Summary of the Canadian BioGeoSCAPES planning workshop for the International BioGeoSCAPES community

Introduction: The Canadian BioGeoSCAPES Planning workshop was convened in Halifax (October 25-27, 2019) by Erin Bertrand (Dalhousie University), Maite Maldonado and Steven Hallam (University of British Columbia). In total, 29 participants from across Canada with diverse expertise in chemical, physical, and biological oceanography, biogeochemistry, ecology, evolution and philosophy, genomics, physiology, biophysical and ocean dynamics, mathematical and statistical modeling, as well as in-situ sensor technology assembled together to develop a shared perspective. The workshop aimed to gather feedback from Canadian scientists on the preliminary BioGeoSCAPES Mission Statement drafted during the "Biogeotraces-like program" workshop organized in Woods Hole, MA (USA) in November 2018 (Summary document found here). The workshop was organized around three charge questions suggested by participants in the Woods Hole meeting, for discussion during the upcoming national meetings.

1. The preliminary BioGeoSCAPES Mission Statement is "*To improve our understanding of the functioning and regulation of ocean metabolism and its interaction with nutrient cycling within the context of a hierarchical seascape perspective*"

Canadians felt that some words in this statement were not punchy enough (e.g. improve), too vague (e.g. understanding), or too restrictive (e.g. nutrient). Two revised BioGeoSCAPES Mission statement were proposed:

V1 - *To develop mechanistic and quantitative knowledge of ocean metabolism and elemental cycling on a changing planet*.
V2 - *To transform our understanding of ocean metabolism on a changing planet*.

2) How would Canada best contribute to BioGeoSCAPES efforts – e.g. fieldwork, laboratory work, modelling, intercalibration efforts, project coordination, data management, bioinformatics?

Canadians felt that our contributions to the international BioGeoSCAPES efforts should build directly on pre-existing strengths, which include:

a) **Modelling:** NEMO Ocean dynamics modelling, Paul Myers (Univ. of Alberta); bio-physical modelling, and coupled biogeochemical modelling, Susan Allen (UBC); mathematical and statistical modelling of marine biosphere, Zoe Finkel and Andrew Irwin (Dalhousie Univ.).

b) **Historical time series programs**: Vibrant collaborative research between various Canadian universities and Fisheries and Ocean Canada: i) Bedford Basin in Eastern Canada (sampling weekly since 1992); the Atlantic Zone Monitoring program (Spring and Fall transect cruises yearly since 1998) ii) Line P in the subarctic Pacific (sampling 26 stations in February, May and September, since 1956; only time series in the GEOTRACES dataset); and iii Saanich Inlet (sampling since 1953). These time series provide remarkable data sets of, for example, temperature, salinity, dissolved oxygen, nutrients, zooplankton and phytoplankton abundance and community composition, and in some cases trace metal and multi-omic information.

c) **Ongoing Arctic Research in Canada**: Fisheries and Oceans Canada investment in long-term monitoring/sampling across Canada's 3 ocean basins (i.e. Pacific, Arctic and Atlantic) in collaboration with various Canadian universities to elucidate basin connectivity patterns and investigate Atmosphere-Ice-River-Ocean coupling processes and interactions in the Arctic. For the past 14 years, ArcticNet has promoted and funded research to determine the impacts of climate change and modernization in the Canadian North. ArcticNet works closely with federal and provincial organizations and universities, collaborating with more than 150 partner organizations in 14 countries. There are presently 30 new projects funded. There are currently two Canadian Arctic and Subarctic Marine stations: the Churchill Northern Research Centre in Churchill, Manitoba, founded in 1976, and the Canadian High Arctic Research Station (CHARS) campus in Cambridge Bay in Nunavut. A new Arctic observatory is currently being developed in Hudson Bay, Churchill Marine Observatory. A new Institute called, Institut nordique du Québec (INQ) has been established in collaboration with Université Laval's Sentinel North (SN), and a proposal was submitted on Jan. 2020 for a 'Baffin Bay Observing System' (U. of Manitoba).

d) **Systems ecology of marine food webs across spatial and temporal scales** with strong research and training capacity at disciplinary interfaces, including modelling growth dynamics of phyto/zooplankton and coupled biogeochemical cycling between microorganisms along defined nutrient and energy gradients. Infrastructure for developing high-throughput functional metagenomic screens for biological engineering applications and "blue" technology innovation.

