Proceedings of the Multidisciplinary Arctic Program (MAP) - Last Ice: Science Planning Workshop, January 16-17, 2018

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PROCEEDINGS OF THE MULTIDISCIPLINARY ARCTIC PROGRAM (MAP) – LAST ICE: SCIENCE PLANNING WORKSHOP, JANUARY 16-17, 2018

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The Fisheries and Oceans Canada (DFO) Last Ice Area (LIA) Science Program was established after a Ministerial Announcement by the Government of Canada asserted Canada's commitment to the LIA in the fall of 2017. The four-year Multidisciplinary Arctic Program (MAP) – Last Ice Science Program, aims to characterize the only region expected to retain summer sea ice over the next decades. As permanent Arctic sea ice cover recedes, the LIA will be essential for sea ice associated species, ecosystems and communities that depend on them. This region is one of the most remote and inaccessible regions in the world and therefore generally lacks baseline ecological knowledge. The Government of Canada has committed to work in collaboration with northern partners and national and international stakeholders to better understand the LIA. Extensive field sampling is planned for spring 2018 and subsequent years. The LIA Science Planning Workshop, held in Ottawa from January 16-17, 2018 brought together national and international partners, and stakeholders to share scientific knowledge of the LIA, identify key science questions, and provide input to a Science Plan.

RÉSUMÉ

Loewen, T. N., and Michel, C. 2018. Proceedings of the Multidisciplinary Arctic Program (MAP) – Last Ice: Science Planning Workshop, January 16-17, 2018. Can. Manuscr. Rep. Fish. Aquat. Sci. 3159: vii + 53 p.

Le programme scientifique relatif à la zone de glace séculaire de Pêches et Océans Canada (MPO) a été mis sur pied après que le gouvernement du Canada a fait une annonce ministérielle affirmant l'engagement du Canada à l'égard de la zone de glace séculaire à l'automne 2017. Le Programme multidisciplinaire de l'Arctique (MAP) – Glace séculaire, d'une durée de quatre ans, vise à caractériser la seule région qui devrait conserver sa glace de mer en été au cours des prochaines décennies. À mesure que la couverture de glace de mer permanente dans l'Arctique recule, la zone de glace séculaire sera essentielle pour les espèces, les communautés et les écosystèmes associés à la glace de mer qui en dépendent. Cette région est l'une des plus isolées et des plus inaccessibles dans le monde et, par conséquent, elle souffre généralement d'un manque de connaissances écologiques de base. Le gouvernement du Canada s'est engagé à travailler de concert avec des partenaires du Nord et des parties intéressées à l'échelle nationale et internationale pour mieux comprendre la zone de glace séculaire. Un échantillonnage intensif sur le terrain est prévu pour le printemps 2018 et les années suivantes. L'atelier de planification des sciences portant sur la zone de glace séculaire, qui a eu lieu à Ottawa les 16 et 17 janvier 2018, a permis à des partenaires nationaux et internationaux et des parties intéressées d'échanger leurs connaissances scientifiques sur la dernière zone de glace, de cerner les questions scientifiques clés, et de contribuer à l'élaboration d'un plan scientifique.

ACKNOWLEDGEMENTS

The Last Ice Science Planning Workshop was planned and coordinated with the assistance of Joclyn Paulic, Diane Jones, Kim Thomas, and Donald Cobb. Dr. Robert Young helped to co-chair the meeting. The participants in the workshop (**Appendix 2**) provided presentations that advanced and helped to achieve the purpose of the science planning meeting. These contributions and discussions of LIA science were greatly appreciated during the workshop. The Last Ice Area Science Planning Workshop was financially supported by Fisheries and Oceans Canada, LIA Science Program. Thank you to (Jim Reist) and (Chantelle Sawatzky) for providing a review of the Science Workshop Proceedings before publication.

INTRODUCTION

The Science Planning Workshop can be considered the official kick-off of the LIA Science Program. The 2-day workshop brought together 35 participants from 14 agencies in Canada and abroad to discuss the science of the LIA.

Drs. Christine Michel and Robert Young co-chaired the Last Ice Area (LIA) Science Planning Workshop. Dr. Michel gave the welcoming address and extended thanks to workshop participants. She provided background on the early development of the LIA Science Program in 2010. Dr. Michel presented the workshop objectives, reviewed the agenda, and detailed the break-out sessions. Specific objectives of the workshop were to: i) provide a forum to discuss science in the LIA, ii) take stock of the current understanding and key science questions for the LIA, iii) discuss linkages of the LIA science program with national and international Arctic Science Initiatives, and iv) provide the basis for the development of the LIA Science Plan.

The breakout sessions aimed to: i) identify key science questions, knowledge gaps and challenges, ii) link LIA science to Arctic policy and science initiatives, and iii) discuss program coordination and communication.

Dr. R. Young highlighted the importance of unique Arctic habitats associated with the disappearing remnant multi-year sea ice and the need of protection for future generations, as well as the need to understand the ecology of the region and how it may change over the next 40-50 years. He welcomed participants to the science planning workshop. A round table of introductions by participants followed (**Appendix 2**).

PRESENTATION SUMMARIES

MULTIDISCIPLINARY ARCTIC PROGRAM (MAP) – LAST ICE

C. Michel presented the introduction to the LIA Science Workshop, titled "***Multidisciplinary Arctic Program (MAP) – Last Ice***". The presentation provided background on the LIA Science program both in terms of Arctic science and of how science-to-policy communication has influenced Arctic priority initiatives, setting the stage for the LIA program. The acronym "MAP" (Multidisciplinary Arctic Program) – Last Ice was introduced as a reminder that science in the LIA is ground-breaking in a poorly studied region.

The overarching scientific context for LIA science is the rapidly changing sea ice in the Arctic Ocean and in particular, the shift from multi-year ice to first-year ice (ice that remains over multiple years versus ice that melts in summer). The comparison between the sea ice extent in March 1985 (30 years ago) with the latest data in March 2017 was presented, showing tremendous changes taking place in the Arctic Ocean as multi-year ice decreased from ca. half of the sea ice extent in the 1980s to less than 20% according to latest records (**Figure 1**).

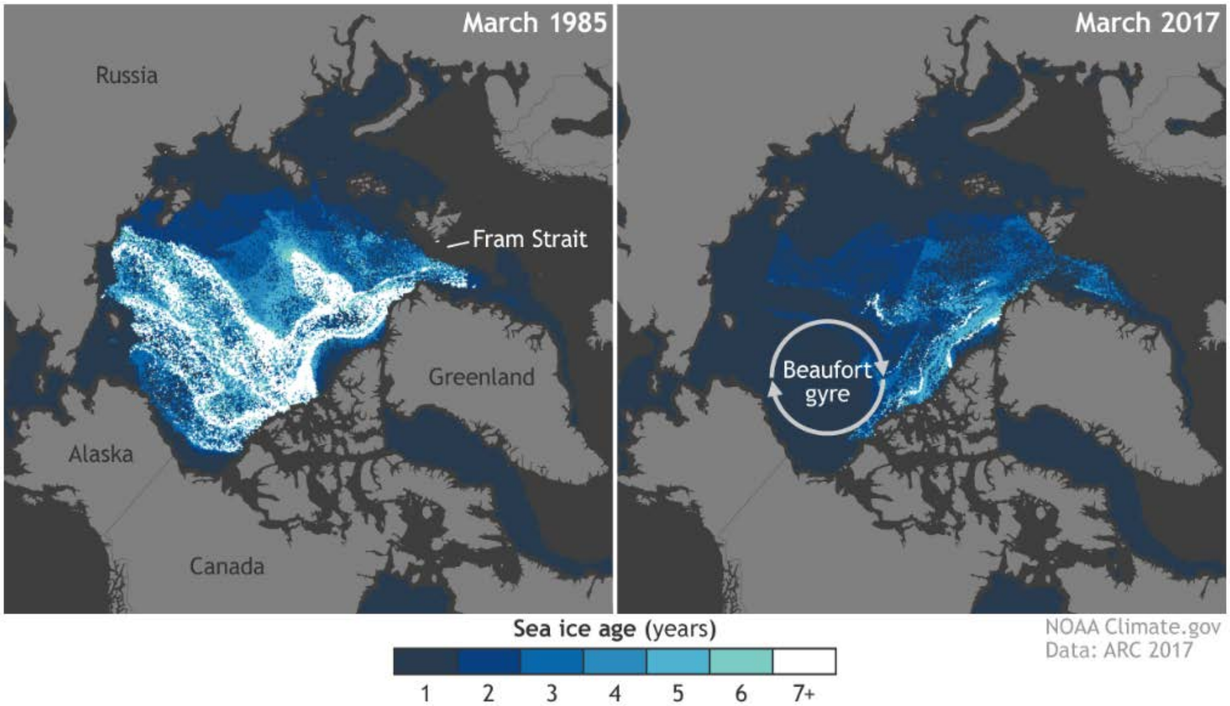

Figure 1: Maps showing the extensive loss of multi-year sea ice in the Arctic Ocean during the past three decades (March 2017 vs March 1985). From: https://www.climate.gov/news-features.

The dramatic and rapid shift from multi-year towards younger sea ice affects physical, chemical and biological processes at multiple scales and trophic levels. For ecological processes, changes affecting the ice and snow habitat alter how marine mammals such as seals and polar bears use the sea ice for denning. At the other end of the trophic spectrum, changes in sea ice can affect the ice algal and microbial biodiversity living within. Changes in sea ice not only affect the ice but also the ocean beneath it. Snow/sea ice change light transmission to the ocean and therefore the ocean's primary production. Changes in sea ice also have broader larger-scale impacts on the climate and ocean circulation. For example through the albedo effect, as less reflective sea ice is spatially present, warming the upper ocean, and a positive feedback loop reinforcing sea ice melt is created. This also influences ocean circulation through the warming of surface water masses.

Models of sea ice extent in the Arctic project a summer ice-free Arctic by mid-century and observations suggest that these projections are optimistic. The Last Ice Area is the only Arctic region where summer sea ice is projected to persist over the coming decades. It is a unique and important region within which to study sea ice associated processes and ecosystems.

The development and implementation of the LIA Science Program was described as a multi-phased process (**Figure 2**). Phase 1 (2010-2013) started in 2010 with the Arctic Council Climate Change Assessment SWIPA (Snow Water Ice, Permafrost in the Arctic); followed by the Arctic Biodiversity Assessment. These two Arctic Council Assessment Reports recommended science to better understand sea ice processes and changes in the Arctic, including the ecological role of sea ice, and its biodiversity and productivity. The reports recommended science and conservation efforts in the Last Ice Area, recognized as the only region where multi-year sea ice remains in the Arctic, and provided an impetus for program development.

In Phase 2 (2013-2016), science policy linkages and programs were further developed, with Arctic Council reports highlighting the importance of safeguarding important marine areas and biodiversity, as well as the importance of sea ice associated species and ecosystems in the Arctic. A recent IUCN-WWF Report specifically identifies the remnant Arctic multi-year ice, the Last Ice area, as a potential area of outstanding universal value due to its unique nature. The region identified in the report is broader than DFO's focal area for the MAP – Last Ice Science Program, as our focus is on the multi-year ice region within Canada's Exclusive Economic Zone (EEZ) and accessible from established transportation bases such as Alert, Canada, at least in the early stages of implementation of the science program.

The third phase (2017-2021) is the implementation stage of the DFO MAP – Last Ice Science Program. Launched through a Ministerial Announcement by the Government of Canada in 2017, DFO established the 4-year Last Ice Area Science Program.

DFO is adopting and developing a collaborative framework to combine expertise across regions (4 DFO regions), using a whole-government approach (5 Departments), and with national and international partners (5 partnering organizations). DFO Science in the LIA underpins Oceans Management requirements for policy development (e.g., marine protected areas).

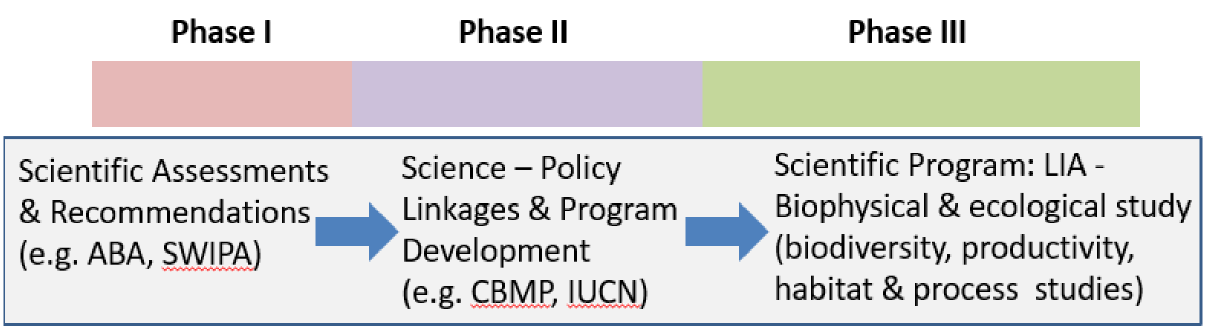

Figure 2: The development and implementation of the Last Ice Area Program, through step-wise phases.

DFO recognizes the essential value of Northern partnerships. DFO engaged in initial dialogue with the Government of Nunavut, Nunavut Wildlife Management Board (NWMB), the Inuit Circumpolar Council (ICC), and Nunavut Tunngavik Inc. (NTI). The closest communities to the Last Ice Area are Grise Fjord and Resolute Bay; communication with the Iviq Hunters and Trappers' Association and Resolute Bay Hunters and Trappers' Association is on-going. Suggestions for potential avenues for communication and engagement with northern partners include providing input to annual planning meetings with NWMB, NTI and possibly FJMC

(Fisheries Joint Management Committee), providing annual reports to the nearest communities and co-management boards, and fostering engagement with the Government of Nunavut, and taking part in science training and activities in programs such as N-CAMP (Nunavut Community Aquatic Monitoring Program) and SMART Ice.

Partnering organizations in government, academia, and international partners were mentioned as well as potential linkages in terms of science of the LIA.

The overarching scientific question for the LIA program was suggested as: “How does multi-year sea ice in the LIA influence the structure and functioning of Arctic marine ecosystems; and how is it changing?”

