Arctic Large Aquatic Basin climate change assessment part 2: Impacts, Vulnerabilities and Opportunities (IVO) - A contribution to the Aquatic Climate Change Adaptation Services Program

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2016

Canadian Manuscript Report of Fisheries and Aquatic Sciences 3091

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Cat. No. Fs 97-4/3091E ISBN 978-0-660-04453-8 ISSN 0706-6473 (print version)
Cat. No. Fs 97-4/3091E-PDF ISBN 978-0-660-04513-9 ISSN 1488-5387 (online version)

Correct citation for this publication:

Niemi, A. Schimnowski, O. and Reist, J.D. 2016. Arctic Large Aquatic Basin climate change assessment part 2: Impacts, Vulnerabilities and Opportunities (IVO) - A contribution to the Aquatic Climate Change Adaptation Services Program. Can. Manuscr. Rep. Fish. Aquat. Sci. 3091: viii + 67 p.

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ABSTRACT

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DFOs Aquatic Climate Change Adaptations Services Program (ACCASP) incorporates adaptation science into decision-making processes across its sectors to effectively manage the risks that climate change poses to mandate delivery. This report examines how climate change will impact DFO priorities in the Arctic Large Aquatic Basin (LAB) by assessing climate change impacts, vulnerabilities and opportunities (IVO) relevant to DFO sectors, programs and clients. Climate change IVO are presented for four categories (Arctic resources, Arctic structure, Arctic stability and the emerging Arctic) that reflect specific ecosystem components integral to sectoral activities and management responsibilities. The impact level and likelihood of individual IVO are presented and linked to program level activities of DFOs Program Alignment Architecture for eight different agencies/sectors as well as co-managers/resource users. The results indicated that over the next 50 years, climate change IVO will no longer be manageable under normal business circumstances of DFO. Rather, critical events are expected to require additional management steps by DFO. Unanticipated and variable effects on DFO business are also anticipated given the complex interactions of ecosystem and climate systems and the current status of risk-based scenarios assumptions. We recommend that DFO Science target the description and prediction of ecosystem thresholds and triggers within a strategic program that integrates monitoring, including mechanistic research, modelling and synthesis activities. These actions will enhance DFOs capacity to anticipate change and reduce uncertainties of climate change IVO.

RÉSUMÉ

Niemi, A. Schimnowski, O. and Reist, J.D. 2016. Arctic Large Aquatic Basin climate change assessment part 2: Impacts, Vulnerabilities and Opportunities (IVO) - A contribution to the Aquatic Climate Change Adaptation Services Program. Can. Manuscr. Rep. Fish. Aquat. Sci. 3091: viii + 67 p.

Le Programme des services d'adaptation aux changements climatiques en milieu aquatique (PSACCMA) intègre la science de l'adaptation aux processus décisionnels dans tous ses secteurs afin de bien gérer les risques que pose le changement climatique pour la réalisation du mandat. Ce rapport montre l'incidence qu'aura le changement climatique sur les priorités du MPO dans le grand bassin aquatique de l'Arctique, en évaluant ses impacts, vulnérabilités et opportunités (IVO) pour les secteurs, les programmes et les clients du MPO. Les IVO du changement climatique sont présentés dans quatre catégories (ressources de l'Arctique, structure de l'Arctique, stabilité de l'Arctique et nouvel Arctique) qui correspondent aux différentes composantes écosystémiques visées par les activités des secteurs et les responsabilités de gestion. Le niveau d'impact et la probabilité de chaque IVO sont indiqués et reliés aux activités des programmes selon l'architecture d'alignement de programmes du MPO pour huit organismes/secteurs différents, ainsi que pour les cogestionnaires et les utilisateurs des ressources. Les résultats ont montré que d'ici 50 ans, il ne sera plus possible de gérer les IVO du changement climatique dans le cadre des activités normales du MPO. Le Ministère devrait plutôt se préparer à prendre des mesures de gestion supplémentaires pour faire face à des événements extrêmes. On prévoit aussi des effets imprévus et variables sur les activités du MPO compte tenu des interactions complexes entre les systèmes climatiques et l'écosystème et de l'état actuel des hypothèses des scénarios axés sur les risques. Nous recommandons que le Secteur des sciences du MPO s'attache à décrire et à prédire les seuils et les éléments déclencheurs écosystémiques dans le cadre d'un programme stratégique qui intégrera les activités de surveillance, y compris la recherche mécaniste, de modélisation et de synthèse. La description et la prévision de ces seuils et éléments déclencheurs renforceront la capacité du MPO à anticiper le changement et à réduire les incertitudes liées aux IVO du changement climatique.

ACKNOWLEDGEMENTS

We acknowledge regional and sectoral partners of the ACCASP program who have contributed to consultations and discussions. We also thank Joclyn Paulic for contributing to data and synthesis collections and for technical assistance with the report. We also thank Nadja Steiner for input to and review of the trends and projection summary.

SECTION I: Climate Change in the Arctic LAB

1.1 Canada’s action on climate change

As part of the Government of Canada’s “Helping Canadians Adapt to a Changing Climate” program, Fisheries and Oceans Canada (DFO) has undertaken the Aquatic Climate Change Adaptations Services Program (ACCASP). ACCASP aims to incorporate adaptation science into decision-making processes across DFO sectors by assessing the risks that climate change poses to the delivery of DFO’s mission and vision, as well as enabling adaptation in support of DFO’s strategic outcomes: economically prosperous maritime sectors and fisheries; sustainable aquatic ecosystems; and safe and secure waters (Annex 1).

The ACCASP specifically assesses how climate change will impact the delivery of DFO priorities in Canada’s four large aquatic basins (LAB); the Arctic, Pacific, Atlantic and Freshwater. This report focuses on the Arctic LAB which comprises five Arctic sub-regions (Beaufort Sea, Canadian Arctic Archipelago, Baffin Bay/Davis Strait, Mackenzie River Basin and Hudson Bay Complex; Figure 1), each with specific ecological and climate adaptation considerations.

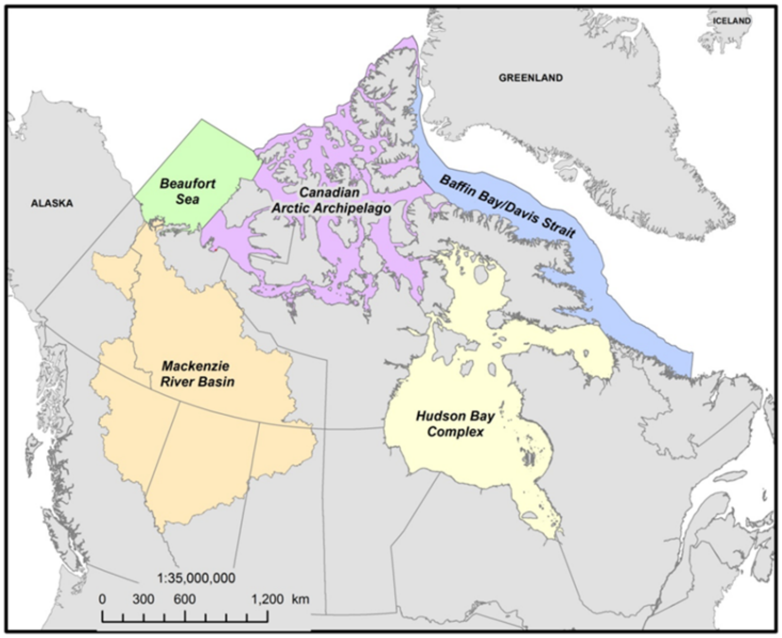

Figure 1. The ACCASP Arctic Large Aquatic Basin (LAB) including five sub-regions.

1.2 DFO Risk-Based Assessment.

A risk-based assessment of climate change impacts and risks on biological systems and infrastructure within DFO’s mandate has been completed, with the Arctic assessment completed in October 2012 (DFO 2013a). The risk assessments were conducted as part of a science advisory process involving DFO Science sector and other experts. The assessments were based on six main climate change related risks that could limit DFO's ability to deliver on its mandate (Interis 2005, 2012). Risks #1 (ecosystem and fisheries degradation) and #2 (changes in biological resources), representing biological risks, were identified as posing the greatest risk to DFO's current responsibilities in the Arctic LAB. An initial summary of threats and opportunities was provided in the risk assessment (DFO 2013a). All risks were expected to increase over a 10 to 50 year time horizon in the Arctic LAB, in particular the risk of species reorganization and displacement (Risk #3). The assessment demonstrated that program activities for all agencies and sectors will require action in response to the diverse range of climate change IVO, including the need for cross-sectoral management. The DFO context and impacts for each of the six risks are summarized in Table 1. The risk assessment for the Arctic LAB discussed here (DFO 2013a) was a first step towards integrating adaptive science for the delivery of DFO's mandate in the expansive Arctic, where the rate of environmental change caused by climate change is evident and occurring more rapidly than elsewhere in the world (Olsen and Reiersen 2011; Cowtana and Way 2014).

Table 1. DFO climate change risks (Interis 2005, 2012) for evaluation of Arctic LAB climate change impacts, vulnerabilities and opportunities (DFO 2013a).

Risks	DFO Impacts/Considerations	Context
Risk 1: Ecosystem and Fisheries Degradation and Damage	There is a risk that climate change will affect DFO's ability to meet its strategic and policy objectives related to Oceans Management, and the sustainable development and integrated management of resources in Canada's aquatic environment.	This risk focuses on DFO's stewardship role to managing and protecting fish habitat, the leadership role of the Department in Canada's Ocean Strategy and the sustainability of the oceans and their resources.
Risk 2: Changes in Biological Resources	There is a risk that climate change will affect DFO's ability to manage and protect the abundance, distribution and quality of harvested fisheries and aquaculture stocks.	This risk refers to DFO's management of fisheries resources (fish stocks, shellfish and marine mammals).
Risk 3. Species Reorganization and Displacement	There is a risk that climate change will affect DFO's ability to protect species diversity and species at risk.	Climate change may lead to changes in the range and diversity of species in various Canadian aquatic habitats. Climate change can limit or extend the range of aquatic species or the introduction or spread of invasive species.
Risk 4: Increased Demand to Provide Emergency Response	There is a risk that climate change will affect DFO's ability to provide acceptable levels of environmental response and search and rescue activities.	The emphasis in this risk is the potential for an increased incidence of marine incidents due to climate change factors and the associated strain on Canadian Coast Guard's (CCG) capacity to respond.
Risk 5: Infrastructure Damage	There is a risk that climate change will result in damage and the need for alterations to DFO	DFO maintains considerable infrastructure to support its operational and scientific

	vessels, coastal and Small Craft Harbour infrastructure.	activities in both the marine and freshwater environments (e.g., harbours, wharves, bases, stations, buoys, slipways, buildings, labs, lighthouses, navigation aids, hatcheries and DFO aquaculture facilities).
Risk 6: Changes in Access and Navigability of Waterways	There is a risk that climate change will affect DFO's ability to provide safe access to waterways.	This risk deals with impeded access due to changes in factors such as sedimentation, water levels, severe weather, wave energy, icebergs and ice.

1.3 Impacts, Vulnerabilities and Opportunities of Climate Change in the Arctic LAB

To facilitate the incorporation of adaptation science in decision-making processes across DFO sectors, this report provides an assessment of the impacts, vulnerabilities and opportunities (IVO) of climate change as they relate to DFO activities in the Arctic LAB. The assessment is based on integrative, ecosystem science to enhance our understanding of the nature, rates and complexities of climate change in the Arctic. The synthesis of Arctic LAB IVO will inform decision-making processes for sectoral specific management of climate change impacts.

Report Objectives

1) To examine how climate change will impact the delivery of DFO priorities in the Arctic Large Aquatic Basin (LAB).
2) To inform adaptive science decision-making for climate change impacts, vulnerabilities and opportunities specific to DFO sectors.

Throughout this assessment, the IVO of climate change are linked to specific sectors, programs or external clients where adaptive decision-making and management is required. The range of clients for each of the five sub-regions within the Arctic LAB is presented in Table 2. In preparation for this report, DFO programs, responsibilities and client services were reviewed through ACCASP consultations with sectors and clients such as Fisheries Management, Fisheries Protection Program, Oceans Program, Small Craft Harbours, Canadian Hydrographic Services and Canadian Coast Guard. The DFO program architecture (Annex 1) guided the analyses.

The delivery of DFO's mandate within the Arctic LAB encompasses DFO activities in all sectors within five of the six DFO Regions (Pacific, Central and Arctic (C&A), Quebec, Maritimes, Newfoundland/Labrador), and exclusive of the Gulf region. DFO sectors include the Canadian Coast Guard (CCG), Small Craft Harbours (SCH), Resource Management and Aboriginal Affairs (RMAA), Fisheries Protection Program (FPP), Species at Risk (SAR), Oceans Management (OM) and the Canadian Hydrographic Services (CHS). The Canadian Science Advisory Secretariat is responsible for the organization of science advice relating to climate change to sectors. There are limited sectoral concerns for Small Craft Harbours in the Arctic LAB, with only three facilities in the Mackenzie River Basin sub-region and one facility in the Baffin Bay/Davis Strait sub-region.

Table 2. Primary internal and external DFO clients, in the five sub-basins of the Arctic LAB, whose activities and management processes will be impacted by climate change, in the context of IVO. Specific DFO regions and Government partners are listed when applicable.

Internal and external DFO clients affected by Climate Change IVO	Mackenzie River Basin	Beaufort Sea	Canadian Arctic Archipelago	Hudson Bay Complex	Baffin Bay/ Davis Strait
DFO Agencies					
Canadian Coast Guard (CCG)	✓	✓	✓	✓	✓
Small Craft Harbours (SCH)	✓				✓
DFO Fisheries/Ecosystem Management Programs					
Resource Management and Aboriginal Affairs (RMAA)	C&A	C&A	C&A	C&A, Quebec	C&A, Quebec, NFLD
Conservation & Protection (C&P)	✓	✓	✓	✓	✓
Fisheries Protection Program (FPP)	C&A	C&A	C&A	C&A, Quebec	C&A, Quebec, NFLD
Species at Risk (SAR)	C&A	C&A	C&A	C&A, Quebec	C&A, Quebec, NFLD
Oceans Management (OM)		C&A	C&A	C&A, Quebec	C&A
DFO Science	C&A	C&A, Pacific	C&A, Pacific, MAR	C&A, Quebec	C&A, Quebec, NFLD, MAR
Canadian Hydrographic Service (CHS)	✓	✓	✓	✓	✓
Canadian Science Advisory Secretariat (CSAS)	✓	✓	✓	✓	✓
Other Government					
Provincial Governments	BC, AB, SK			SK, MB, ON, QC	NFLD/LAB
Territorial Governments	YK, NT	YK, NT	NT, GN	GN, Nunavik	GN, Nunatsiavut
Parks Canada Agency (PC)	✓	✓	✓	✓	x
Environment Canada	✓	✓	✓	✓	✓
Co-management groups					
Wek'eezhii Land & Water Board (WLWB) - Tlicho	✓				
Fisheries Joint Management Committee (FJMC)	✓	✓	✓		
Gwich'in Renewable Resources Board (GRRB)	✓				
Sahtú Renewable Resources Board (SRRB)	✓				
Wildlife Management Advisory Council (WMAC)	✓				
Nunavut Wildlife Management Board (NWMB)			✓	✓	✓
Yukon Fish and Wildlife Management Board	✓				
The Nunavik Marine Region Wildlife Board			✓	✓	✓
Makivik Corporation			✓	✓	
Nunavut Tunngavik Incorporated (NTI)			✓	✓	
Labrador Inuit Association (LIA)					✓
Regional wildlife (RWO), Hunter's & Trappers organizations/committees (HTO/HTC)	✓	✓	✓	✓	✓
International					
Arctic Council (AC)		✓	✓	✓	✓
North Atlantic Fisheries Organization (NAFO)					✓

Table 2 illustrates that management processes within the Arctic LAB are highly integrative among sectors, governments and clients. Minor peripheral connections are not included in Table 2, however, these connections may be substantial depending upon individual situations (e.g., IVO considerations in the Archipelago may affect ‘downstream’ areas such as Baffin Bay/Davis Strait). It is essential that DFO work effectively within the integrated management structure to be responsive, in a timely and informed manner, to the complexities of climate change.