e) Marine observatory technology for biogeochemical cycles (e.g. Sea Cycler, led by Doug Wallace; and BioGeoChemical Argo, led by Roberta Hamme, Katja Fennel, Blair Greenan and others). The SeaCycler is a mooring system that profiles a large suite of sensors through the upper ocean to collect simultaneous, high vertical resolution measurements.

f) Bioinformatics and high-performance computing capacity for processing and analyzing high-dimensional multi-omics (DNA, RNA, protein and metabolites) data at the individual, population and community levels of biological organization: Development of modular pipelines for metagenome assembled genome (MAG) and single-cell genome (SAG) interpretation and machine learning approaches for metabolic pathway prediction at different levels of sequence complexity and completion. Development of the environmental genomics encyclopedia (EngCyc) portal system for pathway-centric analysis of multi-omic data sets. Massive archival data sets from ongoing time-series for comparative community analysis of marine microbes and viruses.

We envision contributing primarily to BioGeoSCAPES research in the Arctic, as well as the northeast subarctic Pacific and North Atlantic. Our ongoing Canadian time series, particularly our repeat transects, are ideal sampling opportunities and model systems for international intercalibration and standardization efforts. We also aim to be actively involved in BioGeoSCAPES bioinformatics initiatives, and possibly lead the international Rate Processes intercalibration and standardization effort.

3) What science questions are most important to Canadians within the broad scope of BioGeoSCAPES on a 10-year timeframe?

The preliminary Canadian BioGeoSCAPES mission is: *To transform our understanding of how ocean metabolism in Canada's diverse, connected seascapes responds to and influences global change. Themes: comparisons and connectivity.* Canada is an ocean nation with marine waters spanning its west, east and north coastlines. Canada's three bordering oceans (Pacific, Arctic and Atlantic) are indeed closely connected and are all experiencing pronounced physical and biological changes due to climate variations and anthropogenic activity (i.e. increased temperatures; degrading habitats; shifts in species distributions; and food webs dynamics). The preliminary Canadian BioGeoSCAPES mission is *to transform our understanding of how ocean metabolism* (i.e. defined as the chemical processes within individual organisms and populations, as well as among communities and ecosystems) *in Canada's diverse, connected seascapes responds to and influences global change*. We aim to understand controls on ocean metabolism in the contexts of this marine connectivity and change. We envision asking questions about how alterations in physiochemical properties across Canada's three oceans will affect integral metabolic processes such as primary production, nitrogen transformations, and mixotrophy. Specific questions of interest include:

- *What are the most important physical, chemical and biological controls on ocean metabolism, and how do these vary regionally and in time?*
- *What are the important processes that control the distribution of elements and organic material in the water column?*
- *How do contaminants influence ocean metabolism and vice versa?*
- *Is marine productivity decreasing or increasing in Canada's three oceans?*
- *Is ocean metabolism resilient on human timescales?*
- *How do organismal assemblages' impact and control recycling vs export of organic material from the mixed layer?*
- *How do microbe- particle interactions control the release of elements in the water column?*
- *How does ocean metabolism emerge across different levels of biological organization?*
- *Are there "keystone metabolites" that structure ocean metabolic interactions in coherent ways?*
- *Can we harness knowledge of ocean metabolism to define units of conservation or develop new technologies?*

We plan to answer these questions through intensive, collaborative, and interdisciplinary study of data collected on established Canadian sampling lines, including Line P and in Saanich Inlet, the Halifax line and in Bedford Basin, transects in Baffin Bay, and other locations with established time series measurements in a spatial context. This work would build on Canada's long history of monitoring these locations through efforts by Fisheries and Ocean Canada and many academic ocean researchers who have come before us. This will require the simultaneous collection of extensive physiochemical parameter datasets, multi-omic datasets and rate measurements. Measuring metabolic processes and the development of new algorithms, models and software applications for integrated analysis of geochemical parameters and multi-omic information, as well as advances in ocean biogeochemical modelling will be key to the success of Canadian BioGeoSCAPES.

4) Are there impediments that the International program could seek to mitigate via training or collaboration?

