RISK-BASED ASSESSMENT OF CLIMATE CHANGE IMPACTS AND RISKS ON BIOLOGICAL SYSTEMS AND INFRASTRUCTURE WITHIN FISHERIES AND OCEANS CANADA'S MANDATE – ARCTIC LARGE AQUATIC BASIN

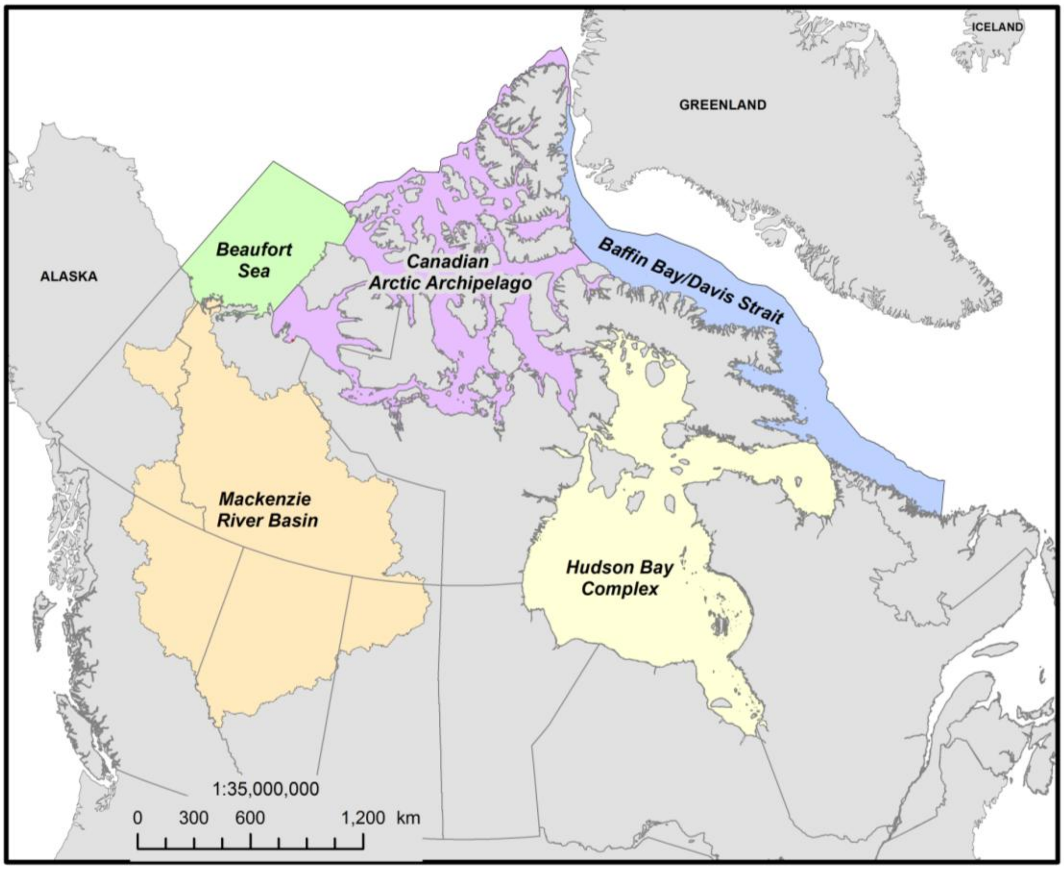

Figure 1. Map of the Arctic Large Aquatic Basin (LAB) as defined by the Aquatic Climate Change Adaptation Services Program (ACCASP). The Arctic LAB is divided into five sub basins: Beaufort Sea, Canadian Arctic Archipelago, Baffin Bay/ Davis Strait, Hudson Bay Complex, and Mackenzie River Basin.

Context

In keeping with the *Federal Adaptation Policy Framework*, Fisheries and Oceans Canada (DFO) received funding for the Aquatic Climate Change Adaptation Services Program (ACCASP; 2011-2016) in order to implement a science-based climate change program focused on adaptation and delivery of Fisheries and Oceans' mandated areas of responsibility. The Program will undertake risk assessments, foster the development of applied science-based tools and research projects to increase our understanding of the impacts of climate change, and enable adaptation in support of DFO's strategic outcomes.

One of the primary objectives of the Program is to assess the risks that climate change poses to the delivery of DFO's mandate within four defined Large Aquatic Basins (LABs), namely the Arctic, Pacific, Freshwater and Atlantic. The assessment of regional risks will help front-line managers respond to climate change.

As a first step towards this objective, a Canadian Science Advisory Secretariat (CSAS) Science Special Response Process (SSRP), which consisted of one face-to-face meeting in each of the LABs, was conducted to assess the risk to biological systems and infrastructure that fall under the purview of DFO. Each assessment was based on interim summary documents that describe climatic 'Trends and Projections' (TP) and 'Impacts, Opportunities and Vulnerabilities' (IVO) evaluations based on two separate temporal scales (10 & 50 years). The detailed TP and IVO reports, which are extensive detailed assessments of the climatic changes and impacts at the sub basin level in each LAB will be published by the end of 2012-2013 fiscal year (*to be published*[1,2]). The basis of this work followed two internal DFO national climate change risk assessment reports (Interis 2005, 2012) which provided preliminary assessments of the impacts of climate change on DFO's strategic outcomes; these assessments served as the departure point for the four LAB assessments.

Following these CSAS meetings, the results of the SSRP for each LAB, along with the results of concurrent socio-economic and policy analyses, will be collectively used to inform four additional LAB-based Integrated Risk Management workshops. The objective of these integrated workshops will be to take the evidentiary base provided by science, socio-economics, and policy and incorporate DFO program area (e.g. fisheries management, oceans management, etc.) considerations to determine the most acute basin-level climate risks for the Department. The results will help DFO decision-makers adapt decisions to reflect climate change considerations so that Canadians may continue to derive socio-economic benefits from our oceans and inland waters. This information will also be instrumental in informing priorities for ACCASP's competitive funding envelopes, which are aimed at understanding climate change impacts and developing applied adaptation tools, for the 2013-14 funding year and beyond.

The SSRP was used due to the short timeframe within which this advice was required. The urgency for this advice stems from the need to identify and apply linkages between the science, socio-economic and policy background documents for the Integrated Risk Assessment workshops, which are scheduled for early winter/spring 2013.

Participants were provided with background documents which summarized the scientific information available on TP and the IVO for each LAB. However, these advisory meetings were held specifically to peer review the resulting Risk Summary Sheets for each DFO Departmental risk. A separate review process for the background documents will occur once they are finalized, prior to the end of the 2012-2013 Government of Canada fiscal year (*to be published*[1,2]).

This Science Response Report (SRR) details the results from the National SSRP meeting of October 15-17, 2012 on the Risk-based assessment of climate change impacts and risks on biological systems and infrastructure within Fisheries and Oceans Canada's mandate - Arctic Large Aquatic Basin, Winnipeg, Manitoba. The SRR resulting from this Arctic LAB and the other

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[1] Climate Change Trends and Projections Assessment in the Arctic Basin -A Contribution to the Aquatic Climate Change Adaptation Services Program. Can. Tech. Rep. Fish. Aquat. Sci. (provisory title, unpublished manuscript)

[2] Arctic Large Aquatic Basin – Climate Change Impacts, Vulnerabilities and Opportunities – Aquatic Climate Change Adaptation Services Program. Can. Manuscr. Rep. Fish. Aquat. Sci (provisory title, unpublished manuscript)

three SSRP LAB advisory meetings will be posted as they become available on DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

Background

Climate change is an important issue that has the potential to affect DFO's ability to meet its mandated obligations and commitments. Climate change issues are complex and it is often difficult to predict how, where, when and at what magnitude impacts will occur. Furthermore, DFO is a complex and diverse government department and there is a high likelihood that climate change impacts will affect all of its sectors and regions to some extent. These effects, however, will vary greatly spatially and temporally among and throughout the regions of Canada. As such, past DFO climate change risk assessment reports (Interis 2005, 2012) have identified six main climate change related risks that could limit the Department's ability to deliver on its mandate. These are:

- Risk 1: Ecosystem and Fisheries Degradation and Damage;
- Risk 2: Changes in Biological Resources;
- Risk 3: Species Reorganization and Displacement;
- Risk 4: Increased Demand to Provide Emergency Response;
- Risk 5: Infrastructure Damage; and
- Risk 6: Change in Access and Navigability of Waterways.

Further to this, DFO must also recognize its obligations to Northern co-management bodies (i.e., Northern Aboriginal organizations) legally established under legislated land claim agreements. Climate change could limit DFO's ability to deliver on its mandate to these clients. For example, in the western Arctic, the subsistence fishery based on the Dolly Varden, a coastally fished char listed by COSEWIC as a species of Special Concern, represents a complex issue due to this species status. Climate change will very likely affect Dolly Varden through habitat change and biological parameters. This, in turn, will increase the complexity of management of this species and of the delivery of DFO advice and management options to the bodies established through the co-management process (e.g., West-Side Working Group of the Inuvialuit and Gwich'in, Rat River Working Group of the Gwich'in).

Current fishing activities in the Canadian North are limited to mainly subsistence harvests, however, there are a few commercial fisheries in the southern Northwest Territories (e.g., Great Slave Lake) and the Eastern Arctic (e.g., Cumberland Sound Turbot Fishery, Cambridge Bay Arctic Char Fishery). Recreational fisheries are extensive throughout the area. Management and advice regarding these will become more complicated as a result of climate change. Furthermore, new fisheries may be developed in the north as a result of the changing climate.

There is also a limited amount of infrastructure in the Arctic LAB in comparison to other regions in Canada, with the majority of sector concerns from the Canadian Coast Guard (CCG) and the Canadian Hydrographic Service. Currently there are three SCH facilities in the Northwest Territories (Mackenzie River Basin), and one Small Craft Harbours (SCH) facility in Pangnirtung, Nunavut (Baffin Bay/Davis Straight).

For the Arctic LAB, the geographical scope of the ACCASP includes both marine and freshwater ecosystems in five Arctic sub-basins: the Mackenzie River Basin, Beaufort Sea, Canadian Arctic Archipelago, Baffin Bay/Davis Strait and the Hudson Bay Complex (Figure 1).

The geographic area is large and expansive and includes a multitude of aquatic environments. In general, freshwater and marine ecosystems in the Arctic LAB experience strong seasonality in sunlight and low temperatures and are influenced by riverine input. Ice cover (e.g., multi-year pack ice, fast-ice) is a unique and important physical feature, affecting heat exchange and light penetration. Polynyas and flow lead systems provide critical habitat for a variety of organisms (e.g., under-ice algae, Arctic Cod, seals) and are often described as areas of enhanced productivity (e.g., North Water Polynya, Cape Bathurst Polynya) and ice is also considered an important structure where migration (e.g., Caribou ice-crossing) and foraging (e.g., Polar Bear movements) take place. This platform is also important for travel and access to resources by humans. The loss of sea-ice will have profound effects to the loss of habitat, change in infectious disease transmission, contaminant pathways, species distribution and range expansion (e.g., invasive or colonizing species) and an increase in other anthropogenic stressors. The specialization of many of the Arctic and sub-Arctic species within the LAB make them potentially more sensitive to environmental change.

There are considerable observed differences in both physical and chemical trends and projections and in the nature, magnitude and frequency of the associated impact(s) that follow (e.g., linkages within a pathways of effects model) within the Arctic LAB across the five sub basins. However, the science advice from this meeting is based on the integration of information from the five sub-basins and is delivered as advice for the entire Arctic LAB.

Over the last few decades in the Arctic, changes in physical factors, such as sea-ice extent, ice breakup dynamics, water and air temperatures, and water chemical properties (e.g., pH, calcium carbonate saturation states, salinity, nutrients) have been observed (Appendix 1). These changes are likely to continue into the future and are expected to further impact the delivery of DFO’s activities in this LAB (Appendix 1). Furthermore, the Arctic is expected to experience an accelerated rate of change due to global warming. Climate models submitted to the Intergovernmental Panel on Climate Change (IPCC 2007) project that the rate of change will be greater in polar regions than at lower latitudes, which will enhance concerns on the delivery of DFO’s mandate in Arctic waters (i.e., earlier and more extensive delivery of DFO services in response to climate change will be required in the Arctic).

Analysis and Responses

Each risk summary sheet (Risks 1-6) was based on a compilation of the Arctic LAB sub-basin background reports. Participants discussed the differences between the main climate drivers and the resulting impacts of these drivers. The key physical and chemical trends and projections for each LAB are the main drivers of climate change in the environment and provide the basis for assessing the potential impacts, vulnerabilities, opportunities and threats to DFO. Since these climate drivers are typically common across the entire LAB (to varying degrees), participants recommended that a separate summary table of the drivers be created since they are the fundamental basis of the identified environmental changes and the resulting advice in this report (Appendix 1). The resulting risk summary sheets (Appendices 2-7) are therefore organized with this consideration.