A key component of program delivery in the Arctic LAB is collaboration with co-management boards established under legislated land claims agreements (Inuvialuit, Gwich’in, Sahtu, Nunavut, and Tlicho) (Table 2). DFO also works with Aboriginal groups currently without legislated land claim agreements (not listed in Table 2). Climate change IVO that relate to fisheries or species management (i.e., COSEWIC), for example, require the involvement of appropriate co-management bodies and regional working groups in adaptive decision-making processes, recognizing that co-management partners are integral to DFO’s response to the complexities of both climate change and resource management.

1.4 Climate Change

To assess the IVO for the Arctic LAB we require a clear understanding of what climate change represents and the key parameters and characteristics of climate change that will affect the delivery of DFO priorities. According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to a change in the state of the climate that can be identified (i.e., using statistical tests) by changes in the mean and/or variability of its properties and that persists for an extended period, typically decades or longer. The change can occur due to natural processes or as a result of human activity. To integrate climate change into adaptive management it is critical to understand the nature or type of expected/observed change. Our understanding of climate change must take into account both the shifts in the normal circumstances (i.e., changes in mean values or typical magnitudes) as well as the alterations of the typical variabilities within the system (i.e., frequencies of event occurrences, magnitudes of events). Both types of changes appear to be occurring and, moreover, may interact (e.g., through feedback mechanisms) to exacerbate consequences to human considerations (IPCC 2007, 2014). Three key climate change scenarios to consider are included (Interis 2005):

1) A smooth change, but rapid in comparison to natural climate system fluctuations,
2) Increased variability in the climate system and/or increased frequency of extreme events, and
3) Threshold changes, or rapid shifts in the system from one state to another.

As climate change occurs, the manifestation of DFO risks are not expected to be uniform or regionally consistent. Similar to scenarios for climate change, risks to DFO may be manifested as follows:

1) The degree or level of a risk may change smoothly,
2) The level or priority of a risk may increase in a step-wise fashion, with periods of rapid impacts and plateaus of stability, and/or

3) Risks may appear or intensify abruptly, with or without warning.

Climate change and DFO risk scenarios may occur in the same way. For example, a rapid shift in sea-ice distribution could be paired with an abrupt mortality of narwhal (DFO 2012). Alternatively, climate change and DFO risk scenarios may occur at mismatched temporal and/or spatial scales. A gradual, smooth increase in water temperatures could at some point in time coincide with an abrupt change in fish distribution or survivability, depending on species tolerances. Additionally, changes may also occur unpredictably thus represent surprises in the contexts of DFOs sector activities.

1.5 Climate Parameters

Temperature is the basic climate parameter driving changes in the climate system. Global temperature (land and ocean combined) has warmed, on average, 0.85°C over the period 1880 to 2012 (IPCC 2014). Surface temperatures are increasing for both the land and the ocean with the oceans absorbing the majority of the additional heat entering the climate system (Fig. 2, IPCC 2007). The Canadian national average temperature in 2013 was 0.8°C above the baseline average (mean over 1961-1990 reference period, Environment Canada 2014), thereby closely matching global trends. Changes in temperature and precipitation are not homogeneous at global, Canadian and Arctic LAB scales.

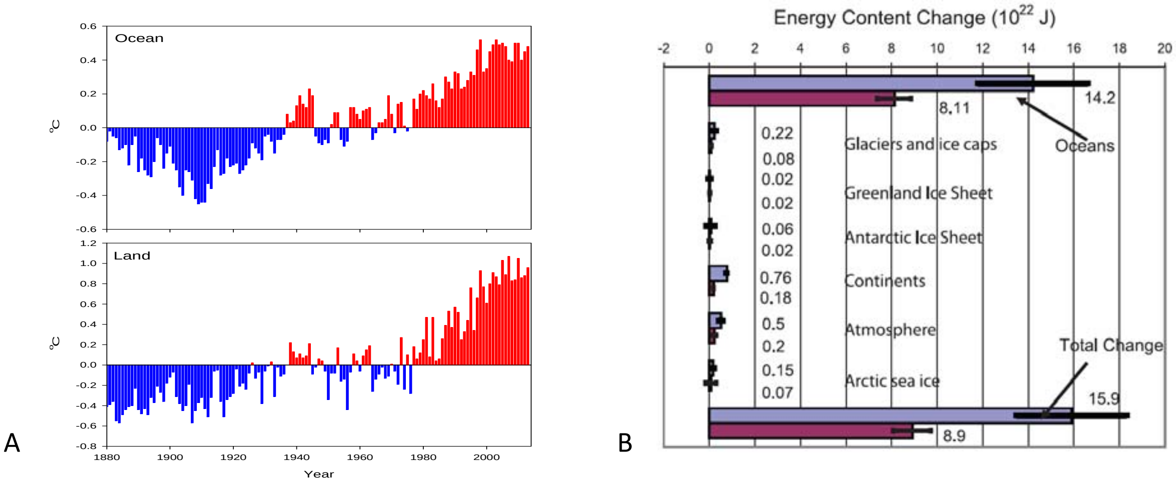

Figure 2. Annual (Jan-Dec) global temperature anomalies 1880-2013 for the ocean and land relative to mean (A, data from NOAA) and earth systems energy content changes for two periods (blue: 1961–2003, burgundy: 1993–2003) showing that the oceans are absorbing the bulk of the world's increased heat content (B, IPCC, AR4 WG1, Fig. 5.4).

All regions of Canada exhibited positive trends in annual temperatures during 2013, however, the strongest regional trend (+2.6°C) was observed in an area encompassing the northern portion of the Mackenzie River Basin sub-region of the Arctic LAB (Environment Canada 2014). Recent analyses of temperature records and models indicate that the Arctic is warming about eight times faster than the rest of the planet (Cowtana and Way 2014).

It is evident that the climate is warming a system that creates the opportunity for more extreme and rare climatic events (Fig. 3, IPCC 2007). Atmospheric circulation patterns, winds and storms will play a central role in extreme or rare events such that future predictions of event frequency, strength and size will be essential for DFO adaptive management.

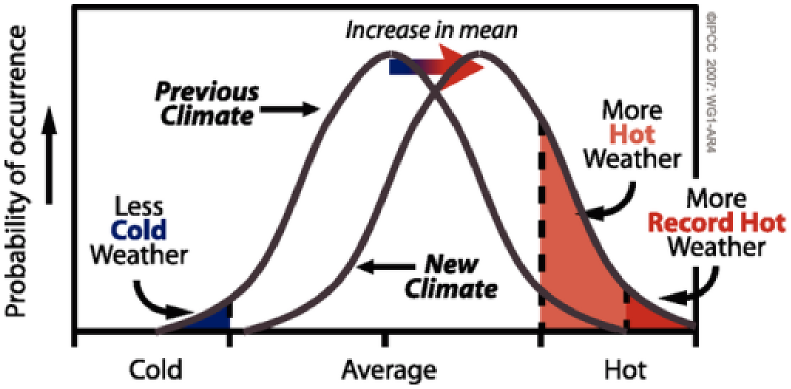

Figure 3. Schematic showing the increased probability of temperature driven extreme events under a warmer global climate (IPCC AR4 TS Box TS.5, Fig. 1).

Within the changing climate, derived or secondary parameters will be critical to the IVO for the Arctic LAB. Ocean surface layer warming and freshening, as well as aspects of water stratification and mixing are key derived variables specific to ocean structure and function. Thickness, extent, area, age, duration and mobility are key derived variables specific to sea ice, which affect physical, chemical and biological components of the four marine sub-regions of the Arctic LAB. Similar parameters for lake or river ice are pertinent in the Mackenzie River Basin sub-region, as well as but to lesser extents, in the other sub-regions. Perhaps the most conspicuous change in the Arctic LAB has been, and continues to be, the reduction of sea ice (Fig. 4). Sea-ice trends are just one example of the variability that can exist within climate parameters and demonstrate the essential need for long term observations to enable prediction and adaptation to the risks of climate change. In 2013 sea-ice trends appeared to “recover” from recent years of record lows. However, long term trends associated with the warming Arctic continue and 2013 Arctic temperatures and sea ice extent remain the 6th warmest and lowest, respectively, in satellite records (Jeffries et al. 2013).

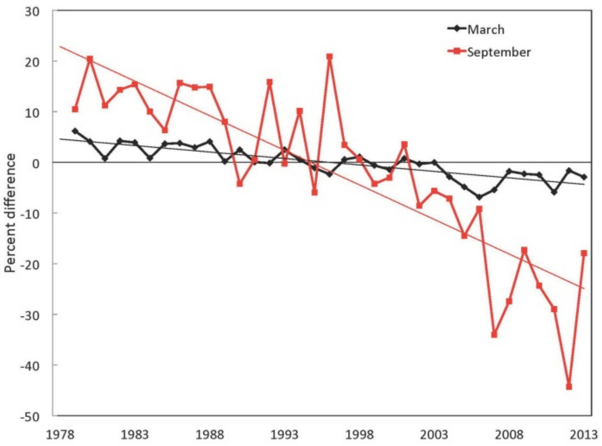

Figure 4. Arctic sea ice anomalies in areal extent in March (month of maximum ice extent) and September (month of minimum ice extent). The anomaly value for each year is the difference (in %) in ice extent relative to the mean values for the period 1981-2010. The black and red linear regression lines indicate ice losses of -2.6% and -13.7% per decade in March and September, respectively (Perovich et al. 2013).

1.6 Trends and Projections

To meet the goals of the ACCASP, knowledge of past and current climate trends and future projections within the LABs is required. Trends and projections (TP) are a tool to anticipate change, including the probability and severity of the changes. Under ACCASP, trends and projections on a 10 and 50 year time horizon are targeted to facilitate DFO decision-making for delivery of future (near and long term) priorities. Given the limitations in knowledge of past and current climate parameters (both basic and derived), challenges associated with existing data, and inherent variability of climate and ecological systems, measures of uncertainty with respect to TP and IVO assessments are important. The uncertainty of climate trends and IVO scenarios must be well understood and captured within decision-making processes to provide confident direction for sectoral activities and adaptive policy changes. Uncertainties pertinent to assessment of TP and IVO for the Arctic LAB include a) the level of impact (Table 3) and b) the likelihood of occurrence (Table 4). These two categories of uncertainty have been previously defined in DFO risk assessment processes (Interis 2005, 2012).

Trends and projections for the Arctic LAB have been summarized in a review by Steiner et al. (2013, 2015). Steiner et al. (2013) stands as Part 1 of the ACCASP risk assessment for the Arctic LAB with the current report on IVO representing Part 2. Anticipated climate trends and their likelihood in the five sub-regions of the Arctic LAB, over the next 10-50 years, are summarized in Table 5. Projections from various models provided estimated mean values for basic and derived climate parameters in the future, with climate variability represented by the range of mean values generated by decadal (or other periodicity), seasonal and/or regional differences shown in the models.

For the next decade, natural intra-decadal variability is expected to be of similar importance as the longer-term trends in the Arctic LAB, adding a layer of complexity to estimating risk to DFO priorities in the Arctic. Air temperatures across the entire Arctic LAB are expected to increase by 0-3°C in summer and 3-7°C in winter, over the next 50 years. The increase in temperature is projected to coincide with a slight increase in precipitation and snow depth. Due to expected changes in atmospheric circulation patterns, projections suggest an increase in extreme events including hot spells, extreme precipitation, and storm surges leading to enhanced coastal erosion (Steiner et al. 2013).

Due to the large area of the Arctic LAB as well as serious logistical restrictions to accessing the majority of the Arctic for much of the year, direct observational data are limited from a historical and spatial perspective. Significant gaps continue to exist for basic climate parameters on a regional basis and for ecosystem derived parameters in general (e.g., primary production and species presence and abundances). These gaps limit the assessment of trends and projections for multiple key parameters that are central to DFO activities in the Arctic. Global models used for the identification of trends and projections lack relevant details at the scale of the LAB sub-regions. Steiner et al. (2013, 2015) utilized regional modelling based on available atmospheric processes to provide sub-region resolution projections that are limited to air temperature, precipitation and wind (Table 5). Models for predictions of ocean properties and sea ice at scales relevant to the Arctic LAB sub-basins are more limited.

To approach the IVO for the Arctic LAB based on Part I, Trends and Projections (Steiner et al. 2013), the limitations and incompleteness of future scenarios must be recognized such that the full range and uncertainties of events are captured in decision-making processes. We also reiterate the conclusions of Part I, for the need to improve and develop two critical components that form the basis for a) understanding climate change IVO and b) creating adaptation tools and strategies. The two component needs are:

1) more consistent (i.e., long-term) datasets, especially for marine biogeochemical parameters, and
2) higher resolution basin-scale ocean ecosystem models that provide scale-appropriate projections relevant to DFO priorities.

Another complicating factor is that associated with limited understanding, in the Arctic in particular, regarding the ecological connections between basic and derived climate parameters and biological systems of interest. For example, mechanistic understanding of many of the freshwater and marine systems is limited, basic biotic inventories and the structural and functional characteristics of much of the component ecosystems are lacking for many areas, and understanding of tolerances and preferences of key biota are similarly limited. Accordingly, predicting the nature and magnitude of climate change driven effects on the systems has high inherent uncertainty. A further complication is that other anthropogenic stressors (e.g., industrial activities, exploitation) may induce effects similar to those of climate variability and change, thus either masking climate change effects or perhaps interacting with them to result in cumulative impacts. Uncertainty of outcomes (and thus risk/preparedness scenarios) increases as systems of greater complexity are considered (i.e., ecosystems), as time horizons increase, and as the number of drivers or stressors involved increase. Predictability accordingly decreases, however, this uncertainty must be recognized and planned into management risk analyses and potential responses.

Table 3. Level of Impact scale for climate change IVO in the Arctic LAB (Interis 2005, 2012).

Level	Definition of Impact
Extreme	A major event that will require the organization to make a large scale, long term realignment of its operations, objectives or finances.
Very High	A critical event that with proper management can be addressed by the organization.
Medium	A significant event that can be managed under normal circumstances by the organization.
Low	An event, the consequences of which can be absorbed but management effort is required to minimize the impact.
Negligible	An event, the consequences of which can be absorbed through normal activity.

Table 4. Likelihood scale for the occurrence of climate change IVO in the Arctic LAB (Interis 2005, 2012).

Level	Experience/Observed Frequency	% Probability	History of Occurrence	Probability of Occurrence
Almost Certain	Occurs regularly here	>80%	It has occurred more than once in the last five years	It may happen within the next two years
Likely	Has occurred here more than once, or is occurring to others in similar circumstances	61-80%	It has occurred once in the last three years	It may happen sometime in the next three to five years
Moderate	Has occurred here before, or has been observed in similar circumstances	41-60%	It has occurred once in the last five years	It may happen sometime in the next five years
Unlikely	Has occurred infrequently before to others in similar circumstances, but not here	20-40%	It has never occurred here, but there is a possibility it could occur in the future	Although possible, it is doubtful it will happen in the next five years
Rare	Almost never observed - may occur only in exceptional circumstances	<20%	It has never occurred here, nor is it expected to occur	It is almost impossible for it to happen in the next five years

Table 5. Past trends and projected changes of basic and derived climate change parameters for the five sub-regions of the Arctic LAB. Colors of projected trends indicate the likelihood of the change: red/certain, yellow/likely, orange/moderate, green/unlikely. Empty cells under Project Change indicate uncertainty of responses due to current data availability and/or uncertainty in climate system linkages to the projected change. Summary based on Steiner et al. (2013).

