 layers: one epipelagic (0 to 60 m) composed of age-0+ individuals, the other one meso- and benthopelagic (~200 to 400 m), especially concentrated on slopes, composed of juveniles and adults.

• Arctic cod biomass in Amundsen Gulf in fall 2003 was estimated to 250 000 t.

### Objectives

• Determine where pelagic and benthic hotspots (or coldspots) of productivity and diversity occur, how they function and are likely to shift in the future.

• Adapt remote-sensing techniques for the estimation of phytoplankton biomass in the particular environment of the Arctic Ocean, with the aim of better characterizing the spatio-temporal variability of primary production at different spatial scales.

• Elucidate the oceanic, cryospheric and atmospheric drivers of microalgal primary production and microbial diversity in surface waters.

• Relate key indices of primary production to the biomass and diversity of consumers in the lower pelagic and benthic food web.

• Assemble decadal time-series to deconvolute the effect of different forcing mechanisms (interannual variability, climate oscillations, climate change) on productivity and biodiversity.

• Develop and/or implement cutting-edge approaches to augment the spatial and temporal coverage and resolution of observations on the productivity and biodiversity of the lower food web.

### Introduction

Living, harvestable resources in the upper Arctic Ocean ultimately depend on the production of marine microalgae, which is recognized as a universal index of ecosystem richness and fisheries yield (Chassot et al. 2010, Conti and Scardi 2010). Microalgal production also mitigates global warming by fixing the greenhouse gas CO\(_2\) into biomass, of which a portion sinks to the seafloor. This process, called the “biological CO\(_2\) pump”, supplies food to the benthic organisms living at the bottom.

Microalgae require light and the nutrients supplied from deep waters, rivers and currents. By blocking light and the wind-driven mixing or upwelling of nutrients from deep waters, sea ice continues to restrict photosynthesis and the yield of harvestable resources over much of the Arctic. Ongoing environmental alterations will have profound impacts on the growth conditions of primary producers, affecting the timing, productivity and spatial extent of biological hotspots (i.e. areas of elevated food web productivity against the low background typical of the Canadian Arctic). These changes may also favor harmful algal blooms, which disrupt food webs and human health at lower latitudes.
Hotspots can be observed using in situ and remote sensing approaches, each with their strengths and limitations. We have been progressing on all these fronts and the results presented here show recent achievements and successes obtained by exploiting the complementary nature of those techniques. While essential knowledge on ecosystem function and processes will continue to be derived from scientific expeditions to the Arctic, the estimation of biological productivity through satellite remote sensing of ocean color offers the only means to detect temporal and spatial trends in productivity at a variety of scales ranging from local, to regional and hemispheric (Arrigo and van Dijken 2011, Kahru et al. 2011, Perrette et al. 2011). These methods currently tend to overestimate surface chlorophyll a (Chl a) due to large riverine input of organic matter in the coastal Arctic (Bélanger et al. 2008, Matsuoka et al. 2009) and to overlook the occurrence of subsurface chlorophyll maximum (Martin et al. 2010). Moreover, ice and clouds continue to hamper the acquisition of ocean color data in the Arctic. We have thus been working toward the development of new remote sensing algorithms designed specifically for the Beaufort Sea/Amundsen Gulf region, which now allows a more rigorous estimation of chlorophyll concentration (Mustapha et al. 2012).

The resource and services of an ecosystem depends largely on the relationship between the different levels of the food web, especially the link between primary producers and the benthic fauna, which plays a key role in the recycling of organic matter and channeling of food to higher trophic levels. It has been suggested that the shift in primary producers caused by global warming will impact on both the quantity and the quality of food exported towards the seabed (Forest et al. 2011, Link et al. 2011, Tremblay et al. 2011). Finally, apart from playing a fundamental role in marine food webs, plankton communities have been recognized as bioindicators of climate changes since the variability in ice cover, temperature, stratification and ocean currents are reflected in their biomass, diversity, productivity and spatial distribution (Comeau et al. 2011, Li et al. 2009).

1. Dissemination of scientific results

- Dissemination of results to the scientific communities, public, partners and stakeholders in high-ranking articles submitted (10), accepted and/or published (19), oral presentations (26), poster presentations (27), master dissertations (1), Ph.D defense (1), book chapter (3), international newspaper (2).

- Invited talks were given at the most prestigious international “polar” conferences, including the Gordon Research Conference on Polar Marine Science, Arctic Frontiers 2013 (keynote plenary lecture) and the Third Pan-Arctic Symposium.

- Presentation of the results at international conferences: IPY Knowledge to Action (Montreal), Goldschmidt conference (Montreal), CMOS congress (Montreal), Cold regions estuary workshop (Winnipeg), SOLAS Open Science (Seattle), XXII International Diatom Symposium (Belgium), Ocean Optics Conference (Scotland), Third Pan-Arctic Symposium (Motovun, Croatia), Arctic in Rapid Transition Science Workshop (Poland), Quebec-Ocean Annual Meeting (Montreal), ArcticNet 8th Annual Scientific Meeting (Vancouver), ASLO spring meeting (Salt Lake City), ASLO summer meeting (Otsu, Japan), SCAR open science meeting, (Portland), ISME Power of the Small, (Copenhagen), Arctic Frontiers (Tromso, Norway).

- Participation in the development of future expeditions plans in the Hudson Bay region (Cold regions estuary workshop, Winnipeg) and in the central Arctic (Arctic Ocean Drift Study workshop, Winnipeg).

- Contribution to a World Ocean synthesis publication and data archives of picophytoplankton abundance in three taxonomic groups: Prochlorococcus, Synechococcus, and picoeukaryotes (Buitenhuis et al. 2012). All of the data were obtained by flow cytometry. Picophytoplankton abundance data collected in the Canadian High Arctic in Aug.-Sept. 2005.
were provided for the compilation. Both the raw data and the gridded data are available from PANGAEA (http://doi.pangaea.de/10.1594/PANGAEA.777385) and the MAREDAT webpage (http://maremip.uea.ac.uk/maredat.html).

- Contribution to the identification of ecologically and biologically significant benthic areas (EBSAs) in the Canadian Arctic (Kenchington et al., 2011) in the frame of a Scientific Advisory Report on EBSAs in the Canadian Arctic (DFO 2011). This use of ecosystem function in ecosystem assessment has further been presented at the IPY conference 2012 (Montréal).