Trends and Projections

Participants reviewed the trends and projection summary table (Appendix 1) which summarizes past climate trends (up to approximately the last 50 years) as well as future projections (next 50 years) for the Arctic LAB. All of the information contained in the TP summary table is supported by literature that is published or under review.

The climate trends and projections identified are typically common across the entire LAB (to varying degrees) and represent the fundamental basis of the resulting environmental change and advice in this report (Appendix 1).

Risk Summary Sheets

Participants reviewed six risk summary sheets that described the main climate change risk drivers, consequences (threats), opportunities and gaps for each of the previously identified Departmental climate change risks (Interis 2005, 2012; Appendices 2-7). These risk summary sheets are based on the trends and projections identified in Appendix 1. The main risk drivers are supported by peer reviewed literature, whereas the consequences, opportunities and gaps were developed through consensus in plenary. Note that there is no direct linkage between the main risk drivers and the consequences in Appendices 2-7.

During the review of the risk summary sheets participants used the following definitions:

- Risk driver: (also known as risk source) is an element which alone or in combination has the intrinsic potential to give rise to a risk.

- Consequence: is described as an outcome of an event affecting objectives (the event being the occurrence or change of a particular set of circumstances).

The risk summary sheets, as well as the TP summary table (Appendix 1) are the key advice resulting from this process and are relevant for both the 10 and 50 year timescales. The timescales were combined either because a) TP and IVO were too difficult to predict and/or model and were therefore inconclusive or, b) the impact results were the same for each risk and only the likelihood or probability of occurrence changed between these timescales.

The first three identified risks (risks 1-3) are related to marine and freshwater ecosystems, and the participants from the Science Sector are considered the primary experts in this field. Risks 4-6 focused on DFO's marine and freshwater infrastructure. In these cases, Science participants assessed risk to the best of their ability, recognizing that this portion of the advice would have benefited from input by technical experts most of whom were not available at this meeting (i.e., DFO sectors who manage infrastructure including SCH, CCH, Real Property and Canadian Hydrographic Services). SCH participated in the meeting. The context and definitions for each of the six Departmental risks are as follows:

Risk 1 - Ecosystem and Fisheries Degradation and Damage: Climate change poses a risk to 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 environments. The risk focuses on DFO's stewardship role in managing and protecting fish habitat, the leadership role of DFO in Canada's Ocean Strategy, and in maintaining the sustainability of the oceans and their resources (i.e., *Ocean's Act*, *Fisheries Act*). The main risk drivers that were identified within this risk were primarily based on future changes in habitat characteristics and dynamics, and on shifts in species biodiversity, altered productivity and/or shifts in trophic pathways. Several of the main risk drivers, threats, opportunities and gaps were common to Risks 1, 2 and 3.

Risk 2 - Changes in Biological Resources: Climate change poses a risk to DFO's ability to manage and protect the abundance, distribution and quality of harvested fisheries and aquaculture stocks. The risk refers specifically to DFO's management of fisheries resources (i.e., *Fisheries Act*). The term fisheries can include a range of species (e.g., marine mammals, fishes and shellfish) and encompasses varying scales, including commercial and recreational fisheries as well as subsistence, social and ceremonial fisheries.

Risk 3 - Species reorganization and displacement: Climate change will affect DFO's ability to protect species diversity and species at risk (i.e., *Species at Risk Act*). It assumes that climate change will lead to changes in the distributions and type of species in various aquatic habitats. Climate change can limit or extend the range of an aquatic species or facilitate the introduction and/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 is on the potential for increased occurrences of marine incidents due to climate change and the associated strain on the 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 vessels, coastal and Small Craft Harbour (SCH) infrastructure. DFO maintains considerable infrastructure to support its operational and scientific 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: Climate change poses a risk to 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.

During the discussions of Risks 1-3, participants noted some additional considerations that needed to be taken into account when assessing the risks to DFO. For Risk 1, although climate models do not predict significant changes in nutrient concentrations, changes have been observed in the past, are documented in the scientific literature and are anticipated to continue into the future; therefore changes in nutrient concentrations should be considered. Furthermore, there is evidence in the literature of both increases and decreases in past and predicted primary productivity at varying regional/local scales, which may have negative or positive impacts on the ecosystem. With our current state of knowledge, it is difficult to predict what these future trends will be as well as the subsequent impacts they will have on ecosystems.

For Risk 2, participants discussed the importance of considering changes in access to Arctic fisheries by local community members because of changes in open water seasons, currents and flow rates.

Lastly, for Risk 3, participants discussed the process by which species are listed under the *Species at Risk Act* (SARA). Species identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) that were not listed on any of the SARA Schedules were not assessed within the context of this advice. Furthermore, a lack of baseline information for endemic populations in the Arctic made it difficult to assess the risk posed by aquatic invasive or non-native species. Additionally, participants noted that a large portion of the oceanic phytoplankton in the Arctic can be considered non-endemic, although these are not considered invasive species.

Risk Evaluation

Following a review of each risk summary sheet, participants went through a formal process to assess DFO Departmental risk using pre-established criteria (Appendix 8). Participants were asked to vote on the impact of each risk, and the probability of that risk occurring over a) the next 10 years, and b) the next 50 years. This voting process was conducted for each of the six identified Departmental Risks defined in the above text. All participants were given the choice to vote and all voting was conducted anonymously using the BPS Resolver Ballot software (version 7.2.0.20) (n=17 for Risks 1-2-3, and n=18 for Risks 4-6). Voting results were reviewed in plenary. In cases where there was a significant lack of agreement between the votes; results were discussed and the vote was repeated. The impact and the probability of the risk were considered independently. The results of the assessments were illustrated using standard heat maps (Figures 2 and 3).

Prior to the voting process, participants discussed and reviewed a list of assumptions that were prepared and noted during meeting discussions:

- The assessment was based on the best understanding of the Science that was available to the participants at the time of the meeting.
- Infrastructure damage risk was assessed based on the current level of infrastructure.
- There is inherent spatial and/or temporal variability in several of the risk drivers.
- The assessment of non-biological risks (Risks 4-6) was conducted with limited contribution from engineers and/or technical experts.
- The assessment was conducted with a low sample size and combined the opinions of experts that had a wide range of background experiences (scientific and corporate). For example, an individual’s perception of DFO’s current capacity to control risk was considered while voting.
- There is uncertainty with respect to the variability of the system; more specifically, how and at what rate the system may change in the future.
- The evaluation of the risks assumed that there is a certain level of predictability in the ecosystem.

Individual Risk Voting Results

Most of the voting produced normal distribution curves; however, a number of the distributions were considered platykurtotic, with a flatter peak around the mean and thin tails within the distribution (Appendix 9).

The impacts and probabilities for both the risk of ecosystem and fisheries degradation and damage, and changes in biological resources (Risks 1 and 2) were perceived as very high to extreme by the participants. Participants considered the risk of changes in biological resources to be high due to both the potential for increased commercial fishing pressure as a result of increased access to resources and increased pressure on currently harvested species that will be negatively impacted by identified climate change variables and their effects on the system (cumulative impacts).

Current management of Arctic fisheries resources relies heavily on local management boards (under a co-management regime). However, DFO has the ultimate responsibility for these resources and as climate change continues to alter biological systems and the environment, DFO may be called on to protect and/or manage more of these harvested species. This will likely be the case for a number of current subsistence fisheries but also for any new fisheries that are developed as a result of climate change. It should also be noted that the same governance structure exists for recreational fisheries in the North, where territorial governments manage the fisheries but DFO has the ultimate responsibility.

Species reorganization and displacement (Risk 3) was deemed to be a medium to very high risk to DFO. The distribution of impact votes was uniform, due in part to slightly differing views on the importance of commercial species versus other species of interest (e.g., subsistence fisheries or ecologically important species).

The impact vote for the risk due to increased demand to provide emergency response (Risk 4), was clearly platykurtotic. Participants did agree that there is a risk that DFO will have to deal with environmental damage as a result of marine incidents (e.g., oil spills) and risks associated with management of human rescue operations in marine environments (e.g., search and rescue, vessel assistance) but the intensity of the impact was hard to assess. The distribution on the 50 year probability timescale was uniform.

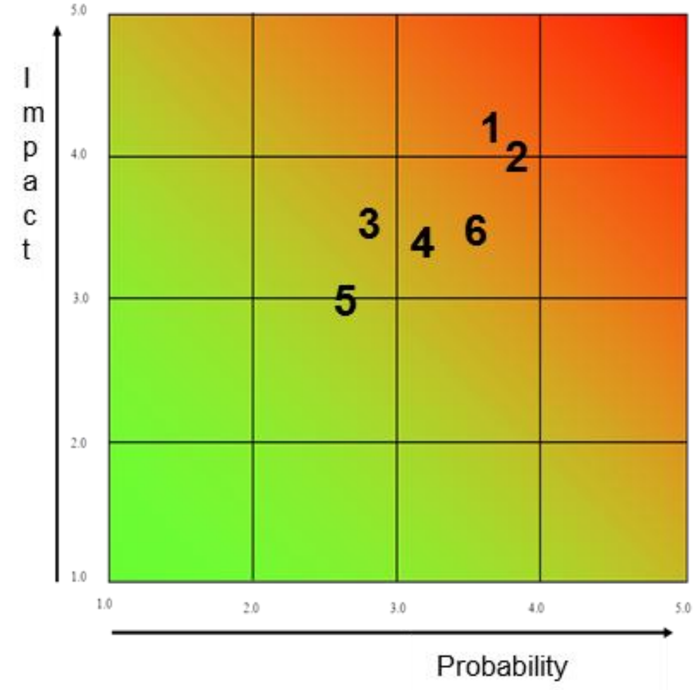
Infrastructure damage and changes in access to navigability of waterways (Risks 5 and 6) would have a medium and a medium to very high impact, respectively, on DFO's ability to deliver on its mandate.

Risk Heat Maps

Voting on the impact ranking of each risk was only conducted once; therefore, the impact results (y-axis) are the same in Figures 2 and 3. The resulting location of each Risk in Figures 2 and 3 along the x-axis was based on the probability voting for each risk.

Overall, ecosystem and fisheries degradation (Risk 1) and changes in biological resources (Risk 2) were considered to present the greatest risk exposure to DFO, i.e., the greatest impact on DFO and probability of occurrence for both timescales (Figures 2 and 3). Risk 5, infrastructure damage, was perceived to have the least impact and the lowest probability of occurrence over both timescales, likely due to the general lack of current infrastructure within the Arctic LAB. Additionally, based on voting results, participants felt that for all risks the probability or occurrence increased from the 10 to the 50 year time scale (Figures 2 and 3). This was particularly true for Risk 3, species reorganization and displacement.

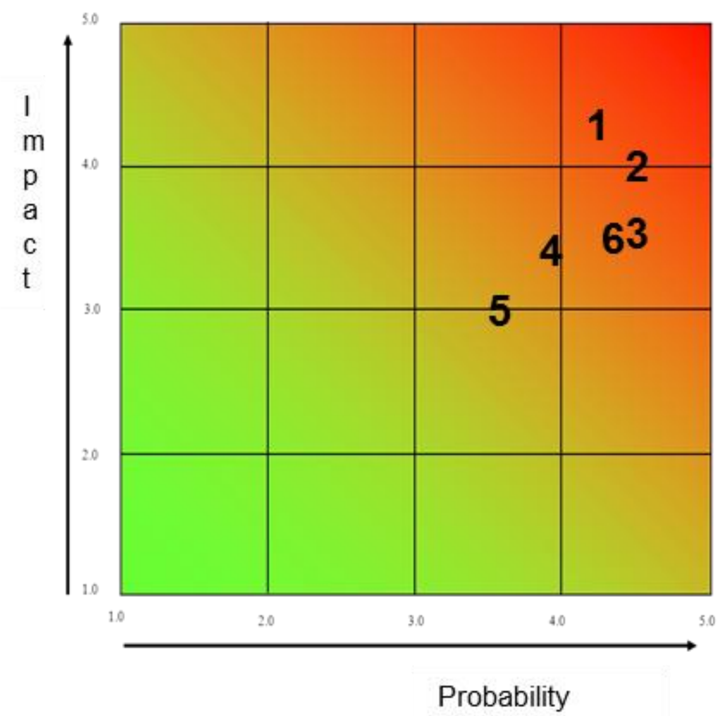
Risks 4 and 6, increased demand to provide emergency response, and changes in access and navigability of waterways generally fell within the medium to high range on the heat maps (Figures 2 and 3, respectively). There was great concern among participants about the extent and accuracy of navigational charts that are currently available for the Arctic, which will impact navigation and increase the risk of marine incidents and subsequent emergency response.