		Projected Change		
	Past Trend	**Projected Trend**	**Change around mean values**	**Change in variability**
Beaufort Sea				
Air Temperature	⇧	🟨⬆	Summer +0-3°C Winter +4-7°C	
Precipitation	ND[1]	🟧⬆	+0.15 mm/d	
Winds (atmospheric circulation)	⇧	🟧⬆		Increased storm size & strength
Sea ice extent/ concentration	⇩	🟥⬇	Summer -10-80% Winter no change	Regionally variable
Sea surface temperature	ND	🟨⬆	Summer +0-2°C Winter +0.5°C	
Sea surface salinity	ND	🟨⬇	-0-1.5 ppt	
CAA				
Air Temperature	⇧	🟨⬆	Summer +0-3°C Winter +3-6°C	
Precipitation	ND	🟧🟨⬆	+0.15 mm/d	
Winds (atmospheric circulation)	ND	🟧🟨		
Sea ice extent/ concentration	ND	🟥⬇	-0-80% in September	Regionally variable
Sea surface temperature	ND	🟨⬆	Summer +1-2°C Winter +0.5°C	
Sea surface salinity	ND	🟨⬇	-0-1.5 ppt	

Table 5. Continued.

		Projected Change		
	Past trend	**Projected Trend**	**Projected Trend**	**Projected Trend**
Baffin Bay/ Davis Strait				
Air Temperature	⇧ trend NS	⬆	Summer +1-3°C Winter +1-5°C	
Precipitation	⇧	⬆	+>15%	Seasonality uncertain
Winds (atmospheric circulation)	⇧	⬆	Winter ~+1.1 m/s, Summer ~+-0.6 m/s	# of storms increase +5-10%
Sea ice extent/ concentration	⇩	⬇	->30% in late spring and fall	
Sea surface temperature	⇧	⬆	Winter +1°C +1-2°C during ice free period	Seasonal variability
Sea surface salinity	⇩	⬇	-0.5-1.0 ppt	Seasonal variability
Hudson Bay complex				
Air Temperature	⇧	⬆	+1-6°C	
Precipitation	ND	⬆	-6-15%	
Winds (atmospheric circulation)	ND north/south variability	NS		High variability
Sea ice extent/ concentration	⇩	⬇	-8 to 27% per decade, mostly in fall	
Sea surface temperature	⇧	⬆	+1.0-1.5°C	
Sea surface salinity	⇧ Bottom water	⬇	-0.5-0.75 ppt at surface	

Table 5. Continued.

		Projected Change		
	Past trend	**Projected Trend**	**Projected Trend**	**Projected Trend**
Mackenzie River Basin				
Air Temperature	⇧	⬆	Summer +1.5-3°C Winter +2.5-7°C	Regionally variable
Precipitation	⇧	⬆	+15-50%	Regionally variable
Winds (atmospheric circulation)	ND	NS		
Lake ice	ND	delayed freeze-up earlier melt (likely)		
Lake temperature	⇧	⬆	+5-10°C	
River flow	⇩ ⇧ Summer Winter Earlier freshet	⬇ ⬆ Summer Winter Lower & earlier freshet	Winter/fall +50% maximum increase	Strong decadal variation

[1] ND: No data due to insufficient geographic and/or temporal information

[2] NS: Trend is statistically not significant

SECTION II: Impacts, vulnerabilities and opportunities in the Arctic LAB

This section examines impacts, vulnerabilities and opportunities of ecosystem components in response to climate change in the Arctic LAB. IVO specifically relevant to Northern communities are also included, recognizing that the communities are an integral component of Arctic ecosystems as well as adaptation and management processes. For the entire expansive and ecologically diverse Arctic LAB, the compilation of climate change IVO is extensive. To facilitate the understanding of linkages between climate change IVO and the delivery of DFO priorities, the IVO have been organized into four categories that reflect specific ecosystem components relevant to sectoral activities and management responsibilities.

2.1 IVO assessment methodology

The four IVO categories presented in this report are Arctic resources, Arctic structure, Arctic stability and the emerging Arctic, as described in Sections 2.2-2.5. The IVO are presented in detailed tables for each category (Tables 6-9). The impact (Table 3) and likelihood (Table 4) of each IVO is rated separately for the 10 and 50-year time horizon and the impact and likelihood rating is assumed to be the same for the DFO business of each agency, sector or program listed. An uncertainty ranking is also provided for each IVO based on uncertainty categories from Mandrak et al. (2012). A ranking of high (H) indicates that little published information is available and the IVO is largely based on expert opinion. A ranking of medium (M) is based on a combination of available information and expert opinion whereas an uncertainty ranking of low (L) indicates that the IVO is based primarily on peer reviewed information.

The IVO are generally applicable to all of the marine sub-regions. However, when region-specific IVO occur, they are indicated by the blue text in the IVO column. The blue numbers, also in the IVO column, refer to the DFO climate change risks (Table 1) that are linked to each IVO. For example, [MRB; 1-3] indicates that the IVO is specific to the Mackenzie River Basin sub-region and is associated with climate change risks 1, 2 and 3. For some IVO, it is recognized that an associated risk is new or not fully covered by the existing DFO risks previously identified and as such is identified as [new] in the IVO column (e.g., Table 9).

To indicate how the delivery of DFO priorities will be impacted by climate change in the Arctic LAB, the 2013-2014 DFO Program Alignment Architecture (PAA, Annex 1) is referenced in Tables 6-9. Program level activities (e.g., 1.1 Integrated Fisheries Management, 2.5 Oceans Management) that are impacted by the IVO are identified for DFO Science, Canadian Coast Guard (CCG), Small Craft Harbours (SCH), Fisheries Protection Program (FPP), Species at Risk (SAR), Oceans Program, Conservation and Protection (C & P), Resource Management and Aboriginal Affairs (RMAA) as well as co-managers and resource users.

We acknowledge that Other Governmental Departments (OGDs) would also be impacted by changes in DFO business and are not captured using DFOs PAA. Additionally, co-management linkages are reflected primarily by the PAA program activity 1.2 (Aboriginal Strategies and Governance). We recognize that there are likely to be additional consequences and adaptations for co-management and community processes that are independent of the PAA and are not reflected from this Departmental perspective.

The PAA program activities have been fitted, from the perspective of DFO Science, to illustrate the impacts to DFO business. In Tables 6 to 9, the number of PAA "hits", i.e., number of program activities listed, indicates the relevancy of the specific IVO for the various agencies/sectors/programs. Program activity 1.11 (Climate Change Adaptation Program) was not included as it is considered highly relevant for each IVO. The impact, likelihood and uncertainty ratings as well as the PAA linkages have been identified by DFO Science using logical inferences based on expert scientific knowledge. Known causal relationships (ecosystem and DFO business based) and logical linkages between multiple processes have been considered to provide the range of IVO and DFO business impacts listed in Tables 6 to 9.

2.2 Arctic Resources

Climate change is expected to impact not only the abundance but also the distribution and fitness of Arctic species (Moore and Huntington 2008; Williams et al. 2011). Such changes to species and populations will impact DFO's activities with respect to quotas and management plans as well as COSEWIC listing processes. For example, the range expansion and increased occurrence of killer whales (Ferguson et al. 2010) in the Arctic represents the introduction or increased presence and access of a new apex predator. Such a shift in species interactions could require the revision of marine mammal management and recovery plans for the entire Eastern Arctic. Another key resource-based consideration is the opening of the Arctic due to sea ice loss, and the opportunity for new fisheries that would require DFO's involvement in international governance processes. In addition to international governance developments, climate change may provide opportunities for an increased number or size and/or species compositions of fisheries for co-management partners. Table 6 lists IVOs identified for Arctic biological resources.

Table 6. Impacts, vulnerabilities and opportunities (IVO) for Arctic Resources within the Arctic LAB. Impact and likelihood ratings are defined in Tables 3 and 4, respectively. Uncertainty is rated as low (L), medium (M) or high (H). The IVO apply to all marine sub-regions unless otherwise indicated by sub-regions in blue text (Mackenzie River Basin (MRB), Beaufort Sea (BS), Canadian Arctic Archipelago (CAA), Hudson Bay Complex (HBC) and Baffin Bay/Davis Strait (BBDS)). The blue text also references applicable DFO climate change risks (1-6, Table 1) for each IVO. DFO business linkages are identified by Program Alignment Architecture (PAA, Annex 1) activity numbers. See Section 2.1 for further details.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	Co-managers/ resource users (CM/RU)
Loss of sea ice will dramatically increase Arctic productivity in the short term (Arrigo 2013). The short term increases include increased occurrence and/or detection of under-ice phytoplankton blooms (Arrigo et al. 2014). [1-3]	**VH**	61-80%	**M**	61-80%	L	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
Existing or strengthened stratification (e.g., in Arctic basins) may inhibit nitrogen supply to surface waters (i.e., mixing) thereby limiting continued increases in Arctic productivity. The supply of new sources of nitrogen will be higher near the coast than offshore (Arrigo 2013). [1-3]	**M**	41-60%	**M**	41-60%	M	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
The condition (and therefore listed status of species) that are considered "species at risk" may be altered by changing competition, ecosystem structure and distributions as well as their interactions with indigenous and/or new species. [1-3]	**VH**	21-40%	**VH**	61-80%	L	1.1; 1.2; 1.5; 2.2; 2.3; 2.5; 2.6			1.1; 1.2; 2.2; 2.6	1.1; 1.2; 2.2;2.3; 2.6	1.2; 2.5; 2.6		1.1; 1.2; 2.6	1.2

Table 6. Continued

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Increased freshwater inputs to the Beaufort Sea may negatively affect zooplankton diversity and biomass in the nearshore and offshore via the displacement or decline of marine species (Cobb et al. 2008; Niemi et al. 2010). Adaptable Arctic copepods such as *Calanus glacialis* may be favoured (ACIA 2005). [BS; 1-3]	**M**	61-80%	**VH**	61-80%	M	1.1; 1.2; 2.2; 2.5			1.1; 2.2		2.5		1.1	1.2
Declining body condition, growth and reproduction of marine fish species may occur as fat-rich Arctic zooplankton species are replaced by southern species having lower fat stores (Beaugrand et al. 2010; Hopcroft et al. 2010). [1-3]	**M**	41-60%	**M**	41-60%	M	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 2.2	2.3	2.5		1.1	1.2
Increased stratification in estuarine environments as a result of increased freshwater inputs will likely cause a shift in fish community composition favouring relatively more euryhaline and anadromous species over marine species (Prowse et al. 2006). [1-3]	**M**	41-60%	**VH**	61-80%	L	1.1; 1.2; 2.2; 2.5; 2.6			1.1; 2.2; 2.6	2.3; 2.6	2.5	2.1	1.1; 1.2; 2.6	1.2
Reduction in sea ice and associated snow cover may reduce Arctic cod spawning success and larval growth. (Geoffroy et al. 2011). [1-3]	**VH**	21-40%	**VH**	61-80%	M	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 2.2	2.3	2.5		1.1	1.2

Table 6. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
The timing in migration patterns of anadromous fish species (e.g., Broad Whitefish, Arctic Cisco, Least Cisco, Dolly Varden) to and from summer feeding grounds will be altered as a result of earlier open-water seasons (Prowse et al. 2011a). Alterations in timing of migrations may lead to declines in foraging success of anadromous species as well as for coastal piscivorous species (e.g., sculpins, flatfishes). [1-3]	**L**	41-60%	**M**	41-60%	M	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 2.2	1.2; 2.3	2.5	2.1	1.1; 1.2	1.2
Increased sediment loading and filling of interstitial spaces in substrate may reduce spawning and rearing habitat for riverine and coastal fish species. Sedimentation may also affect the depth of anadromous fish migratory habitat (Wrona et al. 2005; Niemi et al. 2012). [1-3]	**L**	41-60%	**L**	41-60%	M	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 2.2	1.2; 2.3	2.5	2.1	1.1; 1.2	1.2
Altered substrate composition in overwintering habitat may reduce fish survival and reproduction (e.g., Dolly Varden, COSEWIC 2010). Enhanced permafrost thawing may increase biological oxygen demand (BOD) and infilling of spawning beds via nutrient and sediment loading, respectively (Wrona et al. 2005). [1-3]	**VH**	61-80%	**VH**	61-80%	M	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 2.2	1.2; 2.3	2.5	2.1	1.1; 1.2	1.2
Cumulative temperature and associated climate changes may initially benefit the survival, abundance and size of young freshwater life-history stages, with the benefits cascading to older, normally anadromous stages (Reist et al. 2006b). [1-3]	**M**	61-80%	**M**	61-80%	M	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 2.2	1.2; 2.3	2.5	2.1	1.1; 1.2	1.2

Table 6. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Potential for faster, temperature-driven growth and maturation rates and reductions in winter mortality for many Arctic anadromous fish species. However, somatic gains may be offset by increased maintenance-ration demands to support temperature-induced increases in metabolism (Reist et al. 2006c). [1-3]	**M**	61-80%	**M**	61-80%	L	1.1; 1.2; 1.5; 2.2; 2.5			2.2	2.3	2.5		1.1; 1.2	1.2
Increased habitat availability and survival of freshwater and anadromous fish species during winter as a result of increases in winter stream flow and reduced thickness and duration of ice cover in riverine environments (Reist et al. 2006a; Prowse et al. 2006; Wrona et al. 2006a, b). [1-3]	**M**	61-80%	**M**	41-60%	M	1.1; 1.2; 1.5; 2.2; 2.5			2.2	2.3	2.5		1.1; 1.2	1.2
Reduced sea ice and enhanced offshore primary production may provide increased quantity and quality of food for anadromous fish during summer (e.g., Dolly Varden, COSEWIC 2010). [1-3]	**M**	41-60%	**M**	41-60%	M	1.1; 1.2; 1.5; 2.2; 2.5			2.2	2.3	2.5		1.1; 1.2	1.2
Increased lake productivity may promote residency and reduced anadromy (e.g., Arctic char) leading to smaller fish that are more prone to parasites and less desirable for fisheries (Finstad et al. 2011; DFO 2013b). [1-3]	**M**	21-40%	**M**	21-40%	H	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 1.2; 1.5; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2
Potential redistribution of fish stocks due to the effects of changing sea ice or water column characteristics on fish movement and residency (Peklova et al. 2012). [1-3]	**VH**	21-40%	**VH**	21-40%	H	1.1; 1.2; 1.5; 2.2; 2.5			1.1; 1.2; 1.5; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2; 1.7

Table 6. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Potential extirpations of locally adapted Arctic species as environmental conditions begin to exceed their physiological tolerances and/or ecological optima (Reist et al. 2006a; Wrona et al. 2006a). Vulnerability is highest for specialized species with limited environmental tolerances and/or specialized/restricted habitat requirements (e.g., Atlantic walrus, Stewart et al. 2013). [1-3]	**M**	41-60%	**VH**	61-80%	M	1.1; 1.2; 1.6; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	2.1; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.2; 1.7
Changes in the distribution, stability and annual duration of sea ice and snow will have significant impacts on marine mammal populations (e.g., Ringed Seal, Narwhal, Polar Bear, Beluga, Bowhead). Species that rely on the ice-edge environment, such as Beluga, are most vulnerable to the effects of projected decreases in sea-ice cover (Prowse et al. 2009a). Bowhead, Beluga and Narwhal production may decline throughout the Arctic (Moore and Huntington 2008). [1-3]	**VH**	61-80%	**VH**	61-80%	M	1.1; 1.2; 1.5; 1.6; 2.2; 2.5			1.1; 1.2; 1.5; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2; 1.7
Reductions in sea ice impacts the abundance, migration, seasonal distribution and species composition of fish and marine mammals, resulting in shortages of traditional foods (Hovelsrud et al. 2011). [1-2]	**M**	41-60%	**M**	61-80%	L	1.1; 1.2; 2.2; 2.5			1.1; 1.2; 2.1; 2.2; 2.5	2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.1	1.1;1.2; 2.1; 2.2; 2.5	1.2