- Outreach activities were performed with local communities during an ice camp in Resolute. There was a science day organized for the local school and student were invited to volunteer on the weekend to help out with the data collection.

- Participation to the planning of the IRIS-2 report and meeting in Iqaluit. Two draft chapters were produced, to be completed for the final document in 2013.

2. Field and laboratory work, instrumentation, analyses

- Participation of HQP’s to the Arctic-Ice project in Resolute Bay. Sampling focused on ecological processes occurring during the spring-summer transition (i.e. transition from ice-covered to open waters).

- Sampling expeditions to Lancaster Sound, Baffin Bay and the Labrador Sea (IRIS 2) with the CCGS Henry Larsen and CFAV Quest as part of a DFO-ArcticNet collaboration (Sept. 2012). Facilitated by ship-time money from ArcticNet. The full suite of samples normally collected during the annual Amundsen expedition were taken. Lab analyses of samples are ongoing.

- Participation of two HQP to in the Joint Ocean Ice Study (JOIS) 2012 IOS Cruise # 2012-11 onboard the Louis St. Laurent (1 Aug.-20 Sept. 2012) facilitated by ArcticNet ship-time money.

- Collection of full profiles of DNA and RNA from a key station in Amundsen Gulf as well as 20 other stations from around and in the Canada Basin.


- Processing of radiometric data collected during the 2011 ArcticNet expedition on board the Amundsen.

- Acquisition of over 350 000 short sequences using high throughput pyrosequencing technology. This new technology enables to reduce to backlog the archived samples from different Arctic regions and dates. Lab analyses are ongoing.

- Successful NSERC equipment proposal for an in situ RNA MacLane sampling system. The equipment was redesigned for our needs and will be delivered in June 2013.

- Analysis of the 3D distribution, size and density of arctic cod in Eastern Beaufort Sea in pre-winter conditions from multifrequency split-beam acoustic data collected on Mackenzie shelf, Amundsen Gulf and offshore in Beaufort Sea before the observation of a dense overwintering benthopelagic aggregation in Franklin Bay in 2004. Consolidation of the understanding of the arctic cod overwintering aggregation process.

3. Scientific stewardship and elaboration of new research partnerships

- PL Tremblay joined Louis Fortier to participate in a Canada-Japan workshop Tokyo. The goal was to re-kindle old collaborations and develop new ones in order to foster joint research between ArcticNet and scientists from NIPR and JAMSTEC. A statement has been presented before the joint Canada-Japan Commission on Science and Technology.

ArcticNet NI’s participated in several high-profile
research comities, including:

- Arctic marine biodiversity monitoring indicators CSAS peer-review comity
- Arctic Biodiversity Assessment Lead authors workshop
- Circumpolar Biodiversity Marine Plan (CBMP) Steering Group Expert network
- Science advisory board of the international ART initiative (Arctic in Rapid Transition)

Results

1. Improvement of remote sensing algorithms for phytoplankton biomass. (NI: Larouche, Bélanger, HQP: Ben Mustapha)

New remote sensing algorithms designed specifically for the Beaufort Sea/Amundsen Gulf region now allow the accurate estimation of chlorophyll a (Chl a) concentration within 50 %, which is a major improvement over conventional algorithms that were shown to generate an overestimation of up to 500 %. The overestimation was found to result mostly from the dominance of colored dissolved organic matter in the light absorption budget, a problem that is particularly acute in coastal Arctic waters. It was also found that fluorometrically measured Chl a were two times greater than those determined from High Performance Liquid Chromatography (HPLC), contributing to the observed discrepancies. These results are particularly important as Chl a is the most important input parameter for the estimation of biological productivity from space. Our results clearly show that standard algorithms do not work well in high CDOM-low chlorophyll areas (Fig. 1).

2. Optical properties of Canadian Arctic waters. (NI: Larouche, Gosselin, HQP: B. Brunelle)

Phytoplankton light absorption spectra ($a_\phi(\lambda)$) were measured in the Canadian Arctic (i.e., Amundsen Gulf, Archipelago, northern Baffin Bay, Hudson Bay system) to improve algorithms used in remote-sensing models of primary production. The major light absorption factor in the four provinces was the colored dissolved organic matter (CDOM) contributing up to 70 % of total light absorption (Fig. 2).

During the fall, the low total chlorophyll a-specific absorption coefficients $a_\phi^*(443)$ ($a_\phi(443)/TChla$) were associated with photoacclimation processes (i.e., the package effect) occurring in light-limited environments (Fig. 3). Low light availability and a high proportion of CDOM (which absorbs strongly in the ultraviolet) seem to favor the growth of phytoplankton types possessing accessory pigments that absorb at long wavelengths. The ratio of photoprotective to photosynthetic pigments (PPC:PSC) for carotenoids was inversely proportional to salinity and cell size and mostly decreased during fall. The highest $a_\phi^*(443)$ were observed in the Hudson Bay system from September to October (i.e., fall) as well as in the Amundsen Gulf from May to July (i.e., spring/summer).
These results showed that light limitation, nutrient availability as well as the taxonomic composition and size structure of phytoplankton communities are the most important sources of the observed variability in $a_\phi^*(443)$ across the Canadian Arctic. We hypothesize that during fall and winter, phytoplankton cells adapt to their light-limited environment by producing and concentrating photosynthetic pigments (i.e., package effect). Further work is required to understand the effects of nutrient limitation on phytoplankton light absorption spectra. Ongoing environmental changes presently observed in the Arctic (loss of sea ice cover, increased freshwater fluxes, enhanced thermal stratification, etc.) are thus expected to modify phytoplankton communities with yet undetermined effects on the food web.

3. Spatial and temporal variability of sea-surface temperature fronts in the Beaufort Sea from
high-resolution satellite data (NI: Larouche, HQP: Ben Mustapha)

An analysis of 11 years of high spatial resolution sea surface temperatures maps allowed to determine the probability of frontal occurrence (i.e. a front is a sharp transition zone between water masses of distinct physical properties) in the southeastern Beaufort Sea using the single image edge detection method (Fig. 4).