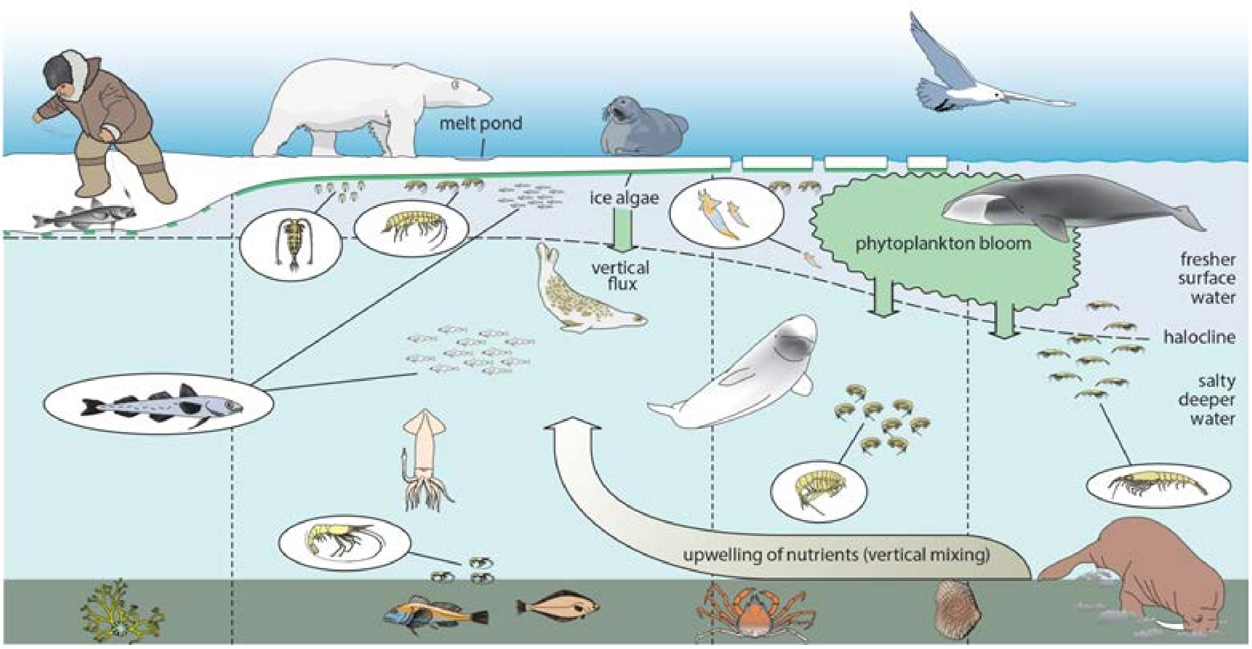

Figure 3: Sketch representing the generalized role of sea ice in Arctic marine ecosystems. From AMAP (2012).

Scientific objectives for LIA are as follows:

1. Characterizing the LIA in terms of physical and biological processes in the context of unique sea ice conditions (specifically old multi-year sea ice);
2. Documenting and improving knowledge of Arctic biodiversity and sea ice habitat and habitat use;
3. Providing sea ice and ocean data to inform and better parameterise climate and biogeochemical models.

An integrated bio-physical system approach is proposed (**Figure 3**), combining aerial surveys for habitat characterization and marine mammals, continuous observations of meteorological conditions, ice conditions, and water conditions, using autonomous samplers and new technology (e.g., unmanned aerial vehicle). Under-ice sampling, sea ice biochemical (e.g., nutrients, biomass, and diversity) and physical measurements will accompany autonomous observations in our multidisciplinary approach. Partners from the Alfred Wegener Institute (AWI) will use a remotely operated vehicle to characterize under-ice conditions, to collect zooplankton, and to collect fish larvae at the under-ice surface.

Dr. Michel presented a Gantt chart showing the LIA Science Program time table for 2017-2021, indicating a second LIA workshop planned for January 2019. Dr. Michel concluded by reinforcing the overall objective of this workshop, i.e., to discuss science of the LIA, and that the discussions and presentations would help inform the LIA Science Plan. Workshop Proceedings will follow.

A short discussion followed C. Michel's presentation. The first question asked about the status and interest of a working relationship between Greenland and Denmark in the LIA since the science program is focused around Alert, NU. There is strong interest in working with Greenland/Denmark due to proximity/influence of the Lincoln Sea. There were initial discussions to this effect. A second question focused on the productivity of the LIA – how productive is the LIA and is it considered a productive area? There are currently no production estimates for the LIA; this is a science gap that needs to be addressed. The recent Lange et al. (2017) paper suggests it is more productive than previously thought due to the potential role of hummocked ice. A further comment was made that productivity of the region may increase in the future due to changes in the multi-year sea ice conditions. A third question addressed scoping for the LIA science field research – why was the current field season location scoped for LIA? The rationale for scoping had to do with boundaries of the LIA – the exact boundaries for LIA are not established. The LIA for the Science Program focusses on the region where old multi-year sea ice remains (i.e., the main driver of LIA) and importantly, the logistics capability to carry out the science. The wider LIA (northern boundary of the Canadian Arctic Archipelago) is extremely poorly characterised so there is a need to establish a start point. The area chosen also has some earlier sea ice data that can be used to complement the new data collection. Further, based on the Treasury Board submission, this is the area targeted by the program. Accessibility to the multi-year ice region north of the Canadian Arctic Archipelago is very limited; it is possible that declining sea ice will make it easier to access some of the areas in the future.

ARCTIC SCIENCE AT FISHERIES AND OCEANS CANADA

B. Keatley provided a presentation titled "***Arctic Science at Fisheries and Oceans Canada***". The presentation focused on DFO's national program and provided a broad overview. The Arctic science component is a key part of decision making and strategic outcomes. Arctic science supports DFO strategic outcomes in three areas: 1. economically prosperous maritime sectors and fisheries, 2. sustainable aquatic ecosystems, and 3. safe and secure waters. This is done through supporting ongoing operations, contributing to national and international issues, and collaborating with co-management and other partnerships. The scope of departmental Arctic science includes freshwater, coastal, and marine ecosystems. It additionally includes physical, chemical, and biological processes. Finally, the scope ties together the linkages between biogeochemical and physical processes through food webs. Examples of DFO Arctic science activities include: stock assessment, research and monitoring of structure/function of aquatic ecosystems, impacts of aquatic ecosystem stressors and change, science advice, hydrographic charting and mapping products, co-management and research with northern partners, and participation in international scientific initiatives. Some recent national drivers within the department are: 1. ministerial mandate commitments (i.e., implications of climate change in Arctic marine ecosystems, marine conservation targets, and restored funding to DFO science programs), 2. State of the Ocean ecosystem reporting, 3. northern Marine Transportation Corridors, 4. Ocean Protection Plan, and 5. co-development of a new Arctic Policy Framework (with Indigenous, territorial, and provincial partners). Recent international drivers relevant to the department include: 1. US-Canada Joint Statements, 2. White House Arctic Science Ministerial, 3. Central Arctic Ocean fisheries agreement, and 4. the Arctic Council. The USA-Joint Statements (March, December 2016) sought to help ensure a strong, sustainable and viable Arctic economy and ecosystem. This included low impact shipping corridors with a focus on sensitive ecological areas as well as exploring the protection of the Last Ice Area. With the White House Arctic Science Ministerial (September 2016), joint statements on international collaboration and inclusion of Indigenous peoples in science and decision-making were made. There was also an agreement to have a 2nd Arctic Science Ministerial in October 2018. The Central Arctic Oceans fisheries agreement was successfully negotiated in late 2017 and was supported by science input. Finally, the Arctic Council, through the Protection of the Arctic Marine Environment (PAME) working group, the International Council for the Exploration of the Sea (ICES), and the North Pacific Marine Science Organisation (PICES) working group helped with the assessment of the Central Arctic Ocean. The Conservation of Arctic Flora and Fauna (CAFF) working group of the Arctic Council provided updates to the Circumpolar Biodiversity Monitoring Program (CBMP) Arctic Marine Biodiversity Report. From a national DFO perspective, there is a large number of Arctic initiatives that are quickly moving forward leading to an exciting time for Arctic science.

A short discussion followed B. Keatley's presentation regarding the political context and potential impacts on Canada's commitments.

FROM PROCESS STUDIES TO SYSTEM UNDERSTANDING: ALFRED WEGENER INSTITUTE'S (AWI) INTERDISCIPLINARY RESEARCH IN THE ARCTIC OCEAN

C. Haas provided a presentation titled "***From Process Studies to System Understanding: Alfred Wegener Institute's (AWI) Interdisciplinary Research in the Arctic Ocean***". Science studies done at AWI were presented and focussed on interdisciplinary research from process studies to system understanding. Dr. Haas has worked in the LIA for approximately 10 years. Germany's interest in polar research is to better understand global views of climate and social responsibility. Germany has logistical and infrastructure developed to support Arctic programs.

AWI's mission statement is to be an international leader in polar research. AWI makes significant contributions by promoting awareness of how our global environment and Earth system are changing in the context of climate and coastal research. AWI provides the science basis for political decisions and provides essential polar and marine infrastructures. Science (geological, biological, and climate science) interest encompasses the past, present, and future as well as ocean floor to the atmosphere. Research infrastructure includes 3 stations within the Antarctic and 2 stations in the Arctic. Each pole has an established and operating year-round station. In addition, 6 ocean going vessels support polar science programs.

AWI has cooperative partnerships that are international and extensive. Canada is one partnership which has resulted in more than 200 joint publications. On an international level, AWI has provided support and aid to the development of the Weddell Sea Marine Protected Area. This is an example of science knowledge dedicated to research and the importance of protection. The AWI research program relating to Polar regions and Coasts in a Changing Earth Systems (PACES II 2014-2018) focuses on 4 main topics: 1.) changes in the Arctic and Antarctic, 2.) fragile coasts and shelf seas, 3.) earth system from a polar perspective (data acquisition, modelling and synthesis), and 4.) interactions between science and stakeholders. Specific focus on topic 1 demonstrates where LIA falls within the research program. An aspect of this theme is the examination of Arctic sea ice and its interaction with ocean ecosystems. The main driver is global change. This is manifested in a multitude of environmental changes with unknown consequences for humans, ecosystems, biodiversity and biogeochemical fluxes. For example, Arctic sea ice extent in the month of September has decreased from 1980-89 to 2008-17. The climate interacts with polar seas, marine ecosystems, and biogeochemical processes. The science goals are to unravel the causes of sea ice variability, ice-shelf loss and its impact to ecology and biodiversity and to quantify and model the physical, chemical, and ecological changes in association to their climate feedbacks. Field observations, process studies and laboratory experiments with particular focus on long-term observations from sea ice to the ocean floor are methods to achieve outlined goals. An example study is the export of algal biomass from melting Arctic sea ice that examines the consequences of primary production and export (Boetius et al. 2013). Future research developments include Frontiers in Arctic Marine Monitoring (FRAM: 2014-2021) and the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC: 2019-2020). FRAM is designed to help build strategies for long-term, year-round synchronous observations and biogeochemical modelling. MOSAiC research will focus on the biophysical processes of the sea ice ocean ecosystem during the Arctic winter period. MOSAiC is a major international research initiative under the International Arctic Science Committee (IASC) to improve the representation of Arctic processes in climate and ecosystem models.

A short discussion followed C. Haas's presentation. A question was asked about the governing body that protects the Weddell Sea Marine Protected Area. Antarctic treaties are the governing body for protecting the Weddell Sea Marine Protected Area. A second question was asked regarding how to link into other programs like MOSAiC. Presently, there are no agreed linkages but there may be something in development for the Beaufort Sea in the near future in association with the Amundsen. Gathering of key observations made at all key sites is occurring which is further allowing for identification of complements and linkages of studies. A further comment was made asking if formal research arrangements would benefit this program instead of informal arrangements. There are political aspects to create formal international agreements. If formalizing agreements increases funding opportunities, it would be worthwhile to pursue. There are still opportunities to join MOSAiC if funding is available although it is expensive to join.

ARCTIC MARINE PROTECTION

C. Wenghofer provided a presentation titled "***Arctic Marine Protection***". The presentation provided a background to the Oceans program, DFO's approach to Arctic Marine Protection, the interest in the LIA, the linkages of science/traditional knowledge to co-management, and the next steps forward. At the federal level, Canada has recently committed to international marine conservation targets (MCT) to conserve 10% of coastal and marine areas by 2020 (with specific targets to protect 5% of Canada's marine and coastal areas by 2017 and 10% by 2020). In 2016, the Joint Statement on Climate, Energy, and Arctic Leadership was made between the Canadian Prime Minister and the USA President that reaffirmed their commitment to protect 10% of marine and coastal areas by 2020. This helped to launch a new process with Northern and Indigenous partners to explore options to protect the "Last Ice Area" within Canadian waters, in a way that benefits communities and ecosystems.

The Oceans Act Marine Protected Areas (MPAs) are established to conserve and protect commercial and non-commercial fishery resources, endangered or threatened species, unique habitats, and high biodiversity/biological productivity. Two Oceans Act MPAs have been designated to date within the Western Canadian Arctic (Tarium Niryutait (TNMPA) in 2010 and Anguniaqvia niqiqyuam (ANMPA) in 2016). DFO is pursing work to establish new MPAs in the Eastern Canadian Arctic. Presently, a number of areas have been identified by an Area of Interest (AOI) working group (DFO, Regional Inuit Associations, and NTI) and DFO is awaiting recommendations from Regional Inuit Associations.

The LIA is being considered as a World Heritage Site. The World Wildlife Fund's (WWF) application to have the LIA put on the Canadian Tentative list was not moved forward, however, Park's Canada's application was accepted for Simirlik and Lancaster Sound. The LIA is a large region within the high Arctic of Canada and Greenland. It is a region where the oldest Arctic multi-year sea ice is found and is considered a refuge for Arctic species based upon expected presence and persistence of summer sea ice. The LIA includes some of the most biologically productive areas in the Arctic Ocean. It is projected to retain multi-year sea ice into the future thus providing important habitat for ice-dependent and culturally significant species. For assessment purposes, DFO (Oceans Program) is looking at a broad area to work with communities and have direct involvement in the process.

WWF Canada, Arctic Net and other organizations have been collecting science and traditional knowledge about the LIA for years and have led calls for its protection. A number of resources are available to examine the LIA including reports on the Ecologically and Biologically Significant Areas (EBSAs) by DFO, the Nunavut Coastal Resource Inventory by the Government of Nunavut, the draft of the Nunavut Land Use Plan, and the Inuit Qaujimajatuqangit (IQ)/traditional knowledge studies. Results from this workshop and resulting science plan will inform management decisions in the future.

The Government of Canada has committed to renewing its relationship with Indigenous Peoples on a nation-to-nation basis, based on recognition of rights, respect, co-operation, and partnership. Indigenous rights and land claim obligations are respected when advancing MPAs and partnerships with Indigenous groups are integral to meeting our common marine conservation goals. Indigenous groups will be essential in science and monitoring programs as well as in IQ collection. The Nunavut Agreement is respected by the Canadian Federal Government. Much of the LIA includes areas outside of the land claim, areas in the Canadian Exclusive Economic Zone (EEZ), portions of the Inuvialuit Settlement Region, and the Nunavut Settlement Area (NSA). The approach will be to focus solely on the NSA extending out to the EEZ boundary. There is a requirement to enter into the Inuit Impact and Benefit Agreements (IIBA) for any areas considered within the Nunavut Settlement Area. A "Whole of Government Approach" is being developed.

There are a number of other initiatives in the region that should be considered. The Government of Canada is committed to creating an Arctic Policy Framework to identify shared interests and priorities.

In partnership with Qikiqtani Inuit Association (QIA), the Government of Nunavut, the Government of Canada announced (14 August 2017) the final boundaries and the interim protection of the Tallurutiup Imanga (Lancaster Sound) as a National Marine Conservation Area (NMCA). The Pikialaorsuaq Commission (23 November 2017) issued its report on the current state of the North Water Polynya. The report has been acknowledged and will be discussed with Inuit leaders.

We do not know how each area will look into the future and this needs to be considered in any design. There is a need for more modelling and flexibility in the consideration of design. As well, opportunities exist for considering locally driven management options and areas being considered for protection under land use planning processes. This unique opportunity lends itself to broader integrated management approaches for the entire area. The area is expansive and the opportunity to utilise a variety of tools and/or approaches is available (e.g., Oceans Act MPAs, NMCAs, Integrated Oceans Management, industry guidance, Community Management Plans, etc.). Lack of capacity is an issue for partnering groups.

The federal government is making an investment in taking the next steps forward in conservation targets. The Government of Canada will work with Inuit and Northern partners to support and protect the future of this area in Canada's High Arctic Ocean. Dialogues with QIA, NTI, ICC, and the Government of Nunavut will occur. There will be continued information gathering from existing sources that considers both ecological and cultural values. There is engagement with broader external partners (NGOs, academia, etc.). And consultations are being done with nearby communities to determine support.