DFO Risks

1) Ecosystem and Fisheries Degradation and Damage
2) Changes in Biological Resources
3) Species Reorganization and Displacement
4) Increased demand to provide Emergency Response
5) Infrastructure Damage
6) Changes in Access and Navigability of Waterways

Figure 2. Heat map showing the impact and probability of occurrence for each DFO Risk on the 10 year timescale.



DFO Risks

1) Ecosystem and Fisheries Degradation and Damage
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3) Species Reorganization and Displacement
4) Increased demand to provide Emergency Response
5) Infrastructure Damage
6) Changes in Access and Navigability of Waterways

Figure 3. Heat map showing the impact and probability of occurrence for each DFO Risk on the 50 year timescale.

Gaps in Knowledge

For each of the six DFO risks, participants identified gaps in knowledge that limit their understanding of climate change impacts on the Department (Appendices 2-7). During voting, participants ranked the impact and probability of occurrence based on qualitative information because quantitative information was insufficient for this exercise. Furthermore, a significant knowledge gap results from the inherent complexity of the impacts (i.e., cumulative impacts). The Arctic is an extremely large and multifaceted geographic region that has a variety of issues associated with access (e.g., scientific sampling, subsistence, economic prosperity). For this reason, data sets frequently contain spatial, temporal and seasonal gaps. Often spot measurements (single sampling stations) are often used to represent larger areas (e.g., regional representation). Misrepresentation also arises in cases where terrestrial station data is the only data available to represent marine areas.

The temporal scarcity of data in the Arctic is also reflected in the lack of long-term monitoring data sets for many regions. These limitations severely affect the ability to develop and validate models and hence reduce the confidence in model projections of climate change impacts. These limitations will be reflected by inaccuracies in the interpretation of past trends and future projections, ultimately in our analysis of impacts, vulnerabilities and opportunities for the LAB. Generally, participants agreed that at least 10 years of data are needed for some variables to allow some form of trend analysis.

Overall, the availability of Arctic climate models is extremely limited. Global Climate Models (GCMs) are generally too coarsely resolved to adequately represent the complex structure present in the Arctic LAB and higher resolution regional climate models are currently limited to the atmosphere. In particular, projections for the most unique feature of the Arctic, sea-ice, are lacking. Losses of sea-ice and changes in sea-ice morphology represent significant features and drivers of change in the Arctic. Many of the impacts on the environment and infrastructure could be predicted based on how sea-ice will change in future years. Similarly, model projections for Arctic Ocean variables are extremely sparse and nonexistent for biogeochemical variables. This gap is exacerbated by our inability to differentiate natural variability (seasonal, annual, multi-decadal) from climate change and anthropogenic stressors in the system on shorter time scales. Furthermore, in the future (i.e., on the 50 year timescale), anthropogenic changes may become dominant over those changes associated with natural variability.

Participants also discussed our lack of understanding of cause and effect relationships (i.e., pathways of effects models) for climate change variables and cumulative impacts within a multi-stressor environment. Knowledge of DFO's sectors' concerns, and perceived or known threats to their mandates will also help to populate linkages to environmental drivers and impacts within a pathway of effects model (i.e., scenario-based).

Threats and Opportunities identified for DFO

Along with a number of specific threats and opportunities that were identified for each risk, several were common to all three of the biological or infrastructure risks (Table 1).

Table 1. Identified threats and opportunities that were common among the biological risks (risks 1-3) and infrastructure risks (risks 4-6).

	Threats	Opportunities
Biological Risks	• Increased incidence of disease. • Loss of critical habitat. • Extirpation of locally adapted Arctic species.	• Increased habitat and food availability for some species and/or species groups (endemic and new species). • Increased opportunity for fisheries (commercial, subsistence, recreational).
Infrastructure Risks	• Reallocation of resources. • Increased health and safety issues (public and employee). • Increased demand in geographic and temporal scope.	• Increased accessibility to the Arctic LAB (e.g., marine shipping, tourism, economic potential and diversification).

Conclusions

The background reports that the meeting’s working papers were based on were prepared for individual sub-basins and were written by various authors. The methods used to compile the background reports for each sub-basin were not necessarily the same and the assumptions and understanding of the magnitude of impact on DFO could have been interpreted differently. For this reason, a proper peer review of these background documents will be important for future assessments. This will likely improve the prioritization of risks. Further refinements of the definitions and context of each of the Risks should be considered; for example, focusing the risks on particular themes.

The Arctic LAB risk summary sheets were prepared by compiling information from the background reports for all five sub-basins. However, it was noted during the review that the Mackenzie River sub-basin impacts and risks were considerably different than those of the other sub-basins because it is an extremely large freshwater sub-basin, while the other sub-basins are predominantly marine aquatic basins.

The results of this meeting suggest that the biological risks associated with climate change in the Arctic pose the greatest risks to DFO. This assessment will benefit from future integration meetings (Science, socio-economic and policy assessment results), which will assist in the prioritization of risks and will more accurately reflect DFO departmental impacts. In addition, the ACCASP risk assessment is considered to be an iterative process, information from the integration workshops, updated background documents and increased participation by other scientific and technical experts in future Science advisory risk assessment meetings (i.e., increased sample size for voting, broadened expertise and experience) will increase the confidence in future assessments.

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Appendix 1.

Trends and projections summary table for the Arctic LAB

Risk Factors (variables)	Trends (past conditions)	Projections (next 50 years)
Surface Air Temperature	Surface air temperature increase of 0.3-0.5°C per decade over Arctic land areas during the last 30-50 years. Records over marine basins are sparse.	Very likely increase in air temperature by 0-3°C in summer and 3-7°C in winter.
Precipitation	No clear observational record of precipitation trends across the Arctic LAB	Likely slight increases in precipitation, less in summer than in winter (15-50%).
Atmospheric Circulation (Wind)	Appreciable change in patterns of Arctic atmospheric circulation during the last 1-2 decades. Sea level pressure has increased in the eastern Canada Basin creating a stronger N-S pressure gradient and increased east wind across the southern Beaufort Sea.	Likely increase in storm strength and size with increased potential for storm surges (Beaufort Sea), coastal erosion and loss of coastline. Projections indicate only small changes in wind speed.
Waves	In the southern Beaufort Sea during the last decade: Observations suggest that northward retreat of the ice edge in summer and increased wind have fostered larger waves during autumn storms.	Likely small increase in summer in mean significant wave heights (SWH); increased storm waves and sediment mobilization.
Sea Ice	The Arctic-wide decrease in the extent of multi-year ice during the last 20 years has become evident in the Canadian Beaufort Sea, over the Canadian Polar Shelf and in Baffin Bay during the last decade. The expanse of ice-free water in late summer has increased correspondingly. The average age of remaining multi-year ice has decreased and its average thickness is less. First-year ice is forming later in the autumn in most areas and dissipating earlier in summer. However, available data do not reveal any clear changes in the thickness of first-year ice throughout the Arctic LAB, either in the land-fast or pack-ice domains.	Very likely continued decrease in mean sea-ice thickness (0.25-1.75m). Further decline in multi-year ice area, possibly enabling an ice-free Arctic in late summer. Decrease in summer ice extent (10-80%), Longer open water season: earlier ice breakup and later freeze up. Little change in winter ice conditions.

Risk Factors (variables)	Trends (past conditions)	Projections (next 50 years)
Ocean Surface Temperatures and Salinity	The temporal and spatial coverage of data are insufficient to delineate trends across the Arctic LAB. In the Beaufort Sea during the last decade, surface salinity has decreased in the Canada Basin and increased on the southern shelf. For Hudson Bay sea surface temperature trend is warming by 0.7-1.3°C over the 1985-2011 period. For Baffin/Davis weak warming at surface, no trend at depth.	Very likely increased summertime sea-surface temperature (0-2°C) in ice-free areas. Some decrease in sea surface salinity by 0-1.5 ppt due to river inflow and sea ice melt. Little change in winter ocean conditions.
Stratification (Mixed Layer Depth)	The temporal and spatial coverage of data are insufficient to delineate trends across the Arctic LAB.	Likely strengthening stratification with basin averaged maximum mixed layer depth decreasing by 1.5m and 10-40m locally in the central Beaufort Sea.
Large-Scale Circulation	The temporal and spatial coverage of data are insufficient to delineate trends across the Arctic LAB. In the Beaufort Sea during the last decade, the speed of westward surface drift has increased.	Likely intensification of large scale circulation, in response to strengthening of the Northern Annular Mode (NAM) Reduction in volume and freshwater transports through the Canadian Arctic Archipelago.
Sea Level	The temporal and spatial coverage of data are insufficient to delineate trends across the Arctic LAB.	Contributions to relative sea level from post-glacial rebound, compaction subsidence, ocean warming and melting of terrestrial ice sheets vary greatly across the Arctic LAB. The anticipated rise in global sea level via melting of the Greenland ice sheet may be masked over much of the Canadian Arctic by post-glacial rebound and lowered gravitational pull from Greenland.
Acidity (pH)	Near-surface ocean acidity has been observed to increase (i.e., pH decrease) during the last decade in the Beaufort Sea and over the Canadian Polar Shelf.	Very likely increased ocean acidity due to rising atmospheric CO_2. Very likely decrease in pH (0.1-0.2) and decreased saturation states for aragonite and calcite forms of $CaCO_3$.
Nutrients	The temporal and spatial coverage of data are insufficient to delineate trends across the Arctic LAB.	Likely no major changes in open ocean basins. Changes in nutrient inventories in coastal and shelf areas.

Risk Factors (variables)	Trends (past conditions)	Projections (next 50 years)
Lakes	Earlier ice break-up and later freeze up (0.7 to 1.0 days in each direction per year) for northern Arctic lakes.	Likely increase in lake temperatures and stratification, earlier ice break-up and later freeze up. Increase in evaporation, longer water renewal times and decline in oxygen levels with potential hypoxic conditions at the bottom. Some increase in primary production with shifts in community structure.
Rivers/Stream Flow	The temporal and spatial coverage of data are insufficient to delineate trends across the Arctic LAB. Increased runoff for Hudson Bay since early 1990s.	Likely increase in winter and fall flows (up to 50%) and reduction in summer flows. Lower and earlier spring freshets, regionally variable, depending on headwaters. Increase in annual discharge from Greenland ice sheet, but magnitude uncertain. River ice break-up 15-35 days earlier and freeze-up 10-12 days later.
Permafrost	There has been widespread warming of terrestrial permafrost during the last two decades as well as a thickening of the permafrost active layer during the same period. Slow warming of sub-sea permafrost (Beaufort Sea) reflects the flooding of the shelf with rising sea level at the end of the last Ice Age.	Very likely continued permafrost degradation and increase in active layer depth.
Snow depth (land and lakes)	The temporal and spatial coverage of data are insufficient to delineate trends across the Arctic LAB.	Both increase or decrease in snow depth projected depending on the sub basin.

Changes during the next 10 years may in some cases be pro-rated versions of the 50-year projection. However, in most instances, natural intra-decadal variability is expected to be at least as important during the next decade. The continuation of trends during the last decade is expected in the case of ocean acidity, surface air temperature, multi-year ice extent, first-year ice characteristics, storm waves and permafrost.

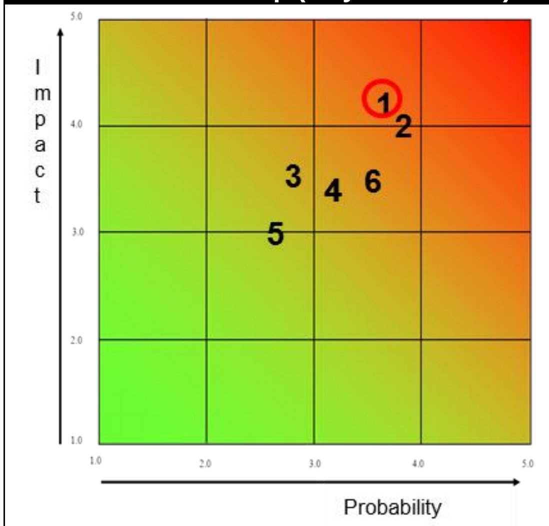
Useful estimates of past trends are extremely limited. Even with 10 years of data, uncertainty in the calculated trend contributed by natural variability generally makes even the sign of the trend uncertain, let alone the magnitude. Moreover, in most cases, data are only available for specific locations. Trends are unlikely to be representative of even an entire sub-region of the LAB (e.g. Canadian Arctic Archipelago), and even less so of the entire Arctic LAB itself. Moreover, the inclusion of the Mackenzie River Basin, a terrestrial domain, within the Arctic LAB, which is otherwise marine, is problematic. Large regional variability has been found in trends and projections across the Arctic LAB

Appendix 2.

