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

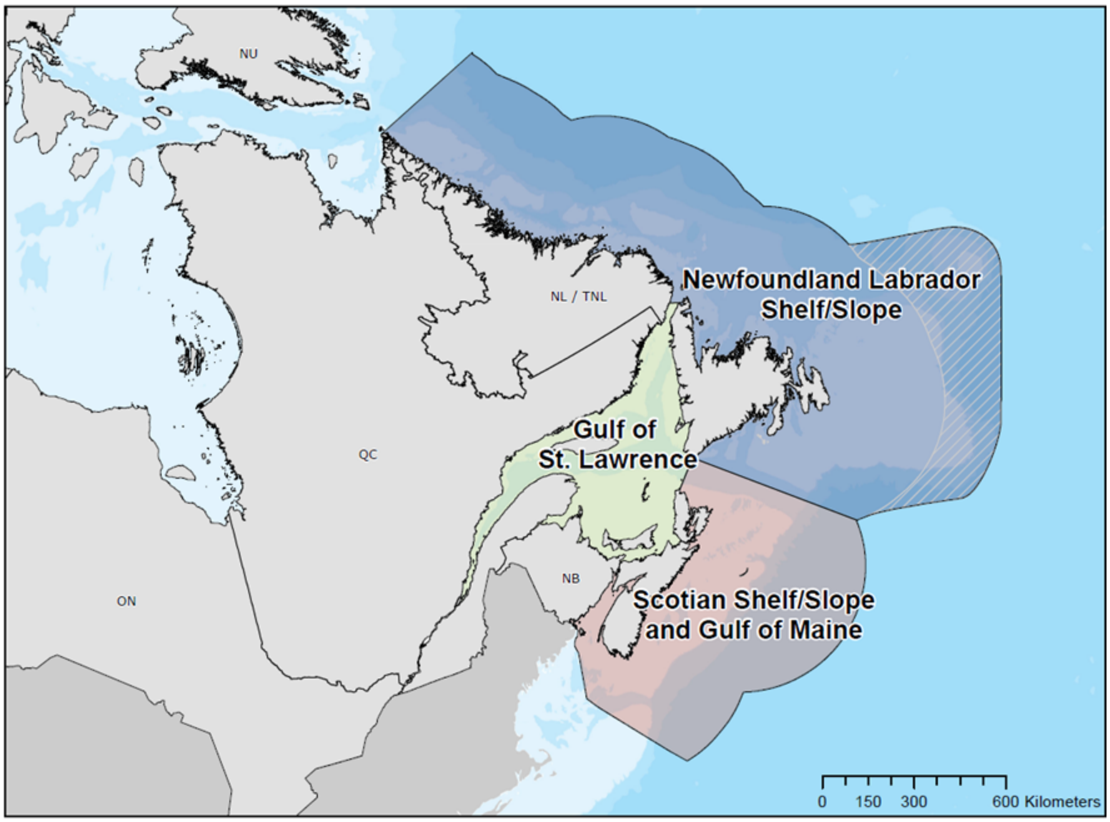

Figure 1 Map of the Atlantic Large Aquatic Basin (LAB) considered by the Aquatic Climate Change Adaptation Services Program (ACCASP). The geographic scope of the advice includes Canadian marine areas (Gulf of St. Lawrence, Scotian Shelf/Slope and Gulf of Maine, and Newfoundland-Labrador Shelf/Slope), selected freshwater environments, and offshore areas (e.g. hashed) affecting the shelf and slope waters.

Context

In keeping with the *Federal Adaptation Policy Framework*, Fisheries and Oceans Canada (DFO) initiated an Aquatic Climate Change Adaptation Service 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 research projects to increase the understanding of the impacts of climate change as well as the development of applied science-based tools to enable adaptation in support of the Department's strategic outcomes.

One of the primary objectives of the Program is to assess the risks posed by climate change 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 involved one face-to-face meeting in each of the four 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 over two temporal scales (10 and 50 years). The detailed TP and IVO reports, which are extensive and 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]*)*.This work was based on two national internal DFO 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.

A SSRP was used due to the short timeframe to provide this advice. The urgency for the advice stems from the need to assess the linkages between the science, socio-economic, and policy risk assessment background documents which will collectively inform the LAB-based Integrated Risk Assessment workshops, scheduled for early winter 2012/2013. 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.

Summary background documents were provided to participants who reviewed the scientific information available on trends and projections and the impact, vulnerabilities and opportunities for each LAB. However, this advisory meeting was held to peer review the resulting risk summary sheets for each Departmental risk identified in the Interis reports (2005,2012). A separate review process for the publication of background documents will occur once they are finalized, prior to the end of the 2012-2013 departmental fiscal year (*to be published*[1,2]).

This Science Response Report (SRR) details the results from the National SSRP of November 6-7, 2012, on the Risk-based Assessment of Climate Change Impacts and Risks on the Biological Systems and Infrastructure within Fisheries and Oceans Canada's Mandate: Atlantic Basin, in St. John's, Newfoundland and Labrador. This meeting carried out a risk-based assessment of climate change impacts and risks to the biological systems and infrastructure within Fisheries and Oceans Canada's mandate for the Atlantic LAB. The SRRs resulting from the SSRPs for each of the four LABs will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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[1] Loder, J.W., Chasse, J., Galbraith, P.S., Han, G., and co-authors, in prep. Summary of Climate Change Trends and Projections for the Atlantic Large Aquatic Basin of Canada, Canadian Technical Report of Fisheries and Aquatic Sciences.

[2] Shackell NL, Pepin P, Greenan B, Warburton A (eds), in prep. Climate change impacts, vulnerability and opportunity (IVO) analysis of the marine Atlantic Basin. Canadian Manuscript Report of Fisheries and Aquatic Sciences 3012.

Background

Climate change is an important global issue that has the potential to affect the Department'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 the impacts will occur. Furthermore, DFO is a complex and diverse department and there is a high likelihood that climate change impacts will affect all of its sectors and regions to some extent. As such, past DFO climate change risk assessment reports (Interis 2005, 2012) have already 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.

For the Atlantic LAB, the geographic scope of the advice includes both marine (Gulf of St. Lawrence, Scotian Shelf/Slope and Gulf of Maine, and the Newfoundland-Labrador Shelf/Slope) and select freshwater environments (Figure 1). Although significant differences exist in the physical climatologies of these sub-basins, the science advice from this meeting, as per the SSRP's objectives, is based on integrated information from the sub-basins and is delivered as advice for the entire Atlantic LAB.

The oceanographic setting of the Atlantic LAB involves a transition from subpolar waters in the north to a mix of subpolar and subtropical waters at mid-latitudes, with strong seasonal atmospheric forcing and run-off from the North American continent (e.g. Loder et al. 1998; Brock et al 2012). In the north, the Labrador Shelf and Slope are dominated by the influence of the Northwest Atlantic's subpolar gyre, involving the Labrador Current carrying relatively cool and fresh water, as well as sea ice, south from the subarctic to the Newfoundland Shelf and Slope (including the Grand Banks). The southern part of the LAB, from the southern flanks of Flemish Cap and the Grand Banks, across the Scotian Shelf and Slope to the Gulf of Maine, is a transition zone with a subpolar influence dominating over most of the shelf, but with increasing subtropical influence from the Gulf Stream system as one proceeds westward. The semi-enclosed Gulf of St. Lawrence is somewhat unique, with waters primarily of subpolar origin, but with a strong influence from the freshwater discharge of the St. Lawrence River system and seasonal ice cover dynamics, and a weak influence from subtropical water at depth. There is strong seasonality in near-surface temperatures in the Atlantic LAB, in particular associated with solar and atmospheric variability, and additional seasonality from run-off and strong current systems.