A short discussion followed C. Wenghofer's presentation. A question was asked regarding the meaning of an MPA and Oceans Act MPA and the variation of activities that can occur in individual MPAs (i.e., can you take a tanker through an MPA?). Activities that are allowed or prohibited are based on the objective(s) of the MPA and the impact(s) of those activities. Other measures such as fisheries closures that meet specific criteria also help to reach the 2020 targets whereas Oceans Act MPAs are referring to legislated MPA regions. The ability to undertake a specific activity is dependent upon the protection targets for the specific region. There is discussion on minimum standards but this has not yet been established. In a warming climate, how will we incorporate this into the MPA objective development? This is a question that is open beyond climate change and can be based on conserving the environment from other activities to protect new ocean areas. Any area we protect will be subject to change with environment and ecology being fluid. The contradiction is very apparent. There is a lot of need for discussion and interaction with Arctic communities for the development of MPAs and this is seen as a good approach. This usually means that there is a tendency to develop coastal MPA's due to community interaction. This then led to a question about how to develop more marine offshore MPAs. Offshore MPA development is happening. Partners have been supportive of offshore marine refuges. It is acknowledged as a challenge and part of the discussion for the protection of the LIA.

A general discussion followed. The first topic related to the terminology around conservation and MPAs. There is another term used called other effective area-based conservation areas. MPAs refer to Oceans Act legislation and marine refuges are considered other area based conservation areas. A second topic was discussed regarding the Government of Canada's consideration for the biodiversity convention for management planning (in reference to the biodiversity convention beyond national consideration). The United Nations discussions are occurring to develop new instruments for conservation beyond jurisdiction. This would occur through new treaties. There is no overarching mechanism right now but this doesn't mean it cannot occur (e.g., Antarctic Weddell Sea MPA). Within Canada we are only looking to develop conservation areas (i.e., MPAs, etc.) within our own jurisdiction. We can do this with other partners and have on international issues such as the central Arctic Ocean (high seas management). This is usually resource based versus conservation based. A third topic was discussed on the flexibility of the

LIA scope for DFO (Science Program) and its difference from WWF's scope. The scope of science for the LIA is smaller than some definitions of the LIA (more than 1 provided in the meeting). DFO (Science Program) is operating under the constraints of funding and hope to do a very effective job within the region where they are working. There is a willingness to discuss the number of different programs that can be integrated through collaboration as the LIA program moves forward. The objective for the department is to provide the best advice and ecosystem science for the region at large as further discussion occurs on conservation targets and protection. A follow-on topic relating to LIA boundaries was discussed relating to the differences and areas not considered for the science program. If other areas were considered there may be more synergies with N-CAMP and other similar programs to engage northern community members. The boundaries for the LIA provided on the map are variable. The science work being completed is bound by funding constraints and accessibility. As well there is a focus in this initial stage on where multi-year sea ice will remain and the only way to access this area is by land. N-CAMP is linked to communities whereas this research program is not. There is a desire to incorporate Northern individuals into programs whenever possible and the LIA science program team hopes to do this through stewardship and mentorship. There are strong links between the remote Northern Archipelago and downstream regions near communities. A participant pointed out that the LIA is understudied but not un-studied so information does exist on the region from programs such as Joint Ocean Ice Studies (JOIS) and Arctic Net where ships were used to collect data around the marginal regions of the LIA. Another participant asked about the purpose of the meeting (to decide what will happen based on the area chosen already or can there be discussion and openness to consider other logistical areas). There are no other options for other Canadian bases at the present time. Everyone is here to help the development of the LIA science program around the region already highlighted and discussed. A follow on question related to the use of Alert and why this area was selected for the LIA science program. Plenty of areas that have multi-year sea ice are logistically easier to access and cheaper than the area selected. The one important difference is the division between the types of multi-year sea ice: 1.) where it is formed, and 2.) where it is wasted (melts). Multi-year sea ice is formed to the north of Alert and more southern locations in the Arctic are where multi-year sea ice is wasted (or melts). There is a need to distinguish these two types of regions and this is the reason why work is being done near Alert. To follow on, a participant commented that there is a large emphasis on ecology and thus it may be less important to be near forming multi-year sea ice versus near wasting areas. There is a large difference between ecological production in the multi-year sea ice formation regions and wasting regions (i.e., the microbiological communities are significantly different and there are differing dynamics at play). As well, looking to the future, there is a need to examine seasonality. It is then better to work in an area where multi-year sea ice is persisting for a longer period of time. Is there an interest in the mechanics of sea ice (i.e., different types of formation)? Yes, this is what links the LIA to the Arctic Ocean on a broader scale.

PARK'S CANADA ARCTIC CONSERVATION INITIATIVES

F. Mercier provided a presentation titled "***Park's Canada Arctic Conservation Initiatives***". Parks Canada Agency (PC) is responsible for protecting representative examples of Canada's natural and cultural heritage. There are 46 national parks and one national urban park under PC's mandate. Additionally there are five national marine conservation areas (NMCAs), 981 national historic sites, and nine historic canals under PC's mandate.

NMCAs have been developed by PC. Their purpose is to protect and conserve areas representative of Canada's 29 marine regions. They encourage the understanding, appreciation, and enjoyment of marine heritage. They are established and managed under the *Canada National Marine Conservation Areas Act*. The objective of NMCAs are to represent the diversity of marine ecosystems, maintain ecological processes and life support systems, preserve biodiversity, protect endangered species and critical habitats, protect cultural resources, encourage ecological research and monitoring, use traditional knowledge and science to inform management and planning, and provide interpretation of marine areas for the purposes of conservation, education and tourism. NMCAs are considered multiple use protected areas managed for ecological sustainability. They must be zoned, including zones of high protection. There is a prohibition of activities such as hydrocarbon and mineral exploration and development as well as disposal at sea. Renewable use activities consistent with objects are permitted (i.e., fishing, shipping). Management of NMCAs occurs in cooperation with other federal departments (DFO and Transport Canada) and is supported by local management committees. Currently, there are eight national parks with marine components (~8,950 km^2), one NMCA (Tallurutiup Imanga: 109,000 km^2) and funding to assess three new NMCAs. The Tallurutiup Imanga Inuit Impact Benefit Agreement has been discussed and negotiations will start next month and will involve other government departments. One of the NMCAs being considered is in the LIA and is offshore of Quttinirpaaq National Park.

There is limited science capacity for large projects. Site ecologists are assigned to each national park/NMCA. Their focus is on monitoring ecosystem health to inform adaptive management. They work with local community members to better understand each site and inform management. There are several needs associated with NMCAs including more complete species/habitat inventories for sites, research on food webs, oceanography, etc. to better understand how the ecosystem works, how to best approach interpretation and visitor experience, and simplify effective means of monitoring.

There are potential opportunities for collaboration. PC has a presence at each of its sites and has the possibility of in-kind support. PC has purchased ***RV David Thompson*** to support PC's marine science and underwater archaeological work. It will be used to conduct research on the wrecks of ***HMS Erebus***, ***HMS Terror*** (Queen Maud Gulf near King William Sound) and ***HMS Investigator*** (Mercy Bay, north of Banks Island), and for marine biology and survey projects in Lancaster Sound.

A short discussion followed F. Mercier's presentation. A question was asked regarding selected NMCA proposed sites and whether they would be counted towards 2020 conservation goals (10% marine protection). There is a desire to count these areas towards the 2020 conservation goals but this will be dependent on the QIA. The capacity of our northern partners is stretched presently. A following question asked about the potential expansion plans for shelter areas on Ward Hunt Island. There is shared interest to use this shelter. Plans are not presently known about expanding the shelters but will be looked into and participants can be connected with individuals taking care of this for PC after the science workshop. Another question was asked regarding collaboration between PC and DFO on marine conservation areas. There is collaboration and these NMCAs will be considered to be part of MPA network planning that is led by DFO. PC is establishing NMCAs to represent bioregions close to the proximity of other existing land-based parks. A further comment inquired about the advantage of joint conservation areas. PC can add DFO's interest into protection plans for an NMCA. Parks works with communities to deal with management. There is no advantage right now to double up as agencies from the perspective of the communities or organisations. A final question was asked regarding the implications for world heritage listing for NMCA (referencing LIA). PC is the lead for world heritage site and designation (in Canada). To be listed, the area has to be under some protection legislation and have a management plan. A follow on question concerned the rationale of choosing the proposed LIA above Quttinirpaaq National Park. It is the best representation of the region and proximity to another land-based park. Objectives of the NMCA can be achieved here most easily in comparison to other proposed regions for LIA.

LIA: FROM WWF PROJECT TO CANADIAN ACCOMPLISHMENT

C. Tesar provided a presentation titled "***LIA: From WWF Project to Canadian Accomplishment***". C. Tesar was the international lead of the LIA project for WWF's Arctic programme for the past 8 years and is now a consultant that works on WWF Canada's LIA. M. Giangioppi is a colleague with WWF Canada leading work on Arctic Marine Conservation. The LIA developed in 2008 out of a meeting in Washington held by WWF to discuss the future of polar bear conservation, collect of science and knowledge, predict future issues and threats, and discuss how to address challenges. The common decision was that the biggest threat to polar bear conservation was not hunting or development but habitat loss as a result of climate change.

The WWF boundaries for the LIA are based on a summer minimum ice projection for 2040 based on the RCP4.5 scenario within the national jurisdictions of Canada and Greenland. The margins for LIA are purposefully blurred since it is a projection and the extent and location of the ice edge in 2040 is imprecise science. Areas outside the boundary could be just as important ecologically, economically, and culturally as areas inside the line. The rationale was based on the ice-modelling work commissioned by WWF from Bruno Tremblay and team at McGill University. WWF Canada then developed a more optimistic scenario and prepared a projection based on RCP4.5. This scenario is one that most closely follows the implementation of the Paris Agreement.

The WWF’s vision for the LIA is a mosaic of management that would lead to integrated management of the area (i.e., various management tools). The vision is to have some areas within the LIA potentially managed entirely by Inuit (i.e., Pikialasorsuaq) while others could be comprised of co-management between Inuit and the Canadian Government (already observed in some areas). **Figure 4** shows a variety of existing and proposed conservation management measures.

Official consultation with Inuit groups started in 2012 in Nuuk, Greenland. Representatives from the QIA, NTI, NWMB, and the Government of Nunavut were present at the meetings along with Greenlandic Government representatives. The workshop was co-hosted by the ICC. The meetings were intended to introduce the project, and to receive guidance on how we should proceed in reference to the research agenda. The meeting outcomes identified gaps such as the need to do more ice modelling, to better understand the polynya, and to better define the likely outcomes for ice-associated life with decreased sea ice. Two more workshops also co-hosted by the ICC have since followed. These meetings, held in Iqaluit, had a broad scope in both audience representation and discussion topics.

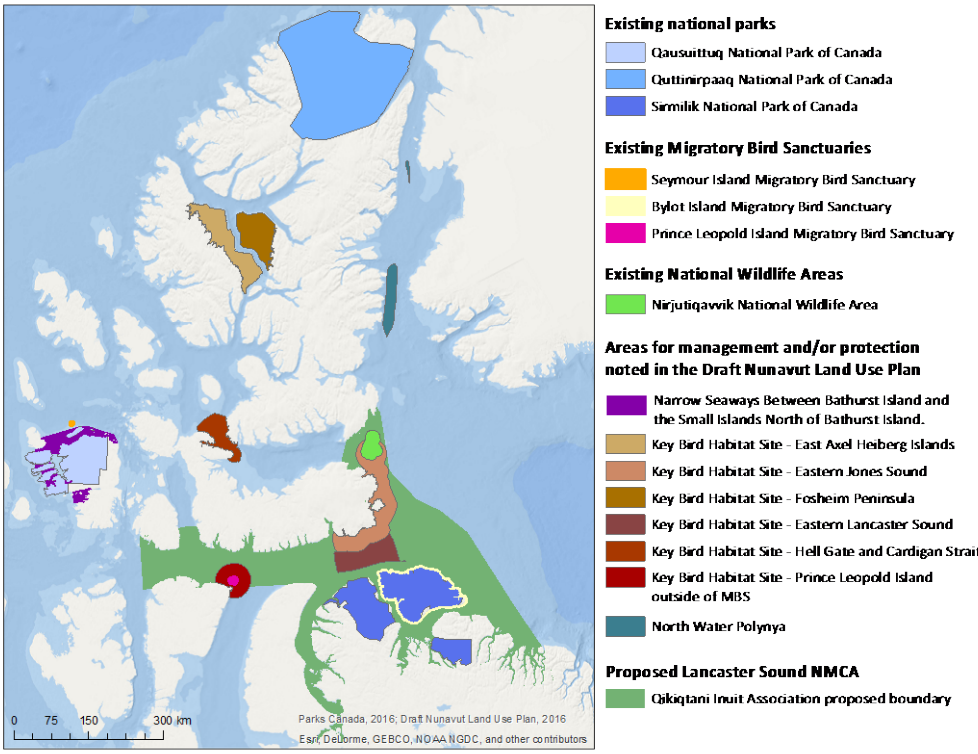

Figure 4: A map made in support of world heritage designation within the Last Ice Area which brings together all the current and proposed conservation management measures within the region.

WWF's international reach has allowed for broader public support for the project. This helps to start discussions at a policy level, and move to higher level engagement with Inuit and with governments. International efforts include taking a sailboat through the LIA with both science and media on board. International WWF efforts also included presentations to the International Marine Protected Areas Congress, the World Parks Congress, and the Arctic Council.

WWF's national vision is the construction of an MPA network for the Eastern Canadian Arctic. The scope of the project overlaps with the LIA. The purpose of the project is to help identify candidate areas for marine protection including an analysis to help map out and inform management decisions. WWF held the first expert workshop (February 5-6, 2018, Ottawa, Canada) to discuss conservation features and methodology to identify candidate areas.

WWF, in support of their international vision, has helped support the ICC's Pikialasorsuaq Commission. This polynya is a particular location of importance for Inuit. One way to support this project was the commissioning of an interactive atlas that brings together ecological and cultural information in one place from a team at Dalhousie University. WWF is continuing to support and engage with the work of the ICC.

WWF has commissioned research to help address questions from Inuit. Better modelling of sea ice was identified as a research gap and this was done at the outset of the LIA project. Another research study commissioned by WWF examined polynya persistence in the region to understand detectable patterns in how polynya physical characteristics might react in response to changing climate. Further studies examined how ice-dependent and ice associated life might use ice in the future. Model projections of animal populations need to start with baseline assessments in the present day. WWF has contributed to several assessments of ice-dependent animals including polar bear populations, and to modelling work that examined sea ice projections and attempted to determine ice persistence for polar bear habitats. In brief, it is predicted that the LIA will be the best polar bear habitat in the future (2050). Other activities to ensure the support of management measures, include IQ knowledge collection, Inuit involvement in the field programs relating to narwhal surveys (Tremblay Sound) and hosting workshops on seals. WWF has commissioned from ICC a compendium of existing published Traditional Ecological Knowledge (TEK) about the LIA and has also published a compendium of published science on natural resources in the LIA. A study on economic opportunities was commissioned to independently study the non-renewable resources of the LIA.

WWF does not view the LIA as a WWF project. Government of Canada commitments for the LIA are welcomed. As well, Inuit themselves are leading the Pikialasorsuaq Commission. International and national levels of WWF are still committed to supporting this project by generating as much knowledge as possible.