Our analysis indicates that some recurrent features can be identified in the summer climatology such as the Shelf break front and the Mackenzie River plume front. The Cape Bathurst front, the Mackenzie Trough front and the Amundsen Gulf fronts were identified as new frontal areas that appear to be mostly driven by wind and tidal mixing along steep shelf slopes. Automatic detection of SST fronts represents an efficient way to simplify the rich structure inherent in the SST field. The analysis of 11 years of AVHRR data showed patterns of SST fronts on the Mackenzie Shelf and in the Amundsen Gulf region especially at the peak of summer. The 1-km resolution data used in this study provided more information on SST spatial variability than the 9 km resolution data used by previous studies leading to the identification of two new frontal features (Cape Bathurst and Amundsen Gulf) that could act as major drivers to locally enhanced biological productivity (hotspot). There is prior evidence that fronts are ecologically significant.
Figure 5. A) Mean yearly downwelling flux of PAR above the sea (ice) surface (PAR(0+)) for the 1998 to 2009 period, B) Absolute PAR(0+) trends calculated using the TSA, and C) the standardized PAR(0+) trends (i.e., PAR(0+) trends / climatological PAR(0+) *100).

Figure 6. A) Mean yearly downwelling flux of PAR penetrating in the ocean (PAR(0-)) for the 1998 to 2009 period, B) Absolute PAR(0-) trends calculated using the TSA, and C) the standardized PAR(0-) trends (i.e., PAR(0-) trends / climatological PAR(0-) *100).
for foraging seabirds and marine mammals. Even though many oceanographic studies concentrated on the Beaufort Sea area during the last 10 years, only a few measurements were done in these biologically important frontal areas. Their influence on carbon cycling, nutrient balance and food webs in the Beaufort Sea is thus poorly understood. The spatial distribution of fronts described here can be used as a planning tool to design future oceanographic sampling targeting biological hotspots.

4. Increasing cloudiness damps the increase in phytoplankton primary production due to sea ice receding (NI: Bélanger, Tremblay, Coll: Babin)

Here we present the results of a diagnostic model used to elucidate the main drivers of temporal trends in primary production (PP) over the 1998-2010 period at pan-Arctic, regional and local (i.e., 9.28-km resolution) scales. Photosynthetically active radiation (PAR) above and below the sea surface was estimated using precomputed look-up tables of spectral irradiance and satellite-derived cloud optical thickness and cloud fraction parameters from the International Satellite Cloud Climatology Project (ISCCP) and sea ice concentration from passive microwave data. A spectrally resolved PP model, designed for optically complex waters, was then used to produce maps of PP trends. Results show that incident PAR above the sea surface (PAR(0+)) has significantly decreased over the whole Arctic and sub-Arctic seas, except over the perennially sea ice covered waters of the central Arctic Ocean (Fig. 5). This fading of PAR(0+) (-8 % decade\(^{-1}\)) was caused by increasing cloudiness in May and June.

Meanwhile PAR penetrating the ocean (PAR(0-); Fig. 6) increased only along the sea ice margin over the large Arctic continental shelf where sea ice concentration declined sharply since 1998. Overall, PAR(0-) slightly increased in the Circum Arctic (+3.4 % decade\(^{-1}\)), while it decreased when considering both Arctic and sub-Arctic seas (-3 % decade\(^{-1}\)).

We showed that rising phytoplankton biomass (i.e., chlorophyll a) normalized by the diffuse attenuation of photosynthetically usable radiation (PUR) by phytoplankton accounted for a larger proportion of the rise in PP (Fig. 7) than did the increase in light availability due to sea-ice loss in several sectors and particularly in perennially and seasonally open waters.
Figure 8. A) Near-surface variability of salinity and temperature measured from the CTD attached to an optical package deployed from the barge at station 460 on August 19th. B) Spectral absorption of particles sampled manually near the sea surface from the barge using a Kemmerer bottle (grey curves) and from two rosette casts (147 and 148). An additional bucket sample was collected from the ship deck simultaneous with the rosette cast #148 less than three meters apart.

Figure 9. Variability of the spectral slope ratio between UV (SUV) and visible (VIS) domains. Variation of SUV: VIS with: A) depth; B) water masses; C) aNAP at 440 nm.
5. Light absorption and partitioning in Arctic Ocean surface waters: Impact of multi-year ice melting (NI: Bélanger, Coll: Cizmeli, Ehn, Matsuoka, Doxaran, Hooker and Babin)

Ice melting in the Arctic Ocean exposes the surface water to more radiative energy with poorly understood effects on photo-biogeochemical processes and heat deposition in the upper ocean. In August 2009, we documented the vertical variability of light absorbing components at 37 stations located in the southeastern Beaufort Sea including both Mackenzie river-influenced waters and polar mixed layer waters. We found that melting multi-year ice released significant amount of non-algal particulates (NAP) near the sea surface relative to sub-surface waters (Fig. 8).

NAP absorption coefficients at 440 nm (aNAP(440)) immediately below the sea surface (0-) were on average ~3-fold (up to 10-fold) higher compared to sub-surface values measured at 2-3 meters depth. The impact of this unusual feature on the light transmission and remote sensing reflectance (Rrs) was further examined using a radiative transfer model. A 10-fold particle enrichment homogeneously distributed in the first meter of the water column slightly reduced photosynthetically available and usable radiation (PAR and PUR) by ~6 % and ~8 %, respectively, relative to a fully homogenous water column with low particles concentration. In terms of Rrs, the particle enrichment significantly flattered the spectrum by reducing the Rrs by up to 20 % in the blue-green spectral region (400-550 nm). Spectral slope of aNAP spectra calculated in the UV domain decreased with depth suggesting that this parameter is sensitive to detritus composition and/or diagenesis state (e.g., POM photobleaching) (Fig 9).