DFO has a number of responsibilities and activities within this LAB. Current commercial species include: Atlantic Cod, Atlantic Halibut, Capelin, clam and quahog, eel, flatfish (a mix of American Plaice, Greysole or Witch Flounder, Winter Flounder and Yellowtail Flounder), Greenland Halibut, Haddock, Hake, Herring, Iceland Scallops, American Lobster, Mackerel, Northern Shrimp, Pollock, Snow Crab, Redfish spp., Rock Crab, Sea Scallop, sea cucumber, sea urchin, Swordfish, Bluefin Tuna, and whelk. Recreational fisheries are also extensive throughout the LAB (e.g. Atlantic salmon, Atlantic cod, molluscs, Greenland Halibut). Primary DFO coastal infrastructure and navigational support in this area includes Small Craft Harbours (SCH) facilities and Real Property, Safety and Security (RPSS) sites as well as Canadian Coast Guard (CCG) vessels used for research, ice breaking, search and rescue, as well as emergency response activities. SCH operates and maintains a national system of harbours to provide commercial fish harvesters and other harbor users with safe and accessible facilities. The Canadian Hydrographic Service (CHS) conducts hydrographic surveys and produces official nautical charts and publications for the navigable waters in the Northwest Atlantic.

It is anticipated that the climate change that is already occurring for some variables will continue to alter the Atlantic marine and freshwater aquatic ecosystems as indicated by the projected increases in sea temperature and coastal sea level, and changes in ocean acidity and dissolved oxygen (Appendix 1), to name a few. These changes are expected to impact the delivery of DFO's mandate, on both the short and longer term, in the Atlantic LAB.

Analysis and Responses

The present SSRP was based on the integration of information from three sub-basins within the Atlantic Zone (Gulf of St. Lawrence, Scotian Shelf/Gulf of Maine, Labrador Sea/Grand Banks) and is delivered as combined advice for the entire Atlantic LAB. **The information provided in the TP summary table (Appendix 1) and in the six risk summary sheets (Appendix 2-7) represents the key advice resulting from this meeting** and is supported by scientific peer reviewed publications and available data. The detailed, referenced information will be made available through the publication of the detailed Atlantic LAB TP and IVO reports (*to be published*[3,4]).

Trends and Projections

Participants reviewed the TP summary table (Appendix 1) which provides a high-level summary of past climatic trends and future projected climate changes for the Atlantic LAB, on a 10 year timescale and on a 50 to 70 year timeframe. The climate trends and projections identified are typical of the entire LAB (to varying degrees) and provide the basis for the predicted environmental change and the resulting advice in this report.

The 10 year projections were obtained from recent trends, scaling of the 50 year projections, and present understanding based on the published literature. There are currently no models that can predict the combination of natural and anthropogenic changes at the regional level on the decadal scale.

Projections for the 50 year timescale were developed using results from the Fourth Assessment Report (IPCC 2007) of the Intergovernmental Panel on Climate Change (IPCC) and from other more recent global climate models (GCM), regional climate models, scientific literature, and observed trends for the past 110, 60, and 30 years. The ensemble means from the six state-of-the-art coupled climate models being assessed for the IPCC's Fifth Assessment Report (2013) was used in the 50-year projections for key atmospheric and ocean variables, following IPCC practice that no single model should be relied upon for climate projections.

Overall, there remains substantial uncertainty in climate projections for the Atlantic LAB. Climate projections over larger scales and longer time frames have more certainty than those in the near-term and at the sub-basin scale. The uncertainty is in part due to the large spatial gradients in Arctic, continental and ocean circulation influences, and the strong natural decadal-

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[3] Loder, J.W., Chasse, J., Galbraith, P.S., Han, G., and co-authors, in prep. Summary of Climate Change Trends and Projections for the Atlantic Large Aquatic Basin off Canada, Canadian Technical Report of Fisheries and Aquatic Sciences.

[4] Shackell NL, Pepin P, Greenan B, Warburton A (eds), in prep. Climate change impacts, vulnerability and opportunity (IVO) analysis of the marine Atlantic Basin. Canadian Manuscript Report of Fisheries and Aquatic Sciences 3012.

scale variability such as the North Atlantic Oscillation (NAO) and the Atlantic Multi-decadal Oscillation (AMO). Furthermore, the limited spatial resolution of GCMs means that there is reduced confidence in certain key elements in the Atlantic LAB such as: the Arctic-Atlantic linkage including the through flow in the Canadian Arctic Archipelago (CAA); proper representation of the major transport conduits (e.g., Labrador Current, Gulf Stream) in the subpolar and subtropical ocean gyres; and sea ice variability and regional spatial structure. Lastly, there is no regional atmospheric climate model with active ocean and ice components.

The 50-year projections for key atmospheric variables include a general increase in air temperature and precipitation with seasonal and regional variations, a poleward shift in storm tracks, and an increase in the number of fall storms in the northern part of the LAB. **The key projections for hydrologic and cryospheric variables** are a decrease in the extent and duration of sea ice, a decrease in the duration of the iceberg season south of 48ºN, an earlier spring peak of river run-off, and lower summer river levels at some sites. **For oceanographic variables**, sea temperature is expected to increase everywhere and in all seasons, salinity is expected to decrease in all seasons with the exception of deep-ocean areas in the south where it may increase, and seasonal near-surface stratification is expected to increase everywhere (with associated reduced mixed-layer depths) with the possible exception of areas which no longer receive advected sea ice. **Expectations for chemical oceanographic variables** are widespread reductions in subsurface concentrations of dissolved oxygen, lowering of pH with associated shallowing of $CaCO_3$ saturation depths, and reductions in the supply of nutrients to the euphotic zone.

There is also clear evidence that coastal sea level is already rising significantly in the southern part of the LAB, associated with a combination of land subsidence and anthropogenic climate change. It is expected that mean and extreme high sea levels will continue to rise in these areas and this will expand to all areas on the 50 year scale.

On the decadal time scale, it is expected that there will be a tendency toward much smaller changes of the same sign for most variables, but these may be dominated in some (perhaps many) cases by unpredictable natural decadal-scale variability. Anthropogenic changes which are nonetheless considered likely on the decadal scale include warmer sea temperatures, earlier spring freshets, reduced sea ice extent, higher coastal mean sea levels, and reduced pH.

Risk Summary Sheets

Participants reviewed the six risk summary sheets (Appendices 2-7) that describe the main climate change risk drivers, potential consequences (threats), opportunities, and gaps for each of the previously identified Departmental climate change risks (Interis 2005, 2012) for the Atlantic LAB. These summary sheets are based on the TP summary table (Appendix 1) and consider both the 10 and 50 year timescales.

A risk driver is an element which alone, or in combination, has the intrinsic potential to give rise to a risk. When possible, the main risk drivers are linked to specific groups of organisms or community characteristics (e.g. lower trophic levels, phenology, species at risk (SAR)). When a risk event occurs, the consequence is an outcome of that event which either alters the physical environment, the ecosystem, or affects the delivery of a program or activity. In many cases an event has the potential for environmental and anthropogenic consequences. Potential consequences were developed during plenary discussions. The main risk drivers and the potential consequences (threats) are directly linked within each risk summary sheet. There are situations where the risk driver can also be considered a potential consequence.

The first three Departmental climate change Risks (Risks 1-3) are ecosystem-based risks related to marine and freshwater ecosystems; the SSRP participants from DFO Science are considered the primary experts in this field. Furthermore, these experts were able to support their opinion with a considerable amount of published and available information. Several of the main risk drivers, threats, opportunities and gaps were common to Risks 1, 2 and 3.