Table 6. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Increased abundance of temperate migrant marine mammals during summer with longer residence times in the Arctic as a result of decreasing sea-ice extent and longer open-water season. Increasing numbers of temperate species may lead to increased competition for resources and shifts in pathogen transmission and mammal health (Burek et al. 2008). [1-3]	**M**	41-60%	**VH**	61-80%	M	1.1; 1.2; 1.5; 1.6; 2.2; 2.5			1.1; 1.2; 1.5; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2; 1.7
Decreased reproductive success of ice-associated pinnipeds (e.g., seals) due to reductions in habitat (ice extent, thickness and duration) and prey availability (Moore and Huntington 2008; Niemi et al. 2010). [1-3]	**VH**	61-80%	**VH**	61-80%	L	1.1; 1.2; 1.5; 1.6; 2.2; 2.3; 2.5			1.1; 1.2; 1.5; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2
Northward shift in breeding distributions of pack-ice breeding pinnipeds as a result of decreasing sea-ice extent and longer open-water season (Usher 2005). [1-3]	**L**	21-40%	**M**	41-60%	M	1.1; 1.2; 1.5; 1.6; 2.2; 2.3; 2.5			1.1; 1.2; 1.5; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2
Alterations in marine mammal migration routes and timing of migrations as a result of changes in water temperatures and the extent and duration of sea ice (Moore and Huntington 2008). [1-3]	**VH**	61-80%	**VH**	61-80%	M	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2	1.1; 1.2; 2.3	1.1; 1.2; 2.5	2.1	1.1; 1.2; 2.2	1.2
Higher numbers of killer whales, as a result of warming waters and decreased sea-ice extent, will increase predation pressure and impact the selection of summering/nursery habitat for marine mammal populations such as Beluga and seals, with top-down effects on entire ecosystems (Ferguson et al. 2010). [1-3]	**M**	41-60%	**VH**	61-80%	M	1.1; 1.2; 1.6; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2

Table 6. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Earlier sea-ice melt and longer growing season may result in a greater flux of organic carbon to the benthos resulting in increased foraging opportunities for benthic-feeding fishes and marine mammals (e.g., Beluga, Greenland Halibut, Peklova et al. 2012). [1-3]	**M**	61-80%	**M**	41-60%	M	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	2.1	1.1; 1.2; 2.2; 2.3	1.2; 1.7
Alterations in Bowhead whale distribution throughout the Beaufort Sea sub-basin are predicted as a result of changes in zooplankton distribution, diversity and biomass. Bowhead whale distribution is strongly influenced by the physical and biological factors influencing zooplankton communities (Walkusz et al. 2012; Citta et al. 2015). [BS; 1-3]	**M**	61-80%	**VH**	61-80%	L	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5		1.1; 1.2; 2.2; 2.3	1.2
Though subsistence hunters and fishers are highly adaptive to changing conditions, lost earnings (cash and in-kind) related to reduced seal or Narwhal harvests are likely due to reduced access or greater distances required to travel to ice-edge leads (Hovelsrud et al. 2011). [3]	**VH**	41-60%	**VH**	41-60%	L	1.1; 1.2; 2.2; 2.5; 3.7; 3.8	3.1; 3.2		1.1; 1.2; 2.1; 2.2; 2.5	2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.1	1.1;1.2; 2.1; 2.2; 2.5	1.2
Changes in seasonal patterns of ice melt, wind dynamics and weather variability will exacerbate community risks associated with hunting and travel. One adaptation may be a switch in targeted harvest species (Pearce et al. 2010). [3]	**VH**	41-60%	**VH**	41-60%	L	1.1; 1.2; 2.2; 2.5; 3.7; 3.8	3.1; 3.2		1.1; 1.2; 2.1; 2.2; 2.5	2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.1	1.1;1.2; 2.1; 2.2; 2.5	1.2

Table 6. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Future commercial fishing activities in the Mackenzie Delta will be impacted by northward shifts in species and the response of anadromous fish to climate change drivers (Hovelsrud et al. 2011). [MRB; 3]	**M**	61-80%	**M**	61-80%	H	1.1; 1.2; 2.2; 2.3			1.1;1.2;2.2	2.2		2.1	1.1; 1.2; 2.2	1.2
Sport fisheries will need to exercise flexibility with respect to fishing gear, species targeted and location of fishing to adapt to climate change impacts on species and/or habitats. [MRB, HBC, BBDS; 1]	**N**	<20%	**N**	<20%	L	1.1; 1.2; 2.2; 2.3			1.1;1.2;2.2	2.2		2.1	1.1; 1.2; 2.2	1.2
Fishery expansions (size or number) may be supported by the expansion of species' distributions and extended duration of fishing seasons. [1-3]	**M**	21-40%	**M**	61-80%	M	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 3.7; 3.8	3.1; 3.2; 3.3: 3.4:3.5		1.1; 1.2; 1.7; 2.1; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.1; 2.2	1.2; 1.7
Changes in the timing of sea-ice formation/melt and in sea-ice stability may lead to reductions in the duration of winter commercial fisheries (e.g., Cumberland Sound Turbot Fishery). [BBDS; 1-3]	**M**	21-40%	**M**	61-80%	M	1.1; 1.2; 2.2; 2.3; 2.5; 3.8			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2	1.2
Longer ice-free season in Baffin Bay and Davis Strait may increase the duration of commercial fishing for Greenland Halibut and Northern and Striped Shrimp. [BBDS; 1-3]	**VH**	21-40%	**VH**	61-80%	M	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 3.7; 3.8	3.1; 3.2; 3.3: 3.4:3.5		1.1; 1.2; 1.7; 2.1; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.1; 2.2	1.2; 1.7

Table 6. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Climate warming may increase catch potential in offshore regions of the Arctic (Cheung et al. 2010, Sumaila et al. 2011). [BS, BBDS; 1-3]	**M**	21-40%	**VH**	61-80%	H	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 3.7; 3.8	3.1; 3.2; 3.3: 3.4:3.5		1.1; 1.2; 1.7; 2.1; 2.2; 2.3	1.1; 1.2; 2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.1; 2.2	1.2; 1.7

2.3 Arctic Structure

Arctic diversity is defined not only by species and communities but also by the physical environment that creates ecosystem structures which support and connect Arctic resources and sub-regions. What challenges will DFO face to deliver sustainable aquatic ecosystems as climate change shifts and potentially rearranges Arctic ecosystem structure? Ecosystem structure in the Arctic LAB is largely defined by frozen water; permafrost, glaciers and in particular sea ice, but also includes geographical features (e.g., Beaufort Sea canyon) and bathymetric distinctions (e.g., shelf versus basin ecosystems). Land-ocean interactions including riverine flow and their associated drainage basins (e.g., Mackenzie or Churchill-Nelson drainage basins) also contribute significantly to ecosystem structure in the Arctic.

Ecosystem structures are not static features or habitats, rather they exhibit inherent temporal (e.g., seasonal, inter-annual) and spatial variability. For example, the North Water (NOW) polynya is a distinct Arctic ecosystem structure supporting enhanced biodiversity and productivity at multiple levels of the food web. The NOW has recurred for centuries with its annual location and opening governed by atmospheric and oceanographic forcings (Barber and Massom 2007). However, recent failures in ice bridge formation to the north of the NOW (i.e., across Nares Strait) have allowed the transfer of more thick multi-year ice into the region such that the NOW could cease to exist as a polynya (Michel et al. 2015). Such a significant loss of critical ecosystem structure within the Arctic LAB would greatly impact ecosystem capacity and integrity regionally, and potentially downstream where commercial fisheries exist (NAFO division 0). Table 7 lists IVO identified for Arctic structural components such as sea ice, highly productive areas, and coastlines.

Table 7. Impacts, vulnerabilities and opportunities (IVO) for Arctic Structure within the Arctic LAB. Impact and likelihood ratings are defined in Tables 3 and 4, respectively. Uncertainty is rated as low (L), medium (M) or high (H). The IVO apply to all marine sub-regions unless otherwise indicated by sub-regions in blue text (Mackenzie River Basin (MRB), Beaufort Sea (BS), Canadian Arctic Archipelago (CAA), Hudson Bay Complex (HBC) and Baffin Bay/Davis Strait (BBDS)). The blue text also references applicable DFO climate change risks (1-6, Table 1) for each IVO. DFO business linkages are identified by Program Alignment Architecture (PAA, Annex 1) activity numbers. See Section 2.1 for further details.

Climate Change IVO	10-year		50-year		Un-certainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	Co-managers/ resource users
Changes in ecosystem structure (e.g., loss, gain, spatial or temporal shifts) from existing characteristics and dynamics will affect our ability to define ecologically important areas (e.g., Ecologically and Biologically Significant Areas) for Marine Protected Areas, fisheries or other management tools. [1-3]	**VH**	41-60%	**VH**	61-80%	L	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 3.7; 3.8			1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.1; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.2; 1.7
Relatively small changes in the timing of sea-ice breakup and freeze-up (i.e., in the order of a few weeks) will have a disproportionate effect on the physical forcing of Arctic waters by exposing surface waters to winds thereby impacting mixing and shelf-basin exchange processes (ACIA 2005; Long and Perrie 2012; Perrie et al. 2012). [1-4, 6]	**VH**	>80%	**VH**	>80%	L	1.1; 2.2; 2.5; 3.8			1.1; 2.2		1.2; 2.5		1.1; 1.2	
Significant declines in sea-ice extent, area, thickness and duration will occur as a result of complex processes which include melting via increasing air temperatures, melting via influxes of warm water masses and ice being exported/broken by wind forcing that is influenced by atmospheric conditions (e.g., Arctic Oscillation) (Köberle and Gerdes 2003; Steele et al. 2008; Wang et al. 2009). [1-4, 6]	**VH**	61-80%	**VH**	>80%	L	1.1; 1.2; 2.2; 2.3; 2.4; 2.5; 3.7; 3.8	1.8; 2.4; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9; 3.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2

Table 7. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Timing, extent and quality of first-year (i.e., seasonal) ice will continue to change significantly (e.g., Barber et al. 2009), altering the breeding and hunting success associated with ice-dependent marine mammal species (Laidre et al. 2015). [1-3]	**M**	41-60%	**VH**	61-80%	L	1.1; 1.2; 2.2; 2.3; 2.5; 3.7; 3.8	1.8; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9; 3.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Sea-ice reduction and increased variability will impact whale entrapment events, availability of breathing holes, suitable denning locations and the availability of marine mammal platforms (Laidre et al. 2015). [1-3]	**M**	41-60%	**VH**	61-80%	L	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	2.1; 2.2; 2.3	1.1; 1.2; 2.1; 2.2; 2.3; 2.5	1.2
Increased advection of multi-year ice (MYI) out of the Arctic Ocean and into the North Atlantic (Curry et al. 2014) is expected to result in the total loss of MYI ecosystems, with the development of an ice-free Arctic summer. [CAA, BS, BBDS, 1-4, 6]	**VH**	61-80%	**VH**	61-80%	M	1.1; 1.2; 2.2; 2.3; 2.5; 3.7; 3.8	1.8; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9; 3.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
The northwestern Canadian Arctic Archipelago and west Greenland will be the last refugia for summer and multi-year sea ice in the entire Arctic (Huard & Tremblay 2013). There is a proposed World Heritage Site to protect ice-associated species (Eamer et al. 2013). [CAA, BBDS; 1-4, 6]	**M**	61-80%	**VH**	>80%	L	1.1; 1.2; 1.7; 2.2; 2.5; 3.7; 3.8	1.7; 1.8; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9; 3.5	1.1; 1.2; 1.7; 2.2; 2.5	1.1; 1.2; 1.7; 2.2; 2.5	1.1; 1.2; 1.7; 2.2; 2.5	1.2; 1.7; 2.1	1.1; 1.2; 1.7; 2.2; 2.5	1.2; 1.7
Expected increase in interannual variability in basin-wide and regional sea-ice extent. This variability will decrease over time as sea-ice extent and duration declines (Meier et al. 2014). [1-4, 6]	**VH**	>80%	**M**	61-80%	M	1.1; 1.2; 2.2; 2.4; 2.5; 3.7; 3.8	1.8; 2.4; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9; 3.5	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.2; 2.5	2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2

Table 7. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Changes will occur in the location, duration, timing and prevalence of highly productive areas (e.g., polynyas, leads, ice-edges, upwelling) (Michel et al. 2013). [1-3]	**M**	41-60%	**VH**	>80%	L	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
Increasing water temperatures, decreasing distribution and extent of ice cover, and changes in the formation and location of polynyas will influence prey species' (e.g., benthos, zooplankton, fish) distributions, and thus affect the distribution and range of many marine mammal (e.g., Bowhead, Beluga) (Carmack and Macdonald 2002; ACIA 2005; Prowse et al. 2009a). [1-3]	**M**	41-60%	**VH**	>80%	L	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 3.8			1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.2; 1.7
A change from highly concentrated production associated with ice edges and polynyas to more dispersed pelagic production may negatively impact foraging success for ice-associated fish, marine mammals and bird species (Meier et al. 2014). A decline in concentrated areas of primary production may also limit benthic production in those areas (Carmack and Macdonald 2002). [1-3]	**M**	61-80%	**VH**	61-80%	M	1.1; 1.2; 2.2; 2.3; 2.5; 3.8			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Changes in polynya morphology and availability may alter habitat use by marine species. Polynyas may become larger, disappear, change location and/or transition into marginal ice zones (Michel et al. 2015). Species will be required to adapt spatially and/or temporally, or be forced to adapt to less productive habitats (Williams et al. 2007). [1-3]	**M**	61-80%	**VH**	>80%	L	1.1; 1.2; 2.2; 2.3; 2.5; 3.8			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2

Table 7. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Freshening of Arctic surface waters will impact zooplankton composition and potentially the foraging success of Bowhead whales. (Walkusz et al. 2012; Citta et al. 2015). [BS; 1-3]	**M**	41-60%	**M**	41-60%	M	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.2; 2.5	2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2
Declining sea-ice extent and duration will enable increased shipping with the potential for increased incidences of disturbance and/or harm to marine mammals (e.g., ringed seals, polar bears, bowhead) and fish (Niemi et al. 2010, Michel et al. 2013). [1-3]	**M**	41-60%	**M**	61-80%	M	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 3.7; 3.8	1.7; 1.8; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9; 3.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.2; 1.7
Changing sea-ice conditions are expected to negatively affect the predictability of travel and access associated with domestic fishing and hunting which, in turn, affect human nutrition, health and household and community economies (Hovelsrud et al. 2011). [1]	**M**	61-80%	**M**	>80%	M	1.1; 1.2; 2.2; 2.5; 3.7; 3.8	3.1; 3.2		1.1; 1.2; 2.1; 2.2; 2.5	2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.1	1.1;1.2; 2.1; 2.2; 2.5	1.2
Hunters/fishers are staying closer to communities due to safety concerns associated with unpredictable sea-ice conditions (ACIA 2005) resulting in changing geographic and temporal patterns of hunting and fishing harvest pressures. [2,4,6]	**M**	61-80%	**M**	>80%	L	1.1; 1.2; 2.2; 2.5; 3.7; 3.8	3.1; 3.2		1.1; 1.2; 2.1; 2.2; 2.5	2.2; 2.3	1.1; 1.2; 2.2; 2.5	1.1; 1.2; 2.1	1.1;1.2; 2.1; 2.2; 2.5	1.2

Table 7. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Loss of unique habitats and ecosystem biodiversity (e.g., epishelf lakes, Mueller et al. 2003) due to the collapse and loss of ice shelves. The only ice shelves in Canada are found on Ellesmere Island (Vincent et al. 2011). [CAA; 1-3, 5,6]	**M**	61-80%	**M**	>80%	L	2.3; 2.5				2.3	2.5			
A more severe wave climate is projected with increasing storminess and increased wind speeds due to decreasing ice concentrations (ACIA 2005; Steiner et al. 2015). [4,6]	**VH**	61-80%	**VH**	61-80%	L	1.2; 2.4; 2.5; 3.7; 3.8	2.4; 3.1; 3.2; 3.4; 3.5	1.8; 1.9	2.2		2.5		1.1	1.2
Increased frequency and aerial extent of rain-on-snow events will change surface hydrology and sea-ice habitats (Chassé et al. 2013). [4,6]	**VH**	41-60%	**VH**	41-60%	M	2.5; 3.8			2.2		2.5			
Permafrost melt causing coastal destabilization and thickening of the active layer is expected despite mitigative effects of changing snow conditions. Melting of permafrost in marine sediments could also occur. Permafrost loss would have a positive feedback to warming temperatures with the release of CO_2, methane and nitrous oxide (Prowse et al. 2009b; Callaghan et al. 2011, b). [4,6]	**VH**	61-80%	**E**	61-80%	M	1.1; 1.2; 2.2; 2.5; 3.8			2.2		2.5		1.1	1.2
Increased winter stream flow, decreased summer peak flow will contribute to increased freshwater inputs to coastal waters (Callaghan et al. 2011, b). [1-3]	**M**	61-80%	**VH**	61-80%	M	1.1; 1.2; 2.2; 2.5			1.2; 2.2	1.2; 2.3	1.2; 2.5		1.1; 1.2; 2.2	1.2