Predicting water-column phytoplankton biomass from near-surface measurements is a common approach in biological oceanography, particularly since the advent of satellite remote sensing of ocean color (OC). However, this new method tends to overlook variability in the vertical chlorophyll a (Chl a) distribution and the occurrence of subsurface chlorophyll maximum (SCM) in both space and time in the Arctic Ocean. To overcome this problem, 5206 vertical Chl a profiles from various Arctic environments were pooled to generate a typical annual time series for each sub-Arctic and Arctic Sea.
Figure 11. Water temperature distribution in Hudson Bay, Hudson Strait, and Foxe Basin from 2003 to 2006. Note the change in depth scale between panels (From Estrada et al., 2012).
Figure 12. Chlorophyll (in vivo, fluorescence measured with the CTD fluorometer) distribution in Hudson Bay, Hudson Strait, and Foxe Basin from 2003 to 2006. Note the change in depth scale between panels (From Estrada et al., 2012).
The spring bloom occurs around DOY 150-160 in Baffin Bay, Barents and Beaufort seas. The latest blooms are observed in the central Arctic Ocean (DOY 193) and Canadian Archipelago (DOY 224). The magnitude of the bloom also differs significantly among regions, with highest surface Chla concentrations in Bering Sea, Baffin Bay and Canadian Archipelago (6-18 mg m$^{-3}$) and lowest concentrations in the Beaufort Sea, the central Arctic Ocean and Hudson Bay (1-2 mg m$^{-3}$). A fall bloom, less important than the spring bloom, also occurs in different sub-Arctic and Arctic seas. The intervening period between blooms is characterized by low surface Chl a concentrations and the potential occurrence of SCM, when the surface Chl a concentrations decrease below 0.5 mg m$^{-3}$ (Fig. 10).


Apart from playing a fundamental role in marine food webs, plankton communities have been recognized as bioindicators of climate changes since the variability in temperature, stratification and ocean currents are reflected in their biomass, productivity and spatial distribution. However, very little is known on how the fast changing conditions in the Hudson Bay system will alter plankton assemblages. Thus, in a recent paper, Estrada et al. (2012) tried to link community structures to water mass properties and origins in order to establish a baseline for the future physical and ecological changes expected in this region. To do so, they carried out sampling in the Hudson Bay system from 1 to 14 August in 2003 and 2004 and from 31 August to 10 September in 2005 and 2006. They observed that upper water column was highly stratified during all sampled years. In 2003, this stratification was more important on the east side of the Hudson Bay transect, but in 2006 the stratification was uniform across the whole transect. The warm surface layer was also notably thicker in 2006, when it reached about 25 m deep, compared with 2003 and 2004, when it was about 15 m deep (Fig. 11).

Figure 13. Phylogenetic tree showing the classification of uncultivated Arctic taxa. The bottom cluster is sufficiently different to be a new class of algae.
This increased stratification in the two later years had repercussions on phytoplankton biomass, as shown by chlorophyll a (Chl a) concentration (Fig. 12). Along all transects during the 4 years of this study, the maximum Chl a values (in vivo, as measured by the CTD fluorometer) were registered between 25 and 50 m. The depth-integrated Chl a concentration averaged over all stations was four times higher in August 2003 and 2004 compared to September 2005 and 2006 (mean ± SD = 125 ± 58 vs 30 ± 10 mg Chl a m⁻², respectively). The difference between 2003–2004 and 2005–2006 was particularly evident at the offshore stations HB2 to HB5 (Fig. 12).

8. Small phytoplankton in Arctic Seas: vulnerability to climate change (NI: Lovejoy, HQP: Terrado)

We assessed the biodiversity of small-celled phytoplankton in Arctic Seas, focusing on the molecular taxonomy of phytoplankton in classes that have been historically overlooked due to their small cell size or lack of distinctive morphological characters (Fig. 13). New data from clone libraries from Baffin Bay and the Beaufort Sea were combined with previously published records to confirm the panarctic distribution of a single cold ecotype within the Mamiellophyceae. Other chlorophytes, as well as cryptophytes, haptophytes, chrysophytes, dictyochophytes, pelagophytes and bolidophytes were reported from most Arctic sites. Many of these taxa had distinct nucleotide motifs or substitutions, suggesting an Arctic specific pelagic flora.

9. Distribution and diversity of a protist predator Cryothecomonas (Cercozoa) in Arctic marine waters (NI: Lovejoy, HQP: Thaler)

Heterotrophic nanoflagellates (HNFs) are key components in microbial food webs, potentially influencing community composition via top-down control of their favored prey or host. We developed a Cryothecomonas-specific fluorescent in situ hybridization (FISH) probe targeting ribosomal 18S rRNA to estimate cell concentrations over different regions and years. Comparison of simple and partial correlation coefficients showed that salinity, depth, and overall biological biomass are important factors determining Cryothecomonas abundance. We found no evidence of parasitism in our samples. Hybridized cells included individuals smaller than any formally described Cryothecomonas, suggesting the presence of novel taxa or unknown life stages in this genus. A positive relationship between Cryothecomonas abundance and ice and meltwater suggests that it is a sensitive indicator of ice melt in Arctic water columns.

10. Protists in arctic drift and land-fast sea ice (NI: Lovejoy, HQP: Comeau)

Since smaller flagellates are fragile, often poorly preserved, and are difficult for non-experts to identify, we applied high-throughput tag sequencing of the V4 region of the 18S rRNA gene to investigate the eukaryotic microbiome within the ice. The sea ice communities were diverse (190 taxa) and included many heterotrophic and mixotrophic species. Dinoflagellates (43 taxa), diatoms (29 taxa) and cercozoans (12 taxa) accounted for approximately 80 % of the sequences. The sympagic communities living within drift ice and land-fast ice harbored taxonomically distinct
communities and we highlight specific taxa of dinoflagellates and diatoms that may be indicators of land-fast and drift ice (Fig. 14).

11. Production of a synthetic draft chapter for the IRIS-2 report: “Marine ecosystem productivity in the changing eastern Canadian Arctic” and “Marine protected areas and biodiversity conservation” (NI: Tremblay, Archambault)

During 2012, PL’s Tremblay and Archambault let the production of drafts for the IRIS-2 report in preparation of the Iqaluit meeting of November 2012. The general approach is based on the fact that fish and marine mammal surveys at the spatial and temporal scale needed to dress a complete picture of resources and their temporal change/fluctuations in the IRIS region are desirable but unfortunately not available. Other variables measured by the Hospots project, like chlorophyll, primary production and benthic resources, are more amenable to synoptic monitoring through time and provide an acceptable surrogate for the productivity of harvestable resources. The chapters review current knowledge, based on the stations sampled by ArcticNet expeditions over the past 7 years (Fig. 15) and the results of other expeditions in the area, and propose plausible scenarios for the future.