Risks 4-6 focus on DFO's marine and freshwater infrastructure as well as operations such as search and rescue. Science consulted with other Sectors of DFO to receive input on the vulnerability of such infrastructure to climate change (e.g., vulnerability of Small Craft Harbours breakwaters to changes in mean sea level). It should also be noted that the non-ecosystem consequences result from a combination of the direct effects of climate drivers and the indirect effects of changing social constructs.

The following list describes the context and definitions for each of the six Departmental risks (*sensu* Interis 2005, 2012):

<u>Risk 1 - Ecosystem and Fisheries Degradation and Damage</u>: There is a risk that climate change will affect DFO's ability to meet its strategic and policy objectives related to Oceans Management, and the sustainable development and integrated management of resources in Canada's aquatic environment. This risk focuses on DFO's stewardship role in managing and protecting fish habitat and its leadership role in Canada's Ocean Strategy and the sustainability of the oceans and their resources (i.e., *Oceans Act* and *Fisheries Act*). The main risk drivers identified for this risk are primarily based on future changes in habitat characteristics and dynamics, and on changes in species biodiversity, altered productivity and/or changes in trophic pathways.

<u>Risk 2 - Changes in Biological Resources:</u> There is a risk that climate change will affect DFO's ability to manage and protect the abundance, distribution and quality of harvested fisheries and aquaculture stocks. This risk refers 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, fish and shellfish stocks) and encompasses, at varying scales, commercial fisheries, recreational fisheries and subsistence or food, social and ceremonial fisheries.

<u>Risk 3 - Species Reorganization and Displacement:</u> There is a risk that 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 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 facilitate the introduction or spread of invasive species.

<u>Risk 4 - Increased Demand to Provide Emergency Response</u>: There is a risk that climate change will affect DFO's ability to provide acceptable levels of environmental as well as search and rescue response. The emphasis in this risk is on the potential for increased occurrence of marine incidents due to climate change and the associated strain on the Canadian Coast Guard's (CCG) capacity to respond.

<u>Risk 5 - Infrastructure Damage:</u> There is a risk that climate change will result in damage and the need for alterations to DFO vessels, as well as coastal and Small Craft Harbours infrastructure. DFO maintains considerable infrastructure to support its operational and scientific activities in both the marine and freshwater environments including harbours, breakwaters, wharves, bases, stations, buoys, slipways, launchways, buildings, labs, lighthouses, navigation aids, hatcheries and DFO aquaculture facilities.

<u>Risk 6 - Changes in Access and Navigability of Waterways:</u> The risk that climate change poses 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 the ecosystem-based risks (Risks 1-3) it was agreed that the overall impact of climate change will be highly dependent on the current state of species' populations and ecosystems (e.g. stressed populations and/or degraded ecosystems may be more vulnerable). Also, it was agreed that the impacts of climate change on natural ecosystems at the 10 year timescale will likely remain within the range of past observations. Furthermore, the anticipated impacts of climate change will not be uniform throughout the Atlantic basin. In general, the ecosystems of the Scotian Shelf and Gulf of St. Lawrence may be more severely impacted by the changing climate than those of the Newfoundland Shelf.

Species with key life history events in sensitive habitats (such as young of the year Atlantic cod in eelgrass habitat) may also be highly vulnerable to climatic changes. Changes in thermal habitat and circulation patterns will result in shifts in distribution for species and stocks that are near the upper and lower thermal limits of their range. This may also lead to an increased occurrence of aquatic invasive species. Changes in seasonality will be important for DFO as the Department manages fisheries on a seasonal basis. Changes in sea ice cover and ice dynamics are likely to have a profound effect on many ecosystem components.

The summary sheet that assesses the risk associated with species reorganization and displacement (Risk 3, Appendix 4) addresses species at risk, Aquatic Invasive Species (AIS), and depleted species; however it does not specifically address biodiversity issues. The Beluga Whale populations of the eastern Hudson Bay area are an example of a SAR that will be affected by climate change. The loss of ice has been documented to affect Beluga and other mammals by influencing predator-prey interactions. There are populations of Beluga found in the Arctic that overwinter in the eastern Hudson Shelf. Another population of Beluga, in the Gulf of St. Lawrence is ice-dependent and will also be challenged considering the forecasted loss of ice in its habitat. Furthermore, species listed by the Committee on the Endangered Wildlife in Canada (COSEWIC), but not listed in Schedule 1 of the *Species at Risk Act*, are not included in this assessment, although they are of interest to DFO. These are species that DFO will have to assess and for which resources will need to be allocated.

Changes in sea ice extent and ice dynamics, mean sea level and coastal erosion will also have implications for the three non-ecosystem risks to the Department (Risks 4-6; Appendices 5-7) which concern providing emergency response, maintaining infrastructure, and ensuring that waterways are safe and accessible. It is likely that there will be an increased demand for emergency response and changes to the navigability of waterways primarily driven by decreases in the spatial and seasonal extent of sea ice, which among other things, will increase the geographic scope of human activities within the Atlantic LAB. Adapting to this increase in geographic scope will likely involve reallocation of resources within the Atlantic LAB.

An increased demand for emergency response (Risk 4) is linked to the ability of CCG to adequately deliver its mandate. In general, CCG is capable of dealing with changing weather conditions; however, there is potential for a more significant impact to CCG because of the reduction and change in spatial extent of sea ice. A projected decreased demand for icebreakers in the Gulf of St. Lawrence may cause a reassignment of those vessels to other areas. Sea level rise will also affect CCG infrastructure, but not delivery on their search and rescue activities. If climate change leads to increased client activities in areas not previously exploited, then this will affect the way that CCG will deliver services. The TP models do not clearly indicate an overall increase in storm frequency or intensity, but there is some indication of a northward movement of storm tracks and potential for more severe storms. This may impact both the demand for and CCG’s ability to provide emergency response.

Infrastructure damage (Risk 5) discussions not only addressed managing or replacing damaged infrastructure, but also dealt with moving or relocating infrastructure for other climate-related reasons, such as changing the location of harbors based on changes in the location and nature of fishing activities resulting from climate change. The most significant vulnerability for this non-ecosystem risk relates to damage of coastal infrastructure. Increased precipitation and increased runoff is predicted to lead to increased erosion. Less sea ice will also lead to increased winter-time exposure of coastline, enhancing erosion risk. There are areas of the LAB that are already experiencing issues related to changes in sea level and coastal erosion and these are likely to intensify in the future. Hence, this is an issue for which the changes in the ocean environment are significantly impacting DFO on both the 10 and 50-year time frames. It is believed that Newfoundland may expect to experience more significant coastal infrastructure damage than other areas of the LAB.

Risk Evaluation

Following the review of each of the risk summary sheets, participants went through a formal process to assess Departmental risk using pre-established criteria (Appendix 8). Participants were asked to vote on the impact of each risk to the Department, and the probability of that risk occurring over a) the next 10 years, and b) the next 50 years. This voting process was repeated for each of the six identified Departmental Risks defined above. All voting was conducted anonymously using the Resolver Ballot© Software (Version 7.2.0.20) (n=28 total votes for each impact and probability vote). Voting results were reviewed in plenary. In cases where there was a significant lack of agreement between the votes, results were discussed, possible misunderstandings of the risk statements were resolved and the vote was repeated

Prior to voting, participants discussed and reviewed a list of assumptions. The assumptions were that:

1. The vote is elevated to the level of the Atlantic LAB in its entirety, although it is recognized that heterogeneity exists, with differences within and between sub-basins.
2. The impact is assessed separately from the probability.
3. The impact of a risk occurring has no timescale.
4. Changing intensity of human activities not directly linked to climate change, such as fishing, is not taken into account
5. Participants assumed that DFO would conduct its business "as usual" over the 10 and 50 year timescales

Two important aspects of the assessment that should be noted are:

- The large spatial variability within the Atlantic LAB is not reflected in the summary sheets, and
- The voting group had limited technical expertise with respect to non-ecosystem Risks 4 to 6.