WWF also partnered with National Geographic's Pristine Seas Program for a presentation to the Arctic Council working groups. A full length feature on the LIA is available as a printed article and featured in National Geographic. A movie is in production. The WWF has an ongoing role for policy in the Arctic Council as an observer to the council and participant in the Council's MPA projects.

A short discussion followed C. Tesar's presentation. The best polar bear habitat is the margins of the LIA. Would they move further north if multi-year ice shrinks? The margins of the LIA are the most productive. They will change over long periods of time. Southern polar bear stocks are in more trouble. The open-water season is key to determining the health of polar bear populations. Polar bear populations further north are likely doing well. A secondary question was asked regarding an upcoming workshop. Can more information be provided? The workshop will focus on the five marine priority areas for network planning. The Government of Canada is focused on network planning in the Western Arctic and so WWF is focused on filling the gap in the Eastern Arctic. The process to identify candidate MPAs has begun to develop a network. The first workshop will be held from 1st February to 7th February, 2018 and will be followed up by a panarctic network workshop. There will be two more workshops before the end of 2018. The first workshop is to discuss conservation features as part of the network and discuss conservation objectives. This will help to identify gaps. A third question/topic followed regarding the LIA map boundaries. The predicted summer sea ice extent in 2040 (RCP4.5) is being used as a guide since the exact boundary is arbitrary. A follow on question asked about the relationship between WWF's work and the Paris Accord. The model, RCP4.5, used by WWF for predicting sea ice extent moving forward in time is one that best accounts for Paris Accord measures (although it is not a perfect fit).

WHAT MAKES AN ICE AREA LAST? WHAT CHANGE MIGHT MAKE IT DISAPPEAR?

H. Melling provided a presentation titled "**What Makes an Ice Area LAST? What Change Might Make it Disappear?**" LIA is a persistent year-round haven for sea ice that is dynamic. Today's climate already enables a LIA. A future warmer climate will likely enable one too where summer sea ice is most persistent today.

There are several reasons to believe in a LIA. First is the observed retention of sea ice in Northern Canadian waters despite loss elsewhere. Specifically, the decline in sea ice over all of the Arctic has been 13.2% per decade since 1968 (Richter-Menge et al. 2017, USA NOAA), whereas the rate has been 4-5 times slower in the Canadian High Arctic (3.2% per decade). Second, choke points for High Arctic navigation have stayed the same over 150 years despite appreciable warming since the mid-19th century (Overland and Wood 2003). Third, it is possible to infer a year-round ice presence in Canada's High Arctic even during the Holocene Warm Period (HWP; 8000-5000 BP) when the Arctic was 3-5°C warmer. The evidence comes from the bones of Bowhead from the HWP, found on beaches in the south and east of the Canadian Archipelago but not those in the north and west (Dyke and England 2003). Absence of bones in the High Arctic is indicative of ice conditions too heavy for the whales to transit. Fourth, climate models predict that summertime sea ice will linger in Canada's High Arctic after it disappears elsewhere (Laliberté et al. 2016).

The northern marine cryosphere has four distinct sea ice domains (pack ice that is either annual or multi-year, and fast ice that is either annual or multi-year). Each domain likely has different sensitives to a changing climate. Canada's high Arctic is populated predominantly by multi-year ice, drifting year round within the Arctic EEZ but fast in winter (November through July) over the Canadian Polar Continental Shelf.

Multi-year sea ice is thick ice that survives the summertime melting within the climatic zone in which it is located. In surviving the summer, the sea ice becomes thicker, less porous, less saline, more reflective, and more snow covered. These properties increase its resilience to melting so long as it does not drift into a more benign climatic zone. Although thick ice is a prerequisite of a LIA, little is known about ice thickness in the Canadian LIA in the past or even now. Naval submarines have acquired ice canopy data using sonar since the 1960s, but few data from Canadian waters have been declassified (Bourke and Garrett 1987). Our best resource for the Canadian Polar Shelf (Sverdrup Basin) is borehole data acquired during seismic surveys during nine winters in the 1970's (Melling 2002).

Being at high latitude the LIA is cold; the annual average temperature at Mould Bay is -18°C; summers bring temperatures barely above freezing and only for 2 months. Near-freezing temperature in summer enables melting but radiant energy from the sun actually does the work. Numerical modelling has shown that Arctic ice cannot thicken much past 3 m via freezing mechanisms, even if it remains for decades in the coldest regions. Although ice grows during cold winter weather, the rate of growth slows as it thickens. In summer, however, the rate of melting does not depend on thickness. The multi-year ice floes reach a maximum thickness when as much ice melts in the summer as grows in the winter. It takes 10 years to reach this state.

The survival of the thick multi-year ice of the LIA is dependent upon three R's. The first R is recruitment, the promotion of some first-year ice to second-year ice when it survives the summer. Thick floes, close pack ice, cold seawater, short summers, and high latitude favour recruitment. The second R is retention, the harbouring of recruited floes in cold areas with closely packed ice, such as the LIA. One contributor to recent shrinking of the LIA has been change in the circulation of ice around the Arctic. Before 1990, the Beaufort Gyre was a large almost closed circulation in which ice could remain for decades; the trans-polar drift which marked its northwestern boundary was a narrow fast track (3 years) out of the Arctic. Since 1990, the Beaufort Gyre has become smaller, and the fast track has widened so that less old ice is now retained (Rigor et al. 2002). The loss of multi-year ice via the fast track can be followed using satellite data in the winter. The shrinkage of the polar pack observed by satellite during winter indicates that ice export to the Atlantic has played a role in ice loss from the LIA. The third R is ridging. Sea ice begins life in thin flat sheets, but the action of storm winds very quickly builds a landscape of floes and ridges of much greater overall thickness. The deepest observed keels, having 40-45 m draft, form within mixed pack ice (old ice crushes young). Ice ridging is a consequence of ice pressure, which in turn develops when prevailing wind pushes ice against a coast. Onshore wind is prevalent between Fram Strait and M'Clure Strait and maintains the high ice concentration and high pressure characteristic of the LIA. This feature of Arctic circulation critical to the LIA has persisted throughout the changes of the last two decades.

Wind, geography and fast ice conspire to create a nursery for the thick multi-year ice in the LIA. Prevailing northwest wind pushes ice against Arctic Canada and Greenland. Geography (these land masses) impede the southward drift of ice to lower latitudes where melting is more severe. In so doing it enables a build-up of ice pressure, increases in ice concentration and reflectivity and the failure of level ice sheets that create thick extensive piles of ice rubble. The resulting thickened stronger ice block become fast within the channels of the Canadian Polar Shelf for many months each year, enhancing the effects of the geographic barrier to its escape from the LIA. The prolonged entrapment of rubble within the harsh climatic regime of the LIA provides time for it to weather and become old-ice hummock fields.

The climatic influence on sea ice includes snow as well as temperature. Accumulated snow insulates the ice and reduces ice growth during winter. However, this effect is not important for thick ice which does not grow much anyway. A thick snow cover at the start of summer is an effective reflector of the sun’s energy and delays the date when sea ice starts to melt. Because the sun is lower in the sky by this time and there is less remaining summer, less ice melts if snow is thick. The net effect of deeper winter snow is therefore thicker sea ice (Walker and Wadhams 1979).

The climatic influence on the sea ice also includes heat flow from the ocean beneath. The impact of warm ocean inflows to the Arctic are clear in satellite views of Arctic ice. The warm inflows push back the ice edge as they slide beneath the Arctic surface waters, which have lower density, and lose contact with the ice. A warm Pacific inflow interleaves below 60 m depth and a warm Atlantic inflow interleaves below 250 m depth. The Arctic Ocean is astonishing in having an extremely thin (3 m) layer of ice surviving on top of 3,000 m of water above freezing. The paradoxical existence of Arctic ice involves a delicate interplay of freshwater flow and annual freezing that creates a cold stable top layer to the ocean. Beneath this there is a cold halocline layer that protects the ice from the deeper warmer waters flowing in from the Pacific and Atlantic Oceans (both are “damaging influences”). A tiny (3-5 watts/m^2) up-leakage of heat can have a big impact on the ice thickness (for reference a human puts out about 50 watts/m^2). Such a leakage can occur where tidal currents are strong, at the shelf edge during wind-driven upwelling, and via solar heating of the open-ocean areas (albedo effect).

Recent data from the perimeter of the LIA reveal continued presence of very thick (6-15 m average) ice floes. These thick floes demonstrate that high Arctic conditions continue to enable, create and nurture such ice. For example, the maximum thickness of ice measured over a 9-year period in Nares Strait was close to 45 m (December 2005). A year’s observation in Penny Strait during 2009-10 revealed ice thickness comparable to that measured during borehole surveys in the 1970s. Several years’ observations in Byam Martin Channel show ice comparable to and perhaps thicker than in the 1970s. Recent observations of multi-year ice leaving the LIA via the eastern Beaufort Sea reveal thickness similar to those measured Nares Strait, Penny Strait and Byam Martin Channel.

The LIA is maintained by high latitude, wind (direction and variability), confining geography (land and fast ice), cold stable upper ocean, and accumulation of snow and feedback loops among the above. Factors that might make it disappear are changed wind direction, loss of fast ice, instability in the cold upper ocean, changes in snow accumulation and feedback loops. Current global climate models do not account for all these factors and may therefore be of limited value in foreseeing the future of the LIA.

The short discussion following H. Melling’s presentation was pushed back into the next discussion period due to time.

No questions were brought forward to H. Melling at the end of the day where his question period was fit into the schedule.

OCEAN MYSTERIES OF THE GREATER LINCOLN SEA (AND BEYOND)

M. Steele provided a presentation titled "**Ocean Mysteries of the Greater Lincoln Sea (& Beyond)**". The Lincoln Sea was named after Robert Todd Lincoln, the USA Secretary of War. There are three Arctic water mass layers that are important to understanding the LIA. The Atlantic water layer is relatively warm and salty. It has enough heat to melt the Arctic Ocean sea ice. Above this sits the halocline, a stratified layer consisting of modified Atlantic and North Pacific water masses. It prevents the Atlantic water heat from rising up. On top of the halocline and at the ocean surface sits a freshwater layer. It is made up of a combination of river inflows, North Pacific water masses, and net precipitation and ice melt.

The Atlantic water layer is warming over time. With a change in temperature and salinity, will the volume flux change as well? Presently, the volume inflow into the Arctic Ocean is not changing much over time. Circulation of the Atlantic water layer comes in through the North Atlantic and then circulates around the Arctic Ocean. There is lack of understanding as to why the Atlantic water layer is flowing into the Arctic Ocean. Wind "push" and freshwater outflow "pull" are two current hypotheses attempting to describe this water mass movement.

The halocline future is unknown. The stratification could decrease due to enhanced mixing from ice loss, and/or winds increasing, and/or surface waves increasing. Alternatively, stratification could increase due to an enhanced global hydrological cycle from increased river discharge, and/or more marine precipitation minus evaporation (P-E). The depth range of the halocline (20-250 m) is right at sill depths. This may cause big changes in the future properties of flow to Baffin Bay and beyond.

The freshwater layer solid component is the sea ice and this is decreasing. The liquid fresh water layer is variable. The LIA has a large spatial gradient in freshwater content, as well as a large gradient in freshwater export to the south. Changes are occurring over time, as exemplified by increased freshwater in the Beaufort Gyre (Proshutinsky et al., 2009; Morison et al. 2012). Freshwater has increased through the 2000s in the Beaufort Gyre and has reached a plateau in recent years (Zhang et al. 2016). It is not yet understood how fresh water exits the Beaufort Gyre. Will it move through the Central Arctic Ocean toward the Nordic Seas, or will it exit via the LIA to Baffin Bay? The transport of fresh water as described is an unknown research gap that needs better understanding. Sea surface height (SSH) is directly related to freshwater (Steele and Ermold, 2007), and maps of this quantity indicate a general flow from high SSH in the Beaufort Sea to lower values in Baffin Bay and the Nordic Seas (e.g., McGeehan and Maslowski 2012). Flow through the LIA is controlled by both the Beaufort high pressure system and Baffin low pressure system. Actual observations are needed in locations like the LIA to validate the model. Further, little is understood about the salting process of exiting fresh water in polynyas (i.e., liquid fresh water becoming solid fresh water). Wind forcing of ocean transport may also change in the future (Moore et al. 2018). For example, the long term average for the Beaufort has been a high pressure system. However, this is sensitive to thinning ice which may allow more low pressure systems to penetrate into the area in the coming years. This has implications for freshwater transport, e.g., there is a suggestion of strong freshwater export through the LIA in winter 2017.

The LIA is a Canadian/Greenland data hole. It is perhaps the most poorly sampled region of the Arctic Ocean. Further, there is a lag in incorporating new data into global gridded ocean databases. Projects such as The Freshwater Switchyard of the Arctic Ocean existed to measure fresh water leaving the region (2003-2013). A camp was set at Alert, NU and had twin otter support. There is a desire to re-start the project with potential land bases at Alert, Eureka, Mould, Bay, Isachsen, Sachs Harbour, and other temporary camps. The use of autonomous sampling equipment such as drifters, vehicles, and moorings would be the best approach. Equipment such as Upper Temperature of the polar Oceans (UpTempO) and Warming and irradiance Measurements (Warm) buoys can help to collect data (i.e., photosynthetically active radiation (PAR), Chlorophyll *a* (Chl *a*)).

A short discussion followed M. Steele's presentation. The first question concerned saltification and mixing aside from polynyas: can it be divided between different sources? No, this has not been examined. The next topic related to warming from underneath. Could there be a possibility of underneath melting by a warm upper ocean that is stratified? Yes, this is a possibility. The sun can be important to the albedo effect. The North Atlantic is warming but not as rapidly as in other parts of the world. Stratification is caused because it is an estuary. The upper water layers could warm enough to cause issues despite stratification.

CANADA-THE LAST ICE AREA?

C. Haas provided a presentation titled "**Canada-The Last Ice Area?**". Much of this introduction likely overlaps with talks already given. Canada may remain the LIA but sea ice will be different from before. As already noted, the Arctic sea ice cover is shrinking. Ice extent is decreasing but regional patterns are very different every year. There is a role of winds, currents, and feedbacks. Variability is noted from year to year. Regional summer sea ice trends exemplify these trends: above average trends in the Hudson Bay, and below average trends in the Baffin Bay and the central Arctic Ocean. What is the role of fresh water and Greenland iceberg calving?

Sea ice model predictions for 2100 suggest that Canada will be the LIA even under the most severe greenhouse gas forcing scenarios. Economically the Arctic will be more accessible to shipping in summer months (Barnhart et al. 2016). However, the Northwest Passage will be less accessible. Predicting September ice concentrations in CMIP5 is difficult (Koenigk et al. 2014). From 1984-2005, there are different spatial patterns that are dependent on ice motion. The atmospheric winds are hard to predict.

Ice thickness processes change the ice thickness distribution (Haas 2003). Warm climate, dynamic deformation of ice through ridging, and wind current drifts can all play a role.

Divergence in some areas can cause new ice formation. Convergence occurs where ice floes are pushed against each other. All this results in ice thickness that is variable, has less to do with temperature, and more to do with dynamic processes. Ice thickness is largest along Canada and Greenland due to ice drift patterns. The transpolar drift and Beaufort Gyre push ice towards Canada. Siberian coasts have thin ice thickness. It is very dependent on sea level pressure and winds. The Beaufort Gyre moves clockwise and pushes ice in the same way. If the wind patterns change, then the ice distribution can also change.