Results show how the eastern Canadian Arctic marine environment is shaped by a combination of local and remote processes that must be taken into account to

Figure 15. Stations sampled by ArcticNet expeditions over the past 7 years
understand present and future biological productivity. The oceanographic complex formed by Lancaster Sound, Baffin Bay and the northern Labrador Sea is a central ecological hub where massive southward flows of water, sea ice and glacial ice converge along the eastern Canadian coastline. The region collects waters that, for the most part, originate from the Pacific Ocean, and have spent more than a decade transiting across the high Arctic (e.g., Beaufort Sea), where their properties have been modified by ice dynamics, precipitation, river discharge and biological activity. These waters therefore integrate a myriad of signals that relate to upstream events and the cumulated impact of climate-driven processes in recent years. By modulating the fluxes and configuration of ice and water in the bay, the changing Arctic climate will affect ecosystem services regionally and far beyond in the western north Atlantic. The situation is different along the coast of Greenland, which receives water from the so-called “West Greenland Current” that carries a mixture of relatively warm and salty Atlantic water with some Arctic water originating from the eastern side of Greenland. Along the way, this water collects the melt water produced by the disintegration of Greenlandic glaciers. Most of this water arcs west and then south in northern Baffin Bay and the rest continues northward into Smith Sound.

12. Joint DFO-ArcticNet investigations of pelagic and benthic productivity in Baffin Bay hotspots, with emphasis on sectors with cold-water corals (NI: Tremblay, Archambault, Gosselin, Lovejoy, Gratton, Coll: Kenchington, HQP: Deslongchamps)

Sampling activities were performed aboard the CCGS Henry Larsen. Processing of water samples have been made to compare nutrients (nitrates, nitrites, ammonium, phosphates, silicates), chlorophyll content, molecular biodiversity, primary productivity and nitrogen cycling in different sectors of Baffin Bay. Transects were surveyed with a benthic camera. Preliminary results show very strong east-west gradients in nutrient supply and productivity between Greenland and the Canadian Coasts, which is related to northward intrusions of Atlantic water in the west.

13. Metazoan meiofauna dynamics in the Canadian Arctic (NI: Nozais, Archambault, HQP: Barbier)

The objectives of this project are to describe and compare the biodiversity and secondary productivity of meiobenthic communities in areas of enhanced and reduced productivity and diversity (“hotspots” and “coldspots”). Thus, we analyzed the abundance, composition, spatial patterns and environmental factors structuring Canadian Arctic meiofauna, leading to the definition of Hot and Cold Spot. Results from stations sampled in 2008 and 2009 (n = 20) showed that meiofauna occur in abundances comparable to those of other polar systems and that nematodes are the most numerous group followed by copepods, nauplii larvae and polychaetes. Factors structuring the meiofaunal community are mainly the amount of phytodetritus in the sediment, oxygen and temperature at the water/sediment interface and sediment type. Hot and cold meiofauna spots were identified and correspond to those obtained for macrofauna, suggesting that the large-scale structure of these two faunal communities is defined by the same environmental factors (Barbier 2012, Master 2 thesis). These data together with those published by Bessière et al. (2007) and from the literature are processed for a review on the marine Arctic and their meiofauna (Thompson, in prep).

14. Studying the functioning of benthic ‘hotspot’ vs ‘coldspot’ ecosystems in the Canadian Arctic (NI: Archambault, Piepenburg, HQP: Link)

We measured benthic remineralization (mostly carbon, silicic acid, phosphate, nitrate), diversity and sediment pigment concentration (as proxy for food supply) at 49 stations between the Beaufort Sea and Baffin Bay during the CFL, ArcticNet 2008 and 2009 and Malina expeditions. Six sites were sampled each in spring and summer 2008 to test for seasonal differences, and ten sites were sampled in the same season each once in 2008 and once in 2009 to test for interannual differences. Benthic biomass and diversity has been determined for the ten sites for interannual comparison from 2008 and 2009. Results show that
interannual variability of benthic remineralization and food supply is bigger at hotspots than at coldspots, and that food supply and diversity are complementary in their influence on the benthic ecosystem function remineralization. This has been presented in the frame of Heike Link’s Ph.D thesis and defense and national (A Reality Check on Ocean’s Health, Montréal) meetings. The manuscript will be submitted to PLoS One in early 2013.

15. Tracing organic matter sources of Canadian Arctic benthic invertebrates with stable isotopes (NI: Archambault, Nozais, HQP: Chalut)

Benthic fauna plays a key role in the recycling of organic matter at the seafloor as it can both help organic matter decomposition and channeling to higher trophic levels. It has been suggested that the shift in primary producers inferred by global warming will impact on both the quantity and the quality of food exported towards the seabed. This may lead to possible changes on the structure and function of benthic ecosystems since polar benthic heterotrophs (meio- and macrofauna) depend on allochtonous organic material for their energetic requirements. Here we used the stable isotopes of C and N to determine the origin and sources of organic matter assimilated by Arctic meio- and macrofaunal organisms, along the West-East gradient in Canada. So far, we obtained results for 5 stations. Results suggest that meiofauna (nematodes and copepods) mediates flow of organic matter between muddy deposits and higher trophic levels and that surface deposit-feeders are 13C depleted in comparison with subsurface deposit feeders (Barbier 2012, Master 2 thesis). Furthermore, our isotopic results demonstrate that sediment is a coarse descriptor when it comes to study macrofaunal diet. The next steps in this study will be to analyze the rest of the stations then study specifically meiofauna diet, estimate trophic levels and finally compare isotopic values between stations.