Individual Risk Voting Results

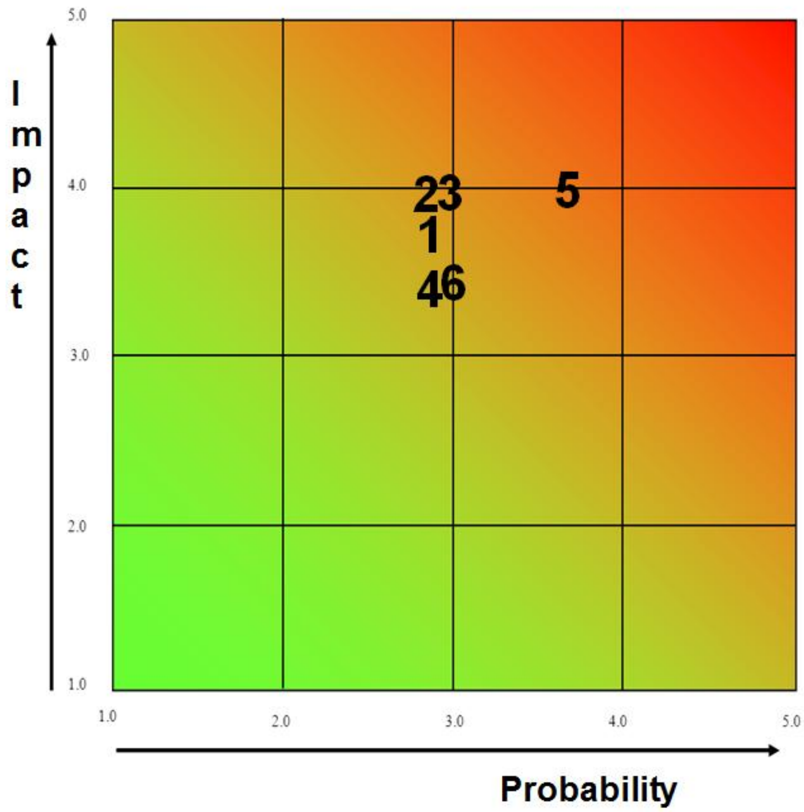
Results from the voting exercise generally corresponded with a distribution curve considered normal, and agreement was achieved among participants (Appendix 9). Voting on the impact of Risk 3 (species reorganization) resulted in a broad distribution of votes, ranging from "very low" to "extreme", and participants agreed to vote again, the distribution remained much the same. A misunderstanding from one participant resulted in a re-vote on the 10 year likelihood of Risk 4 (emergency response). Results for the 10 year likelihood of Risk 5 (infrastructure damage) were surprisingly low so the participants voted a second time after group discussions. The result was an overall higher likelihood for this risk.

Risk Heat Maps

Voting results for the level of impact of each risk by the perceived probability of the impact occurring at the 10 and 50 year timescales were prepared as heat maps (Figures 2 and 4 respectively), using the Resolver Ballot© Software. Voting on the impact ranking for each risk was only conducted once and therefore the location of results along the impact axis is the same in both figures. A risk exposure (or risk index) was calculated as the product of the risk's impact and probability ranking, such that a higher number indicates a greater risk to DFO. The risk exposure for each risk is indicated in Figures 3 and 5 for the 10 and 50 year timeframes respectively.

In the Atlantic LAB, infrastructure damage (Risk 5) and species reorganization and displacement (Risk 3) were considered to present the greatest risk exposure to the Department, on both the 10 and 50 year timescales (very high impact, moderate to almost certain probability of occurrence). Changes in access and navigability of waterways (Risk 6) and increased demand to provide emergency response (Risk 4) posed the least risk to the Department (very high and medium impact, moderate to almost certain probability) although the anticipated risk exposure of the Department regarding these risks does increase over the 50 year timeframe.

The ranking of the risks based on their risk index is the same for the 10 and 50 year timescales; however, the probability of each risk is greater for the 50 year assessment. The three ecosystem risks (Risks 1-3) were all ranked very similarly, with Risk 3 slightly higher. The non-ecosystem Risk 4 (emergency response) and Risk 6 (access and navigability) were also given a similar ranking on the 10-year timescale and both ranked below the ecosystem risks in terms of impact, but were assessed to have the same probability. On the 50-year timescale, Risk 6 ranked higher than Risk 4 in terms of probability.



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.

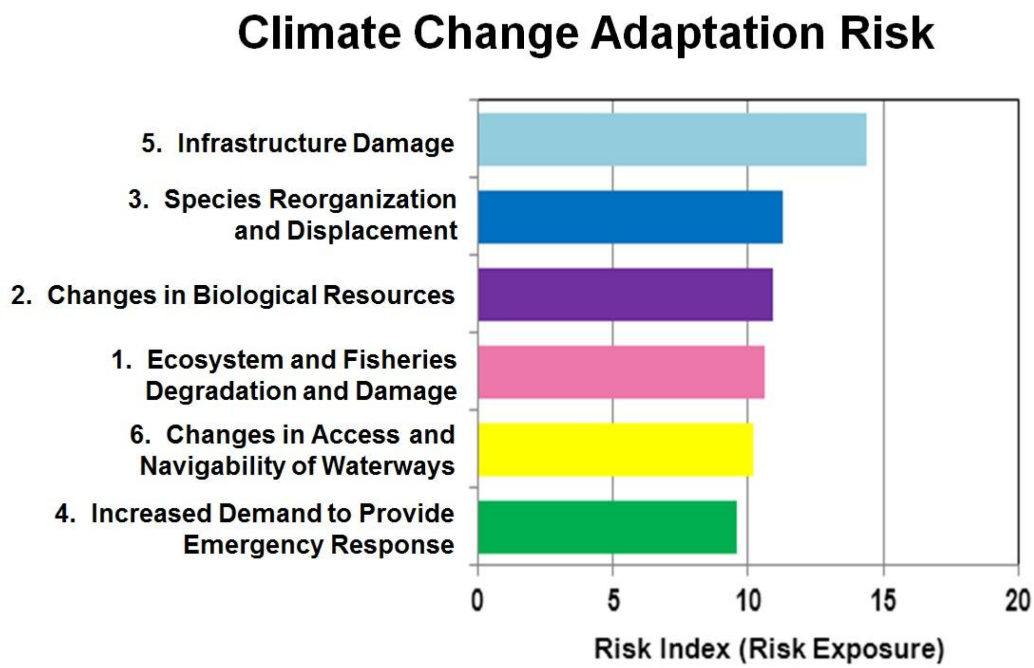
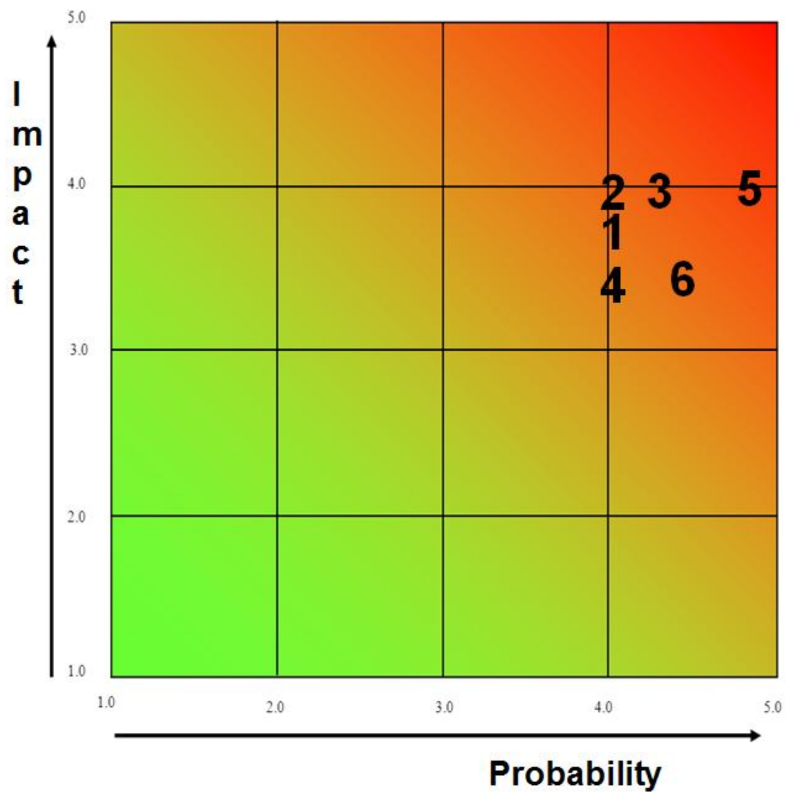