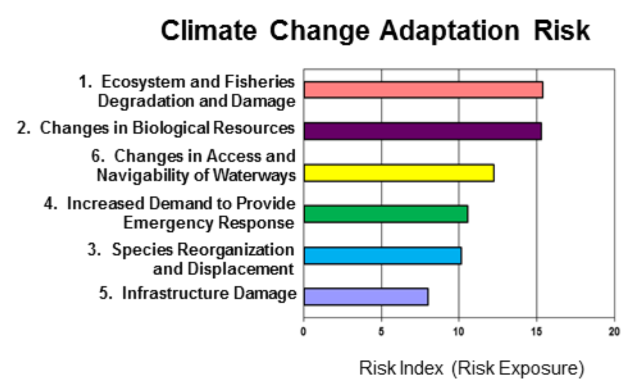
Risk summary sheet for Risk 1: Ecosystem and Fisheries Degradation and Damage for the Arctic LAB. Note that there is no direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Arctic Large Aquatic Basin
Risk 1: Ecosystem and Fisheries Degradation and Damage
Risk Statement: 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.
Context: This risk focuses on DFO's stewardship role to managing and protecting fish habitat the leadership role of the department in the Canada's Ocean Strategy and the sustainability of the oceans and their resources (enabling legislation includes the *Ocean's Act*, *Fisheries Act*).

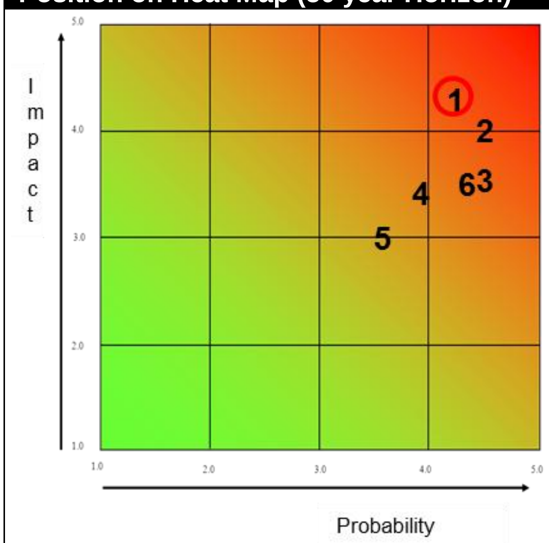
Position on Heat Map (10 year Horizon)



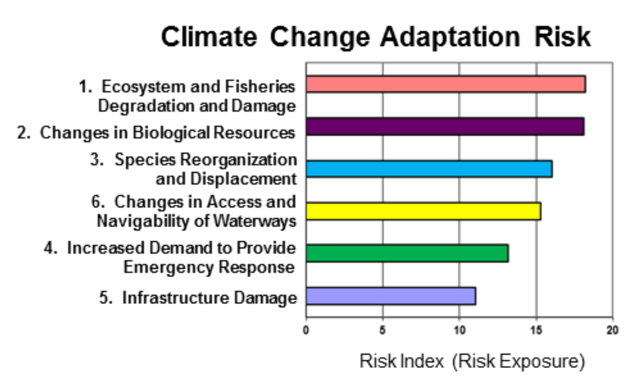
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



Risk Index (Probability x Impact) (50 year Horizon)



Main Risk Drivers	Potential Consequences: Threats
1. Changes in habitat (e.g., loss, gain, spatial and temporal shift) from the existing habitat characteristics and dynamics. ▪ Change in the location, duration, timing and prevalence of highly productive areas (e.g., polynyas, leads, ice-edges, upwelling). ▪ Possible change to a more dispersed distribution of food resources. ▪ Change in important sea-ice habitat features and productivity (e.g., first-year, multi-year). Increase in first-year sea-ice potential habitat. ▪ Alterations in marine mammal migration routes and timing of migrations. ▪ Alteration and loss in habitat suitability for ice-associated species (e.g., increased incidence of whale entrapments, availability of breathing holes, loss of denning habitats, loss of platform) due to increased variability in sea-ice habitat and changes in weather patterns and precipitation. ▪ Decline in quality and quantity of spawning, rearing, overwintering and migratory habitat for some fishes (we have greater certainty for anadromous fishes than marine fishes). ▪ Ocean acidification and reduced calcium carbonate saturation state. ▪ Change in light availability. ▪ Change in the nutrient inventory and the associated productivity. ▪ Changes in water temperature and the duration of the open-water season (physiological constraints on species). ▪ Increased exposure to UV radiation. **2. Shifts in species biodiversity, altered productivity and/or shifts in trophic pathways.** ▪ Changes in community structure, species displacement and range extensions for all taxonomic groups (including emergent aquatic plants). ▪ Changes in the species composition of benthic organisms in the nearshore (increases in colonization time) due to declines in the magnitude and duration of ice scouring.	▪ Affects our ability to define ecologically important areas (e.g., Ecologically and Biologically Significant Areas) for Marine Protected Areas, fisheries or other management tools. ▪ Impacts on local food web structure and function due to alterations in food availability (i.e., zooplankton) for fishes (e.g., Arctic Cod) and marine mammals (e.g., Bowhead, Beluga). ▪ Impact foraging ability and effort, resulting in declines in reproductive success and/or body condition. ▪ Decline in marine mammal health due to loss of critical habitat (e.g., sea-ice as a platform). ▪ Disruption of important habitat due to anthropogenic activities (i.e., ice-breaking). ▪ Increased competition, predation (e.g., Killer whales) and displacement of endemic species due to changes in habitat and distributional ranges. ▪ Decline in the ability of organisms to grow shells and skeletal systems (e.g., calcifying phytoplankton, molluscs, larval fishes). ▪ Increased incidences of disease and parasites; increased mortality and potentially decreased growth and productivity in fishes and marine mammals. ▪ Potential introduction of invasive species through anthropogenic transport and/or an extension of species range allowing for colonization. ▪ Extirpation of locally adapted Arctic species (particularly species with low population numbers and/or those that reside in restricted, patchy and highly specialized environments). Species with limited climatic ranges and/or restricted habitat requirements will also be vulnerable. ▪ Decrease in foraging success of predators (e.g., coastal piscivorous species, larval fishes, marine fishes, Bowhead) due to changes in lower trophic species composition, abundance and biomass. ▪ Declines in foraging success of anadromous fishes due to changes in the timing of migration. ▪ Loss of essential fatty acids produced by ice associated phytoplankton. ▪ Shift in productivity (fish stock: yield and biomass). ▪ Increased uptake of contaminants (e.g., trace metals, mercury) by various freshwater and marine biota due to environmental change and increased potential for fuel/cargo ship spills and contamination. ▪ Increased incidence of fish and marine mammal disturbances (i.e, ship strikes, noise) due to an increase in marine transportation and shipping.

<table>
<tr><th>Main Risk Drivers</th><th>Potential Consequences: Threats</th></tr>
<tr><td>

- Less distinction between macro-invertebrate assemblages within stream systems.
- Change in apex predators due to climate change impacts and changes in species distribution, which will impact trophic structure.
- Increased competition, predation and displacement of endemic and pivotal species due to changes in distributional ranges.
- Potential for large scale shifts in ecosystem structure due to cumulative climate change impacts (i.e., regime shift).
- Shift in trophic pathways, which has the potential to change the quality and quantity of energy within the Arctic marine food web.
- Change in the seasonality, location (horizontally and vertically) and magnitude of primary production.
- Changes in population dynamics; altered growth and production characteristics and declines in the body condition, growth, reproduction and consequently recruitment of individual organisms.
- Reduced frequency of anadromy within fish populations that exhibit facultative anadromy due to increases in freshwater productivity.
- Increased damage to aquatic organisms (biomolecular, cellular and physiological) and potentially a decline in trophic level productivity due to ultraviolet radiation.
- Decline in species/population health of freshwater and marine organisms (to varying degrees) due to bio-magnification of contaminant loading and the alteration of trophic bio-magnification due to changes in trophic structure.

3. There is uncertainty with respect to the variability of the system and how and at what rate it may change.

</td><td>

- Shift in the quality of existing fish populations (e.g., contaminants, disease, smaller bodied fishes) and changes in quantity.

</td></tr>
</table>

Opportunities
▪ With the expansion of species distributions and ranges there is the potential for the development of new commercial and/or subsistence fisheries. ▪ Extended duration of fishing seasons in some regions. ▪ Change in the location, duration, timing and prevalence of highly productive areas (e.g., polynyas, leads, ice-edges, upwelling) ▪ Increased primary (phytoplankton) and secondary (zooplankton) production at some locations will favour species at all levels in nearshore and offshore food webs (i.e., fishes, marine mammals and birds), particularly in the short-term by increasing foraging opportunities for some species (i.e., a shift from slow-growing longer-lived Arctic species to faster-growing temperate species). ▪ Sport fisheries are expected to be readily adaptable to changing climatic conditions due to flexibility with respect to fishing gear, species targeted and location of fishing. ▪ Increased opportunities for wind-driven upwellings of nutrient rich waters during winter as a result of decreased ice thickness, increased ice deformation and increased storminess. ▪ Development of autumn phytoplankton blooms in areas where the open-water period is longer than 5 months, leading to increased secondary production and foraging success for higher trophic levels (e.g., fishes, marine mammals and birds). ▪ Higher river discharge associated with the increased duration and intensity of melt under a warmer climate may result in increased nutrient and allochthonous organic matter inputs that stimulate processes at the base of the marine food web. Increased nutrient and carbon releases from permafrost melting will contribute to increases in primary productivity in freshwater and coastal environments. ▪ Increased water temperatures and declines in sea ice as a result of climate change may cause an increase in bacterioplankton respiration and growth. Increased bacterial production will result in an increased contribution of carbon and minerals to the food web. ▪ Increase in benthic primary production on the shelf as a result of decreased sea ice extent and a longer duration of the open-water season. Ice loss may also allow some species to make greater use of nearshore intertidal and subtidal waters. ▪ Earlier sea-ice melt and longer growing season may result in a greater flux of organic carbon (i.e., primary production) to benthos and result of trophic mis-matches. This may lead to increased benthic production. ▪ Increased survival and abundance of riverine species due to a longer open-water season, decreased ice thickness, changes in ice cover characteristics, increased area containing adequate dissolved oxygen concentrations, and increased primary production. ▪ Increasing benthic production as a result of decreasing sea ice extent and longer open-water seasons will likely increase foraging opportunities for benthic-feeding marine mammals (i.e., Narwhal, Beluga). ▪ Decreasing sea ice cover and increasing duration of the open water season will result in an increase in the extent and duration of spring, summer and autumn habitat. ▪ Potential increase in Bowhead condition and reproductive success in the medium-term as a result of decreasing sea ice extent and increases in primary and secondary production. ▪ Potentially faster, temperature-driven growth and maturation rates and reductions in winter mortality for many Arctic species (e.g., anadromous fishes). ▪ Increased habitat availability and survival of freshwater and anadromous fish species during winter as a result of increases in winter stream flow and reduced ice cover, thickness and duration on rivers. ▪ Increased productivity in lakes and rivers as a result of a longer open-water season may increase food availability for anadromous fish species, particularly early life history stages. However, these increases will be moderated by changes in the timing and magnitude of sediment and nutrient delivery, which may cause shifts in trophic coupling. ▪ Enhanced survival of young-of-the-year Arctic Cod (an Arctic keystone species) due to changes in sea-ice and increased primary production.

Opportunities
▪ Genetic parameters may offer a useful tool for long-term monitoring of Arctic–wide changes within and among species, and for assessing fitness and risk related to climate change.

Gaps

- There is uncertainty with respect to the variability of the system and how it may change (low predictability).However, we currently assume that we operate under a predictably variant system and that we are working in an equilibrated ecosystem.