16. The use of bivalves as proxies for climate change effects on Arctic benthic ecosystem (NI: R. Tremblay, Archambault, Coll: Olivier, HQP: Gaillard)

In the context of global change on the Arctic environment, higher surface water temperatures and reduced ice cover are observed and subsequent severe ecosystem changes propagating through all trophic levels are expected. The project implies the use of mollusks bivalves as recorders of environmental variations in the Canadian Archipelago. The structural (sclerochronological analysis) and geochemical (stable isotopes and trace elements analyses) information archived in bivalve shells can be used to monitor past and recent changes of environmental parameters as temperature, salinity or trophic resources. Moreover, bivalves can be used as indicators of the pelagic-benthic coupling through fatty acid trophic markers analyses. Astarte moerchi is a potential species to trace food webs changes over a long period and preliminary results on their shells contradict the current paradigm, which states that in general, there would be a shift in the relative importance of sea-ice, pelagic and benthic biota in the overall carbon flux from ‘sea-ice algae benthos’ to ‘phytoplankton-zooplankton’ dominance. Sclerochronological analysis show in the NOW polynya area a major change in the growth dynamics of the population over the last ten years related to an increased export of surface microalgae towards the bathyal domain. In further studies, we would like to use the Arctic bivalves Astarte spp. as archives of environmental changes under the influence of the climate change on a large scale and in contrasting trophic environments. The following paper will be submitted next week to Nature (End of January): Gaillard, B, Olivier, F, Thébault, J, Méziane, T, Tremblay, R, Dumont, D, Bélanger, S, Gosselin, M, Chauvaud, L, Martel, M, Archambault, P. Bathyal Arctic bivalves benefit from climate changes, Nature.

17. Degradation state of organic matter in surface sediments from the Beaufort Shelf: a lipid approach (HQP: Link)

For the next decades significant climatic changes should occur in the Arctic zone. The expected destabilization of permafrost and its consequences for hydrology and plant cover should increase the input of terrigenous carbon to coastal seas.
Consequently, the relative importance of the fluxes of terrestrial and marine organic carbon to the seafloor will likely change, strongly impacting the preservation of organic carbon in Arctic marine sediments. Here, we investigated the lipid content of surface sediments collected on the Mackenzie basin in the Beaufort Sea. Particular attention was given to biotic and abiotic degradation products of sterols and monounsaturated fatty acids. By using sitosterol and campesterol degradation products as tracers of the degradation of terrestrial higher plant inputs and brassicasterol degradation products as tracers of degradation of phytoplanktonic organisms, it could be observed that autoxidation, photooxidation and biodegradation processes act much more intensively on higher plant debris than on phytoplanktonic organisms. Examination of oxidation products of monounsaturated fatty acids showed that photo- and autoxidation processes act more intensively on bacteria than on phytodetritus. Enhanced damages induced by singlet oxygen (transferred from senescent phytoplanktonic cells) in bacteria were attributed to the lack of an adapted antioxidant system in these microorganisms. The strong oxidative stress observed in the sampled sediments resulted in the production of significant amounts of epoxy acids and unusually high proportions of monounsaturated fatty acids with a trans double bond. The formation of epoxy acids was attributed to peroxygenases (enzymes playing a protective role against the deleterious effects of fatty acid hydroperoxides in vivo), while cis/trans isomerisation was probably induced by thyl radicals produced during the reaction of thiols with hydroperoxides. Our results confirm the important role played by abiotic oxidative processes in the degradation of marine bacteria and do not support the generally expected refractory character of terrigenous material deposited in deltaic systems.

18. Pre-winter distribution and habitat characteristics of polar cod (Boreogadus saida) in southeastern Beaufort Sea (NI: Simard, Fortier, HQP: Benoit)

Polar cod is a key species of Arctic Ocean food web. This forage fish was shown to form dense under-ice winter aggregations at depth in Amundsen Gulf (southeastern Beaufort Sea). This paper contributes to verify the postulations of the proposed aggregation mechanism by determining the distribution and habitat characteristics of the species before the formation of winter aggregations. Multifrequency split-beam acoustic data collected in October-November 2003 revealed that youngs-of-the-year polar cod formed an epipelagic layer between 0 and ~60 m over the entire region. In contrast, adult polar cod tended to distribute into an offshore mesopelagic layer between ~200 - 400 m before shoaling into a denser (1 to 37 g m–2) benthopelagic layer on sloping bottoms towards the coast, between the 100-m and 550-m isobaths along Mackenzie shelf and into Amundsen Gulf basin. Concentrations peaked in Amundsen Gulf where estimated total biomass reached ~250 kt. The Cold Halocline intermediate coldest waters (< 1.4°C) were generally deserted by the two fish groups.

Polar cod concentration at slopes is likely governed by the combined actions of 1) local 3D currents concentrating both deep-keeping zooplankton and polar cod at the shelf-break and basin slopes, and 2) trophic association with these predictable topographically-trapped aggregations of zooplankton preys. During freeze-up these slope concentrations of polar cod are thought to constitute the main source of the observed dense under-ice winter aggregations. The hypothesis of active short-distance displacements combined with prevailing mean currents is retained as the likely aggregation mechanism.

Discussion

Remote sensing of phytoplankton biomass, and ultimately primary production, in Arctic region is highly dependent on the use of accurate light absorption coefficients. The Arctic Ocean receives the highest amount of river runoff relative to the world ocean with 80 % of it being discharged over the huge
Eurasian continental shelves (East Siberian, Laptev, Kara and Barents Seas). However, even if the entire Arctic ocean is characterized by a DOM content that is much higher than the Atlantic and Pacific oceans, it is mostly in its surrounding seas that the CDOM content has the potential to dominate the light budget and thus affecting the remote sensing estimation of Chl a. Mustapha et al. (2012) hypothesize that SE Beaufort Sea waters are optically similar to a large proportion, though unknown, of the coastal Arctic waters. For instance, the Chukchi Sea is characterized by low Chl a and high CDOM while the Kara and Laptev seas have low Chl a concentrations. Lack of in situ optical data over the Siberian shelves prevents us to extrapolate our findings to other arctic regions, but there are indications that current Chl a operational algorithms should be used with care over the Eurasian Arctic shelves. Moreover, Bélanger et al. (submitted, 2013) found that melting multi-year ice released significant amount of non-algal particulates (NAP) near the sea surface relative to sub-surface waters and the need for considering non-uniform vertical distribution of particles in such systems when interpreting remotely sensed ocean color. Brunelle et al. (2012) suggest the use of regional regressions for the retrieval of chlorophyll a could improve the quantification of phytoplankton biomass in the Canadian Arctic. In fact, the acclimatation of adapted phytoplankton populations to the changing environment (i.e., water column stratification, light and nutrient availability) by altering their cellular content and/or pigment composition could affect the remote sensing interpretation of Chl a.