Our discussion highlighted the urgent need to intercalibrate and standardize sampling protocols and the processing of samples. Canada was involved in the Ocean Nucleic Acids 'Omics Intercalibration and Standardization workshop in January 2020, as well as the Intercomparison of Ocean Metaproteomic Analyses and the SCOR working group 144 for integrated analysis of process rates and multi-omic information in expanding oxygen minimum zones. A workshop for the Intercalibration

and Standardization of Rate Processes is needed and Canada is willing to take the lead, in collaboration with Australian scientists (P. Boyd, R. Strzepek, and D. Suggett). Additional challenges that we expect to encounter in implementing Canadian BioGeoSCAPES include the availability of ship time and sea-going research infrastructure, as well as operational resources to provision these sampling programs with dedicated academic trainees and scientists. Despite these potential limitations, we are well-positioned to make valuable contributions to this international program because of our rich history of making spatially-resolved time series measurements, our expertise in sensor-based ocean monitoring, ecology and evolution, as well as our capacities for modeling, and bioinformatics. Many countries in or near Canadian waters but these international programs/expeditions don't always include Canadian scientists. The international community should strengthen collaborations with Canadian scientists when working in or near Canadian waters. At the same time, we lack expertise on large scale metabolite measurements and collaboration to address this would be beneficial to Canada.

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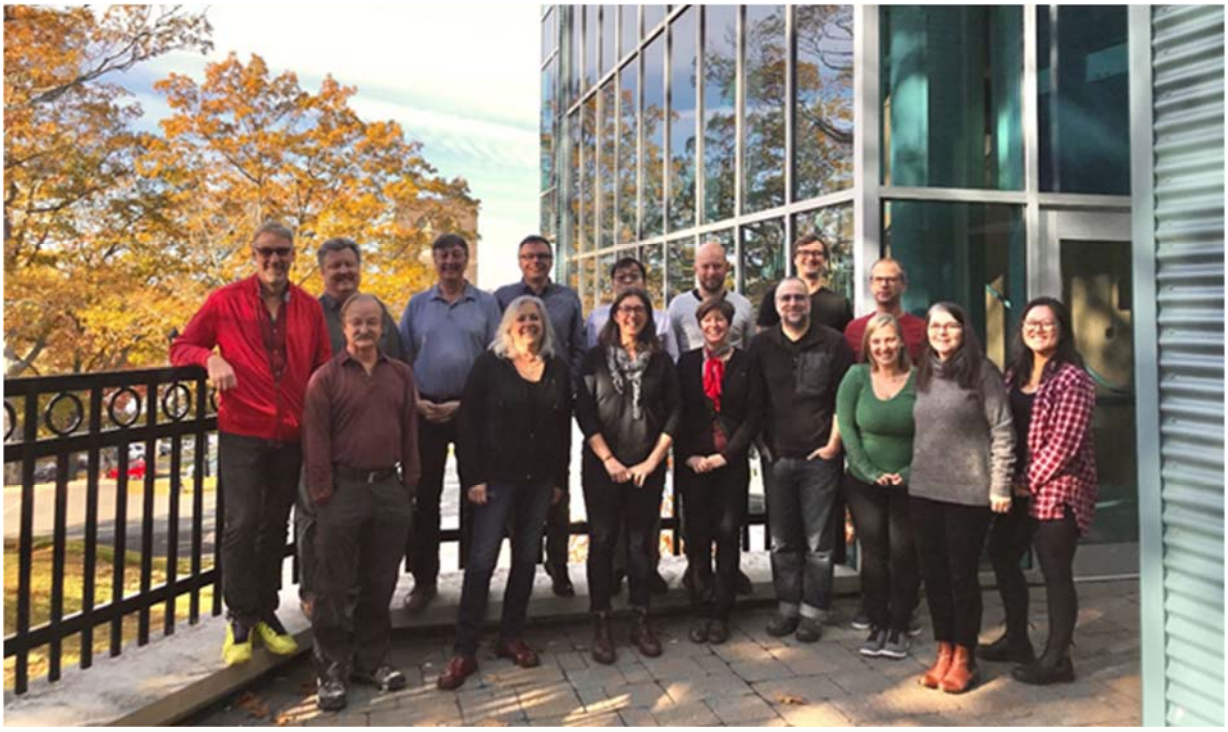

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Middle Row: Rogier Francois, Diana Varela, Erin Bertrand, Maite Maldonado, Steven Hallam, David Walsh
Front Row: Carly Buchwald, Julie LaRoche, Sachia Traving
Remote Participants: Rachel Sipler, Roberta Hamme, Stephanie Waterman, Susan Allen
Not pictured: John Archibald, Ford Doolittle, Zoe Finkel, Andrew Irwin, Andrew Lang

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