Table 7. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Sea-level rise could lead to inundation of low-lying areas adjacent to coasts, partial or complete submergence of small islands and saltwater intrusions into groundwater (Olsen et al. 2011). [1-4]	**M**	61-80%	**VH**	>80%	L	1.2; 2.4; 2.5; 3.7; 3.8	1.8; 2.4; 3.1; 3.2; 3.5	1.8; 1.9	2.2		2.5		1.1	1.2
The amount and timing of flow into Arctic coastal regions is expected to be altered by climate-driven changes in, for example, precipitation, glacier melt and river ice clearance, in the expansive sub-arctic drainage basins (Thorne 2011; Lesack et al. 2013). [1-3]	**M**	41-60%	**M**	21-40%	H	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Reduction in the thermal gradient (south to north) of major rivers will affect spring freshet and ice jams with adverse implications for productive river deltas that require flooding (Reist et al. 2006b; Wrona 2006a, Prowse et al. 2011b). [BS, MRB; 1-3]	**M**	41-60%	**VH**	61-80%	H	1.1; 1.2; 2.2; 2.3; 2.5; 3.7; 3.8			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Decreasing summer water levels will result in a reduction in the quality, quantity and access to freshwater habitats (i.e., lakes and rivers) by anadromous fish species (ACIA 2005; Reist et al. 2006a; Wrona et al. 2006b). [1-3]	**M**	41-60%	**M**	41-60%	H	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Under-ice riverine winter water held within the coastal ice ridge zone (i.e., Lake Herlinveaux offshore of the Mackenzie River) may be released earlier or fail to be retained during winter due to changing ice dynamics. [BS; 1-3]	**M**	41-60%	**VH**	>80%	M	1.1; 2.2; 2.5; 3.8			1.1; 2.2		2.5		1.1	

Table 7. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Increased coastal erosion and mobilization of coastal sediments will occur as a result of a cumulative combination of changing ice dynamics, permafrost degradation, sea-level rise, increased wave action and storm frequency and/or changes in ice scour patterns (Carmack and Macdonald 2002; Manson et al. 2005; Prowse et al. 2009b; Prowse et al. 2011b). [1-4]	**VH**	61-80%	**E**	>80%	L	1.2; 2.4; 2.5; 3.7; 3.8	1.8; 2.4; 3.1; 3.2; 3.5	1.8; 1.9	2.2		2.5		1.1	1.2
The extent and severity of spring ice scouring in coastal environments will decrease as a result of declines in sea ice and increases in duration of the open-water season. Declines in the magnitude and duration of ice scour will impact benthic habitat in nearshore waters (i.e., <50 m) by reducing the disruption of sediments (Cobb et al. 2008). [1-4, 6]	**M**	61-80%	**M**	61-80%	L	1.2; 2.5; 3.7; 3.8			2.2		2.5		1.1	1.2
Increasing freshwater content in Arctic waters will increase stratification and reduce mixed layer depth (Morison et al. 2012; Rabe et al. 2014). [1-3]	**VH**	61-80%	**VH**	61-80%	L	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2

2.4 Arctic Stability

There is a tight connection between physical (structural) and biological ecosystem components in the Arctic LAB. In addition there are tight trophic links within Arctic food webs, as well as overall limited linkages generally due to lower overall biodiversity. These linkages characterize the stability of the ecosystems that support our harvestable resources and healthy environments. The stability of Arctic ecosystem linkages will largely determine the characteristics of IVO that relate to ecosystem resistance and resilience (e.g., direction, rate, persistence etc.) and is therefore critical for gauging DFO needs for responses and the applicability of management strategies.

Arctic species and ecosystem linkages do have adaptive capacity, however, the limits of adaptability are uncertain. The majority of changes in the Arctic are non-linear and complex, making predictions of future states a challenge for the Arctic as a whole and especially at regional scales. Rapid changes and the potential for catastrophic shifts in ecosystem stability (e.g., entrapments, diseases, and/or invasive species) may require a level of responsiveness and management actions that are potentially beyond current sectoral activities or abilities. The way in which IVO occur will impact the way DFO priorities are met and the nature and persistence of the changes (e.g., regime shift or alternative stable states, Collie et al. 2004) will also impact the future of management practices and program priorities within the Arctic LAB. Table 8 provides IVO pertaining to the stability of Arctic processes and ecosystems.

Table 8. Impacts, vulnerabilities and opportunities (IVO) for Arctic Stability within the Arctic LAB. Impact and likelihood ratings are defined in Tables 3 and 4, respectively. Uncertainty is rated as low (L), medium (M) or high (H). The IVO apply to all marine sub-regions unless otherwise indicated by sub-regions in blue text (Mackenzie River Basin (MRB), Beaufort Sea (BS), Canadian Arctic Archipelago (CAA), Hudson Bay Complex (HBC) and Baffin Bay/Davis Strait (BBDS)). The blue text also references applicable DFO climate change risks (1-6, Table 1) for each IVO. DFO business linkages are identified by Program Alignment Architecture (PAA, Annex 1) activity numbers. See Section 2.1 for further details.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	Co-managers/ resource users
Positive feedbacks from the ocean to the atmosphere could lead to rapid or accelerated changes in ecosystem structure and function (Callaghan et al. 2011a, b; Olsen et al. 2011). [1,3,4,6]	**VH**	41-60%	**VH**	41-60%	L	1.1; 1.2; 2.2; 2.3; 2.5; 2.6; 3.8			1.1; 1.2; 2.1; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Reaching thresholds or tipping points (e.g., for changes in sea ice or water circulation) could trigger abrupt shifts in ecosystem alternative states (Duarte et al. 2012). [1-4, 6]	**VH**	41-60%	**VH**	61-80%	H	1.1; 1.2; 2.2; 2.3; 2.5; 2.6; 3.8			1.1; 1.2; 2.1; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Extreme climate events such as thawing in mid-winter are likely to become more frequent and may accelerate shifts in community structure and processes (Olsen et al. 2011). [1-3]	**M**	41-60%	**M**	41-60%	M	1.1; 1.2; 2.2; 2.3; 2.5; 2.6; 3.8			1.1; 1.2; 2.1; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2

Table 8. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
The balance of water volume and freshwater content across the Arctic will be altered by melt and mixing processes thereby affecting energy dynamics and exchange of organisms among water masses and Arctic regions (Niemi et al. 2010; Curry et al. 2014). [1-3]	**M**	41-60%	**VH**	61-80%	L	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6; 3.8			1.1; 1.2; 2.1; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2; 1.7
Declining sea ice will likely alter the size and composition of microbial communities and their functional roles, thereby impacting food web efficiency and biogeochemical cycling, which influences Arctic Ocean capacity to take up or release CO_2 (Li et al. 2009, Comeau et al. 2011). [1-3]	**M**	41-60%	**M**	61-80%	M	1.1; 1.2; 2.2; 2.3; 2.5			1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5		1.1; 1.2; 2.2; 2.3; 2.5	1.2
Increased wind-driven upwelling events create opportunities for rapid pulses of primary production that may eventually benefit higher trophic levels (Niemi 2010; Walkusz et al. 2012). [1-3]	**VH**	>80%	**VH**	>80%	L	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
Increased nutrient and light availability, due to the loss/reduction of seasonal sea ice in summer and fall, may stimulate predictable increases in production on the Arctic shelves. However, similar trends may not occur or be sustained offshore (Arrigo 2013). [1-3]	**VH**	>80%	**M**	61-80%	L	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2

Table 8. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Seasonal succession from ice algae to phytoplankton production will be altered with respect to quantity, quality and timing due to changes in sea-ice extent, snow cover and melt pond formation (Arrigo 2013). There may also be a gradual decline in ice algal contributions to total Arctic primary productivity. [1-3]	**VH**	61-80%	**VH**	61-80%	L	1.1; 2.2; 2.5; 3.8			1.1; 2.2		2.5		1.1	
A shift in precipitation from snow to rain will increase light availability for ice algae and under-ice phytoplankton growth (Arrigo 2014). [1-3]	**M**	41-60%	**M**	41-60%	H	1.1; 2.2; 2.5; 3.8			1.1; 2.2		2.5		1.1	
Decreased sea-ice extent and associated primary productivity (i.e., ice algae) will alter the caloric (e.g., lipid) component of ring seal diet (Brown et al. 2014) and potentially the diets of other higher trophic level organisms. [1-3]	**M**	21-40%	**M**	21-40%	M	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
Decreased sea-ice extent and longer duration of the open-water season may increase benthic primary production on the shelf (Tynan et al. 2010). [1-3]	**L**	21-40%	**L**	41-60%	M	1.1; 1.2; 2.2; 2.5			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
Earlier timing of phytoplankton production as a result of an earlier open-water season may lead to trophic mis-matches and a non-linear decline in secondary (i.e., zooplankton) production (Arrigo 2013). [1-3]	**VH**	41-60%	**VH**	41-60%	M	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2

Table 8. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Increased magnitude of primary productivity (Forest et al. 2011, Wold et al. 2011) coupled with general resilience of Arctic zooplankton to quality and timing mismatches of primary production may result in overall benefit to zooplankton communities. [1-3]	**M**	41-60%	**M**	41-60%	M	1.1; 1.2; 2.2; 2.5			1.1; 1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
Decreased food availability (i.e., zooplankton) for larval fish, as a result of earlier open-water seasons and subsequent trophic mismatches, may lower the recruitment and success of marine and anadromous fish populations (Wrona et al. 2005). [1-3]	**M**	41-60%	**VH**	61-80%	M	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	1.1; 2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2
Gonadal development in freshwater and anadromous fish species (e.g., Broad Whitefish, Least Cisco, Arctic Cisco, Dolly Varden) may be accelerated under warmer conditions and the time of spawning may be altered (Wrona et al. 2005). This may lead to trophic mismatches between larval fish and food sources. [1-3]	**M**	41-60%	**M**	41-60%	H	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	1.1; 2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2
Increased inter-annual variability in aquatic habitats may result in altered patterns of productivity, including anadromous fish growth and production characteristics (Reist et al. 2006a; Finstad et al. 2011). [1-3]	**VH**	41-60%	**VH**	61-80%	L	1.1; 1.2; 1.6; 2.2; 2.5; 3.8			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	1.1; 2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2
Declines in keystone ice-associated marine species (e.g., Arctic cod) may result in rapid decreases or re-distribution of multiple mammal and fish species that rely on these prey items. [1-3]	**VH**	41-60%	**E**	>80%	L	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	1.1; 2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2; 1.7

Table 8. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
The shift from slow-growing, longer-lived Arctic species to faster-growing, temperate species may provide increased foraging opportunities for some animals, with a cost to endemic species (increased competition, predation, displacement) (Wrona et al. 2005). [1-3]	**M**	41-60%	**VH**	61-80%	M	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	1.1; 2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2; 1.7
Declines and shifts in habitat suitability (e.g., availability of breathing holes) may lead to rapid declines in marine mammal populations and diversity (DFO 2012). [1-3]	**M**	41-60%	**VH**	61-80%	M	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	1.1; 2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2; 1.7
Decreased reproductive success of seal species (e.g., ringed seal) may result from sea-ice loss and changes in food availability at the time of pup weaning (ACIA 2005). [1-3]	**M**	61-80%	**VH**	61-80%	M	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	1.1; 2.1; 2.2	1.1; 1.2; 2.2; 2.5	1.2
Increased water temperatures and declines in sea ice may cause an increase in bacteria respiration and growth, shifting an increasing proportion of ecosystem resources away from fish and into microbial food webs (Cobb et al. 2008). [1-3]	**M**	41-60%	**M**	41-60%	M	1.1; 1.2; 1.6; 2.2; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5		1.1; 1.2; 2.2; 2.5	1.2
New or different apex predators will alter species distributions and trophic structure (Ferguson et al. 2010). [1-3]	**M**	61-80%	**VH**	61-80%	L	1.1; 1.2; 1.6; 2.2; 2.3; 2.5; 2.6			1.1; 1.2; 2.1; 2.2; 2.3; 2.6	1.1; 1.2; 2.1; 2.2; 2.3; 2.6	1.1; 1.2; 2.1; 2.2; 2.3; 2.6	1.1; 2.1; 2.2; 2.6	1.1; 1.2; 2.1; 2.2; 2.3; 2.6	1.2

Table 8. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Loss of productive ecosystem structures (e.g., polynyas and leads) will have localized and regional effects on food web and ecosystem structure and function (Carmack and Macdonald 2002; Bergeron & Tremblay 2014). [1-3]	**VH**	41-60%	**E**	>80%	L	1.1; 1.2; 2.2; 2.5; 3.8			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5		1.1; 1.2; 2.2; 2.5	1.2
Changes in trophic structure and animal distributions will alter bio-magnification of contaminants, including persistent organic pollutants and mercury, thereby affecting freshwater, estuarine and marine food webs. Top-level predatory fish and marine mammals will likely be most affected (Macdonald et al. 2003). [1-3]	**VH**	41-60%	**VH**	61-80%	M	1.1; 1.2; 1.6; 2.2; 2.3; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	2.1	1.1; 1.2; 2.2; 2.5	1.2
Increased contaminant concentrations could affect the use of fishes and mammals by northern communities with respect to food sources and fishery targets (Macdonald et al. 2003). [1-3]	**VH**	41-60%	**E**	41-60%	H	1.1; 1.2; 1.6; 2.2; 2.3; 2.5			1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.1; 2.2; 2.3	1.2; 2.2; 2.3; 2.5	2.1	1.1; 1.2; 2.2; 2.5	1.2

2.5 The Emerging Arctic

Given the rapid, climate-related changes in the Arctic (IPCC 2014, Steiner et al. 2015) there is a developed awareness and ample evidence of existing and potential risks from an ecological (e.g., Meltofte 2013; AMAP 2011) and DFO business (DFO 2013a) perspective. However, extensive gaps in our scientific knowledge and management preparedness exist. We are currently faced with large-scale changes, such as Arctic Ocean acidification, where we lack a fundamental understanding of the biological ramifications of this significant shift in basic ocean parameters (AMAP 2013). Moreover, the interactive effects of such changes with those induced more directly by climate change are also poorly understood. That is, for example, feedbacks from climate system changes, many of which are uncertain at this time, may interact with the ecosystem and thus affect DFO business over the short to medium term, as well as further exacerbating climate changes in the Arctic LAB (ACIA 2005), thus affecting activities over the longer term.

Some emerging issues represent potentially significant (e.g., new invasive species) challenges to the health and management of our Arctic resources and ecosystems. It is evident that the Arctic is poised for further change and the potential for unexpected needs for action exists, perhaps on a rapid basis. DFO services, regulatory activities and even international obligations will be challenged as the Arctic continues to evolve with the changing climate.