Model Projections

- Two issues with respect to model projections: 1) Higher resolution regional models for the Arctic LAB are missing, especially with respect to marine ecosystems. Those would provide more locally applicable information. Global Earth System Models (ESMs), which are currently used for a number of variables, are too coarse in both vertical and horizontal resolution. 2) The lack of long-term data sets (e.g., hydrometric networks, tide gauges, oceanographic stations or sections) limits the ability to validate models and develop Arctic specific parameterisations.
- Impacts of Arctic glacier melt on the Beaufort Sea are considered to be indirect due to their relative absence within the sub-basin. While numerous studies have projected the responses of individual glaciers (e.g., Hubbard and Bering glaciers) and/or discussed global impacts (e.g., GSLR), few have attempted to predict the response to Arctic glacier melt and calving on a regional scale (i.e., potential impacts on the Baffin Bay sub-basin).
- Although recent changes in permafrost thaw have been documented for many regions in the Arctic, regional projections (10- and 50-year) related to the impacts of terrestrial and sub-sea permafrost melt (e.g., carbon emissions, freshwater inputs) are lacking. Current projections for Arctic permafrost relate primarily to Russia (terrestrial) and the Laptev Sea (sub-sea).
- Although several studies discuss the potential impacts of climate change on contaminant release in the Arctic, projections (10- and 50-year) related to the release of contaminants via snow, ice and permafrost melt in the Beaufort Sea sub-basin are limited. Although system changes can alter the fluxes and concentrations of contaminants in different locations and in different ways, such considerations have not been incorporated into the interpretation of time series. Changes in contaminant concentrations will have important implications for future fish, marine mammal and human health and population stability.
- There is a need for integrated river ice regime models that consider future combined changes to landscape hydrology, water ice-air energy exchanges, in-stream hydraulics and ice mechanics. Projections (10- and 50-year) related to the impacts of climate change on river ice dynamics and subsequent effects in coastal environments are generally lacking. Whether temporal shifts in river ice duration will produce more or less severe break-up events (i.e., floods) remains unknown due to the role of precipitation. Many of the factors and feedback mechanisms that influence the Mackenzie River are not fully understood.
- Despite existing climate models, uncertainty persists in predications of future impacts due to natural variations in the climate system, the range of plausible trajectories of greenhouse gas concentrations, aerosols and other climate drivers over the next century and to systematic errors in model formulations, particularly in parameterizations of unresolved processes.
- Model validation will be critical in the future, particularly where model trends do not agree.

Biological Environment

- Due to the large expanse of the Arctic and diverse topographical data (e.g., salinity), knowledge and long-term monitoring sets are often site-specific and do not provide large spatial or temporal coverage. Areas where no data exists are priorities for research and areas with good monitoring data sets should be continued.
- Large knowledge gaps limit our understanding of complex interactions between Arctic biota and the physical environment and long-term studies examining biological responses to changes in the Arctic environment are generally lacking. This lack of knowledge is not easily addressed due to the difficulties associated with sampling in the Arctic throughout the year and over multiple years. Variability in Arctic marine ecosystems and the complexity of physical factors make it difficult to establish cause-effect

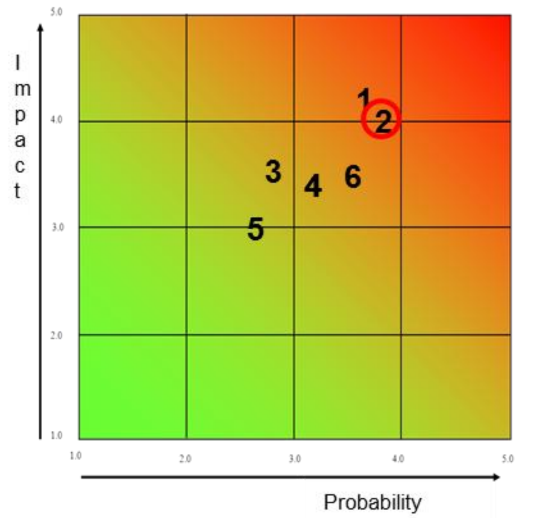
Gaps
relationships. ▪ The Arctic plays an important role in the global dynamics of both carbon dioxide (CO_2) and methane (CH_4), but the sensitivity of the carbon cycle to Arctic climate change is not well understood. ▪ There is limited information on the impacts of climate change on lakes in the Mackenzie Basin. ▪ There is limited understanding of the aquatic food chains and trophic interactions in various Arctic aquatic ecosystems. ▪ Ecosystem effects from the introduction or loss of apex predators (e.g., Killer whales) are largely unknown. ▪ There is a need for additional knowledge with respect to the impacts of ice reductions (both sea ice and freshwater ice) on marine organisms at the base of the food web (i.e., phytoplankton, zooplankton) in order to make reliable predictions about ecosystem changes and departmental risks. For example, little is known regarding possible effects of sea ice declines on benthic processes and associated feedback to pelagic systems. Predictions of seasonal sea ice extent are highly variable, which makes it very difficult to predict the impacts of climate change on Arctic biological systems. ▪ Fisheries research is not evenly distributed across sub-ecosystems (i.e., freshwater, coastal, nearshore benthic, nearshore pelagic, slope benthic, slope pelagic, deep basin, multi-year sea ice) and as a result, there has been a bias towards anadromous vs. marine species (particularly offshore). Key gaps remain with respect to marine fishes in all sub-ecosystems and their ecological roles are not yet fully understood. ▪ Information about habitat use is lacking for a number of key species (e.g., Beluga, Bearded seals, marine fishes). To predict the impacts of climate change on the physiology and ecology of these species, a better understanding of the biological processes and/or habitat characteristics within the region that are important for their survival is required. ▪ Limited data exist for non-commercial fish species. ▪ The potential northern limit for emergent aquatic macrophytes is not fully understood. ▪ There is a general absence of data on dispersal ability and colonization propensity; it will be difficult to predict range expansions. ▪ The rate(s) and ecological implications of ocean acidification are not well understood. Further research is required as these changes could have wide-ranging effects on species diversity, trophic exchange, contaminant cycling and socioeconomics. ▪ Uncertainty about the net change for a number of impacts and/or risk drivers due to uncertainty about the cumulative impacts of climate change. ▪ There is little data on the effects of industrial activities (e.g., hydroelectric facilities, pipeline water crossings, pipeline construction, new barriers) on water quality and contaminant levels in fishes for the Mackenzie Basin; therefore, it will be difficult to determine the cause of specific changes. ▪ Knowledge base to project future Ecologically and Biologically Significant Areas, Critical Habitats and altered habitat use patterns are generally lacking under climate change scenarios. **<u>Monitoring</u>** ▪ Long-term monitoring of multiple sites within the Arctic is needed; current data are spatially and temporally limited. ▪ Evaluation and analysis of current indicator data will be critical in order to identify changes in the system, to determine if the indicators are effective and to help interpret causal relationships. **<u>Management</u>** ▪ There is no consolidation of programs or data with objectives to protect and enhance aquatic ecosystems within the Mackenzie Basin.

Appendix 3.

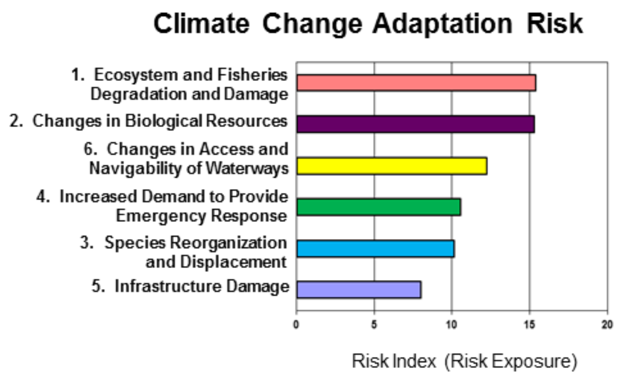
Risk summary sheet for Risk 2: Changes in Biological Resources for the Arctic LAB. Note that there is no direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Arctic Large Aquatic Basin
Risk 2: Changes in Biological Resources
Risk Statement: 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.
Context: This risk refers to DFO's management of fisheries resources (fish stocks, shellfish and marine mammals) (enabling legislation includes the *Fisheries Act*).

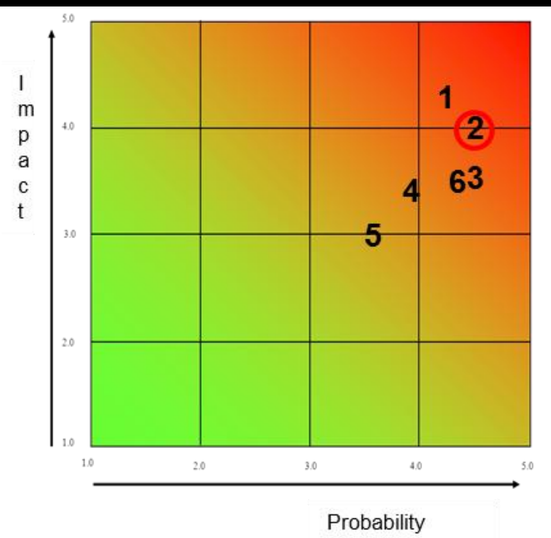
Position on Heat Map (10 year Horizon)



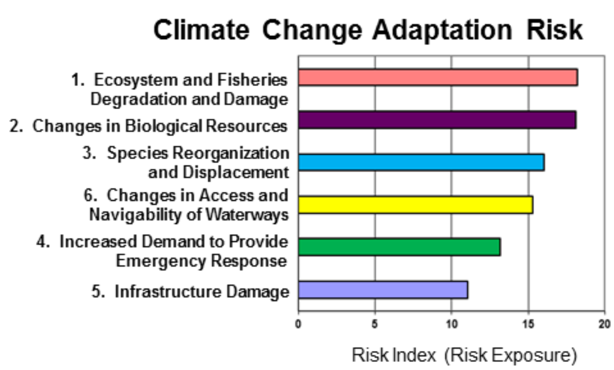
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



Risk Index (Probability x Impact) (50 year Horizon)



Main Risk Drivers	Potential Consequences: Threats
1. Change in habitat (e.g., loss, gain, spatial and temporal shifts) from existing habitat characteristics and dynamics. ▪ Change in the location, duration, timing and prevalence of highly productive areas (e.g., polynyas, leads, ice-edges, upwelling) (opportunity and threat). ▪ Possible change to a more dispersed distribution of food resources. ▪ Change in important sea-ice habitat features and productivity (e.g., first-year and multi-year sea-ice). Increase in first-year sea-ice potential habitat. ▪ Alterations in marine mammal migration routes and timing of migrations. ▪ Alteration and loss of habitat suitability for ice-associated species (e.g., increased incidence of whale entrapments, availability of breathing holes, loss of denning habitats, loss of platforms) due to increased variability in sea-ice habitats and changes in weather patterns and precipitation. ▪ Decline in quality and quantity of spawning, rearing, overwintering and migratory habitats for some fishes (we have greater certainty for anadromous fishes than marine fishes). ▪ Ocean acidification and reduced calcium carbonate saturation state. ▪ Change in light availability. ▪ Change in the nutrient inventory and associated productivity. ▪ Changes in water temperature and the duration of the open-water season (physiological constraints on species). ▪ Increased exposure to UV radiation. **2. Shift in species biodiversity, altered productivity and/or shifts in trophic pathways.** ▪ Changes in community structure, species displacements and range extensions for all taxonomic groups (including emergent aquatic plants). ▪ Changes in population dynamics; altered growth and production characteristics and declines in body condition, growth, reproduction and consequently recruitment of individual organisms. ▪ Increased competition, predation and displacement of endemic and pivotal species due to changes in distributional ranges. ▪ Change in apex predators due to climate change impacts and changes in species distributions, which will impact trophic structure. ▪ Decline in species/population health of freshwater and marine organisms (to varying degrees) due to bio-magnification of contaminant loading and the	▪ Decline in marine mammal health due to loss of critical habitat (e.g., sea-ice as a platform). ▪ Increased uptake of contaminants (e.g., trace metals, mercury) by various freshwater and marine biota due to environmental change and increased potential for fuel/cargo ship spills and contamination. ▪ Increased incidence of disease and parasites will increase mortality and potentially decrease growth and productivity of fishes and marine mammals. ▪ Potential introduction of invasive species through anthropogenic transport and/or an extension of species ranges allowing colonization. ▪ Increased incidence of fish and marine mammal disturbances (i.e., ship strikes, noise) due to an increase in marine transportation and shipping. ▪ Extirpation of locally adapted Arctic species (particularly species with low population numbers and/or those that reside in restricted, patchy and highly specialized environments). Species with limited climatic ranges and/or restricted habitat requirements will also be vulnerable. ▪ Limited duration of winter commercial fisheries (e.g., Cumberland Sound Turbot Fishery) due to reduced sea-ice extent and duration. ▪ Climate change is likely to impact how, when, and where fisheries may be conducted. ▪ Increased desire to develop new models and advice.