An inherent effect of warmer temperature and moisture fluxes in Arctic Ocean is the increase cloudiness (Eastman and Warren 2010, Palm et al. 2010, Vavrus et al. 2011) that partly counteracts the positive influence of declining sea ice on PAR entering the sea surface. Against a general backdrop of rising productivity over Arctic shelves (Arrigo et al. 2008, Arrigo et al. 2011), significant negative trends were observed in regions known for their great biological importance such as the coastal polynyas of northern Greenland (Bélanger et al. submitted). In counterpart, thermal fronts driven by wind and tidal mixing and evidenced along steep shelf slopes could have a significant influence on the global carbon cycling and nutrient balance in the Beaufort Sea. Future work should focus on understanding the links between frontal physics and biological features to predict the response of the Beaufort Sea coastal system to climate change.

Another limitation inherent to the satellite-based PP trends assessments is the occurrence of a subsurface chlorophyll a maximum (SCM, Martin et al. 2010) which can be important in the Arctic waters during the summer period. The magnitude and timing of the spring bloom depends mainly on winter nutrient replenishment in the upper water column, which is driven by vertical stratification, convection and wind forcing events (Carmack and Wassmann 2006, Tremblay et al. 2002, Tremblay et al. 2008). The occurrence of fall bloom is associated with increased vertical mixing, which results from convection (due to surface cooling and ice formation) or increased storminess. These latter blooms have a lower magnitude since they occur at a time when irradiance is rapidly decreasing. Given their oligotrophic status, the Beaufort Sea (Ardyna et al. 2011, Carmack et al. 2004), the central Arctic Ocean (Gosselin et al. 1997, Lee and Whitledge 2005) and Hudson Bay (Ferland et al. 2011) have favorable conditions for the persistence and productivity of SCM due to a rapid surface nutrient depletion at the beginning of the growing season. In the other sub-Arctic and Arctic regions characterized by weakly stratified waters, episodes of SCM are more sporadic and restricted to periods of surface nutrient exhaustion. Ardyna et al. (submitted to Biogeosciences) thus argue that these seasonal features have significant implications for nitrate-based new production, food webs and biogeochemical cycles mainly in oligotrophic regions and during limited periods of nutrient exhaustion at the surface in other sub-Arctic and Arctic seas.

The monitoring of the primary production and SCM is critical in an Arctic Ocean affected by deep and sudden transformation as illustrated by the fast warming in the Hudson Bay since a decade. Galbraith and Larouche
(2011) found that sampling years 2003, 2005 and 2006 were characterized by warmer than normal surface temperatures. Moreover, they noted that 1999 and 2006 had the warmest surface temperatures of the Hudson Bay system since 1985 and since at least the 1930s when considering air temperature proxies, and that the conditions observed then could be similar to those found under future climate change scenarios. Likely related to this warmer and thicker surface water layer, there has been recent drastic and faster than expected change of the sea ice cover. Indeed, based on a study that plotted the difference between a recent 30-year climatological monthly mean dataset (1961–1990) and another future 30-year climatological monthly mean dataset (2041–2070) for 2 m air temperature, Joly et al. (2011) have shown that such a reduction of the sea ice cover was not expected before the mid-century. However, data from the Canadian Ice Service showed that sea ice cover extent has diminished by about one third from December 2007 to December 2010. In response to this sudden change of the sea ice cover, the high stratification season in Hudson Bay is probably longer than before and nutrients essential for primary producers would then be even more reduced, which likely explains lower Ch la biomass in 2006. These fast changes are expected to force plankton assemblages and adaptation strategies towards those compatible with a warmer and more oligotrophic marine environment.

The study of taxonomic and functional biodiversity is of great importance to identify the species able or not to adapt new conditions. At the same time, the high sensitivity of some specific Arctic phytoplankton to environmental changes provides a useful marker of these changes. Small flagellates are often overlooked but ubiquitous in both the ocean and sea ice and indicate complex microbial food webs rather than efficient diatom to zooplankton energy and carbon transfer. Our groups research emphasis within the Hotspots project is identifying and mapping taxonomic and functional biodiversity of marine microbes especially small flagellates but also, bacteria and Archaea. This is important for understanding how energy and carbon are cycled within Arctic food webs, and for monitoring change. Terrado et al. (2012) found that many high latitude ribotypes are specifically adapted to colder waters, and are likely to be vulnerable to the ongoing effects of Arctic climate warming. Thaler and Lovejoy (2012) mapped the distribution of heterotrophic flagellates in the genus Cryothecomonas, which has been reported sporadically in Arctic species lists, and although often absent, occasionally reaches bloom proportions. These flagellates were earlier reported from ice, sediments, and the water column from Arctic and subarctic seas, factors determining its occurrence were not known. Cryothecomonas temporal and geographic distribution strongly suggests that Arctic strains found in the water column are associated with recent ice melt and could be an indicator of recent surface ice conditions. Sea ice itself is a distinct habitat and the morphologically identifiable sympagic community living within sea ice can be readily distinguished from pelagic species. Sympagic metazoa and diatoms have been studied extensively since they can be identified using microscopy techniques. However, non-diatom eukaryotic cells living in ice have received much less attention. With the loss of multiyear ice the nature of extant first-year ice is changing with increasing drift ice present. There are also changes in the duration and extent of both land-fast ice and drift ice. We found that the two types of ice harbored distinct communities (Comeau et al. 2013) suggesting that studies carried out on land fast ice may well miss some key properties of drift ice, including the complexity of ice based food webs and tendency to sink out of the photic zone.

In addition to changing phytoplankton habitat, the ice melting impact the pelagic-benthic coupling widely suggested as a general feature of Arctic shelves (Ambrose and Renaud 1995, Grebmeier and Barry 1991, Piepenburg et al. 1997, Wassmann et al. 2006), in terms of both quantity and quality of the organic matter exported from the water column and/or sea ice to the seabed (Morata et al. 2008).

Astarte moerchi is a potential species to trace food webs changes over a long period and preliminary results on their shells contradict the current paradigm,
which states that in general, there would be a shift in the relative importance of sea-ice, pelagic and benthic biota in the overall carbon flux from ‘sea-ice algae benthos’ to ‘phytoplankton-zooplankton’ dominance. Sclerochronological analysis show in the NOW polynya area a major change in the growth dynamics of the population over the last ten years related to an increased export of surface microalgae towards the bathyal domain (Gaillard et al. in prep).