Table 9. Impacts, vulnerabilities and opportunities (IVO) for the Emerging Arctic. Impact and likelihood ratings are defined in Tables 3 and 4, respectively. Uncertainty is rated as low (L), medium (M) or high (H). The IVO apply to all marine sub-regions unless otherwise indicated by sub-regions in blue text (Mackenzie River Basin (MRB), Beaufort Sea (BS), Canadian Arctic Archipelago (CAA), Hudson Bay Complex (HBC) and Baffin Bay/Davis Strait (BBDS)). The blue text also references applicable DFO climate change risks (1-6, Table 1) for each IVO. DFO business linkages are identified by Program Alignment Architecture (PAA, Annex 1) activity numbers. See Section 2.1 for further details.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	Co-managers/ resource users
Increased transport activities (e.g., shipping) will result in greater black carbon emissions to the Arctic acting as a feedback that enhances climatic warming (Quinn et al. 2011). [4,6]	**L**	61-80%	**L**	>80%	L	1.2; 1.7; 2.2; 2.3; 2.4; 2.5; 2.6; 3.7; 3.8	1.2; 1.7; 1.8; 2.4; 3.3; 3.4; 3.5	1.8; 1.9	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.2; 1.7
The Arctic carbon budget will be altered as opportunities for air-sea CO_2 exchange and the accumulation of carbon on the ocean floor potentially increases (ACIA 2005). [1-3]	**M**	>80%	**VH**	>80%	L	1.6; 2.5			1.1; 2.2		2.5		1.1; 2.2	
Ocean acidification is occurring most rapidly in the Arctic, altering the basic chemistry of the marine ecosystem. [1-3]	**M**	>80%	**VH**	>80%	L	1.6; 2.5					2.5			1.7

Table 9. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Climate change impacts on drainage basins will enhance cumulative impacts of flow regulation and hydro-electric development. [MRB, BS, HBC; 1-3, 5]	**M**	41-60%	**M**	41-60%	H	1.2; 2.2; 2.3; 2.4; 2.5; 3.7	1.2; 2.4; 3.2; 3.3; 3.4; 3.5	1.8; 1.9	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.2; 2.3; 2.5	1.1; 1.2; 2.1; 2.2	1.1; 1.2; 2.2; 2.3; 2.5	1.2
Ocean acidification is expected to impact the survival and health of multiple species (e.g., crustaceans, corals, molluscs) and potentially fisheries via impacts on fish physiology (i.e., bone formation and strength) (AMAP 2013). [1-3]	**M**	>80%	**VH**	>80%	H	1.2; 1.7; 2.2; 2.3; 2.5; 3.8			1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.2; 2.3; 2.5	1.2; 1.7
Diseases and parasites may become more prevalent and new diseases may arrive due to range expansions of marine mammals and/or increased shipping use (i.e., ballast water) (Burek et al. 2008; Niemi et al. 2010). [1-3]	**M**	41-60%	**M**	41-60%	H	1.2; 1.7; 2.2; 2.3; 2.5; 2.6; 3.8	1.2; 1.7; 1.8; 3.4	1.8; 1.9	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.2; 1.7
Reductions in land/sea use for subsistence purposes may reduce local knowledge and observations diminishing the inter-generational transfer of knowledge and culture (Hovelsrud et al. 2011). This change also reduces climate change monitoring capacity due to potential losses of local observations and traditional knowledge. [new]	**M**	41-60%	**VH**	61-80%	L	1.1; 1.2; 2.2; 2.5			1.1; 1.2; 2.2	1.1; 1.2; 2.3	1.1; 1.2; 2.5	1.1; 1.2; 2.1	1.1; 1.2; 2.2; 2.3	1.2

Table 9. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Reduction in land/sea use for subsistence purposes due to diminishing ice and hazardous marine conditions may change ways of life and loss of language impacting health and well-being (Hovelsrud et al. 2011). [new]	**M**	41-60%	**VH**	61-80%	L	1.1; 1.2; 2.2; 2.5			1.1; 1.2; 2.2	1.1; 1.2; 2.3	1.1; 1.2; 2.5	1.1; 1.2; 2.1	1.1; 1.2: 2.2; 2.5	1.2
Introduction of aquatic nonindigenous species through ballast water exchange is expected with enhanced shipping and industrial activity (DFO 2014). [1-3, 6]	**M**	41-60%	**M**	41-60%	H	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6; 3.7; 3.8	1.2; 1.7; 1.8; 3.3; 3.4	1.8; 1.9	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.2; 1.7
Decrease in sea ice and associated increase in shipping activity may require the addition or review of ballast water exchange locations and monitoring (DFO 2014). [1-3, 6]	**M**	41-60%	**M**	41-60%	L	1.1; 1.2; 1.6; 1.7; 2.2; 2.3; 2.5; 2.6; 3.8			1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.1; 1.2; 1.7; 2.1; 2.2	1.1; 1.2; 1.7; 2.2; 2.3; 2.5; 2.6	1.2; 1.7

Table 9. Continued.

Climate Change IVO	10-year		50-year		Uncertainty	PAA linkages to DFO Agencies/Sectors/Programs								
	Impact	Likelihood	Impact	Likelihood		Science	CCG	SCH	FPP	SAR	Oceans	C & P	RMAA	CM/RU
Increased need for tools to support traditional access and activities associated with coastal sea ice (e.g., Floe Edge Service, Laidler et al. 2011). [4,6, new]	**M**	41-60%	**M**	61-80%	M	2.1; 2.5; 3.7; 3.8			1.2; 2.2		1.2; 2.5		1.1; 1.2	1.2
Increased challenge to deliver Canada's biodiversity obligations (i.e., UN Convention on Biodiversity) for the rapidly changing Arctic (Pomerleau et al. 2014). [1-3, new]	**L**	41-60%	**L**	61-80%	M	1.7; 2.5					1.7; 2.5			1.7
Increased demand for access to the Arctic for shipping, research, monitoring, regulatory and sovereignty purposes resulting in increased ship and people days in the Arctic. [1-4, 6]	**VH**	>80%	**VH**	>80%	L	2.1; 1.7; 2.4; 3.7; 3.8	2.1; 1.7; 1.8; 2.4; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9	1.2; 1.7; 2.2	1.2; 1.7; 2.3	1.2; 1.7; 2.5	2.1	1.1; 1.2; 1.7	2.1; 1.7
Increased demand and need for expanded Arctic search and rescue capabilities due to increased access and use of the Arctic as well as unpredictable and variable sea-ice conditions (AMSA 2009). [4,6]	**M**	>80%	**VH**	>80%	L	2.1; 1.7; 2.4; 3.7; 3.8	2.1; 1.7; 1.8; 2.4; 3.1; 3.2; 3.3; 3.4; 3.5	1.8; 1.9						2.1; 1.7

2.6 Summary of DFO Impacts

The number of IVO identified for Arctic Resources, Structure, Stability and Emerging issues were 34, 29, 25 and 14, respectively. Excluding CCG and SCH, >70% of the Arctic Resources IVO were applicable to all DFO programs included in the analyses. Over 50% of the Structure and Stability IVO and >60% of Emerging Arctic IVO were applicable to DFO Science and DFO Fisheries/Ecosystem Management programs (Figure 5).

Impacts on CCG and SCH program activities were highest in the Arctic Structure (e.g., issues pertaining to sea ice) and Emerging Arctic categories (Figure 5). IVO pertinent to CCG and SCH is weighted towards physical components of climate change in the Arctic LAB. The ecologically based categories, specifically Arctic Stability, were not directly related to either the CCG or SCH. However, issues such as ballast water exchange, that would involve both CCG and SCH, could impact Arctic Stability through ecosystem linkages such as invasive species and pathogen introduction. We acknowledge that specific economic and policy IVO is not included in this assessment, which may be applicable to programs other than DFO science, the perspective from which the analyses were conducted.

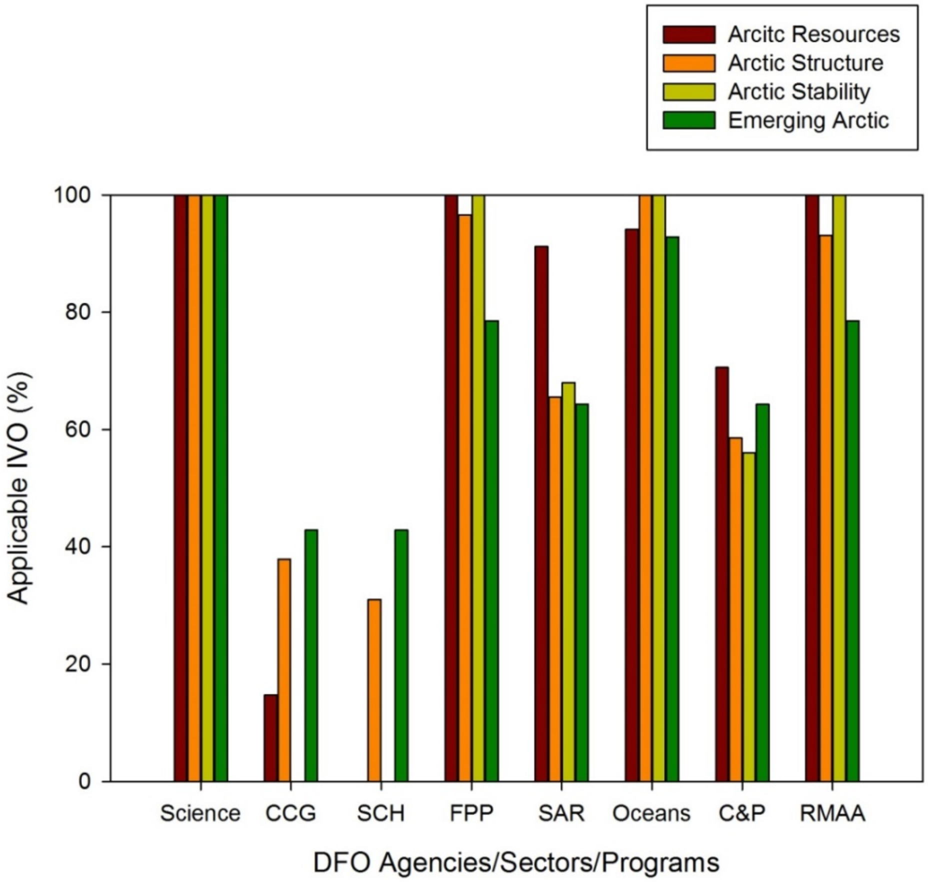

Figure 5. Applicability of the four climate change IVO categories to DFO Agencies, Sectors and Programs. Bars represent percentage of total IVO in each category that would require adaptive measures for DFO program activities.

DFO priorities and activities impacted by Arctic LAB IVO are indicated by the number of PAA "hits" in Tables 6-9. We recognize that sectoral priorities and activities may change with future PAA development. However, the outcomes demonstrate that IVO impacts: 1) are applicable to a wide range of PAA program level activities, and 2) cross-sectoral responses to climate change IVO are required to address potential impacts or opportunities. In general, the highest number of PAA hits is associated with DFO Science and the fewest with CCG and SCH (Figure 6). The total number of PAA hits was not directly related to the number of IVO in each IVO category. For example, the total number of PAA hits for the SAR and Ocean Programs was higher in the Arctic Stability (IVO n = 25) versus Arctic Resources (IVO n = 34) categories (Figure 5). Arctic Stability reflects ecosystem interactions such that multiple responses and feedbacks are expected from a single climate change impact, thereby increasing the effects on DFO business across Sectors and Programs.

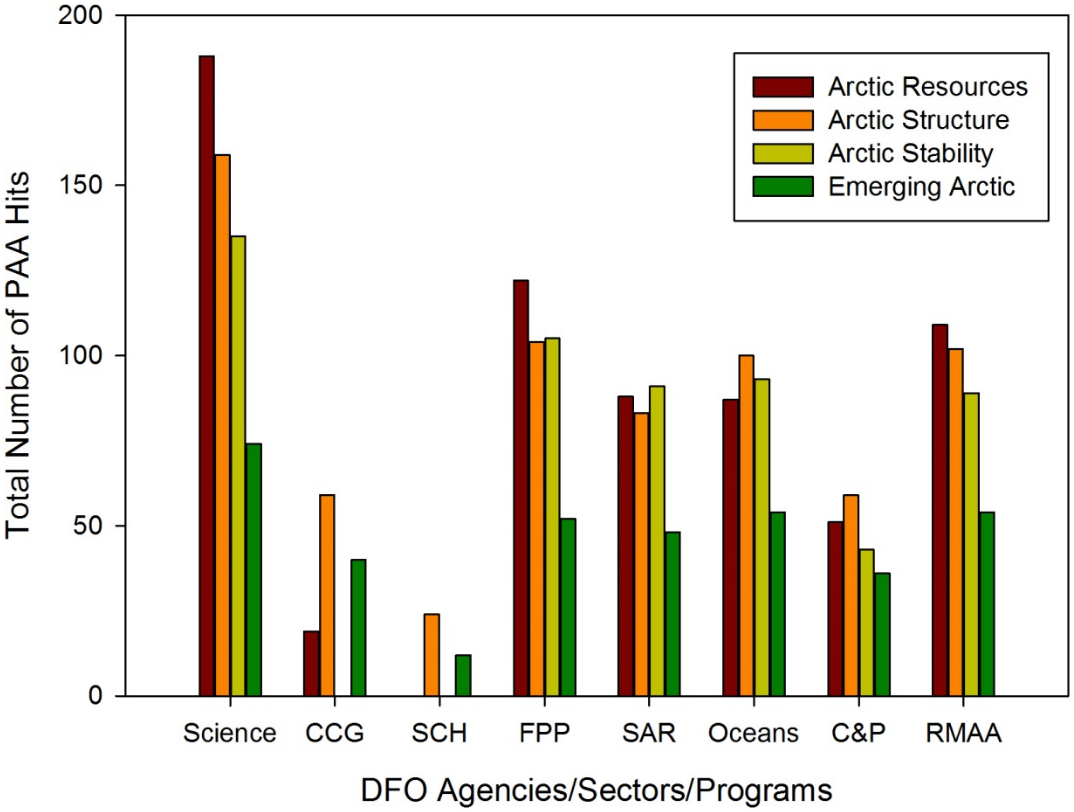

Figure 6. Measure of climate change IVO on DFO program level activities (total PAA hits) relevant to different DFO Agencies, Sectors and Programs. Total PAA hits are presented for the four IVO categories as presented in Tables 6 to 9.

The impact of climate change in the Arctic LAB is expected to increase over the 10 to 50-year time horizon (Figure 7). The impact of climate change on all four IVO categories will move from Medium towards Very High (Table 3) indicating that events will no longer be manageable under normal business circumstances of DFO. Rather, critical events are expected that will require proper management steps by DFO.

Although harvestable resources (Table 5) are a priority of DFO's mandate and Governmental legislation, the impact of climate change on the 10 and 50-year horizons is expected to be higher for the structure and stability of the Arctic ecosystem rather than on harvestable species directly (Figure 7). This outcome supports DFO's ecosystem approach to management as species-specific management will not address the critical ecosystem linkages that will drive the future of biological resources with continuing climate change.