Ice drift and thickness models show very different conditions that can now be measured by CryoSat (Ricker et al. 2014). Only satellite data can provide regional, long-term observations for measuring ice drift and thickness. Freeboard measurements from models have high uncertainties due to snow and sea surface height variations. Other measurements such as electromagnetic (EM) thickness sounding can provide an inventory of ice thickness. These involve airborne surveys that use electromagnetic conductive techniques. Arctic EM ice thickness surveys have collected data since 2004. They focus on thick multi-year ice in the LIA and show thick ice still exists (Haas et al. 2010). Over the last 10 years, there is slow thinning between Canada and the North Pole, although the ice is still considered to be very thick. In April 2017, an extensive *in situ* and satellite validation campaign occurred between Alert, NU and at 12 different sites. The survey crossed the zone from multi-year sea ice to first-year sea ice and measured up to 0.8 m of thinning in 10+ years. Little change has been noted since the 2011-2014 surveys. Snow thickness was also measured and these studies show that average snow thickness has not changed over long periods of time.

It is very likely that Canada will be the LIA and future changes to the LIA are likely to occur. Heavy multi-year sea ice in recent years is expected within the Northwest Passage due to weaker fast ice conditions. As a result, there may be more severe ice conditions both regionally and locally. Multi-year sea ice is thick and deformed as it moves southward. In addition, ice can still be thinner and less predictable for people in their hunting and recreational activities. Ice thickness can be measured as people travel along in the form of community-based monitoring. Ice thickness sounders are used on snow machines to record data. Ice thickness is extremely variable due to tidal currents, water depths, shoals and changes in the heat flux of the water. There is an expectation that ice overall is becoming thinner and will cause more issues in all these areas. The Smart ICE project provides sea ice monitoring and real time information for coastal environments. It integrates on-ice technology, remote sensing, and Inuit Knowledge to generate information on sea ice conditions to enable users to make better decisions. Sea ice algae are of key importance for the whole Arctic marine food web and thereby the entire Arctic ecosystem. Specifically there is a unique role of hummocked multi-year sea ice to algal productivity. Hummocks increase suitable habitat in multi-year sea ice areas for panarctic sea ice algal Chl *a* biomass. Satellite observations, use of in-situ equipment and under-ice optical equipment have helped to determine these biological features related to hummock habitats. The physical properties of the ice as exemplified by the hummocks are directly connected to biological properties of the Arctic ice-ecosystem (Lange et al. 2017).

Canada has the oldest and thickest ice in the Arctic. The LIA will likely survive in the Canadian High Arctic (dependent upon atmospheric and ocean circulation). There are questions to address relating to protection, conservation and management of this region moving forward into the future. Sea ice will still pose a marine hazard during the winter and "shoulder" seasons. The role of sea ice for human use and culture, and for the ecosystem will change.

A short discussion followed C. Haas's presentation. The first question concerned tracking the movement of biological communities associated with moving ice. There is a way to do this systematically from satellite-derived drift products. Buoys can be used to validate drifters and calculated back trajectories. The second question asked about the Smart ICE project and its functionality in the LIA. Presently, the LIA is too far away from communities to work well but the program could expand into this area in the future. Rangers and others could incorporate this work into their excursions. A third question asked about the description of the sheer zone in the Lincoln Sea. This is a region of very deformed ice. Very distinct long pressure ridges exist with very thick multi-year sea ice.

CLIMATE MODELLING AT ECCC: FROM SEASONS TO CENTURIES?

N. Swart provided a presentation titled "***Climate Modelling at ECCC: From seasons to centuries?***". There are several stable models at Environment and Climate Change Canada (ECCC) and all the models share a common framework and components. For example, the Canada Earth System Model (CanESM) is a regional model that has atmospheric, ocean and sea ice components to it. It can simulate the carbon cycle and sometimes the nitrogen cycle (strongest collaboration with DFO). It can use other models and feed into other models for various purposes. It helps provide statistics of how the weather is going to change. CanESM is used to provide global climate projections in support of IPCC assessments at a spatial resolution of $\sim 2.8^0 \approx 250$ km. The data in Canada is used for downscaling, boundary conditions for regional ocean, atmosphere and land models, and climate change assessment. The model has helped to examine Arctic sea ice projections (Swart et al. 2015). The CanESM2 model accounts for uncertainty including that arising from natural variability. The model is the same as the CanESM with the same physics and forcing characteristics. The only different is the change in natural variability that can cause a difference in outcome predictions. This is observed in the Arctic sea ice projections where there is a large spread in trends and in uncertainty of ice free days. There is no way to move away from this internal variability. Sigmond et al. (2018) show different targets (1.5^0C and 2.0^0C) for Arctic sea ice. In both cases, sea ice declines. Once temperature stabilizes so does sea ice decline. The chance of being ice free at any given year is calculated. Even if stabilized at temperature targets, ice free conditions may occur in any given year due to natural variability. In the future, CanESM may be able to incorporate new biogeochemistry into the model (CanESM4.0/CMIP5) and other new changes to the model (Can ESM5.0/CMIP6).

The Canadian Regional Climate Model (CanRCM) has the same “physics” as the global model. It is driven at the boundaries by the global model output. It is used to provide high resolution (~25 km and ~50 km) climate change projections over Canada.

The Canadian Seasonal to Inter-annual Prediction System (CanSIPS) is based on CanCM3 and CanCM4 models. These models are used for seasonal and inter-annual climate predictions (1 month to 5 years). They provide real time seasonal predictions of temperature and precipitation, and provide a seasonal forecast of snow and sea ice.

A higher resolution biogeochemical model for the Arctic is presently being worked on with DFO collaborators. Resolution is presently insufficient for shelf and coastal areas.

In conclusion, ECCC develops global Earth System Models for decadal to centennial scale climate projections, and seasonal to decadal prediction. CanESM is dynamically downscaled using CanRCM including over the Arctic domain. CanESM2 and CanRCM are used as boundary conditions for regional high resolution ocean-ice-biogeochemistry modelling of climate change. The analysis of these models and observations leads to projections of future change, understanding the drivers of this change, and the associated uncertainties.

A short discussion followed N. Swart’s presentation. The first question related to the functioning of the model in relationship to ice thickness. The summer thickness should go up and this is paradoxical. The annual average but not the long term decline is driven by the forcing. The second question related to providing examples of the biological components and factors included in the models (i.e., trophic levels involved). Factors included in the model are carbonate chemistry, one species of phytoplankton, one species of zooplankton, and nutrient ratios. The new model update includes an additional two species including one of sea ice algae. The next question related to the treatment of snow in the sea ice biochemical model and its variability. Future models will account for areas where light is allowed to penetrate through snow. Presently it is accounted for as general snow cover thickness. A follow on question asked about the timelines of new model outputs. Timelines on new model outputs are not known but some data is present now. Another participant asked if winds change in the modelling. It is unsure if winds will change. There are issues with this and no agreement can be reached presently on winds in the Arctic regions. Different models give different results. The next topic discussed was regarding whether climatology will differ as seen in other parts of the world. Is there a lot of model spread everywhere or is this an Arctic problem? This is a regional issue. There is consistency in the southern hemisphere. We cannot get storm tracks correct in the models; they are more zonal in the models. This is likely a resolution issue. We cannot resolve sea ice and wind interactions. These are issues to manage for the future. We need to look at regional models to provide better forcing. The final question related to the existence of the LIA due to winds. The LIA could completely change in the future based on winds. There are uncertainties here that are bigger and need to be resolved. The LIA is a thermodynamic issue.

Closing remarks were made by R. Young at the end of the first day. All the presentations were very informative and provided good discussion.

WORKSHOP DAY 2 OPENING COMMENTS

C. Michel opened the second day of the Workshop and provided a very short summary of the previous day's presentations and discussions. Three main points were discussed:

1. The location of the LIA: where is the LIA?
2. What contributes to the LIA (i.e., thermodynamics, wind and/or ocean currents)?
3. The importance of models, and particularly boundary conditions.

The first speaker was then introduced.

PAME: PROTECTION OF THE ARCTIC MARINE ENVIRONMENT

M. Gold provided a presentation titled "***PAME: Protection of the Arctic Marine Environment***". The Protection of the Arctic Marine Environment (PAME) is one of many working groups (e.g., Arctic Monitoring and Assessment Program (AMAP), Conservation of the Arctic Flora and Fauna (CAFF), Emergency Prevention, Preparedness, and Response (EPPR), Sustainable Development Working Group (SDWG), and Arctic Contaminants Action Program (ACAP)) under the Arctic Council that is dedicated to marine related issues including ocean policy. The work of PAME is based upon scientific findings and recommendations from AMAP and CAFF.

PAME was first established in 1993 as the Arctic Environmental Protection Strategy and became an Arctic Council working group in 1996. PAME has been the focal point of the Arctic Council's policy related to initiatives for the conservation and sustainable use of the Arctic marine environment. Emphasis is placed upon policies for managing marine activities. Six expert groups fall under its mandate: shipping, marine litter, marine protected areas, resource exploration and development, ecosystem approach, and arctic ship traffic data. PAME is not a science body but relies on expertise including membership through its six expert groups.

PAME's role is to address marine policy measures related to the conservation and sustainable use of the Arctic marine and coastal environment in response to environmental change from both land and sea-based activities, including non-emergency pollution prevention control measures. Products include the coordinated strategic plans, the best practices and voluntary guidelines, and the trend analysis and recommendations. Some are strategic documents to coordinate the Arctic Council marine-related efforts helping to set priorities such as the Arctic Ocean Review (2013) and the Arctic Marine Strategic Plan (2004, 2015).

The PAME work plan for 2017-2019 involves: 1.) Arctic marine shipping (12 projects), 2.) a desktop study on marine litter, 3.) implementation of the Arctic marine strategic plan, 4.) an ecosystem approach to management (2 projects), 5.) a framework for a Pan-Arctic network of

MPA's, and 6.) Arctic offshore resource exploration and development (4 projects). Specifically there is an area-based management within the MPA framework (i.e., Framework for a Pan-Arctic Network of Marine Protected Areas). This document brings together MPA managers from the circumpolar north to understand MPA networks across member states, discuss best practices, discuss MPA national jurisdictions and look for a common approach. This includes agreed upon concepts, principles, and a road map for developing a pan-arctic MPA network to build on national efforts. The framework is not binding and thus each Arctic State will proceed with MPA network development based on its own priorities and timelines. However, having a common vision in place confers a number of advantages that can support and enhance the work of individual Arctic States. A framework for a Pan-Arctic network of MPAs also contributes significantly to a number of ongoing Arctic Council objectives such as the ecosystem-based approach to management. The next steps include collecting and reviewing MPA indicators for status and trends, and inventorying management measures linked to Arctic marine biodiversity (e.g., cold water corals).

An ecosystem approach was created to support area-based management. There is a joint expert group (AMAP, CAFF, PAME, SDWG) to develop tools to implement an ecosystem approach in support of area-based management. The ecosystem based management approach is agreed upon as a principal but understanding the definition, practice and implementation, and application is more difficult. The ecosystem approach expert group will consider scientific and technical aspects related to the implementation of the ecosystem approach to the management of the Arctic Large Marine Ecosystems (LMEs) and contribute to ongoing Arctic Council projects of relevance. The aims of the group are to: 1.) provide a forum for, and facilitate exchange of, information and experiences that will support implementation of the ecosystem approach by Arctic states and Arctic Council working groups, 2.) consider methodological development, and develop appropriate documents to support the development, 3.) contribute to and review progress in the development of the Integrated Ecosystem Approach (IEA) within the Arctic, and provide advice and guidance as appropriate, 4.) give input to the development of recommendations for further work in Arctic Council working groups, 5.) help to develop consistency in the ecosystem approach work performed by states and in the working groups, 6.) identify, discuss and address issues of common concern, and prepare scoping papers, if requested, 7.) facilitate access to supporting activities and resources, 8.) contribute to the development of defining/setting ecological objectives, and 9.) develop an integrated ecosystem assessment for the central Arctic Ocean with ICES. An update on the current status of the ecosystem approach implementation in the context of the history of the ecosystem approach adoption and development within the Arctic Council is provided through reports. The ecosystem approach work plan for 2017-2019 includes the preparation of guidelines addressing ecosystem approach implementation in the Arctic (marine) ecosystems following the ecosystem approach framework elements.

There is a PAME/ICES Working Group on Integrated Ecosystem Assessment in the Central Arctic Ocean (WGICA). The purpose of this working group is to provide a holistic and integrated view on the status, trends, and pressures, and to contribute to implementation of the ecosystem approach to management of the central Arctic Ocean. There are two assessment teams (Amerasian Basin/Pacific gateway and Eurasian Basin/Atlantic gateway). Areas of heightened ecological and cultural significance have been commissioned to AMAP, CAFF, and SDWG as per their respective mandates and provide follow up to the Arctic Marine Shipping Assessment (AMSA) recommendation II (2013). A total of 97 areas were identified within Arctic LMEs. They were identified primarily on the basis of their ecological importance to fish, birds, and/or mammals, as these species are the most widely studied Arctic groups.

A short discussion followed M. Gold's presentation. A question was asked about how the areas of ecological significance were examined. There was an attempt to use the EBSAs as a basis and the information is provided in a report. Culturally important spaces were also considered. A follow on question was asked about the relationship of the negotiations in the central Arctic Ocean related to PAME. The central Arctic Ocean committee is a subsection of the Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGCIA) although the connections are not formally noted.

NEW INSIGHTS INTO THE ECOLOGICAL ROLE OF SEA ICE IN THE LAST ICE AREA

C. Michel and B. Lange provided a presentation titled "***New Insights into the Ecological Role of Sea Ice in the Last Ice Area***". The presentation focused on sea ice, knowledge gaps and new insights. C. Michel provided some background on the changing Arctic sea ice conditions, in particular the shift from multi-year to first-year sea ice, and the urgent need to better understand the role of multi-year sea ice in Arctic systems. An overview of pan-Arctic biological studies of sea ice, then of production, was presented, demonstrating data gaps in the LIA in terms of sea ice and ocean science and showing that this region is arguably one of the least studied areas of the Arctic Ocean. Further it is also one of the most logistically challenging regions to study.

Examples of the fundamental role of sea ice in marine ecosystems were presented, including its role for biodiversity, marine food webs, as habitat for a variety of species, and its role in biogeochemical cycles.

B. Lange described how sea ice morphology and structure varies between first-year and multi-year ice. He described hummock features that are formed over time due to variation in pond melt on the air-sea ice surface. These hummock structures are a representative of the oldest ice from the season that has withstood melt. They are hypothesized to have more biomass because of light penetration (i.e., less snow on them; Lange et al. 2015). He presented his recent study (Lange et al. 2017) showing that the highest biomass of ice algae is associated with multi-year ice hummocks in the LIA region. On a pan-Arctic scale, this indicates much higher production (up to 30 times more) than previous estimates. Dr. Lange also discussed spatial and temporal gaps in sea ice and in particular multi-year ice studies.

ROVs, with a spatial coverage of 100 to 500 m, can be used to study sea ice properties with relatively little disturbance of natural conditions (e.g., light penetration). This new technology helps quantitatively assess the contribution of specific features such as ridges into models of primary production. Dr. Lange proposed a "boom and bust" system for first-year primary production processes and a more sustainable system for multi-year ice.

In conclusion, there are large knowledge gaps in regards to the productivity and ecology of the Arctic Ocean, which coincides with the area of thick, old sea ice (LIA). New insights into this area indicate its importance in terms of biological diversity associated with the sea ice, higher production than previously assumed (role of multi-year sea ice, hummocks, sea ice ridges, and thicker sea ice), seasonality of production, particularly in early-spring (onset of growth) and late-summer (end of growth), and Arctic food web structure and sea ice-benthic-pelagic coupling. The LIA influences downstream ecosystems (i.e., Archipelago, Baffin Bay) and has far-ranging impacts on Arctic species and ecosystems.