Conclusion

The year 2012 has provided new scientific advances highlighted by several publications in leading scientific journals. The communication and collaboration between scientists and with stakeholders and the public have been numerous thanks to the organization and participation to international and national conferences such as the IPY conference “From Knowledge to Action”, the ArcticNet ASM and Arctic Frontiers 2013. Efforts in the comprehension of optical properties, planktonic and benthic community distribution, specificity and function underline the unique character of Canadian Arctic waters and the importance of developing state-of-the-art observation tools to acquire reliable knowledge and better interpret and forecast future trends. Questions relating to future biological productivity or the capacity of polar organisms to adapt or acclimate to environmental change are highly debated and need deeper consideration. New projects are taking shape, including the acquisition of a pan-Arctic database on benthic communities, a monitoring of DMS, development of new acoustic method to follow arctic cod or the use of biological archives of Arctic environmental variations (BB polar project). The “hotspot” projects emphasizes a willingness to communicate with Inuit populations through initiatives like Arctic-ICE 2012 as well as the elaboration of chapters by the co-leaders of the Hostpots project for the IRIS-2 report. Science is connected to action and knowledge through participation in projects like CHONE, where academic and government partners work together for the conservation and sustainability of the marine biodiversity. The expected return of the Amundsen icebreaker will provide the opportunity to continue the acquisition of in-situ data and precious time series.

Acknowledgements

We thank Pierre Coupel, Jonathan Gagnon and Marjolaine Blais for their assistance in compiling and organizing the information presented in this report.

References


Arrigo, K. R., P. A. Matrai, and G. L. van Dijken (2011), Primary productivity in the Arctic Ocean: Impacts of complex optical properties and subsurface


Conti, L., and M. Scardi (2010), Fisheries yield and primary productivity in large marine ecosystems, Marine Ecology Progress Series, 410, 233-244.


Estrada, R., M. Harvey, M. Gosselin, M. Starr, P. S. Galbraith, and F. Straneo (2012), Late-summer zooplankton community structure, abundance, and distribution in the Hudson Bay system (Canada) and their relationships with environmental conditions, 2003–2006, Progress in Oceanography, 101(1), 121-145.


Gaillard, B, Olivier, F, Thébault, J, Méziane, T,


Joly, S., S. Senneville, D. Caya, and F. J. Saucier (2011), Sensitivity of Hudson Bay Sea ice and ocean climate to atmospheric temperature forcing, Clim Dyn, 36(9-10), 1835-1849.


Li, W. K. W., F. A. McLaughlin, C. Lovejoy, and E. C. Carmack (2009), Smallest Algae Thrive As the Arctic Ocean Freshens, Science, 326(5952), 539.


Matsuoka, A., P. Larouche, M. Poulin, W. Vincent, and H. Hattori (2009), Phytoplankton community adaptation to changing light levels in the southern Beaufort Sea, Canadian Arctic, Estuarine, Coastal and Shelf Science, 82(3), 537-546.


Thaler, M., and C. Lovejoy (2012), Distribution and Diversity of a Protist Predator Cryothecomonas...


Publications

(All ArcticNet refereed publications are available on the ASTIS website (http://www.aina.ucalgary.ca/arcticnet/).


Burt, A., Wang, F., Pucko, M., Mundy, C.-J., Gosselin,


Campbell, K.L., Mundy, C.J., Barber, D.G. and Gosselin, M., 2012, Characterizing the ice algae biomass-snow depth relationship using transmitted irradiance., ArcticNet 8th Annual Scientific Meeting, Vancouver, 11-14 December (Oral presentation).


Duerrksen S.W., Thiemann, G.W., Niemi, A., Budge, S.M., Poulin, M., Wiktor, J. and Michel,

Duerksen S.W., Thiemann, G.W., Niemi, A., Budge, S.M., Poulin, M., Wiktor, J. and Michel, C., 2012, Spatial variation of the trophodynamic lipid flux in zooplankton during the ice algal spring bloom in the Canadian High Arctic., Arctic in Rapid Transition Science Workshop, Sopot, Poland. 23-26 October (Poster presentation).


Lizotte, M., 2012, DMSP bacterial metabolism at the ice-water interface during the spring melt period in Arctic., ArcticNet 8th Annual Scientific Meeting, Vancouver, 11-14 December (Oral presentation).

Galindo, V., Levasseur, M., Scarratt, M., Kiene, R.P., Mundy, C.J., Gosselin, M., Michaud, S. and Lizotte, M., 2012, DMSP bacterial metabolism at the ice-water interface during the spring melt period in Arctic., Colloque « L’heure juste sur la santé des océans » de Québec-Océan, Hôtel Omni-Mont-Royal, Montréal, 7-9 novembre (Poster presentation).


Link, H., 2012, Studying the Functioning of Benthic Hotspot and Coldspot Ecosystems in the Canadian Arctic, Ph.D thesis, Université du Québec à Rimouski, Canada.


Lovejoy, C., 2013, Microorganisms, chapter 11, Arctic Biodiversity Assessment.


RESEARCH, V.117.

Motard-Côté, J., Levasseur, M., Oswald, L., Gosselin, M., Blais, M. and Kiene, R.P., 2012, Dimethylsulfoniopropionate (DMSP) and dimethylsulfide (DMS) distribution and cycling in the Canadian Arctic., 2012 IPY Conference, “From Knowledge to Action”, Montréal, Canada, 22-27 April (Oral presentation).


Philippe, B., 2012, Changements récents dans la dynamique des algues de glace dans le secteur canadien de la mer de Beaufort, Mémoire de maîtrise (M. Sc.), Université du Québec à Rimouski, Submitted.


Roy, V., Archambault, P., Conlan, K.E., 2012, Effectiveness of Abiotic Surrogates to Describe Benthic Hotspots in the Canadian Arctic, International Polar Year Conference, Montréal, Canada, April 22-27. Oral presentation.


Partnership to Develop Scientific Guidelines for Conservation and Sustainable Usage of Canada’s Marine Biodiversity, Fisheries 37(7), 296-304.