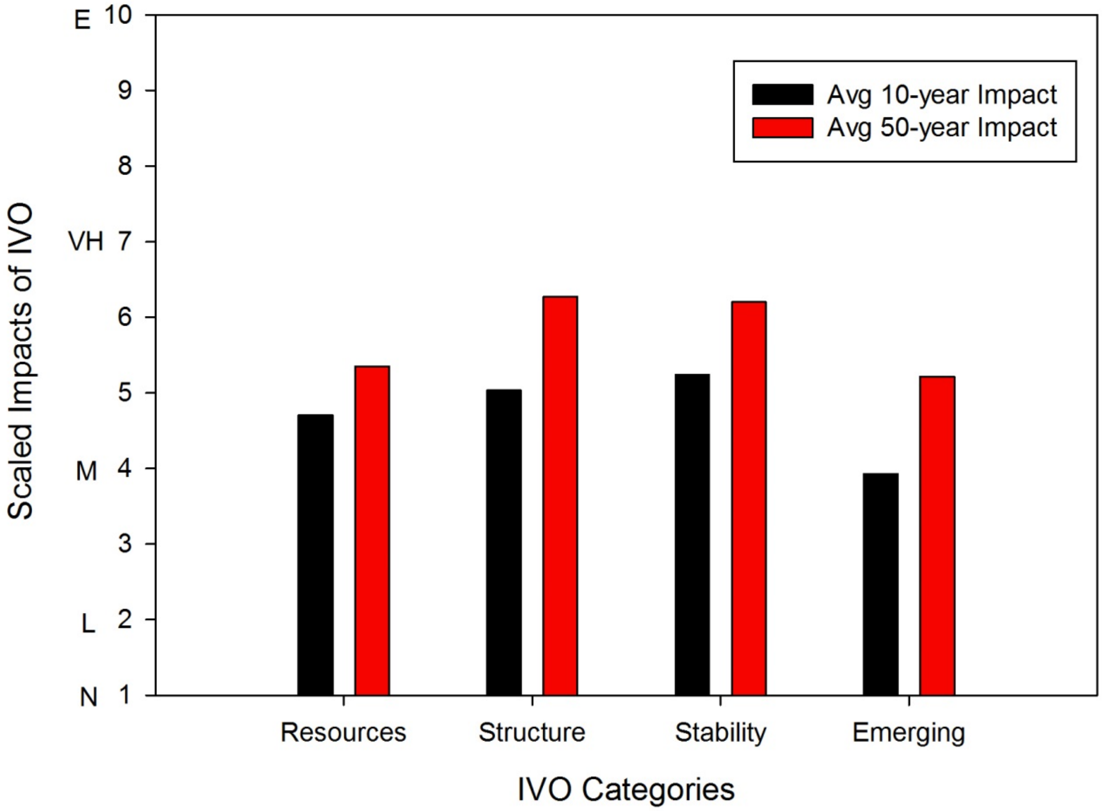

Figure 7. Average impact of climate change IVO for the 10 and 50-year time horizons in the Arctic LAB. The Impact scale (Table 3) was given numerical values as indicated on the y-axis to calculate scaled averaged impact values.

The implementation of proper management for biological resources and supporting ecosystems will require the best possible knowledge and advice for decision makers and policy adaptations (see further discussion in Section 4). Community and International engagement will continue to be essential in management decisions, with highest International engagement required for emerging issues in the Arctic (Table 9). The emerging issues in the Arctic may represent the greatest challenge to DFO adaptive management plans since the impacts may be high and the uncertainty associated with key IVO including disease, nonindigenous species, biological impacts of ocean acidification and drainage basin impacts, is also high.

We also recognize and emphasize that while the analyses presented above for the Arctic LAB IVO may seem reasonably comprehensive and associated coverage may seem adequate, there are likely many aspects of change and cascading effects on northern systems for which DFO has some responsibilities that are not noted above. In large part this is likely due to limited analyses to understand all the logical inter-connections within and among Arctic ecosystems, regions within the Arctic LAB, and client needs and perspectives. Accordingly, while comprehensive, users of this synopsis and clients in general should be aware of potential surprises both in the nature and rate of changes which may affect their business (see also Section IV).

SECTION III: Sub-region IVO

The majority of IVO presented in Table 6-9 would be applicable at the scale of the Arctic LAB sub-regions. For the Mackenzie River Basin, many of the IVO applicable to the marine system would only be applicable to the small estuarine area of the sub-region. Even though the IVO can be largely down-scaled from the entire Arctic LAB to the sub-regions, each sub-region does have unique or significant features susceptible to climate change that may result in significant ecosystem and/or economic changes at the local scale. This section presents a key Arctic feature or activity for each of the five sub-regions. Climate change IVO related to the specific features or activities are discussed, showing relevance for DFO priorities and management considerations.

3.1 Beaufort Sea sub-region

Feature: Sea ice

The most conspicuous climate-driven change in the Arctic LAB is the reduction in summer sea-ice cover. Also strikingly obvious is the loss of the old, thick multi-year sea ice that provided stability to the ice system (Polyakov et al. 2012). The Beaufort Sea sub-region is strongly impacted by sea-ice changes within the sub-region as well as in the Alaska Beaufort Sea and Arctic Ocean, including changes extending along the northwest side of the CAA to Ellesmere Island (Barber et al. 2014). Ice dynamics driven by the Beaufort Gyre are especially critical for the Beaufort Sea sub-region (Galley et al. 2013). The changing ice regime in the Beaufort Sea sub-region suggests opportunities for offshore oil and gas development, marine transport and potentially new Arctic fisheries. However, counterintuitively, the reduction in sea ice does not equate to a removal of ice hazards for such activities. In the area of potential offshore drilling in the Beaufort Sea for example, increased frequency and velocity of some ice hazards have been recently documented (Galley et al. 2013). It is also evident that thick deformed ice and extreme ice hazards, such as those originating from ice islands in the CAA, will continue to be serious concern for ships and stationary platforms in the Beaufort Sea sub-region for years/decades to come (Barber et al. 2014).

The thinner and weaker sea ice in the Beaufort Sea sub-region is responding more readily to winds, as observed during the extensive ice fracturing event in February 2013 (Figure 8). A winter storm fractured the ice over a distance of 1000 km with the ice being transported in a clockwise direction following the Beaufort Gyre. Such events allow for energy exchanges between the water and atmosphere, providing opportunities for mixing which would not normally occur at such a regional scale. Changes in the timing and dynamics of sea-ice motion will impact the existence, location and stability of ecological hotspots, which are currently the focus of exiting or pending Marine Protected Areas in the sub-region.

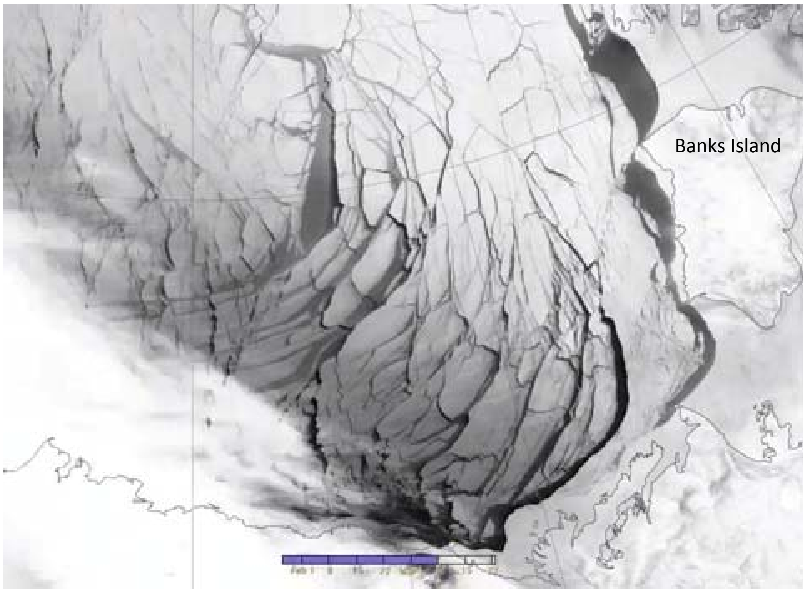

Figure 8. Wind induced sea-ice fracture extending across the Beaufort Sea in February 2013 (http://earthobservatory.nasa.gov).

Changes in sea-ice motion will also drive additional or higher pulses of primary production (Tremblay et al. 2011) and could establish a new primary production regime, potentially raising the status of the Beaufort Sea above that of an oligotrophic Arctic system (Lavoie et al. 2010). In the Beaufort Sea sub-region, climate change will impact DFO priorities and activities on both spatial (e.g., MPA boundary reassessments) and temporal (e.g., timeline for fishery exploration/expansion) scales.

3.2 Mackenzie River Basin sub-region
Feature: Integrated Ecosystem

In this document we focus on climate change IVO in the Arctic. However, for the 1.8 million km^2 MRB (Figure 1) it is important to consider that current and future IVO will be primarily driven by processes operating well outside the Arctic. As for all large river basins, this sub-region is an effective integrator of multiple ecological processes (e.g., terrestrial, freshwater and marine) that produces diverse ecosystems and supports a range of commercially and culturally important resources. The Mackenzie River and its tributaries carry the integrated signal of multiple land uses (e.g., forestry, agriculture, renewable resource extraction), hydroelectric and oil sands development, different hydrologic regimes and numerous other ecological and social factors into the Mackenzie estuary, the location of the first Marine Protected Area in the Arctic (i.e., Tarium Niryutait MPA).

Therefore, to address climate change adaptation for DFO priorities in the MRB, the extensive integrated nature of the ecosystem must be reflected in the management processes. The MRB will continue to require provincial, territorial, co-management and even international engagement to address climate change IVO realized in the Arctic. Such a level of integrated engagement may be higher than for any other sub-region, except perhaps the Hudson Bay complex, if the entire Hudson Bay drainage basin is taken into consideration. Requirements for DFO to develop/revise management plans and extend or establish fishery policies, in collaboration with multiple OGDs in the MRB, may flow from: 1) the northward expansion and/or population increases of commercially valuable species (e.g., salmon and ciscoes; Dunmall et al. 2013, Muir et al. 2014), and 2) potential increases or decreases in commercial (e.g., Great Slave Lake) and subsistence fisheries as water flow changes (Table 6). Additional considerations are needed for long-distance migratory patterns of presently exploited anadromous fishes within the MRB (e.g., Inconnu, Broad Whitefish), as well as those which migrate coastally across the international boundary with the USA (Alaska) (i.e., Dolly Varden, Arctic cisco) (Wrona et al. 2005).

The expected rates and timing of climate-related changes in the MRB may be especially difficult to predict given that the integrated nature of the MRB may attenuate change, resulting in a naturally slow, mitigated ecosystem responses. Alternatively, some changes may be exacerbated through multiple stressors present in the basin. Rapid shift in hydrologic regimes throughout the MRB could have serious impacts for the coastal marine ecosystem and any climate-driven catastrophic pollution event, related to southern resource extraction, could have far reaching impacts within the Arctic LAB.

3.3 Canadian Arctic Archipelago sub-region
Feature: Arctic Corridor

The CAA is known as one of the two outflow shelves of the Arctic (Michel et al. 2015), acting as the exit corridor for sea ice, glaciers, fresh water, and species from the Arctic LAB. The CAA is also recognized as one of the primary shipping corridors in the Arctic. With reduced sea-ice extent and thickness, the shipping season will lengthen and expanded shipping routes may emerge. However, climate scenarios and ice forecasts suggest that even with reduced summer ice pack, significant shipping hazards and barriers will continue to exist in the CAA and throughout the Arctic LAB. For example, the seasonal reduction of first-year fast ice occurrence could allow older, thicker ice to enter the Northwest Passage and increased winds, in combination with the thick old ice, could create dangerous shipping conditions along coastlines and choke points within channels (Wilson et al. 2004; Howell et al 2009). The need for increased ice reconnaissance and forecasting remains a priority to reduce the likelihood of vessel incidents that could require environmental (e.g., spill) or search and rescue responses.

It is now recognized that large increases in international shipping through the Arctic is not expected within the foreseeable future (Lackenbauer and Lajeunesse 2014). Arctic environmental variability, limited infrastructure and navigational aids and uncertain economies remain significant barriers for the Arctic LAB to emerge as a trans-shipping route. However, the Arctic is emerging as a *destination*, with increases in resource, re-supply, and tourist destinational shipping that could increase the need for infrastructure support (Lackenbauer and Lajeunesse 2014).

The IVO related to the primary shipping corridor in the CAA (e.g., economic opportunities, spill preparedness, groundings, impacts of strikes and sound) are directly linked to safe shipping priorities of the Government's Northern Strategy. DFO's Northern Marine Transportation Corridors Initiative, led by CCG, and DFO's involvement in other OGD initiatives (e.g., Transport Canada (TC), World Class Tanker Safety system) are critical priorities to prepare for and respond to shipping IVO in the Arctic LAB. The development of shipping corridors and other developments to guide increased Arctic shipping will need to consider the management of vessel traffic in an increasing number of Arctic MPAs and other protected areas (e.g., marine parks). Such efforts would involve consultations and management among CCG, SCH, TC, co-management partners, and the private sector. As Arctic vessel traffic continues to increase with climate change, multiple sectors and programs will be required to participate in risk assessments throughout the Arctic and provide advice for international engagement, including the Arctic Council and UNCLOS, in support of policy and Arctic sovereignty.

All DFO sectors and programs will be involved in shipping management processes as increased use of marine corridors will likely coincide with marine mammal/fish migration corridors and traditional-use travel routes. Species management and/or recovery plans may require revisions especially for species susceptible to vessel traffic or as habitat use and population dynamics are altered by other climate change factors. Management plans for MPAs and species may need to be updated to identify recommended vessel routes to meet conservation objectives. The CAA corridor likely represents the greatest number of climate change economic opportunities in the Arctic LAB that will impact future DFO business priorities. These needs will be exacerbated if land-based development (e.g., mines) continues or increases in the Arctic.

3.4 Baffin Bay/Davis Strait sub-region
Feature: Commercial Fisheries

The Baffin Bay/Davis Strait sub-region is unique in supporting the only marine commercial fisheries (i.e., Greenland Halibut, northern shrimp) in the Arctic LAB. Despite the economic and cultural importance of these commercial fisheries, long-term monitoring of environmental conditions in the fishing and surrounding areas are lacking. In some areas of the sub-region, ecosystems baselines are also lacking. There is no systematic environmental monitoring in support of the fisheries, as is provided by the neighboring Atlantic Zone Monitoring Program (AZMP) occurring in more southerly Canadian waters and Greenland and German oceanographic programs in waters adjacent to Canada's Exclusive Economic Zones. The critical need for such monitoring to inform and advise future fishery regulations is highlighted by recent observations that Baffin Bay, specifically the productive North Water Polynya, is becoming less productive.

Bergeron and Tremblay (2014) observed a significant decrease in net community primary production between 1997 and 2011 in Baffin Bay. The decline in production was linked to a 65% decrease in nutrient (i.e., nitrate) uptake, such that the once highly productive (eutrophic) northern region of Baffin Bay is now more similar to the oligotrophic Beaufort Sea. The decline in nutrient uptake in Baffin Bay was driven by climate change-related freshening and increased stratification of the water column during the study period (Table 6).

Under a scenario of continued reduced nutrient availability in Baffin Bay, it is expected that primary producers (i.e., algal cells) will shift to smaller species that grow more efficiently at lower nutrient concentrations (Li et al. 2009, Lee et al. 2013). Such a shift will divert ecosystem resources away from fish populations that are the focus of fisheries as the smaller cells generally support microbial rather than higher trophic level processes. Currently it is not known to what extent the reduction in nutrient uptake is occurring throughout Baffin Bay and Davis Strait. In addition, the ramifications of production losses in the "headwaters" (i.e., North Water polynya) of Baffin Bay, for the downstream fishery areas are not known.

Significant climate-driven changes at the base of the food web are early warning signs that Arctic fish and marine mammal resources may be negatively impacted on both the short and long term. The significant shift in productivity of northern Baffin Bay likewise signals the potential for fishery changes that could impact activities of all DFO sectors and programs in the area. Moreover, the potential for further downstream effects on the Labrador Sea is high but uncertain as to their nature.

3.5 Hudson Bay Complex sub-region
Feature: Arctic Seaport

The Hudson Bay Complex is the only sub-region presently with an operational seaport, with climate change supporting longer access to the port (e.g., into November). The Churchill port is considered to receive high traffic relative to other Arctic ports and is therefore more vulnerable to aquatic invasive (AIS) or non-indigenous species (Goldsmit et al. 2014). Hudson Bay is the southernmost Arctic marine ecosystem in the world making this sub-region highly susceptible to climate change. Such susceptibility is a key concern for the introduction, establishment and/or spread of invasive species given that the present climate regime is the primary factor preventing AIS invasions in the Hudson Bay Complex. Low maximum water temperatures and the limited range in water temperatures, relative to potential AIS source regions, is presently the key barrier to AIS (North/South 2006).

Steiner et al. (2013, 2015) indicate an increasing trend for both air and surface water temperatures of 1-6°C and 1-1.5°C, respectively (Table 5) for the Hudson Bay Complex. An increase in water temperature by only a few degrees could remove the effective barrier to AIS. The removal of the climate barrier to invasive species may operate similar to a tipping point, with a potentially rapid and possibly irreversible shifts in ecosystem structure and function. Prior to the onset of a tipping point or ecosystem regime shift (Collie et al. 2004), continued trends of increasing temperatures would elevate the risk status (e.g., from medium to high) of several species identified as potential invaders for the sub-region (North/South 2006).