A short discussion followed C. Michel and B. Lange's presentation. The first topic in the question period related to ice thickness integration when comparing sea ice algae biomass between ice types. It was clarified that only a bottom measurement of the core was used for this comparison. A discussion followed on sea ice growth and algal growth on hummocks. A participant asked for the definition of a hummock. It is a "bump" or thermocarst or hillock. Hummocks and ridges would be productive because they stick out above the snow and allow more light penetration. A participant asked if the Castellani model accounted for ridges in the model and biomass estimates (in the presentation). The answer was not yet but it will be used in the future. This was followed by a discussion on the LIA influence on downstream ecosystems; its potential as a refuge, the role of hummocks as habitat for seals (thermo-protection and possibly food sources), their optical properties, and that of ridges.

AUTONOMOUS LONG-TERM BIO-PHYSICAL OBSERVATIONS IN SEA ICE ENVIRONMENTS

C. Richards provided a presentation titled "***Autonomous Long-Term Bio-Physical Observations in Sea Ice Environments***". There has been a mooring array in the Canadian Arctic for 10-13 years maintained by the Bedford Institute of Oceanography. It helps to measure the freshwater outflow of water from the Canadian Arctic Archipelago. Most of the work has been done in Barrow strait through an array system that has been maintained from 1998-2011. Its principle objective was to quantify the magnitude and variability of the freshwater and volume transports through this important pathway into the Northwest Atlantic. This mooring array was re-deployed in August 2017 (**Figure 5**).

The instrumentation used includes ADCPs with a high accuracy pole compass (currents, ice velocity, and backscatter for phytoplankton biomass), CTDs (+O_2) at various depths (temperature, salinity, and oxygen), ice profiling sonar (ice draft, waves) and an icycler. The icycler in particular provides daily profiles of the upper water column where ice prevents use of traditional mooring technology. The onboard conductivity, temperature and depth (CTD) sensor provides the upper ocean salinity information critical for accurate estimates of the freshwater transports through the strait. The onset of the phytoplankton bloom coincides with ice break-up. It is a unique set of data that provides a view of what is happening under the ice throughout the entire year (freeze-up, break-up, land fast or mobile ice).

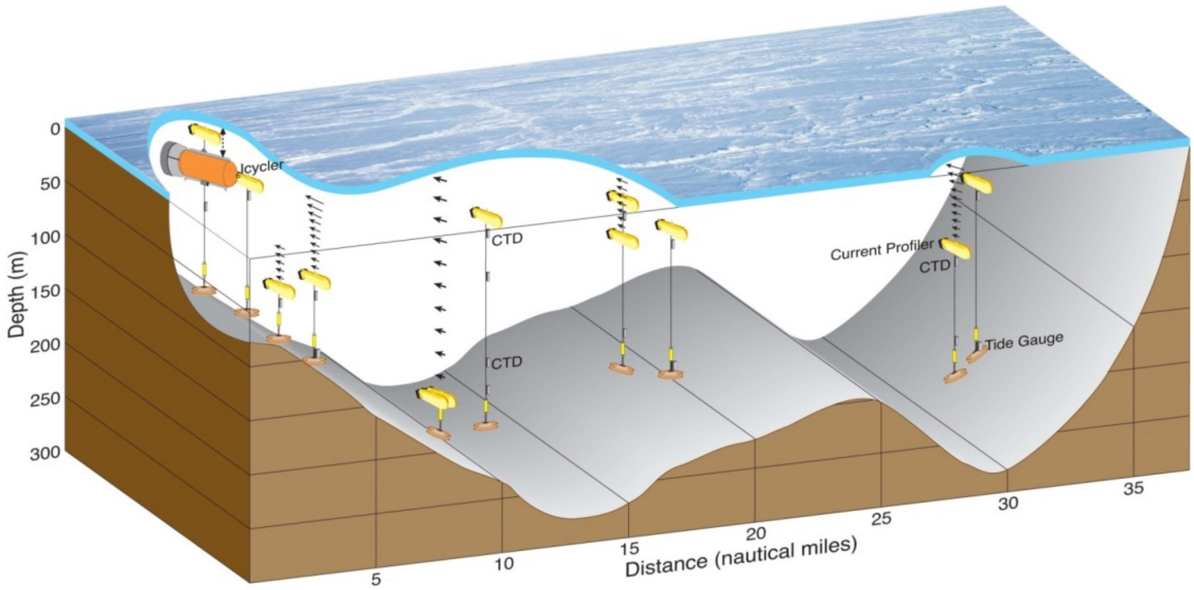

Figure 5: A graphic display of mooring instrumentation arrays for the Icycler, CTDs, and other oceanographic instrumentation.

The mooring array can help to provide an estimate of the monthly mean total freshwater transport. There is high seasonal and inter-annual variability. The mean is 34 mSv. The outflow is confined to the southern half of the strait. The north side of the strait mean flow is near zero. 43% of variability in the transport (monthly means) through the strait is linked to variability in the Beaufort Sea winds. The north-easterly winds control the sea surface slope across the Canadian Arctic Archipelago driving the flow (Peterson et al. 2012). For example, three mean annual freshwater transports through the Canadian Arctic Archipelago are 34 mSv through Barrow Strait (Peterson et al. 2012), ~15 mSv through Jones Sound (Melling et al. 2008), and 32 mSv through Nares Strait (Melling et al. 2008; Rabe et al. 2012). Data suggests that there is a warming trend on the south side of Barrow Strait but the record length is too short to say with confidence that this is significant. There is a significant warming trend on the north side of Barrow Strait. Warming temperatures in spring lead to earlier ice break-up. There is a relationship between freeze-up date and break-up date in that the earlier the passage freezes up in the fall, the earlier the ice breaks up the following summer. There is also a trend in when the growth season starts. From 1998-2006 the start of the growth season occurred earlier and earlier. The re-deployment of the monitoring array will extend the time series. With only a decade of data, high year-to-year variability in local ice conditions make it difficult to identify any trends that may be associated with climate change.

The Barrow Strait Real Time Observatory is a web-accessible real-time ice and ocean data system. It was developed under DFO's Aquatic Climate Change Adaptation Services Program (ACCASP) as a climate change adaption tool for use by mariners and operational planners. In recent years it has been used by the Department of National Defence/Defence Research and Development Canada (CONCEPTS) to provide real time data for validation and constraining of ice/ocean forecast models. One application is using the real-time data to predict freeze-up. The real-time data allows for the use of some relationships identified in the monitoring providing a predictive capability. Freeze-up can be forecast with 2-4 weeks of lead time. All relationships are statistical at this point and there is a desire to add dynamics into these relationships in the future such as ocean ice dynamics. The system itself is portable with no shore infrastructure needed. The shore station runs off of car batteries with no need for consistent power. This system can be used in new areas.

In summary, the continuation of the Barrow Strait monitoring program allows for the further investigation of observed trends and relationships between water properties and ice cover, the biological and physical environments, and how these relationships are holding up in the presence of a changing Arctic. There is a goal to have the icycler back in the water for the summer of 2019. The observatory has provided extended time series measurements on the north side of the strait and provides real-time observations of water properties and ice conditions in the Northwest Passage which is essential for safe navigation as shipping increases. The monitoring and real-time data allows for predictive capabilities. There is a plan to develop more dynamical predictions from the current statistical prediction capabilities. There is proof of concept for portability of the system. All the data is open access.

A short discussion followed C. Richards's presentation. The first topic was the use of the icycler and its promise for data collection. AWI is also developing one for use. If you add acoustic zooplankton recorders on these moorings, they would collect important additional information. An Acoustic Zooplankton Fish Profiler (AZFP) will likely be added to this system and work on this is ongoing. A follow on question concerned the use of acoustics to monitor mammals. Yes, possibly but there are limitations with the frequency and how often they listen. There is no capacity to send raw data due to band width. Presently graphics and data summaries are transmitted. Another question addressed additional statistical relationships that are going to be explored in the future. Other statistical relationships are being investigated such as freeze-up date, convection, and heat fluxes. The goal is to improve predictive relationships to better resolve what is happening. The last topic was related to the freshwater outflow from Bellot Strait, NU. The moorings in this area were lost and it is generally a region where there has been less success at getting flow measurements.

SWEEPING THE ICE: SAMPLING ANIMALS AND ENVIRONMENTAL PROPERTIES FROM THE UNDER-ICE HABITAT

H. Flores provided a presentation titled "***Sweeping the ice: Sampling animals and environmental properties from the under-ice habitat***". As previously discussed, sea ice habitats are changing. This is anticipated to have impacts to Arctic Ocean ecosystems. Linkages exist between ice algae all the way to high trophic prey (i.e., ice amphipods, polar cods, and polar bears). Will changing sea ice habitats increase or decrease economic opportunities?

The under-ice fauna feed on ice algae and assimilate energy into the food web and food chain. There are both temporal and spatial scales of variability to assess a heterogeneous environment. Ice coring is an example of a method used for the collection of algae. ROVs (medium scale) and under ice trawls (1-3 km) can provide a scan of large parts of the ice. Specifically, surface and under-ice trawls were developed in the Antarctic to capture krill (Flores et al. 2012). These techniques can be applied to sample species composition and abundance, in situ profiles of the ice thickness, under-ice spectra, salinity, temperature and Chl *a* concentration. Through the use of a surface and under-ice trawl (ROVnet), simultaneous sampling of species and the environment can occur. With the use of the ROVnet, a zooplankton net is attached to the ROV for towing. An important feature is the construction broom that can sweep the bottom of the ice. This net does not capture fish, thus a large ice breaker would be required to do this work. However, it is not feasible on long term ice stations and is impossible in the LIA.

Species such as Arctic Cod (*Boreogadus saida*), can be captured with under ice nets. Arctic Cod that are captured generally are feeding on zooplankton. They are eaten by larger predators such as seals and seabirds. They are a key species in the food web and are captured throughout the entire Arctic Basin. Through back-tracking of sea ice, it is likely that we can identify Arctic Cod reproductive habitat (David et al. 2016).

Preliminary results are available from work done in Fram Strait. The research vessel drifted with sea ice and spent time around Spitsbergen. Transmittance, chlorophyll, capture of ice algae, zooplankton and all small critters (horizontal and vertical sampling) were done as part of the program. As well, diel patterns and irradiance were examined. There were diel patterns observed from day to night, even during the polar days, that varied depending on species examined (i.e., *Calanus* spp., *Themisto* spp., and *Apherusa glacialis*). Further research examined the ice-ecosystem carbon flux and the dependency of these species on ice algae-produced carbon (Kohlbach et al. 2016; 2017).

Collaboration between AWI-PBO and DFO is important to address science in the LIA. Many collaborations are underway (i.e., Transsiz, LIA, MOSAiC, and Belmont) that are of an international scope. AWI-PBO has done work and has capacity to continue to work on primary producers, export, particle dynamics, nutrient cycling, zooplankton, sea ice fauna, biodiversity, genomics, and transcriptomics. There is a need to understand sea ice algae and its importance to Arctic Cod in Arctic oceans.

A short discussion followed H. Flores's presentation. The first question concerned Arctic Cod and their ability to get back to spawning habitats if ice transport is a mechanism for Arctic Cod. Genetic exchange is being examined to test hypotheses presently. There has been less genetic differentiation in the Beaufort Sea Arctic Cod populations. The next topic related to Arctic Cod distribution. In the Beaufort Sea, there is what appears to be open water upper and lower layers associated with Arctic Cod, young and old, respectively (i.e., use and separation of Arctic Cod life stages based on water mass). What are you seeing in the distribution elsewhere? We are aware of the phenomenon and are looking at it within our data set. A follow on question asked about the age structure of Arctic Cod. Otoliths have been collected but no proper age analysis has been done, instead length structure has been examined. The next question concerned how to quantify and estimate under-ice algae from the under-ice videos. Photo transects are being explored to quantify and make estimates. There is continued discussion on how to do this. There is a paper published on quantification and there is the development of three-dimensional models. Both methods may work with a systematic and forward thinking approach.

DISTRIBUTION AND ABUNDANCE OF MARINE MAMMALS IN THE LAST ICE AREA

S. Ferguson provided a presentation titled "***Distribution and Abundance of Marine Mammals in the Last Ice Area***". This work is done in collaboration with York University on Polar Bears. The presentation will address: 1.) Mammals that are suitable for the LIA, 2.) Ecological theory questions, and 3.) Ringed Seals and other ideas. To some extent, all marine mammals, such as Bowhead, Walrus, Narwhal, Polar Bears, Beluga, and seals (Ring, Bearded, Harbour, and Harp) use the LIA. Seals are the best candidate species for study in the LIA. Ringed and Bearded Seals are circumpolar in distribution. They are captured through community hunting practices in the north and are present year round. There are no management concerns for either of these species and through community collection programs, samples are available for study.

What are the questions? Narwhal are not circumpolar and Bowheads are almost circumpolar but populations in some areas are small. Belugas are circumpolar and Ringed Seal has a good latitudinal gradient. We can address a range of questions for the species over large latitudinal gradients. Ringed Seals are highly abundant, and widely distributed. Their southern limit of range is Hudson Bay and their northerly limit is near the North Pole. Arctic Cod is their main food source in the high Arctic differing from a more diverse diet in the southern extent of their range. Ringed Seals are highly adapted to sea ice. From July to December Ringed Seals forage intensely. Pupping occurs from January to March, pups are weaned in April when mating occurs and in May to June molting occurs while seals fast.

The geographic range model is used to describe density independent and density dependent responses to abiotic and biotic influences. Density independence occurs in the high latitudinal distributions of the species range. Density dependence occurs in the low latitudinal portions of the range. Population-environment models provide insights into life history variation based upon energy in the environment and its spatial/temporal distribution. In the LIA, Ringed Seal productivity is predicted to be low with high environmental disturbance. On a population level, energy would be used to maximize somatic growth at the expense of reproduction. Based upon the density-independent models for high latitudes, populations should respond with low adult mortality, large body size, low population density and older age. Whereas, density-dependent, low latitude populations should respond with high adult mortality, small body size, high population density and younger ages.

There is a latitudinal gradient of sea ice concentration from Hudson Bay, Baffin Island/Southern Ellesmere Island to the LIA. There is more sea ice concentrated in the LIA (65% by area) in comparison to southern reaches (50% by area). There is also more multi-year sea ice when looking northward in the spring breeding season. Life-history predictions can be made for northern bet-hedgers in comparison to southern reproducers. Northern bet-hedgers' energy and seasonality is low and high, respectively. Their body mass is big with greater dispersal. Their longevity is long and sexual maturity is late. Inter-birth intervals are long and the mating system is more polygynous. The survival of young versus adult is low and good, respectively. For southern reproducers energy and seasonality is high to low, respectively. Their body mass is small with reduced dispersal. Longevity is lower than their northern counterparts and sexual maturity is early. Inter-birth intervals are short with a more promiscuous mating system. Survival of young versus adults is high and poor, respectively.

Over 3,000 Ringed Seals have been collected from 56-80^0 latitude in the eastern Canadian Arctic from 1978-2016. Sea ice variation was examined from 1970 to the present day. There was a slightly greater variation (predictability) for the date of autumn freeze-up in the north than the south. Inter-annual variation in timing of spring decreased with increasing latitude (Ferguson and Messier 1996). In high latitudes, seasonality in seal body fat had no discernable pattern however, one is observed in the southern extent of the range. In examination of body size, seals in high latitudes were larger but took longer to reach their adult size. For example, females reached their asymptotic body length at 11 years (149 cm) and 4.2 years (126 cm) for northern and southern populations, respectively. In terms of dispersal, Ringed Seal in northerly locations moved significantly farther than their southern counterparts. In addition northern seals experienced a higher rate of movement to those in the south.