Main Risk Drivers	Potential Consequences: Threats
alteration of trophic bio-magnification due to changes in trophic structure. ▪ Potential for large scale shifts in ecosystem structure due to cumulative climate change impacts (i.e., regime shifts). ▪ Human aided movement and the natural movement of colonizing species, which may result in the establishment of invasive and/or toxic species with consequences for local fauna. **3. There is uncertainty with respect to the variability of the system and how and at what rate it may change.** **4. Perceived increased accessibility to the resource base will drive increased need for science knowledge (output and scientific advice) (consequence) fisheries management, land claims, enforcement.**	

Opportunities
▪ With the expansion of species distributions and ranges there is the potential for the development of new commercial and/or subsistence fisheries. ▪ Increase in the ice-free season in Baffin Bay and Davis Strait will increase the duration of the commercial fishing season (i.e., fisheries for Greenland Halibut and Northern and Striped Shrimp). Extended duration of fishing seasons. ▪ Sport fisheries are expected to be readily adaptable to changing climatic conditions due to flexibility with respect to fishing gear, species targeted and location of fishing. ▪ Increased survival and abundance of riverine species due to a longer open-water season, decreased ice thickness, changes in ice cover characteristics, increased area containing adequate dissolved oxygen concentrations, and increased primary production. ▪ Increased habitat availability and survival of freshwater and anadromous fish species during winter as a result of increased winter stream flow and reduced ice cover, thickness and duration on rivers. ▪ Increased productivity in lakes and rivers as a result of a longer open-water season may increase food availability for anadromous fish species, particularly early life history stages. However, these increases will be moderated by changes in the timing and magnitude of sediment and nutrient delivery, which may cause shifts in trophic coupling. ▪ Enhanced survival of young-of-the-year Arctic Cod (an Arctic keystone species) due to changes in sea-ice and increased primary production. ▪ Genetic parameters may offer a useful tool for long-term monitoring of Arctic –wide changes within and among species, and for assessing fitness and risk related to climate change.

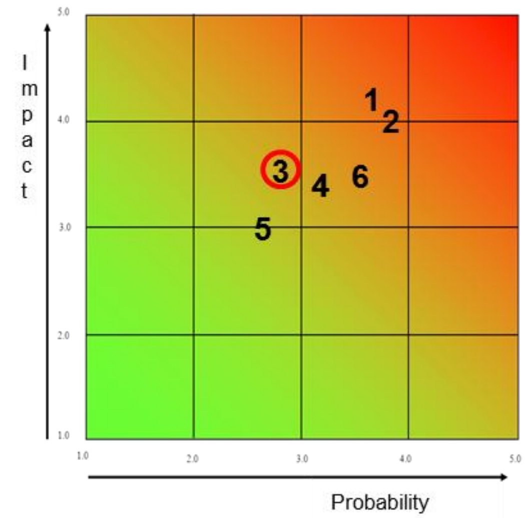
Gaps
▪ Although several studies discuss the potential impacts of climate change on contaminant release in the Arctic, projections (10- and 50-year) related to the release of contaminants via snow, ice and permafrost melt in the Beaufort Sea sub-basin are limited. Although system changes can alter the fluxes and concentrations of contaminants in different locations and in different ways, such considerations have not been incorporated into the interpretation of time series. Changes in contaminant concentrations will have important implications for future fish, marine mammal and human health and population stability. ▪ Fisheries research is not evenly distributed across the sub-ecosystems (i.e., freshwater, coastal, nearshore benthic, nearshore pelagic, slope benthic, slope pelagic, deep basin, multi-year sea ice); as a result, there has been a bias towards anadromous vs. marine species (particularly offshore). Key gaps remain with respect to marine fishes in all sub-ecosystems and their ecological roles are not yet fully understood. ▪ There are limited data with which to define baseline habitat conditions in lakes, streams and rivers. Fish habitat assessments have been typically conducted near residential, transportation and industrial sites only. ▪ There are complexities in identifying individual fish stocks, estimating stock size and the extents of harvested species at various locations. ▪ Fisheries in the Mackenzie Basin are managed under a quota system, however, genetic stocks are not well documented; therefore, current quota systems may be inappropriate. ▪ Fish stock assessment studies are needed in many lakes and rivers in the Mackenzie Basin. As climate change impacts become greater, detailed information is required on fish populations and stocks in order to achieve a good level of fisheries management. ▪ Subsistence fisheries are not well documented and detailed information on these and sport fisheries is necessary for a complete understanding of fisheries resources.

Appendix 4.

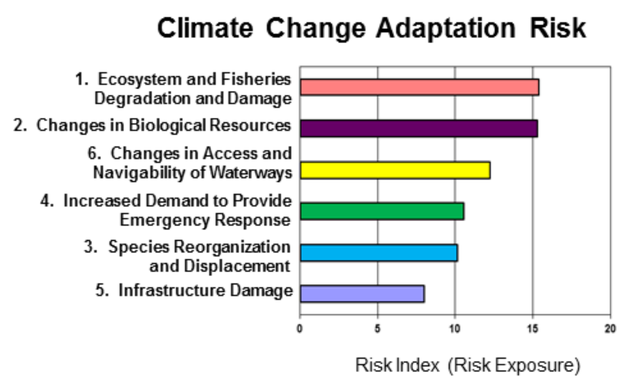
Risk summary sheet for Risk 3: Species Reorganization and Displacement for the Arctic LAB. Note that there is no direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Arctic Large Aquatic Basin
Risk 3. Species Reorganization and Displacement
Risk Statement: There is a risk that climate change will affect DFO's ability to protect species diversity and species at risk.
Context: Climate change may lead to changes in the location and type 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 (enabling legislation includes the *Species at Risk Act*).

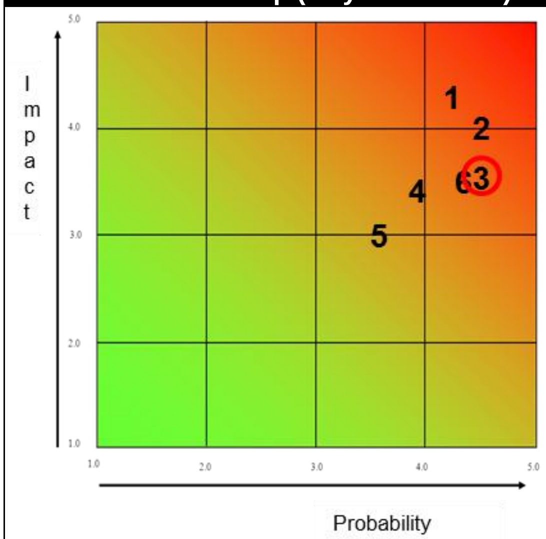
Position on Heat Map (10 year Horizon)



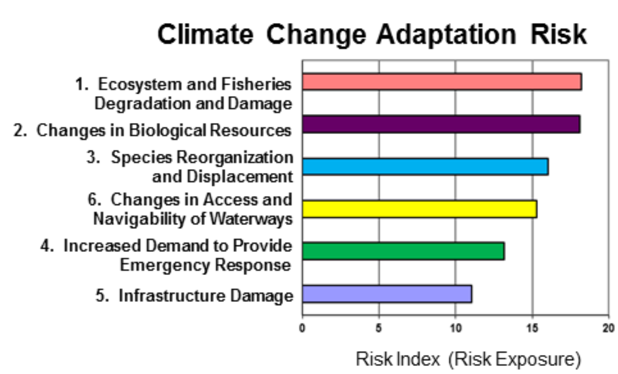
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



Risk Index (Probability x Impact) (50 year Horizon)



Main Risk Drivers	Potential Consequences: Threats
▪ Human aided movement and the natural movements of colonizing species may result in the establishment of invasive and/or toxic species with consequences for local fauna. ▪ Ecosystem shifts and population changes may induce follow-on effects in species at risk. ▪ Changes in community structure, species displacement and range extensions for all taxonomic groups (including emergent aquatic plants). ▪ Potential increases or declines in biodiversity depending on the region or local area of interest. ▪ Changes in population dynamics in many freshwater, anadromous and marine species. ▪ Increased competition, predation and displacement of endemic species due to changes in habitat and distributional ranges. ▪ Declines in species/population health in freshwater and marine organisms (to varying degrees) due to bio-magnification of contaminant loading and the alteration of trophic bio-magnification due to changes in trophic structure. ▪ Potential for large scale trophic shifts in ecosystem structure due to cumulative climate change impacts (i.e., regime shifts). ▪ Loss of apex predators due to climate change impacts and changes in species distributions, which will impact trophic structure. **<u>Anadromous Fishes</u>** ▪ Declines in the quality and quantity of spawning, rearing, overwintering and migratory habitats for some anadromous fishes due to increased sedimentation (e.g., infilling), coastal slumping and erosion, changes in summer water levels, changes in the frequency, duration and location of flooding events and ground water patterns. **<u>Marine Fishes</u>** ▪ Declines in body condition, growth, reproduction and consequently the recruitment of marine fish species due to shifts in zooplankton composition, biomass and abundance (shift from lipid-rich species to boreal species) and potential trophic mis-matches. **<u>Habitat Features</u>** ▪ Changes in the locations and durations of areas (e.g., polynyas, leads, ice-edges) of high productivity (i.e., zooplankton biomass) and diversity to a more dispersed distribution of prey species will impact foraging ability and effort, and subsequent declines in reproductive success and body condition in predators. ▪ Alterations in habitat suitability for ice-associated species (e.g., increased incidence of whale entrapments, availability of breathing holes, loss of denning habitats,	▪ Increased ship traffic with increased ballast water exchange. ▪ Enhanced understanding of the dynamics of species at risk and their interactions with indigenous fauna and drivers, such as climate change are required. ▪ Increased incidences of diseases and parasites will increase mortality and potentially decrease growth and productivity of fishes and marine mammals. ▪ Potential introductions of invasive species through anthropogenic transport and/or extensions of species ranges allowing for colonization. ▪ Extirpation of locally adapted Arctic species (particularly species with low population numbers and/or those that reside in restricted, patchy and highly specialized environments). Species with limited climatic ranges and/or restricted habitat requirements will also be vulnerable.

Main Risk Drivers	Potential Consequences: Threats
loss of platforms) due to increased variability in sea-ice habitat and changes in weather patterns and precipitation. **Marine Mammals** ▪ Alterations in marine mammal migration routes and timing of migrations as a result of changes in habitat (e.g., warmer temperatures, decreased sea ice extent and duration) and disruption of habitat due to anthropogenic activities (i.e., shipping). Species that rely on the ice-edge environment are most vulnerable to the effects of projected decreases in sea-ice cover. ▪ Decline in marine mammal health due to loss of critical habitat (e.g., sea-ice as a platform).	

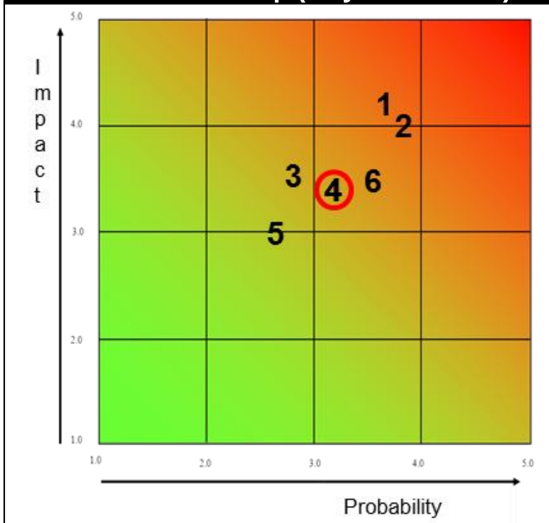
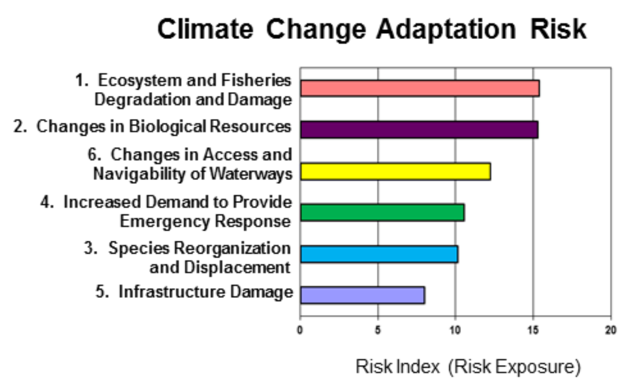
Opportunities
▪ Increased survival and abundance of riverine species due to a longer open-water season, decreased ice thickness, changes in ice cover characteristics, increased area containing adequate dissolved oxygen concentrations and increased primary production. ▪ Increasing benthic production as a result of decreasing sea ice extent and longer open-water seasons will likely increase foraging opportunities for benthic-feeding marine mammals (i.e., Narwhal, Beluga). ▪ Potential increases in Bowhead condition and reproductive success in the medium-term as a result of decreasing sea ice extent and increases in primary and secondary production. ▪ Increased habitat availability and survival for freshwater and anadromous fish species during winter as a result of increases in winter stream flow and reduced ice cover, thickness and duration on rivers. ▪ Increased productivity in lakes and rivers as a result of a longer open-water season may increase food availability for anadromous fish species, particularly early life history stages. However, these increases will be moderated by changes in the timing and magnitude of sediment and nutrient delivery, which may cause shifts in trophic coupling. ▪ Enhanced survival of young-of-the-year Arctic Cod (an Arctic keystone species) due to changes in sea-ice and increased primary production.