DFO risk assessments and management plans that include components of and linkages between port activities, AIS and ecosystem processes in the Hudson Bay Complex sub-region are key examples of DFO program activities that require the inclusion of climate change trends and impacts into planning and execution. Without the inclusion of climate change, the program activities would not be meaningful or relevant at all levels from ecosystem sustainability to policy.

SECTION IV: Uncertainty

The Arctic system, with or without climate change, is characterized by high inherent variability seasonally, inter-annually and over decadal time frames. This variability results in a base level of uncertainty in our understanding of Arctic biological resources and Arctic ecosystems. In recent years, in many respects driven by the recognition of rapid climate change in the Arctic, scientific knowledge of the Arctic system has increased, providing new information on a system already in a state of climate-driven flux. For the climate change IVO presented in Tables 6-9, on average, >80% of the uncertainty rankings were either low or medium suggesting that the potential consequences of current climate change drivers may be meaningfully proposed based on existing expert scientific knowledge of the ecology of species and their ecosystems. However, for Arctic Resources (Table 6) and Arctic Stability (i.e., ecosystem processes, Table 8) less than 40% of the IVO had a ranking of low uncertainty, indicating that for certain species and ecosystem linkages, critical knowledge is still lacking to address even the first steps of climate change adaptation.

The IVO identified for the Arctic LAB often indicate an expected change but lack specificity about the expected direction and/or magnitude of the change. In addition, timing of the change (e.g., onset or seasonality specificity) and spatial dimensions (e.g., large and small-scale regional specificity) of the change are not defined. All of these parameters of climate change are vital to adaptive processes, yet are difficult to define given the uncertainty of the system as well as the uncertainty of the available scientific information and/or modelling outputs. The uncertainty related to scientific information from the Arctic is often based on limited duration or spatial coverage of the studies. Indeed in some areas even baseline data of species and trophic interactions are not available. Uncertainty is also derived from the lack of process studies that would provide direct evidence of climate change consequences for ecosystem linkages and a species fitness.

Uncertainty of climate change impacts is also based on the realization that climate change does not produce single, linear ecosystem changes, but rather alters species and ecosystem in multiple ways. Therefore climate change, in and of itself, is a cumulative stressor for the Arctic LAB. Overlaying the cumulative impacts of climate change are other stressors on the Arctic system including industry, harvest, human population growth and contaminants (e.g., Wrona et al. 2006a). Consequences of the multiple layers of impacts on Arctic biological resources can be countervailing (i.e., less impact than the sum of the parts), additive (i.e., equal to the sum of the parts), or synergistic (i.e., more impact than the sum of the parts). Deciphering the specific consequences of cumulative impacts, within and added to climate change, is a key challenge to adaptive management and is best addressed with comprehensive monitoring of the evolving Arctic system coupled with appropriate mechanistic research.

Addressing uncertainty, although challenging, is critical for delivery of DFO program priorities in the future. The ability to identify early warning signs and indications of abrupt changes as well as anticipate surprises relies on reducing uncertainty through activities such as monitoring, modelling and knowledge synthesis (National Research Council 2013). DFO Science needs to arm managers and support policy and decision-making processes with the best possible knowledge of Arctic resources and ecosystems to reduce the likelihood of surprise impacts that could devastate Arctic ecosystems and/or communities with great cost to DFO.

SECTION V: Recommendations for DFO Science

The climate change IVO identified for the Arctic LAB require adaptive measures across DFO sectors and programs. Climate change can no longer be considered a separate entity or program activity, but rather needs to be integrated into DFO business for the successful delivery of the Departmental mandate and program priorities. DFO Science has been and will continue to be tasked with delivering scientific excellence in support of management and policy. Science priorities should now, more than ever, be directed by climate-driven processes in the Arctic LAB.

To support DFO business adaptations and to reduce uncertainties of climate change IVO, DFO Science can target the description and prediction of ecosystem **thresholds** and **triggers**. Addressing these target indicators would help other sectors and DFO in general, and be anticipatory rather than reactive to climate change IVO.

Ecosystem thresholds (e.g., temperature tolerances of valued fish species) identify the adaptive capacity of species and the potential for expanded or altered habitat for species ranging from microbes to mammals. The point at which sea-ice concentration no longer functions as a structuring element for polynyas (i.e., Nares ice bridge) or as a barrier to apex predators, is an example of a key physical threshold impacting both ecological hotspots and marine mammal population dynamics. Thresholds can be measured and associated uncertainties identified through ecosystem- or species-process studies, including physiological studies, as well as long-term monitoring. The capacity to identify deviations from long-term trends would enable DFO to anticipate the approach of ecological and physical thresholds that would impact priority activities. Utilizing multiple thresholds, against which to measure ecosystem sustainability would be an important adaptive approach to prepare for the likelihood of **abrupt** climate-driven changes that can lead to a new state for Arctic ecosystems.

Ecosystem triggers (e.g., deepening of the water mixed layer) are critical ecosystem features or processes that can initiate **stepwise** or gradual changes toward ecosystem change. Knowledge of ecosystem structure is required to identify the key physical, chemical or biological triggers that initiate radiating changes throughout the ecosystem. From an ecological perspective, triggers may be represented by trophic shifts (e.g., shifts in community size structure) that result in changing feeding, recruitment or other life history processes of one or multiple species. Trophic shifts such as the shift from Arctic Cod to Capelin as dominant prey species in an area of Hudson Bay with concomitant effects on recipient sea-bird components of the ecosystem (Gaston et al. 2003) have previously been observed. Monitoring of triggers, whether a physical feature or species assemblage, will provide the early warning signs of potential significant changes for fishery resources or other valued ecosystem components. Ecosystem triggers also represent a focal point for monitoring activities and process studies when it is not feasible undertake comprehensive ecosystem studies.

A strategic program, incorporating ecosystem thresholds and triggers, is required to ensure that climate change IVO is specifically and adequately addressed in order to transfer Science results to Policy initiatives. From the perspective of Science, monitoring, modelling and synthesis activities are key integrated components of such a program.

- Long-term monitoring is the critical component to build and sustain climate change adaptation capacity in the Arctic. Monitoring in support of climate change adaptation can be built into existing programs but will need to be expanded to include ocean observatories. Automated systems provide excellent opportunities for monitoring certain parameters (e.g., physical and chemical aspects). However, it is recognized that complementary process studies and biological sampling are necessary for data and model validation, understanding the scope of biological responses to climate change, and to address processes not adequately described by automated systems or currently available sensors.
- Modelling provides the trends and projections to underpin risk analyses and is required to prepare mitigative actions and policies. Modelling of the physical, chemical and biological systems is required to understand the timing and magnitude of ecosystem responses that will directly impact DFO business. The Science Sector can continue to enhance the partnership between data collectors and modellers so that specific data needs are provided and modellers can best parameterize models to address specific IVO for the entire Arctic LAB or at regional/sub-region scales.
- Extensive datasets are currently being produced for the Arctic by governmental, academic and private efforts. However, the integration of the data within and among research institutions remains limited. Information generated within DFO should be verified for quality assurance as well as integrated and synthesized to meet the needs of climate change adaptation. Such synthesis is applicable to both monitoring and modelling outputs. Programs for sample and data archiving that support model creation/comparisons and advice preparation are required to maximize the efficacy of current data collection. Collaborative networks and innovative tools for data processing and modelling techniques will advance DFOs capacity to deliver and adapt priorities as appropriate.
- Continued process-based research is needed to deliver a mechanistic understanding of Arctic ecosystem and climate-system linkages. Such knowledge of the drivers, responses, and functionality of linkages is required to reduce IVO uncertainty and enhance necessary predictive and adaptive capabilities of DFO.

A strategic program for integrated, ecosystem-scale, climate change science activities will provide meaningful information for decision making processes. Foundational monitoring, modelling and synthesis program activities will support changing priorities or program realignments. A strategic program for Science should also encompass the flexibility to be re-examined and refined as climates and ecosystems evolve and community vulnerabilities change.

Climate change is a long-term stressor requiring focused attention similar to the delivery of the DFO mandate for industrial or shipping activities. A strategic approach specifically aimed at climate change IVO for Arctic ecosystems and resources is required as a priority. Adaptive and mitigative actions should be taken within DFO to accurately predict preventable catastrophic outcomes for the communities and ecosystems of the Arctic LAB and realize the benefits of fisheries and other development opportunities in the region.

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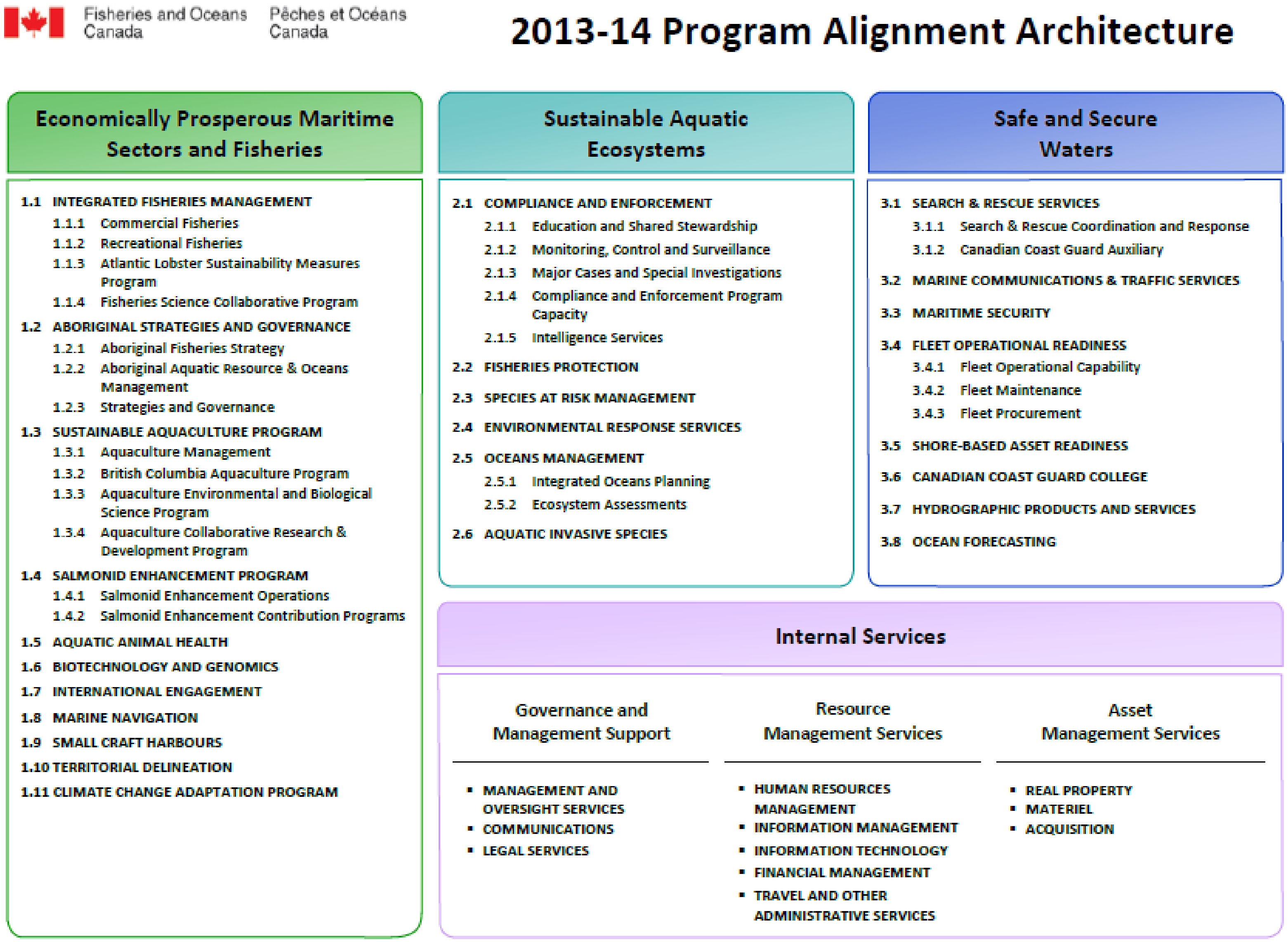
ANNEX 1: DFO Program Alignment Architecture (PAA) 2013-2014



Fisheries and Oceans Canada Pêches et Océans Canada

2013-14 Program Alignment Architecture

Economically Prosperous Maritime Sectors and Fisheries

- 1.1 INTEGRATED FISHERIES MANAGEMENT
  - 1.1.1 Commercial Fisheries
  - 1.1.2 Recreational Fisheries
  - 1.1.3 Atlantic Lobster Sustainability Measures Program
  - 1.1.4 Fisheries Science Collaborative Program
- 1.2 ABORIGINAL STRATEGIES AND GOVERNANCE
  - 1.2.1 Aboriginal Fisheries Strategy
  - 1.2.2 Aboriginal Aquatic Resource & Oceans Management
  - 1.2.3 Strategies and Governance
- 1.3 SUSTAINABLE AQUACULTURE PROGRAM
  - 1.3.1 Aquaculture Management
  - 1.3.2 British Columbia Aquaculture Program
  - 1.3.3 Aquaculture Environmental and Biological Science Program
  - 1.3.4 Aquaculture Collaborative Research & Development Program
- 1.4 SALMONID ENHANCEMENT PROGRAM
  - 1.4.1 Salmonid Enhancement Operations
  - 1.4.2 Salmonid Enhancement Contribution Programs
- 1.5 AQUATIC ANIMAL HEALTH
- 1.6 BIOTECHNOLOGY AND GENOMICS
- 1.7 INTERNATIONAL ENGAGEMENT
- 1.8 MARINE NAVIGATION
- 1.9 SMALL CRAFT HARBOURS
- 1.10 TERRITORIAL DELINEATION
- 1.11 CLIMATE CHANGE ADAPTATION PROGRAM

Sustainable Aquatic Ecosystems

- 2.1 COMPLIANCE AND ENFORCEMENT
  - 2.1.1 Education and Shared Stewardship
  - 2.1.2 Monitoring, Control and Surveillance
  - 2.1.3 Major Cases and Special Investigations
  - 2.1.4 Compliance and Enforcement Program Capacity
  - 2.1.5 Intelligence Services
- 2.2 FISHERIES PROTECTION
- 2.3 SPECIES AT RISK MANAGEMENT
- 2.4 ENVIRONMENTAL RESPONSE SERVICES
- 2.5 OCEANS MANAGEMENT
  - 2.5.1 Integrated Oceans Planning
  - 2.5.2 Ecosystem Assessments
- 2.6 AQUATIC INVASIVE SPECIES

Safe and Secure Waters

- 3.1 SEARCH & RESCUE SERVICES
  - 3.1.1 Search & Rescue Coordination and Response
  - 3.1.2 Canadian Coast Guard Auxiliary
- 3.2 MARINE COMMUNICATIONS & TRAFFIC SERVICES
- 3.3 MARITIME SECURITY
- 3.4 FLEET OPERATIONAL READINESS
  - 3.4.1 Fleet Operational Capability
  - 3.4.2 Fleet Maintenance
  - 3.4.3 Fleet Procurement
- 3.5 SHORE-BASED ASSET READINESS
- 3.6 CANADIAN COAST GUARD COLLEGE
- 3.7 HYDROGRAPHIC PRODUCTS AND SERVICES
- 3.8 OCEAN FORECASTING

Internal Services

Governance and Management Support	Resource Management Services	Asset Management Services
▪ MANAGEMENT AND OVERSIGHT SERVICES ▪ COMMUNICATIONS ▪ LEGAL SERVICES	▪ HUMAN RESOURCES MANAGEMENT ▪ INFORMATION MANAGEMENT ▪ INFORMATION TECHNOLOGY ▪ FINANCIAL MANAGEMENT ▪ TRAVEL AND OTHER ADMINISTRATIVE SERVICES	▪ REAL PROPERTY ▪ MATERIEL ▪ ACQUISITION