Figure 3. Histogram showing risk Index (risk exposure) for each DFO Risk on the 10 year timescale. The risk index is the product of the risk's impact and probability rankings.



DFO Risks

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

Figure 4. Heat map showing the impact and probability of occurrence for each DFO Risk on the 50 year timescale.

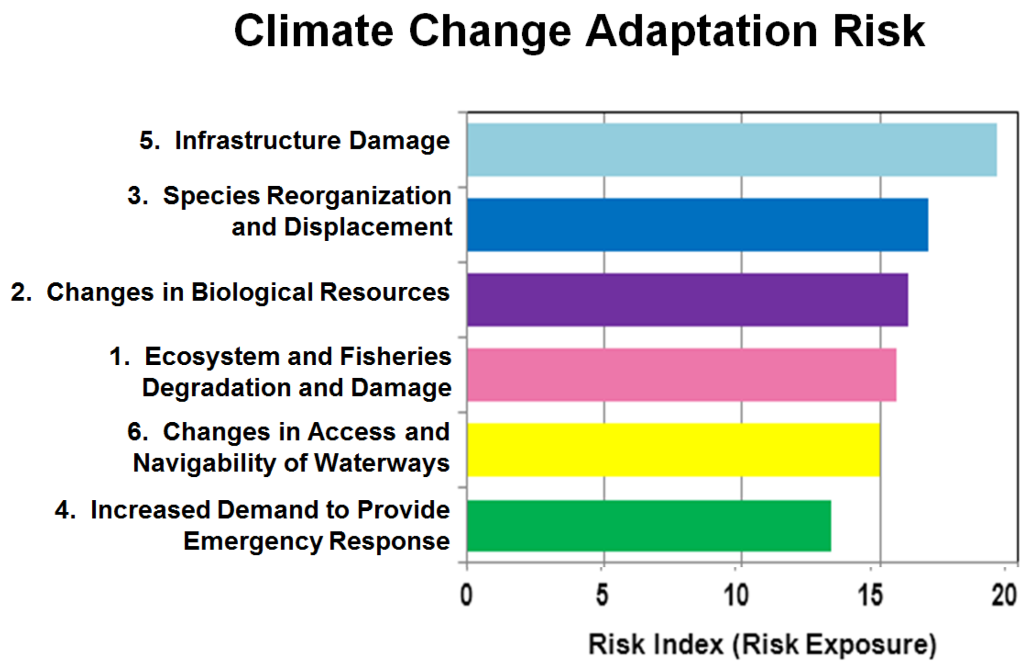

Figure 5. Histogram showing risk index (risk exposure) for each DFO Risk on the 50 year timescale. The risk index is the product of the risk's impact and probability rankings.

Gaps in Knowledge

The gaps in knowledge associated with the development of the TP summary table and risk summary sheets are detailed in the appendices (2-7). Overall, seven key TP gaps were identified for Atlantic LAB. These TP gaps also lead to gaps in the assessment of main risk drivers:

1) Limited knowledge and predictability of the pronounced decadal-scale variability in atmosphere, ice and ocean climate variables in the NW Atlantic.
2) Inadequate resolution of the NW Atlantic and Eastern Arctic in the ocean and ice components of the coupled atmosphere-ice-ocean models being used in climate change projections.
3) Limited knowledge and predictability of the variability in key ocean climate variables and risk factors on sub-basin to smaller geographic scales.
4) Uncertainty in projections of regional sea level rise in the Atlantic LAB, associated with factors such as ocean thermal expansion, ice melt, circulation changes, and glacial isostatic adjustment.
5) Limited knowledge and predictability of the spatial patterns of atmospheric "storminess" over the Atlantic LAB, and of associated extreme high coastal sea levels.
6) Limited knowledge and predictability of coupled physical-biogeochemical variability.
7) Limited knowledge and predictability of changes in multiple (potentially compounding) risk factors in the coastal zone including embayments and estuaries.

Although the TP data does exist for the Atlantic LAB for freshwater variables such as river discharge, time of discharge, flow, levels and river temperature, these characteristics were not assessed in detail during the development of this advice. In future iterations of this exercise, the freshwater environment in the Atlantic LAB should be further considered.

There is also a limited knowledge about biological systems in general, including:

1. The biological impacts of ocean acidification on fish and on most of the invertebrates found in the Atlantic LAB.
2. Consequences of changes in the timing, intensity and duration of the seasonal cycle.
3. Effects of changes in stratification.
4. Effects of changes in the distribution of water masses.
5. Effects of alterations in ocean circulation.
6. Ecological processes in proximity to sea ice.

Many projections of ecosystem impacts are based on the effects of a single factor. The lack of coupled models, of varying trophic complexity, represents a key knowledge gap. The complexity of projections makes linking ecosystem responses to current trends and projections of regional environmental conditions in response to climate change uncertain.

There is a gap in data availability especially for coastal areas. There is a lack of biophysical models, and there are issues with downscaling spatial and temporal models developed for broad geographic areas. Furthermore, it is unclear how to incorporate cumulative effects of climate change in risk and vulnerability assessments; the effects of climate change are likely to be exacerbated when combined with the stress caused by other anthropogenic (e.g. fishing, pollution) and natural factors. The increased frequency and possible duration of extreme events will also affect the ecosystem but this has not been considered during this risk assessment process. The effects of climate change on diadromous species, other than salmon and charr, were not examined in the advice, and should be incorporated in future iterations of this process. The significance of climate change to turtles, Right Whale and Bottlenose Whale were not included in this analysis. MPAs are a spatial management planning tool that will be affected by climate change and will be considered at the Integrated Risk Assessment meetings, where program representatives will be present. Lastly non-climate factors and current effects caused by human activities are not considered in this advice, but may affect the ecosystem response to climate change.

The high uncertainty for climate projections for the non-ecosystem risks (Risk 4-6) is related to the fact many of the risk elements are primarily dependent on changes in the physical environment such as sea-ice extent and sea level rise. The high uncertainty regarding future changes in winds and storms was identified as a gap for Risk 4 (emergency response). The fact that northern waters in the Atlantic LAB are largely uncharted was identified as a gap for both Risks 4 and 6 (change in access) while uncertainty in changes in harvested fish stock distributions is an important gap for Risks 4 and 5 (infrastructure). The lack of knowledge about the various contributions to global and regional sea level rise is a very important gap (Risks 5-6) since there is high certainty in the magnitude of the mean sea level rise. Extreme sea level (storm tide) is poorly known for locations in the Atlantic LAB where tide gauges do not exist and, hence, this is a significant gap for Risk 5. Coastal erosion will change sediment transport and affect navigability, however, it is not fully understood which areas under DFO's responsibility will be most impacted.