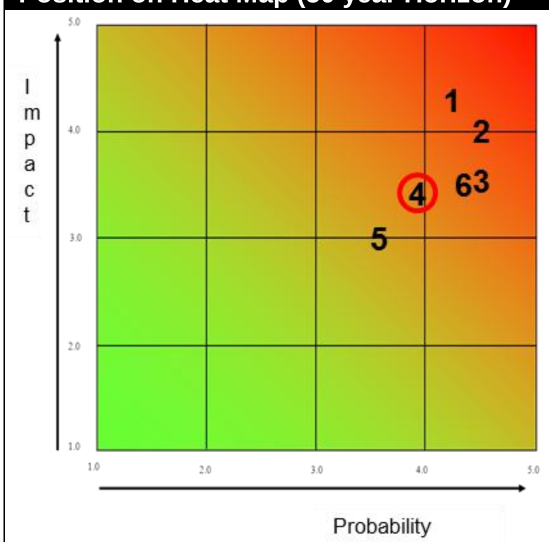
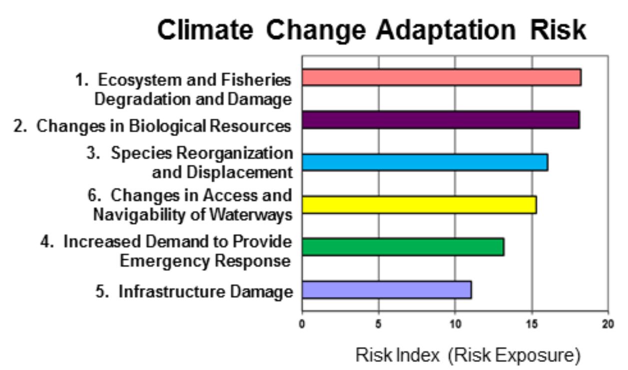
Gaps
▪ Up-to-date and complete knowledge and documented inventories of native biota do not currently exist for any of the sub-basins within the Arctic LAB or for all taxonomic groups. ▪ Large gaps in knowledge limit our understanding of the complex interactions between Arctic biota and the physical environment. Although predictions have been made based on current knowledge of physiological and ecological processes in the Arctic LAB, long-term studies that examine biological responses to changes in Arctic environments are generally lacking. This lack of knowledge is not easily addressed due to the difficulties associated with sampling in the Arctic throughout the year and over multiple years. Variability in Arctic marine ecosystems and the complexity of physical factors make it difficult to establish cause-effect relationships. ▪ There is a general absence of data on dispersal ability and colonization propensity of species; it will be difficult to predict range expansions. ▪ Information about habitat use is lacking for a number of key species (e.g., Beluga, Bearded seals, marine fishes). In order to determine the potential impacts of climate change on the physiology and ecology of these species, a better understanding of the biological processes and/or habitat characteristics within the region that are important for their survival is required. ▪ Ecosystem effects from introductions or losses of apex predators (e.g., Killer whales) are largely unknown. ▪ Long-term monitoring of multiple sites within the Arctic is needed; current data are spatially and temporally limited.

Appendix 5.

Risk summary sheet for Risk 4: Increased Demand to Provide Emergency Response for the Arctic LAB. Note that there is no direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Arctic Large Aquatic Basin
Risk 4: Increased Demand to Provide Emergency Response
Risk Statement: There is a risk that climate change will affect DFO's ability to provide acceptable levels of environmental response and search and rescue activities.
Context: 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.

Position on Heat Map (10 year Horizon)	**Risk Index (Probability x Impact) (10 year Horizon)**
	

Position on Heat Map (50 year Horizon)	**Risk Index (Probability x Impact) (50 year Horizon)**
	

Main Risk Drivers	Potential Consequences: Threats
▪ Increased frequency and intensity of storms (not necessarily linked to wind speed). ▪ Unpredictability of weather patterns given present observational network. ▪ Unpredictability of sea-ice conditions given present observational network. ▪ Increased length of open water season will potentially increase the extent and frequency of foggy conditions. ▪ Change in access to the marine environment (i.e., ice covered areas vs. open water areas) and an increase in the length of the 'shoulder seasons' (the period from when the marine environment transitions from ice-covered to open water and vice versa -during these times travel is not impossible, rather unpredictable). ▪ Increased mobility of multi-year ice and iceberg calving. ▪ Potential changes in tidal flow and wind-driven circulation flow in confined waterways. ▪ A more severe wave climate is projected in open-water areas. ▪ Change in the extent, area, thickness and duration of sea-ice. It is likely that the Arctic will be increasingly dominated by first-year ice. ▪ Considerable spatial variability in sea-level change (including isostatic rebound and ice melt). ▪ Mobilization of sediments resulting in changes to bottom topography and/or water depth (e.g., coastal erosion). ▪ Increase in the intensity, seasonal duration and geographical extent of marine traffic due to increased social and economic potential (e.g., fishing activity, potential expansion of mining, oil and gas development). ▪ Previously appropriate modes of transport (e.g., ice strengthened hulls, ski-doo) may no longer be appropriate in some areas (i.e., local knowledge of the area may become less relevant with changing local conditions). ▪ Increased incidence of vessel icing and sea spray. ▪ The accuracy and availability of charts is limited.	▪ Increased demand in the geographic and temporal scope of DFO's emergency response, navigational aids and channel maintenance activities. ▪ Increased injuries or loss of life associated with marine incidents (e.g., local knowledge less relevant with changing conditions, more accidents). ▪ Potential increase in environmental damage from marine incidents (e.g. increased spills and demand for spill response). ▪ Reallocation and/or an increased demand for monetary resources.

Opportunities
▪ Increase in the intensity, seasonal duration and geographical extent of marine traffic due to increased social and economic potential (e.g., fishing activity, potential expansion of mining, oil and gas development).

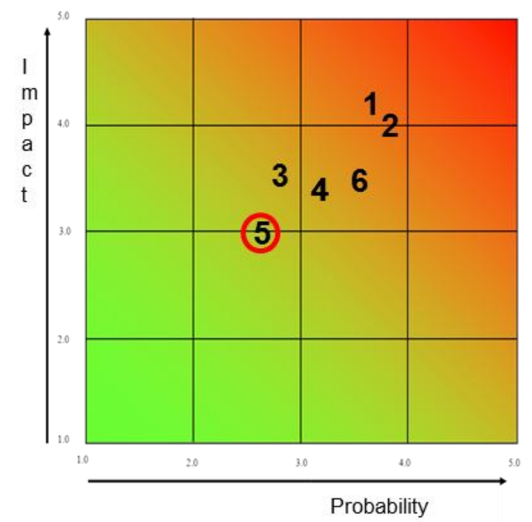
Gaps
▪ Scientific understanding of the spatial and temporal variability in the climate system driver is limited. ▪ Any ability to order risks (prioritize) will depend on better quantifications. ▪ Lack of (need to improve) spatial coverage and resolution of charting. ▪ Monitoring of basic scientific information, in addition to monitoring activities and activity patterns (e.g., vessel traffic, accidents), would help better define resource deployment. ▪ Observations of flows in confined waters and forecast capabilities for currents in these areas are limited.

Appendix 6.

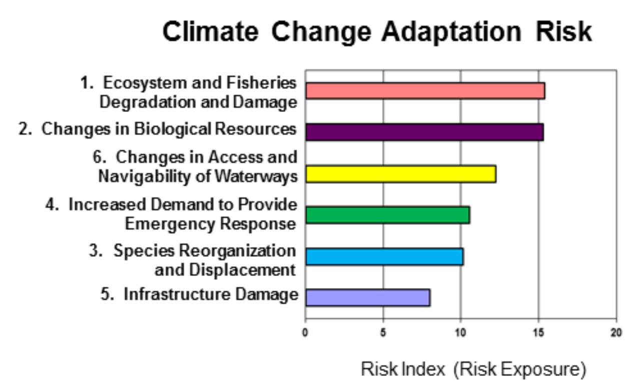
Risk summary sheet for Risk 5: Infrastructure Damage for the Arctic LAB. Note that there is no direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Arctic Large Aquatic Basin
Risk 5: Infrastructure Damage
Risk Statement: There is a risk that climate change will result in damage and the need for alterations to DFO vessels, coastal and Small Craft Harbour infrastructure.
Context: DFO maintains considerable infrastructure to support its operational and scientific 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).

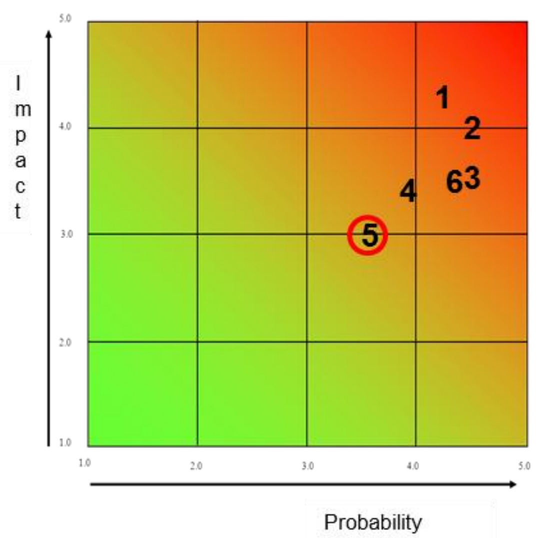
Position on Heat Map (10 year Horizon)



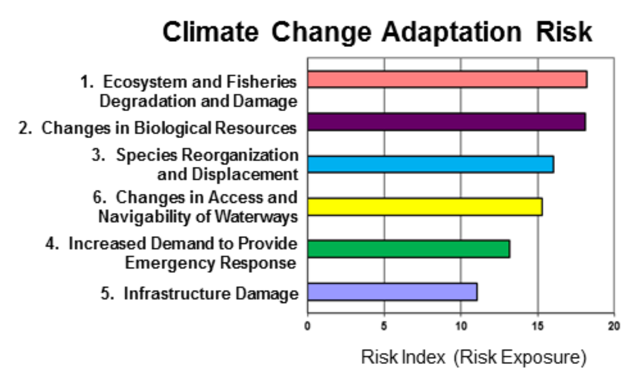
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



Risk Index (Probability x Impact) (50 year Horizon)



Main Risk Drivers	Potential Consequences: Threats
▪ Increased frequency and intensity of storms (not necessarily linked to wind speed). ▪ Unpredictability of weather patterns given present observational network. ▪ Unpredictability of sea-ice conditions can cause damage to infrastructure given the present observational network. ▪ Increased length of open water season will potentially increase the extent and frequency of foggy conditions, which could lead to increased vessel strikes or marine incidents. ▪ Change in access to the marine environment (i.e., ice covered areas vs. open water areas) and an increase in the length of the 'shoulder seasons' (the period from when the marine environment transitions from ice-covered to open water and vice versa -during these times travel is not impossible, rather unpredictable). ▪ Increased mobility of multi-year ice and iceberg calving. ▪ Increased frequency of ice jam flooding in rivers. ▪ Increased frequency, intensity and unpredictability of storm surges (e.g., Beaufort Sea). ▪ Increased permafrost degradation. ▪ Coastal erosion (i.e., loss or gain of coastline). ▪ A more severe wave climate is projected in open-water areas. ▪ Change in the extent, area, thickness and duration of sea-ice. It is likely that the Arctic will be increasingly dominated by first-year ice. ▪ Considerable spatial variability in sea-level change (including isostatic rebound and ice melt). ▪ Increased incidence of vessel icing and sea spray.	▪ Increased demand in the geographic and temporal scope of DFO's navigational aids and channel maintenance activities. ▪ Damage to infrastructure. ▪ Possible closure of fixed infrastructure due to severe damage until reconstructed. ▪ Reallocation and/or increased demand of resources (e.g., altered fuel consumption, additional vessels, access to infrastructure). ▪ Increased demand for fixed infrastructure due to increases in the intensity, seasonal duration and geographical extent of marine traffic from increased social and economic potential (e.g., fishing activity, potential expansion of mining, oil and gas development). ▪ Previously appropriate modes of transport (e.g., ice strengthened hulls, ski-doo) may no longer be appropriate in some areas (i.e., local knowledge of the area may become less relevant with changing local conditions). ▪ Removal of infrastructure and contaminant clean-up due to damage or environmental degradation of infrastructure. ▪ Increased health and safety issues for both DFO personnel and the public due to damaged infrastructure. ▪ Potential decline in DFO's ability to provide safe access to resource users (e.g., local fishers).