Longevity and maturity differed between northern and southern populations as well. In the northern populations, median male and female age was four years and five years, respectively. Age at sexual maturation was 6.1 years and age at first reproduction was 8.6 years. The development of male testes occurred at 5.8 years and the baculum at 4.8 years. In southern populations the median male and female age was three years. The age at sexual maturation was

4.5 years and the age of first reproduction was six years. The development of male testes occurred at 4.3 years and the baculum at 2.5 years.

Inter-birth interval and juvenile survival differed between northern and southern populations. In the northern populations the ovulation rate was 98% and the pregnancy rate was 56%. The percentage of pups was 30% with a 46% mortality rate. In the southern populations the ovulation rate was 88% and the pregnancy rate was 79%. The percentage of pups was 33% with a 58% mortality rate. Mating system differences were measured through testes weight, testes length and baculum length. In northern populations testes weight and length is larger than in their southern counterparts. This suggests that there may be different mating systems for northern seal populations.

In conclusion, the interspecific pattern seems to hold for this particular intraspecific comparison. The mechanism of change will be examined through environmental data on oscillatory environmental anomalies. When there is later ice melt in the spring, there is reduced survival and reproduction (Ferguson et al. 2017). Early ice break-up causes issues with survival and reproduction in the spring season. Seals cannot molt properly and this may create physiological issues for the species. It may manifest in disease issues as observed in past years such as 2010. This is not a species specific issue since Walrus and Polar Bears also had disease issues during the same period of time.

Other ideas for future work include the comparison of Beluga in Canadian populations (e.g., body growth). Proposed work for the LIA is the survey of Ringed Seals on the ice. Infrared (IR)/photographic aerial surveys using twin otter planes will occur. Surveys will be flown in the spring to coincide with the Ringed Seal molting season. During this time, seals will be hauled out on the ice and available to count. Additionally, Polar Bear activity will be assessed based on tracks, predation attempts and kill sites. The survey of Ringed Seals on ice is done at an altitude of 304 m (IR 250 m strip width; DSLR 312 m strip width). The transect spacing of 5 km gives 5% coverage of the study area. The IR imagery is analyzed for potential animals and confirmed using corresponding DSLR photographs. The IR detection of Ringed Seals uses IR imagery that improves the detection rate of seals on ice. This is a more efficient and reliable method of collection compared to traditional techniques. It eliminates the need for large teams of trained observers and it simplifies data analysis and density estimation. Further photographic analysis will examine Polar Bear tracks, polar bear predation attempts, seal kill sites, seal holes, and whales. Marine mammal sampling kits to Inuit hunters in Grise Fiord, will allow for continued collection of Ringed Seals in comparison to southern stocks.

A short discussion followed S. Ferguson's presentation. The first question addressed software needs to automate the detection of seals in processing the data. NOAA has software to do this but we do not. It will be done manually. A second question concerned the comparison of prey availability. It is hard to make reliable population estimates but we can get relative abundance. The comparison will be good to do. There are ecosystem models to determine the fish populations based on marine mammal predator abundance. A follow on comment inquired about the presence of marine mammal observers onboard vessels and suggested this as a means to make comparisons as well. Another question was asked regarding the observation of seals during seal survey flights in high Arctic regions and expectations regarding density. There is an expectation of low density and it will be interesting to see what mammals are present in the LIA, particularly during the short open-water season. This has never been examined before. Cutting a hole in the ice usually means seals will haul out at that hole eventually. Do we want to be prepared to sample seals if observed and there is an opportunity? Another question was asked regarding the knowledge of seal ice use for application to modelling. More ice surveys provide more opportunity to collect data that would support future model development. We need to figure out what ice seals are using. The LIA provides a good opportunity to collect this information. In follow up to the sampling question, is there a means to capture seals that may haul out or show up at holes? People have tried to capture seals on the Amundsen in the moon pool but it did not work. As well during the molting phase seals will lose their tag so the time of the year is not perfect for these types of studies. The open water season is better for tagging studies.

21-YEARS OF SEA ICE EXCHANGE BETWEEN THE ARCTIC OCEAN AND THE CANADIAN ARCTIC ARCHIPELAGO FROM RADARSAT

S. Howell provided a presentation titled "***21-years of sea ice exchange between the Arctic Ocean and the Canadian Arctic Archipelago from RADARSAT***". Ice exchange from the Arctic Ocean exerts a strong influence on sea ice conditions in the Canadian Arctic Archipelago especially during minimum ice conditions (Howell et al. 2010). When ice melts during the melt season, it provides leeway for ice inflow from the Arctic Ocean. This has implications for safe ship navigation routing. The region may be ice free one week and covered by multi-year sea ice the next. Up until recently, record low conditions in the Canadian Arctic Archipelago were in 1998 and most recently 2011.

Ice exchange also influences the thickness distribution within the region. There is a thinning gradient with distance away from the Arctic Ocean but thick ice is still found in the southern channels. Thick ice from the Arctic Ocean moves through the Canadian Arctic Archipelago and eventually melts. This ice is transported quickly through the region (Haas and Howell 2015). Ice is exported out of the LIA via Fram Strait, Nares Strait, Beaufort Sea, and the Canadian Arctic Archipelago. The Canadian Arctic Archipelago is currently the smallest (annual) flux outlet compared to Nares and Fram straits. The ice is exported from all outlets and eventually melts but in the Canadian Arctic Archipelago the process is slower because of narrow channels through the islands, and the onset of land-fast conditions. This could change by mid-century but the Canadian Arctic Archipelago will still house lots of ice.

Through RADARSAT imaging from 1997 to 2017, quantification of ice exchange is possible. The estimated exchange rates will focus on the M'Clure Strait and Queen Elizabeth Islands. A tracking algorithm (Komarov and Barber 2013) was used to estimate ice motion every 1-3 days. It is weighted against ice concentration and then summed over the month. Several studies have used the same approach. An animation was used to examine computing displacement and was quantified with RADARSAT. For M'Clure Strait (1997-2017), there was considerable variability in inflow from August-September and outflow from October-November. There was minimal exchange from 2008-2011 that has increased since 2012. There was record inflow in 2016. There is still exchange despite large decreases in the Beaufort Sea. There has been mostly new inflow over the 21 year period. This is influenced by the sea level pressure in the Beaufort Sea/Canadian Basin particularly by the high pressure in these regions. Typically high pressure in the Beaufort Sea reduces inflow and low pressure increases inflow but this depends on the location of the centre of action. In the Queen Elizabeth Islands, there is mostly inflow for all months, peaking in August and September. This region had approximately half the ice area flux in comparison to M'Clure Strait. The Northern gates (Sverdrup Channel) is experiencing more inflow in recent years. In parallel, this region almost always has had new inflow over the last 21 years. There have been modest increases in recent years. The inflow typically dominates regardless of high or low Sound Pressure Level (SPL) and only land fast ice stops the inflow. If more ice is flowing through the Queen Elizabeth Islands, how come ice conditions are still low in the Canadian Arctic Archipelago? The answer is likely warming. This thick ice is likely melting more quickly as it migrates through the Canadian Arctic Archipelago. In situ multi-year sea ice formation is a large contribution but has deceased in recent years.

In summary, M'Clure Strait total ice exchange over the 21 year period is small at ~116 x 10^3 km^2 due to inflow/outflow variability. It will likely experience variability as the transition to a summertime sea ice-free Arctic continues. In the Queen Elizabeth Islands, the total ice exchange for the 21 year period is ~300 x 10^3 km^2 and is increasing at ~1,300 km^2/year. The exchange is expected to continue and perhaps increase further as the transition to a summertime sea ice-free Arctic continues. It has taken a long time for the Arctic Ocean to export this amount of ice through the Queen Elizabeth Islands, therefore the continued process of dynamic ice loss through the Canadian Arctic Archipelago will be slow. The LIA is unlikely to experience rapid dynamic ice removal.

A short discussion followed S. Howell's presentation. The first question related to terminologies that were resolved. The quick transit of sea ice means thicker ice. There are possible and valid points for ice accumulating in M'Clintock Channel. There seems to be less here which is specific to this region. The ice coming in is thinner than it used to be. How do you know this is the case? It is based on average values not on specific regional values. What about other possibilities that there is less first-year sea ice survival? Is it happening? There is seasonality to the land-fast ice. There is breaking occurring earlier that allows inflow and outflows.

GOVERNMENT OF CANADA CONCEPTS OCEAN ICE FORECASTING

F. Davidson provided a presentation titled "***Government of Canada CONCEPTS Ocean Ice Forecasting***". This is a project done in collaboration with multiple groups including DFO, ECCC, and Defence Research and Development Canada (DRDC). Partnership also occurs with international groups such as Mercator Ocean and Global Ocean Data Assimilation Experiment (GODAE) Ocean View. The oceanographic information provision uses knowledge from observations (i.e., satellites, in situ) to feed into ocean models for the purpose of enhancing observation value to past, present, and future ice information. Observations on their own are insufficient and cannot provide enough resolution and timescale. They also have no predictive capacity.

The Oceanographic Product Provision (aka CONCEPTS) has capabilities to work within the LIA. Global examples include Blue Link, National Climate Outlook Forums (NCOFS), Foam, Mercator-Ocean, India, and Brazil. The observation network feeds into data management and monitoring as well as the prediction/assessment and assimilation modelling. This further feeds into product access for the end users. There are links going back and forth between several of these components. CONCEPTS has not yet delivered on an oceanographic service chain. Staff is needed to help with dissemination and access services to verify the quality of the oceanographic forecast output, prepare web tools and Open Geospatial Consortium (OGC) compliant data products for dissemination and communicate with end users.

The Canadian Operational Network of Coupled Environmental Prediction Systems (CONCEPTS) is a global system that is working to increase resolution to atmospheric and wave forecasts or to run as a standalone system. Computing power is increasing faster than ocean observing capacity. There is not enough data to evaluate and constrain fine scale features in the ocean prediction system. The vision of CONCEPTS is to improve atmosphere-ocean-ice-wave prediction and warnings in Canada for the increased safety, decision support, and economic benefit; and achieving a greater understanding and better-informed management of Canada's marine environment. Its mission statement is to improve prediction of weather, ice, wave, and ocean conditions through sound science, and effective collaboration, and communication within a client focused product delivery network.

CONCEPTS has five systems running in operations: Global Ice Ocean Prediction Systems (GIOPS), Coupled GDPSv6, Regional ice Ocean Prediction System, Great Lakes Coupled Forecasting System, and Coupled A-I-O Gulf of St. Lawrence. There are several other systems in various stages of development; GEM-NEMO Seasonal, EnGIOPS: Monthly Ensemble GIOPS, CIOPS: Coastal (2 km) system for east and west coast, near-shore modelling (1 m-2 km), and waves and storm surge.

CONCEPTS is presently increasing capacity. Three staff members work on the ocean service desk. Through the Ocean Protection Program, an additional 19.5 positions at DFO, three at

ECCC, will all be on staff shortly to work on near-shore NEMO (Nucleus for European Modelling of the Ocean) modelling, improve drift capability, and work on probabilistic forecasting. Currently, the evaluation of impacts in operational systems is being assessed. Arctic drifter, RadarSat, and ringed seal CTD observations are being used and incorporated for model verifications.

With the reduction of ice spatial coverage and temporal extent in the Arctic, there is an increased need to verify sea ice and ocean forecasting performance. Additionally, this information is useful for short-term operational and longer term strategic decisions. The methodology allows data to be collected and shared by a third party to improve the knowledge of the forecast performance in the Canadian Arctic and the Northwest Atlantic. It is easy to predict the in-centre regions where there is much ice but it is more difficult to predict edge regions (need for improvement).

Ocean navigator is a user friendly interface tool that does ocean prediction and assessment discovery. There is access to full resolution in space and time, anywhere from the last 20 years to the present hour as well as global to regional domains down to 2 km resolution. It verifies the prediction/assessment quality with observations such as drifters, gliders, CTDs on seals, etc. It dissects, interprets, and understands all variables in the system. It can handle biogeochemical variables (currently from French system). For example, drifter data collected from deployments via Canadian Coast Guard Services (CCGS).

Plans for 2018 include the deployment of: five ARGO floats for daily profiles of the Beaufort Sea/Arctic regions, two ARGO floats in Hudson Bay, METAREA ice drifter deployment, and three surface drifters in Hudson Strait. In addition, there is potential for the development of a tailored arctic/coastal ARGO type profiler.

In summary, ocean ice forecasting is produced by the Government of Canada as well as world-wide (UK, EU, AUS, USA). There is global to regional modelling capacity. There is deterministic to ensemble data. There is a standalone system to a coupled A-O-I. There is increased realism in the modelling. Verification and accessibility is important for increasing utility of the models. There are Pan Canadian Regional Ice forecast and hindcast systems. There needs to be further development of accessibility (http://navigator.oceansdata.ca) through the maturing of the service desk accessibility service and end use enablement. Research and development is still occurring on the model systems such as delivery drift prediction tools and products in the Oceans Protection Program.

A short discussion followed F. Davidson’s presentation. The first question concerned the Chl *a* measurement techniques (water or ice). It is on ice. The next question asked was about the length of the forecast. The hindcast is provided by France right now and we (DFO) will eventually do it ourselves. The forecast range is 10 days (GEOPS) and as we increase resolution to regions it will be two days with REOPS. The follow-up question concerned the stochastic run of the model and if 50 times is enough to represent the uncertainty. Due to the expense, 50 is a feasible number to run on a daily basis. It is a question of resources and how much precision is desired on the error. We (DFO) are okay with 50 presently.

BREAKOUT SESSIONS

Breakout Session Themes

C. Michel provided an introduction to the breakout sessions. Three breakout groups (***See Annex 2 for the list of workshop participants***) were tasked with discussing three themes:

Theme 1: Identifying key science questions, knowledge gaps and challenges. The groups were asked to propose 3-5 key science questions that should be addressed in the LIA program and identify key knowledge gaps and/or challenges that need to be addressed for each.

Theme 2: Linking LIA science to Arctic policy & science initiatives (current & future). The groups were asked to identify current or future planned Arctic science projects or programs for which synergies could be explored and to identify and discuss potential funding avenues to leverage DFO's LIA science program though national or international collaborations.

Theme 3: Program Coordination & Communication, Data management. The groups were asked to discuss a possible organizational structure for the LIA science program for coordination, communication and delivery of science nationally and internationally (e.g., data sharing, logistics, and outreach) and to discuss data management agreements and frameworks and list examples of existing frameworks and data portals that could be adapted to the LIA science program.