Conclusions

Assessments of risks to the biological systems and infrastructure that fall under the purview of DFO within the Atlantic LAB were conducted during a meeting in St. John's, Newfoundland and Labrador, on November 6-7, 2012. Results from this Canadian Science Advisory Secretariat (CSAS) meeting produced two heat maps comparing each of the six Departmental risks (impact versus probability) for the 10-year and 50-year timescales. Infrastructure damage (Risk 5) presents the greatest risk exposure (combination of impact and probability) to the Department on both the 10 and 50 year timescales with an estimated very high impact on both time scales and a moderate and almost certain probability at the 10 and 50 year time scales respectively. The risk exposure for the three ecosystem-based risks (Risks 1 to 3) ranked below that of infrastructure damage and was higher on the 50 year time scale than on the 10 year time frame. For all risk, the probability of occurrence at the 50 year time frame was higher than at the 10 year time frame. A number of knowledge gaps in the trends and projections, and in the impact these will have on the biological systems and DFO infrastructure have been identified during this advisory process. It was recommended that this assessment be repeated (iterative process) as these knowledge gaps are filled, allowing the present advice to be updated. Furthermore, it was recommended that the 6 main Department risks, as initially defined in the INTERIS report (2005), be redefined and refocused. The results of this SSRP for the Atlantic LAB will be used to inform Atlantic LAB integrated risk assessment workshops. The objective of these integrated meetings will be to determine the most acute basin-level climate risks to the Department, and will inform senior management as they develop policies that will increase the Department's adaptive capability in light of future climate change.

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Appendix 1.

Trends and projections summary table for the Atlantic LAB

High-Level Basin-Scale Summary of Observed Trends and Future Projections for Climate Change for the Atlantic Large Aquatic Basin	Projected Changes (direction and magnitude) and Likelihood (and/or Confidence)
Acronyms and Abbreviations: IPCC AR4 = 4th IPCC Assessment Report; AMOC = Atlantic Meridional Overturning Circulation Sub-basins: Scotian Shelf/Slope and Gulf of Maine (SS-GM), Gulf of St. Lawrence (GSL), Newfoundland and Labrador Shelf/Slope (NLSS)	
Likelihood: Very Likely >80%, Likely 61-80%, Moderately Likely 41-60%, Unlikely 20-40%, Very Unlikely <20%. Confidence (in information): VH = Very High, H = High, M = Medium, L = Low, VL = Very Low. Note: Substantial uncertainty due to strong decadal-scale natural variability in many variables, and to inadequate resolution of the Eastern Arctic and Northwest Atlantic in the ice and ocean components of climate models.	

Risk Factors (variables)	Decadal (changes expected after 1 decade based on past trends)	50-Year (change estimates over 50-70 yrs)
Air Temperature	Positive trends in annual means over past 3 decades. Likely increase everywhere in all seasons (H).	Very Likely increase everywhere in all seasons (VH). Likely increase in annual means by 2-3.5^{o}C in SS-GM and GSL, and 1-3^{o}C in NLSS (M).
Precipitation	No clear pattern in observed trends over past 3 decades. Likely increases in north in winter (M), but changes elsewhere uncertain.	Increasing trend at most sites since 1950. Likely increase in annual means by >10%, except in SS-GM where change uncertain (M). Possible increase in extreme precipitation events (L).
Streamflow and Run-off	No clear pattern in observed trends in annual discharge over past 3 decades. Likely increase in Greenland run-off affecting northern NLSS (M). Moderately Likely earlier peak discharges everywhere (M).	Moderately to Very Likely increases in annual discharge in GSL and NLSS, but uncertain in SS-GM (M-H). Likely earlier peak discharges everywhere (H). Possible lower summer discharges in south (L). Possible increase in extreme river discharge events (L).
River Conditions	Moderately Likely increases in temperatures, decreases in ice days, earlier ice break-up, and reduced levels in summer (L).	Likely increases in temperature, decreases in ice days, earlier ice break-up, and reduced levels in summer (M).
Atmospheric Circulation	No persistent trend in North Atlantic Oscillation (NAO). Uncertain natural variability.	Likely poleward shift of Jet Stream and Likely intensification of Northern Annular Mode (H). Moderately Likely more positive NAO (M), but less confidence than in IPCC AR4.
Winds and Storms	Mixed information on wind trends. Changes over next decade uncertain and may be dominated by unpredictable natural variability.	Likely poleward shift in storm tracks (H). One regional model indicates decrease (increase) in number of fall storms in south (north), and no or small changes in mean wind speeds (M).

Risk Factors (variables)	Decadal (changes expected after 1 decade based on past trends)	50-Year (change estimates over 50-70 yrs)
Sea Ice	Likely further decreases in area, thickness, volume, concentration and duration in all areas (H). Moderately Likely that large rate of observed decline over past 3 decades will continue in most areas (L). Important natural variability.	Very Likely decreases in area, thickness, volume, concentration and duration in all areas. Largest percentage decreases Likely for GSL and southern part of NLSS. Very (Moderately) Likely complete disappearance in SS-GM (GSL), except in coastal areas and elsewhere in coldest winters. (H)
Icebergs	Likely reduced occurrence of icebergs in GSL and NLSS (M). Possible increased occurrence in NLSS due to increased calving rate (L).	Likely reduced occurrence of icebergs in GSL and NLSS (M). Possible increased occurrence in NLSS due to increased calving rate (L).
Ocean Temperature Surface or Near-surface	Warming in last 3 decades in all sub-basins (but not over past century in Labrador Sea). Likely increases in annual means, but differences in magnitude among sub-basins and seasons (H). Large uncertainty in magnitudes due to natural variability. Moderately Likely slightly earlier (later) threshold temperatures in spring (fall) in south (L).	Very Likely increases in all areas and all seasons (H). Largest increases in SS-GM and GSL (Likely 1-4^{o}C in seasonal means) (H), and smaller increases in NLSS (Likely 0-2^{o}C in seasonal means) especially in winter (M). Uncertainties associated with decadal-scale variability and inadequate ocean resolution in climate models. Likely earlier (later) threshold temperatures in spring (fall) (H).
Ocean Temperature Cold Intermediate Layer (CIL)	Moderately Likely increase in minimum temperature, decrease in area and volume, and shallowing of CIL, but uncertainty in magnitudes (M). Important natural variability.	Likely increase in minimum temperature, decrease in area and volume, and shallowing of CIL, but uncertainty in magnitudes (M). Less change expected on ice-covered parts of Labrador Shelf (M).
Ocean Temperature Bottom (shelf) or Deep (off-shelf)	Weak warming over past 3 decades in NLSS but not in SS-GM and GSL (M). Warming over past 80-100 years in SS-GM and GSL (M). Moderately Likely weak warming in most areas, with spatial variations related to water depth (M).	Likely warming in most areas from upper-ocean warming and increased influence of subtropical water in SS-GM, GSL and southern NLSS (H). Expect spatial variations related to water depth, with shallow areas (<100m in SS-GM, GSL and southern NLSS, and <200m on Labrador Shelf) following CIL changes, and deeper areas (>200m) following off-shelf changes (H).
Salinity Surface or Near-Surface	Spatial variability in sign of recent trends. Moderately Likely overall decrease in coastal/shelf/slope areas of all sub-basins (M). Magnitudes <0.2 with increase with latitude (L). Uncertainty due to natural variability.	Very Likely decrease in all coastal/shelf/slope areas in all seasons (H). Magnitude in 0.1-1.0 range, with increase with latitude (H). Relatively small variations with season (M). Possible increase in deep-ocean areas in south (M).