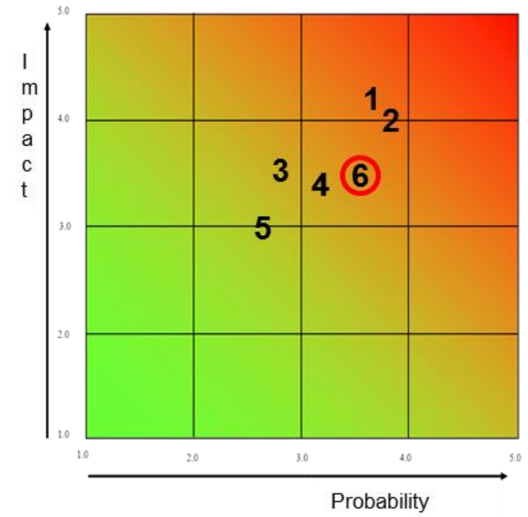
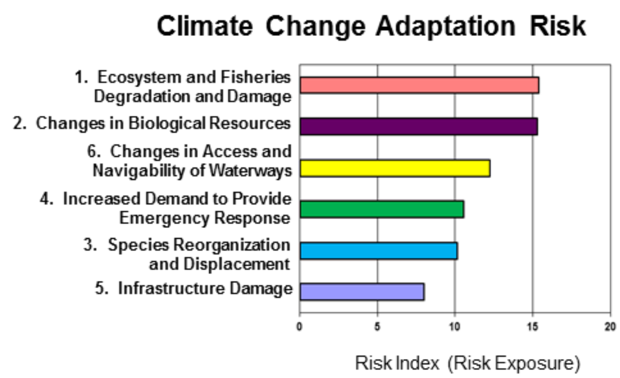
Opportunities
▪ Reduced degree/frequency of ice-related damage to infrastructure as the ice seasons grow shorter, or the possibility of installing new infrastructure in previously ice-infested locations.

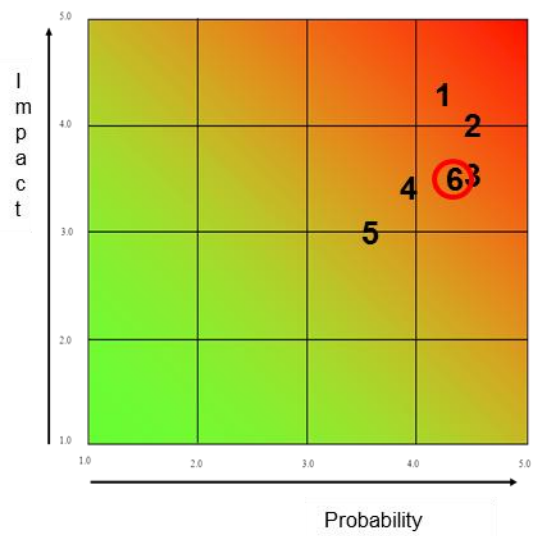
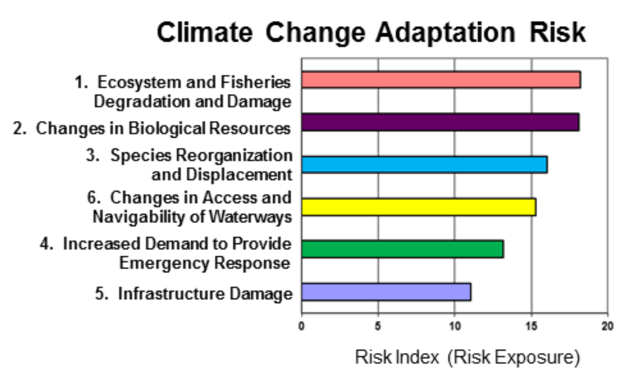
Gaps
▪ Limited data with which to determine optimal locations for new infrastructure. Some of the trends and projections and the main risk drivers have not been downscaled to the local scale.
▪ Increasing need to identify and collaborate to determine and collect data to meet engineering requirements (e.g., permafrost, snow loads, avalanche risk)
▪ Development, expansion and maintenance of observational networks (e.g., sea level gauges, hydrometric networks) is needed.
▪ Current inventory of DFO infrastructure that exists in the Arctic LAB is incomplete.

Appendix 7.

Risk summary sheet for Risk 6: Changes in Access and Navigability of Waterways for the Arctic LAB. Note that there is no direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Arctic Large Aquatic Basin
Risk 6: Changes in Access and Navigability of Waterways
Risk Statement: There is a risk that climate change will affect DFO’s ability to provide safe access to waterways.
Context: This risk deals with impeded access due to changes in factors such as sedimentation, water levels, severe weather, wave energy, icebergs and ice.

Position on Heat Map (10 year Horizon)	Risk Index (Probability x Impact) (10 year Horizon)
	

Position on Heat Map (10 year Horizon)	Risk Index (Probability x Impact) (50 year Horizon)
	

Main Risk Drivers	Potential Consequences: Threats
▪ Increased frequency and intensity of storms (not necessarily linked to wind speed). ▪ Unpredictability of weather patterns given present observational network. ▪ Unpredictability of sea-ice conditions given present observational network. ▪ Increased length of open water season will increase the extent and frequency of foggy conditions, which could lead to increased vessel strikes or marine incidents. ▪ Change in access to the marine environment (i.e., ice covered areas vs. open water areas) and an increase in the length of the 'shoulder seasons' (the period from when the marine environment transitions from ice-covered to open water and vice versa -during these times travel is not impossible, rather unpredictable). ▪ Increased mobility of sea-ice and icebergs. ▪ Increased frequency of ice jam flooding in rivers. ▪ Increased frequency, intensity and unpredictability of storm surges (e.g., Beaufort Sea). ▪ Increased permafrost degradation. ▪ Considerable spatial variability in sea-level change (including isostatic rebound and ice melt).Potential changes in tidal flows and wind-driven circulation flows in confined waterways. ▪ Coastal erosion (i.e., loss or gain of coastline). ▪ A more severe wave climate is projected in open-water areas. ▪ Change in the extent, area, thickness and duration of sea-ice. It is likely that the Arctic will be increasingly dominated by first-year ice. ▪ Increased incidence of vessel icing and sea spray. ▪ Change in sea level may result in changes in water depth and the extent of coastal submersion. ▪ Increases in the intensity, seasonal duration and geographical extent of marine traffic due to increased social and economic potential (e.g., fishing activity, potential expansion of mining, oil and gas development). ▪ Mobilization of sediments resulting in changes to bottom topography and/or water depth (e.g., coastal erosion).	▪ Loss of life or increased injuries associated with marine incidents. ▪ Potential increase in environmental damage from marine incidents (e.g., increased spills and demand for spill response). ▪ Reallocation of resources, both in temporal and geographic scopes (e.g., longer Canadian Coast Guard Services ice breaking season). ▪ Potential decline in DFO's ability to provide safe access to resource users (e.g., local fishers). ▪ The locations of protected areas or areas of significance may impede the accessibility of navigable waterways (e.g., the last remnant of multi-year ice will be located in the Canadian Arctic Archipelago and there will be increases in the numbers of species and/or species groups that need to be assessed under the *Species At Risk Act*). ▪ Changes in overwintering locations and maintenance schedules for vessels.

Opportunities
▪ Increased open-water season and resulting social and economic potential/diversification (e.g., fishing activity, navigation season, oil and gas development) may encourage increased sea-floor mapping, infrastructure and harbours near communities. ▪ Increased accessibility to the Arctic may increase tourism opportunities.

Gaps
▪ Need for greater model development (forecast tools) and the increased operational use of models. ▪ Calculation capacity of high performance computers for model output is restrictive. ▪ Development, expansion and maintenance of observational networks (e.g., sea level gauges, hydrometric networks). The data generated from these observational networks will assist in the improvement of ice and ocean forecasting. ▪ Lack of spatial coverage and resolution of navigational charting. ▪ Observations of flows in confined waters and forecast capabilities for currents in these areas are limited.

Appendix 8.

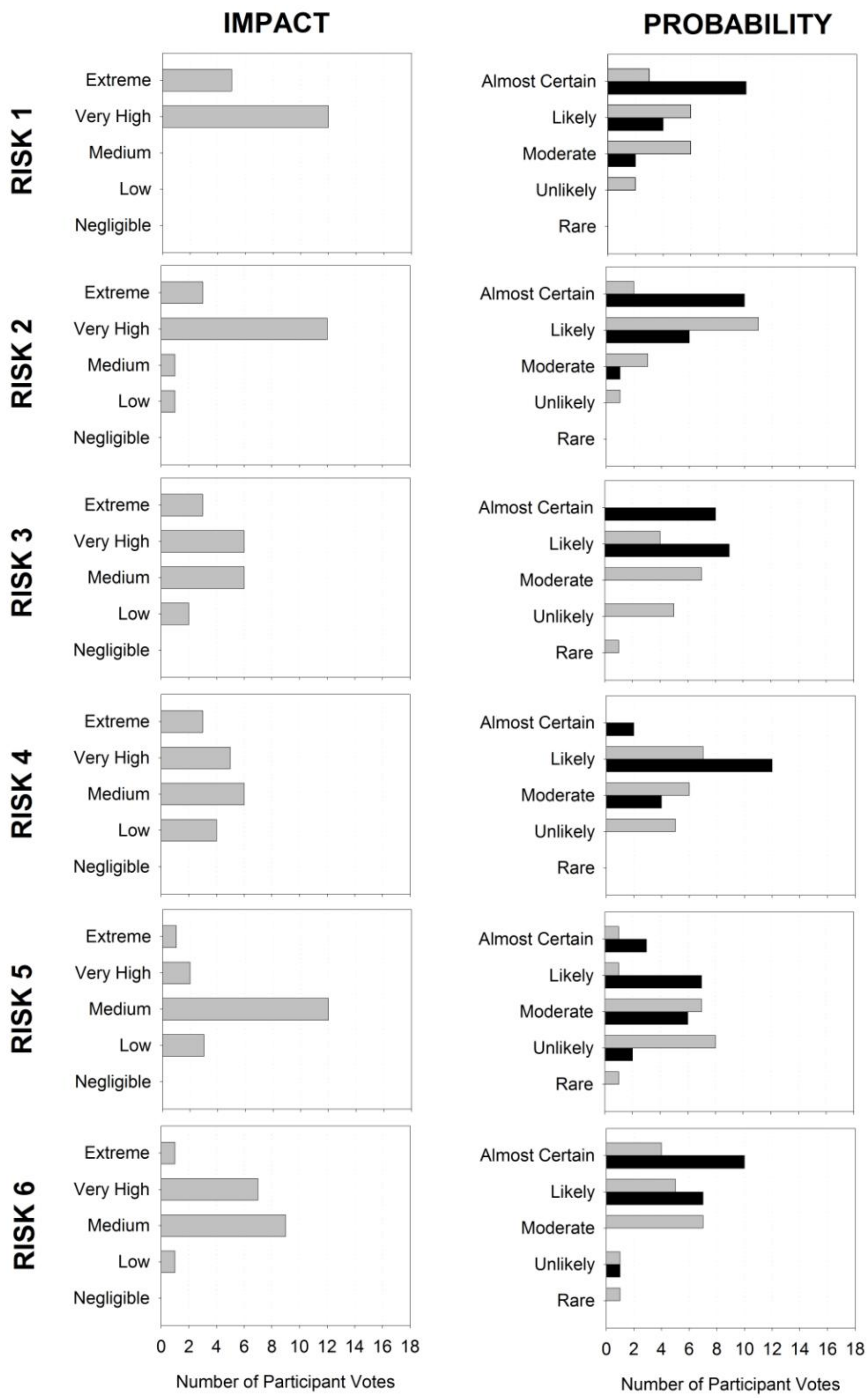
Impact and Probability ranking criteria used to assess DFO Departmental climate change risk

Impact	Definition of Impact
Extreme	A major event that will require DFO 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 DFO.
Medium	A significant event that can be managed under normal circumstances by DFO
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.

Probability Level	Percent Probability
Almost Certain	More than 80%
Likely	61-80%
Moderate	41-60%
Unlikely	20-40%
Rare	Less than 20%

Appendix 9.

Results of Impact and Probability ranking by participants during the meeting using the criteria from Appendix 8.For the Probability, the grey bars indicate the Probability on a 10 year timeframe, and the black bars on a 50 year timeframe



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