Breakout Group 1 Presentations (Chair: M. Steele, Rapporteur: F. Davidson)

Theme 1: The key science aspects for group one were: 1.) what determines the inter-annual variability in multi-year sea ice thickness, recruitment, and export?; and 2.) to better understand sea ice processes vis-a-vis biological productivity (what is out there?, what is the driver?). Other questions that group one thought were important to address were: 1.) describing and understanding the last ice ecosystem presently (biodiversity of all trophic levels, water masses, and ice types), and 2.) studying the transition in the future (time scales, spatial distribution, types of ice). Follow-on questions proposed by group one were: 1.) what are the controls of ice flow and water from the LIA (relevant time scales, weather versus climate scales)?; and 2.) do changes in the LIA matter to areas further south (biogeochemistry properties, physical properties, chemistry, and, describe, quantify and project)? More follow-on topics for this theme included: impacts of snow redistribution, impact of ice on small scales, different length scales between first-year and multi-year sea ice, the composition of source regions of the LIA (where ice comes from now, where will ice come from in the future), and how will the LIA act as a refuge for ice associated species (e.g., In the last 20 years more polar bears are seen near Eureka) if multi-year sea ice disappears. Some of the challenges that need to be addressed are: the need to collate physical and biological ice coupled observations, poorly sampled areas, understanding the bio-physical linkages, and the shortness of traditional observation periods (i.e., lack of full seasonality of observing period, and to better understand full seasonal picture). There is relevancy for traditional food supply. A prediction system could help to predict freeze-up dates, break-up dates, melt dates and the quality of the ice. Can we leverage other studies on disappearing ice in other areas (not necessarily thick ice)?

Theme 2: Group one identified several programs and/or organizations that could work in collaboration with the LIA program: MOSAiC, Switchyard, YOPP: Year of Polar Prediction, CASIMBO: Canadian Arctic Sea ice Mass Balance Observatory, Nansen Legacy, UK NERC: National Environment Research Council, SIPN: Sea Ice Prediction Network (pan Arctic), Central Arctic Ocean Fisheries agreement, Synoptic Arctic Survey, Arctic Council, WWF, sea ice drift forecast experiment, regional wildlife organizations, Arctic College (Environmental Technologies Program), and the EC METAREA program.

Breakout Group 2 Presentations (Chair: H. Flores, Rapporteur: M. Gold)

Theme 1: The key science questions developed by group two include: 1.) how well is the LIA represented in the current generation of models, and what observations can we make to improve the models?; 2.) what is the unique biodiversity located in the LIA?; 3.) what ecosystem processes, functions, and services are occurring in the LIA (e.g., primary productivity)?; and 4.) how can we predict what future physical, biological changes will occur in the LIA? Knowledge gaps included the distribution of biodiversity, the understanding of primary productivity in the LIA, ecosystem function, processes and services in the LIA, links to areas outside the LIA, link in trophic levels, and the habitat properties.

Theme 2: Group two identified several programs and/or organisations that could work in collaboration with the LIA program on a global (e.g., CBD: Convention on Biological Diversity, BBNJ: Biodiversity Beyond National Jurisdiction), international (e.g., Arctic Region, Arctic Council, PAME/MPA expert group, CBMP, CAFF, Arctic Biodiversity Congress, and CAO fisheries agreement), bilateral (e.g., MOSAiC, Horizon 2020, Greenland/Denmark, and the North Water Polynya Commission), national (e.g., APF: Canada's Arctic Policy Framework, MEOPAR: Marine Environmental Observation, Prediction and Response Network, CHARS: Canadian High Arctic Research Station, and DFO Oceans Management/MCT committee) and sub-national (e.g., Nunavut land use plans, and Nunavut fisheries management programs).

Theme 3: Group two identified workshops in the north to communicate about the LIA, northern research priorities and roles for community members. A dedicated website with a portal was put forth for data sharing and communication. Setting up a common communication outreach plan and products for the program was suggested rather than individual scientists taking the lead. A secretariat would be useful to co-ordinate, complete outreach and communicate. Finally, a science steering committee could be developed that has broad representation (national/international/local).

Breakout Group 3 Presentations (Chair: K. Moore, Rapporteur: B. Lange)

Theme 1: The key science questions developed by group three include: 1.) what are the processes involved in maintaining the LIA?; 2.) how do we produce this really thick sea ice?; 3) the need to characterize dynamics of the three different sea ice drift directions up against the Canadian Arctic Archipelago (CAA) and Greenland (modelling); 4.) what controls this drift east of Greenland, down Nares Strait or along the CAA (modelling study combined Remote Sensing data)?; 4.) how is sea ice ecology related to ice features (i.e., first-year ridges versus multi-year ridges)?; and 5.) What is the relationship between seal usage and habitat type (ice types and ice features) and comparison to other areas? Knowledge gaps include the description of this really thick ice at source, processes that generate it, ice mechanics, thickness of sea ice is sensitive to ocean heat flux which is not well quantified here, stratification, interaction of wind and topography, supply of nutrients and spatial variability of light, general ocean circulation and upwelling in this area to supply nutrients, processes that deliver nutrients to the ice bottom, and surveys have not been done north of Alert, NU. Challenges are the logistics (i.e., the choice of working area will be constrained by area and so we should not limit ourselves to Alert/Lincoln Sea), complex interactions, assessing ice types and features and the interaction with wind, getting onto the ice requires two twin otters (generally getting onto the ice will be difficult and very expensive), getting data that is representative of the area, getting a big picture to get the story right, fueling out of Alert, costs, and linking airborne surveys of sea ice thickness and snow with marine mammal surveys (drone surveys could supplement this).

Theme 2: Group three identified the need to link LIA science to Arctic policy and science initiatives. Linking projects are AWI-MOSAiC, NERC: Natural Environment Research Council of the UK, BAS: British Antarctic Survey and NPI: Norwegian Polar Institute (EU-Horizon 2020), Nansen Legacy, Denmark/Greenland, NSF: National Science Fund, NSERC: Natural Sciences and Engineering Research Council of Canada, Arctic Net, universities, CHINARE: Chinese Antarctic Research Expedition, YOPP, WWF (i.e., Arctic Species Fund and other projects depending on availability), and Polar Knowledge Canada (CHARS). The Arctic Council and Arctic in Rapid Transitions (ART) were two other groups where group 3 thought linkages could occur. Finally, linkages could also occur with modelling studies/projects such as the Canadian Arctic ecosystem model and the University of Alberta model.

Theme 3: Group three identified the international community (i.e., AWI, WWF, Greenland Institute of Natural Resources (GINR), University of Washington, ICCC, and liaison for EU projects, Arctic Council), science (i.e., DFO, ECCC, AWI, Natural Resources Institute (University of Manitoba NRI), others as appropriate), outreach (i.e., public outreach by DFO, WWF, National Geographic, AWI, Association of Polar Early Career Scientists (APECS) and engaging communities by DFO, APECS, NRI and Aurora Research Institute), logistics (i.e., Polar Continental Shelf Program (PCSP), DRDC, DFO, AWI, and others as appropriate), and data (i.e., DFO and AWI) as the structure to manage data and outreach for the LIA.

WORKSHOP CLOSING COMMENTS

R. Young provided closing comments to the workshop. The terms of reference for the workshop was addressed efficiently. Thanks were extended to all participants for sharing expertise, and their attendance at the workshop. is The workshop represented a great start to the LIA program. A Workshop Proceedings document was committed to be produced for future use and input. It is intended that the proposed team will come back to the group as time goes by to discuss the LIA project as it moves forward for the length of the program. C. Michel provided additional thanks to the support and administrative teams who aided in setting up the workshop and provided thanks to the participants for their attendance. A recommendation was made by J. Akearok (NWMB) to have more Inuit organizations present in future science workshops.

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APPENDIX 1. TERMS OF REFERENCE

Context: Arguably one of the most fundamental changes in sea ice cover in the Arctic Ocean is the transition from an old, multi-year-ice dominated sea ice cover to annual sea ice. The Last Ice Area is the only region that is expected to retain summer sea ice until 2050. As permanent ice cover recedes, the Last Ice Area will be essential for the communities that depend on ice-dependent species for food, shelter and cultural use. In this context, the Arctic Council recommended scientific research in multi-year ice refuge areas to inform decision-making and maximize the resilience of Arctic ecosystems to climate-associated changes, in particular sea ice loss (CAFF 2013). The Government of Canada has committed to work in collaboration with northern partners and national and international stakeholders to better understand the Last Ice Area.

Workshop Objective: The main objective of the Last Ice Area (LIA) Science Workshop is to bring together national and international stakeholders, government and non-government agencies to discuss research for the Last Ice Area. The Workshop will involve short presentations to take stock of our current understanding and key research questions for the Last Ice Area, as well as discussion time for the development of a science plan for the LIA.

The objectives of the workshop are to:

- Provide an overview of the current scientific knowledge in the Last Ice Area;
- Foster communication between stakeholders, and discuss how science in the Last Ice Area can help inform national and international policy initiatives;
- Describe planned scientific activities in the Last Ice Area and seek linkages with stakeholders and partners;
- Discuss linkages, commonalities and complementarity of the Last Ice Area Science Program with national/international Arctic science initiatives (e.g., MOSAiC, Observation Networks);
- Establish a coordination mechanism for current and future scientific activities in the Last Ice Area (e.g., communications, data sharing, leveraging of science activities);
- Provide the basis for the development of the LIA Science Plan.

EXPECTED PUBLICATIONS: WORKSHOP PROCEEDINGS

PARTICIPATION:

- Fisheries and Oceans Canada (DFO) (Science and Oceans Management)
- Environment and Climate Change Canada (ECCC)
- Natural Resources Canada (NRCan)
- Parks Canada Agency

- Defense Research and Development Canada (DRDC)
- Government of Nunavut (GN)
- Nunavut Wildlife Management Board (NWMB)
- Inuit Circumpolar Council (ICC)
- University of Washington
- University of Toronto
- Alfred Wegener Institute for Polar and Marine Research (AWI)
- National Geographic Pristine Sea
- World Wildlife Fund (WWF)
- Arctic Council – Protection of the Arctic Marine Environment (PAME)

REFERENCES

Conservation of Arctic Flora and Fauna (CAFF), 2013. Arctic Biodiversity Assessment. Status and trends in Arctic biodiversity: Synthesis. 128 p.

APPENDIX 2. MEETING PARTICIPANTS

Christian Haas	Alfred Wegener Institute
Hauke Flores	Alfred Wegener Institute
Chris Browne	Defence Research and Development Canada
Jim Milne	Defence Research and Development Canada
Amie Black	Environment and Climate Change Canada
Steve Howell	Environment and Climate Change Canada
Andrew Platt	Environment and Climate Change Canada
Neil Swart	Environment and Climate Change Canada
Don Cobb	Fisheries and Oceans Canada, Science
Fraser Davidson	Fisheries and Oceans Canada, Science
Steve Ferguson	Fisheries and Oceans Canada, Science
Murray Smith	Fisheries and Oceans Canada, Science
Bronwyn Keatley	Fisheries and Oceans Canada, Science
Benjamin Lange	Fisheries and Oceans Canada, Science
Tracey Loewen	Fisheries and Oceans Canada, Science
Humfrey Melling	Fisheries and Oceans Canada, Science
Christine Michel	Fisheries and Oceans Canada, Science
Shannon Nudds	Fisheries and Oceans Canada, Science
Clark Richards	Fisheries and Oceans Canada, Science
Charlotte Sharkey	Fisheries and Oceans Canada, Oceans Program
Pascal Tremblay	Fisheries and Oceans Canada, Science
Cal Wenghofer	Fisheries and Oceans Canada, Oceans Program
Brent Young	Fisheries and Oceans Canada, Science
Robert Young	Fisheries and Oceans Canada, Science
Jade Owen	Government of Nunavut, Environment
Maya Gold	Arctic Council, PAME, Canada Representative
Francine Mercier	Parks Canada Agency
Dan Myers	National Geographic Society – Pristine Seas
Timothy McCagherty	Natural Resources Canada, Polar Continental Shelf Program
Tom Platt	Natural Resources Canada, Polar Continental Shelf Program

Jason Akearok	Nunavut Wildlife Management Board
Kent Moore	University of Toronto
Michael Steele	University of Washington
Martine Giangioppi	World Wildlife Fund
Clive Tesar	World Wildlife Fund

APPENDIX 3. WORKSHOP AGENDA

Day 1 – Tuesday, 16 January

9:00 a.m. **Welcome** (Chairs)

- Opening Remarks, Terms of Reference & Workshop Objectives
- Review Agenda / Meeting Logistics
- Participant Introductions

9:30 a.m. **Last Ice Area Science Program Background and Context**
(Christine Michel, DFO, Winnipeg, Canada)

10:00 a.m. **Fisheries and Oceans – The National Perspective**
(Bronwyn Keatley, DFO, Ottawa, Canada)

10:15 a.m. HEALTH BREAK

10:30 a.m. **From process studies to system understanding: Alfred Wegener Institute's (AWI) interdisciplinary research in the Arctic Ocean**
(Christian Haas, AWI, Bremerhaven, Germany)

11:00 a.m. **Linking Ocean Management and Science in the Last Ice Area**
(Cal Wenghofer, DFO, Ottawa, Canada)

11:30 a.m. Question/Discussion Period

11:45 p.m. LUNCH

1:00 p.m. **Parks Canada Arctic Conservation Initiatives**
(Francine Mercier, Parks Canada)

1:30 p.m. **Last Ice Area: from WWF project to Canadian accomplishment**
(Clive Tesar, Consultant, World Wildlife Fund)

2:00 p.m. **What makes an ice area last and what makes one go away?**
(Humfrey Melling, DFO, Sidney, Canada)

2:30 p.m. HEALTH BREAK

2:45 p.m. **Ocean mysteries of the Greater Lincoln Sea**
(Michael Steele, University of Washington, USA)

3:15 p.m. **Canada – The Last Ice Area?**
(Christian Haas, AWI, Bremerhaven, Germany)

3:45 p.m. **Climate and sea ice modelling from seasons to centuries at Environment and Climate Change Canada (ECCC)**
(Neil Swart, ECCC, Victoria, Canada)

4:15 p.m. Question/Discussion Period

4:30 p.m. Day 1 Wrap-up

Day 2 – Wednesday, 17 January

9:00 a.m. Review Day 1, Agenda for Day 2 (Chairs)

9:15 a.m. **Arctic Council's Protection of the Arctic Marine Environment (PAME) Working Group-Overview of Work**
(Maya Gold, PAME Representative, DFO, Ottawa, Canada)

9:45 a.m. **New insights into the ecological role of sea ice in the Last Ice Area** (Christine Michel and Benjamin Lange, DFO, Winnipeg, Canada)

10:15 a.m. HEALTH BREAK

10:30 a.m. **Autonomous long-term bio-physical observatories in sea ice environments**
(Clark Richards/Shannon Nudds, DFO, Dartmouth, Canada)

11:00 a.m. **Sweeping the ice. Sampling animals and environmental properties from the under- ice habitat**
(Hauke Flores, AWI, Bremerhaven, Germany)

11:30 a.m. **Ice-adapted marine mammals - circumpolar distribution and abundance patterns**
(Steve Ferguson, DFO, Winnipeg, Canada)

12:00 p.m. LUNCH

1:00 p.m. **21 years of sea ice exchange between the Arctic Ocean and the Canadian Arctic Archipelago from RADARSAT**
(Steve Howell, ECCC, Toronto, Canada)

1:30 p.m. **Overview of Ocean and Ice Forecast systems from the CONCEPTS initiatives: how they work, how to access output and to verify forecast output against observation data**
(Fraser Davidson, DFO, St John's, Canada)

2:00 p.m. **BREAK-OUT SESSIONS (3 BREAK-OUT GROUPS)**

2:15 p.m. **Break-out Theme 1:**
Identifying key science questions, knowledge gaps and challenges

2:45 p.m. HEALTH BREAK

3:00 p.m. **Break-out Theme 2:**
Linking LIA science to Arctic policy & science initiatives (current & future)
Program Coordination & Communication, Data management

4:00 p.m. Plenary Session: Break-out Group Presentations and Discussion (10 min presentations)

4:45 p.m. Workshop Wrap-up

5:00 p.m. Meeting Adjourned

THANK YOU!