Risk Factors (Variables)	Decadal (changes expected after 1 decade based on past trends)	50-Year (change estimates over 50-70 yrs)
Salinity Bottom or Deep (off-shelf)	Moderately Likely small decrease in most areas, but strong influence of natural variability which may dominate (M).	Likely decrease in all seasons and areas with exception of deep (>200 m) waters in southern areas (H) where Moderately Likely small increase (M).
Stratification and Mixed-Layer Depth	Moderately Likely small increase in seasonal near-surface stratification, and Moderately Likely decrease in surface mixed layer depths in most areas (M). Moderately Likely earlier onset of stratification in spring-summer, and later end of stratification in fall (H). Moderately Likely increase in stratification in shelf-water/slope-water front along shelf edge (M).	Very Likely increase in seasonal near-surface stratification in all areas, with possible exception of areas which no longer receive advected sea ice (H). Very Likely decrease in surface mixed layer depths in all areas (H), but large spatial variation in magnitudes: ~1-5 m in SS-GM and GSL, and ~10-60 m in NLSS (M). Very Likely earlier onset of stratification in spring-summer, and later end in fall (H). Likely increase in stratification in shelf/slope front along shelf edge (M).
Large-Scale Ocean Circulation	Possible changes in positions and strength of major ocean currents (Gulf Stream, Labrador Current, Arctic outflow, AMOC), but these are likely to be dominated by natural variability rather than anthropogenic change over the next decade (M).	Likely reduction in AMOC (H), and Moderately Likely intensification of Labrador Current (M) and reduction in Arctic outflows (M), affecting NLSS and SS-GM in particular. Likely northward shift of Gulf Stream affecting SS-GM and GSL (M). Magnitudes uncertain, but net effects on regional ocean climate could be substantial (M).
Coastal Circulation	Uncertain changes dominated by natural variability (M).	Uncertain changes in local and regional circulation and exchange (M).
Significant Wave Height (SWH)	No significant changes observed over past 3 decades (M). Moderately Likely increase in seasons and areas in GSL and NLSS with previous ice cover (M). Uncertainty related to storminess in other seasons and areas.	Likely increases in winter and spring in areas that were previously ice-covered (M). Latest models indicate only small changes in other areas and seasons, including Likely small decreases in summer in GSL and NLSS (M).
Coastal Mean Sea Level (MSL)	Likely increases along SS-GM, southern GSL and Newfoundland coasts (H). Moderately Likely increase by 5-10 cm in these areas (M). Reduced confidence in changes along northern GSL and Labrador coasts (L-M). Uncertainties related to natural variability.	Very Likely increases exceeding global average along SS-GM, southern GSL and Newfoundland coasts due to land subsidence (H). Likely increases by 30-50 cm along SS-GM and southern GSL coasts (H), and 30-40 cm along parts of Newfoundland coast (M). Likely increases elsewhere but smaller magnitudes due to land rebound (M). Uncertainties related to regional ocean dynamics and global-scale factors.

Risk Factors (Variables)	Decadal (changes expected after 1 decade based on past trends)	50-Year (change estimates over 50-70 yrs)
Coastal Extreme Sea Level	Observations indicate increasing occurrence of extreme high levels due primarily to Mean Sea Level (MSL) rise, rather than to stronger events (M). Moderately Likely increase in extreme high levels in most areas, but uncertainties associated with natural variability and storminess (M).	Very Likely increase in extreme high levels in most areas due to a combination of MSL rise, reduced ice cover, possibly intensified storms, and/or increased tides (H). Likely increase in frequency of flooding events in most areas (H), and in coastal erosion in some areas (M).
Acidity	Likely continuation of recent trend of decreasing pH in most areas, with changes of 0.02-0.04 but larger at depth in GSL (M). Likely continued shallowing of $CaCO_3$ saturation depths (M).	Very Likely widespread reduction in pH and shallowing of $CaCO_3$ saturation depths (VH). Likely pH reductions >0.1 in most areas and >0.2 at depth in GSL (amplified by hypoxia) (M).
Nutrients	Moderately Likely small reductions in supply of nutrients to the euphotic zone in most areas, but important natural variability (L).	Likely widespread reduction in nutrient supply to euphotic zone due to increased stratification in most areas. Likely additional changes in nutrients in some areas from circulation and biogeochemical changes. (M)
Dissolved Oxygen	Moderately Likely small reductions in subsurface concentrations and saturation levels in most areas, but may be dominated by natural physical and biogeochemical variability (L).	Very Likely widespread reduction in subsurface concentrations and saturation levels (H). Local physical and biogeochemical processes may dominate in some areas (M).

Appendix 2.

Risk summary sheet for Risk 1: Ecosystem and Fisheries Degradation and Damage for the Atlantic LAB. Note that there is a direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

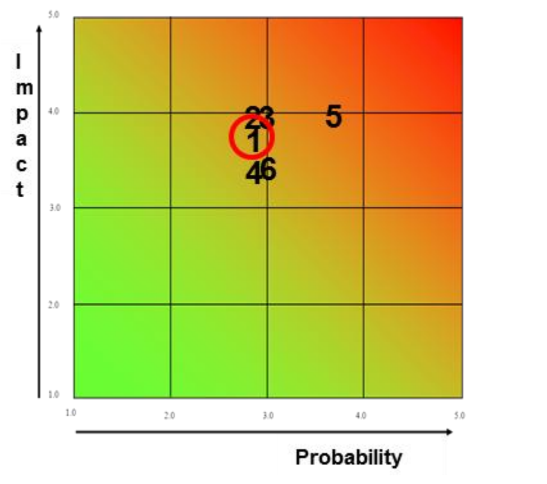
Atlantic Large Aquatic Basin (Gulf , Maritimes, Newfoundland, Quebec)

Risk 1: Ecosystem and Fisheries Degradation and Damage

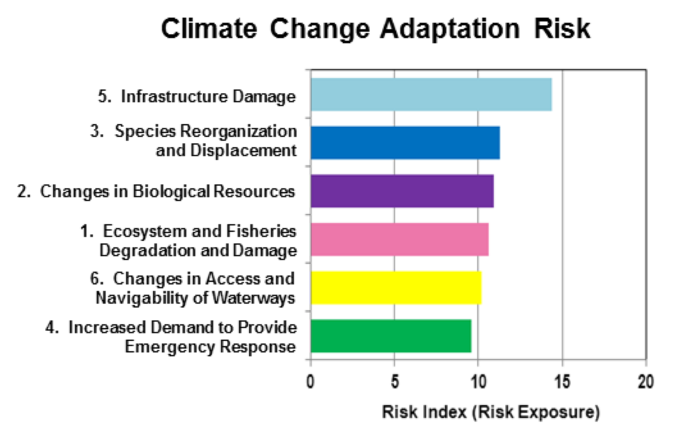
Risk Statement: There is a risk that climate change will affect DFO's ability to meet its strategic and policy objectives related to Oceans Management, and the sustainable development and integrated management of resources in Canada's aquatic environment.

Context: This risk focuses on DFO's stewardship role for 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 *Fisheries Act*, the *Oceans Act*, and the *Species at Risk Act*)

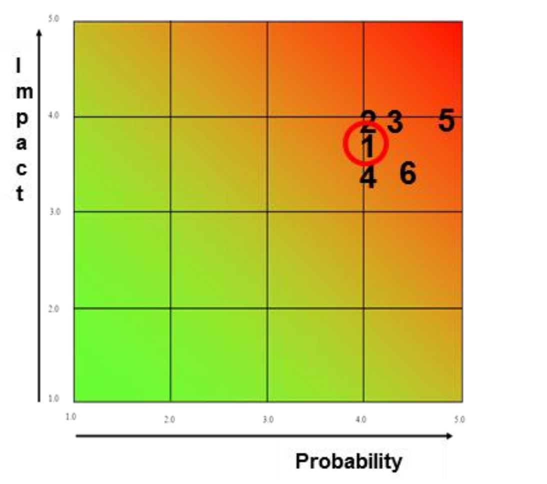
Position on Heat Map
(10 year Horizon)



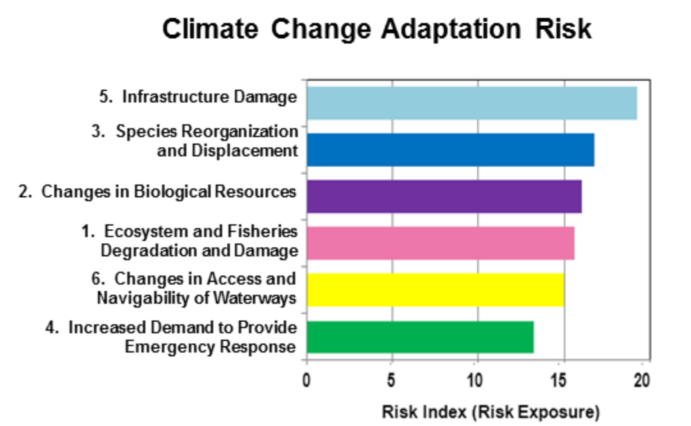
Risk Index (Probability x Impact)
(10 year Horizon)



Position on Heat Map
(50 year Horizon)



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



Main Risk Drivers	Potential Consequences: Threats
A) Projected increase in water temperature and ocean stratification (and its effect on nutrient distribution) will favor smaller phytoplankton cells and smaller-bodied zooplankton communities particularly in southern part of basin. **B)** Reduction of sea ice cover and timing of ice-break-up on Newfoundland and Labrador Shelf/Slope, Gulf of St. Lawrence and projected sea surface temperature increases will result in earlier onset of diatoms/spring bloom.	**A,B)** A decrease in plankton size is likely to favour a larger microbial loop as well as predation by smaller zooplankton, resulting in an increase in food chain length that decreases the efficiency of energy flow from the primary producers to top predators. This may result in a decrease in fishery catch potential**.** Southern basin (e.g. Western Scotian Shelf) and coastal areas will be most affected. The effect may be counterbalanced if phytoplankton production in more northerly latitudes increases by mid-century as a result of a longer growing season. It may also be counterbalanced if earlier onset of the spring phytoplankton bloom, as well as decreased occurrence of Arctic species, allow *Calanus finmarchicus* populations to achieve a prolonged production period throughout most of the western Atlantic basin.
C) Trophic mismatches may occur if the timing of seasonal life history events (such as reproduction, metamorphosis, migration) of predator and prey change at different rates.	**C)** Changes to food-webs will certainly cause changes in the productivity of exploited living aquatic resources, requiring changes in associated management reference points or in the approach used to manage exploited stocks sustainably.
D) Higher temperature and reduced nutrient availability may favour an increased occurrence of harmful algal blooms, particularly in southerly and coastal areas, and allow range expansion into the Newfoundland and Labrador Shelf/Slope.	**D)** Increase in harmful algal blooms leading to shellfish toxicity and increased mortality during peak summer temperatures.
E) Changes in prey distribution as well as decline in sea ice extent, floe size, thickness and duration, and changes in timing will result in changes in the distribution and abundance of key marine mammals.	**E)** A change in distribution and the relative dominance of particular marine mammal species as a result of changes in ice dynamics will affect their prey and thus the ecosystem structure.
F) Warming will cause shifts in some species composition, with a tendency for northward movement in community structures particularly in southern part of basin.	**F)** Northward movement in community structures especially from southern part of basin will require DFO to adjust stock boundaries and to adopt management approaches that account for possible changes in stock productivity resulting from changes in competition and predator/prey dynamics. Potential for change in genotypes composition of population. Climate-driven changes in species distribution may compromise DFO's ability to plan and implement effective marine protected areas (designed to conserve and protect ecosystems).
G) Species that use calcium carbonate to build carapaces and shells may be affected negatively by the continued decrease in pH of the ocean (crustaceans, foraminifera, coccolithophores, corals and mollusks).	**G)** Decrease in pH of the ocean (crustaceans, corals and mollusks) may affect food web structure.
H) Climate changes will exacerbate the effects of other stressors (e.g. overfishing, pollution, habitat degradation).	**H)** Stressors tend to reduce resilience through a reduction of diversity (e.g. intraspecific diversity including genetic, age structure and subpopulation diversity). As diversity connotes resilience, heavily stressed areas and populations can have compromised ecosystem resilience so that they are more susceptible to climate change.

Opportunities
▪ Growth and development rates will increase in nearly all components of the lower trophic levels and the greatest impact may be on life history patterns as a result of prolonged seasonal growth and increased productivity. In addition, an earlier onset of the spring phytoplankton bloom, as well as decreased occurrence of Arctic species, will allow *Calanus finmarchicus* populations to achieve a prolonged production period throughout most of the western Atlantic basin. However in the southern basin (e.g. Western Scotian Shelf) a decrease in plankton size is likely to favour a larger microbial loop as well as predation by smaller zooplankton, resulting in an increase in food chain length that decreases the efficiency of energy flow from the primary producers to top predators. This may result in a decrease in fishery catch potential.

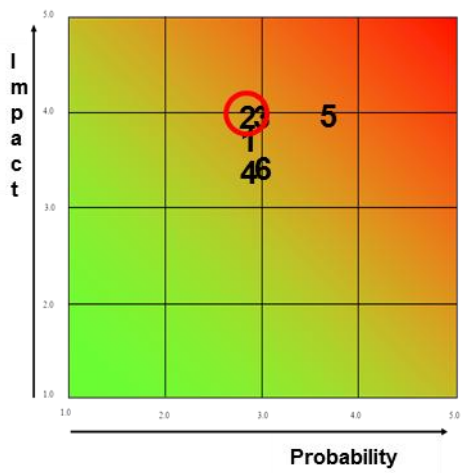
Gaps
▪ Higher temperatures will likely lead to changes in the timing of occurrence of species closely linked with the seasonal temperature cycle. Whether species adapt to changes in the seasonal cycle, and how they do so, will significantly affect the impact on regional productivity but this is a topic for which there is very limited knowledge. Taxa that remain active during periods of lower nutrient/prey abundance, which normally occurs between the spring and autumn blooms, will likely benefit from climate change but species that enter prolonged periods of dormancy may be subjected to increased competition from taxa that can take advantage of the longer "productive" season.
▪ A large gap is the lack of climate change information to assess impacts on bays and estuaries and in general for the near-shore coastal region (<50 m).
▪ The potential effects of harmful algal blooms on non-commercial species (e.g. marine mammals) have not been fully reviewed.
▪ There is a significant need for development of regional biophysical and downscaling models.
▪ There is a gap in our understanding of adaptive capacity; climate change can result in differential selection on genotypes without a change in distribution and consequences are unknown.
▪ There is a gap in our understanding of how to incorporate cumulative effects into assessment (risk, vulnerability, etc.) processes.
▪ There is a gap in our understanding of species interactions and trophic dynamics. Climate driven interannual and seasonal shifts in distribution and local abundance set the template for possible intra and inter-specific interactions. Response of phytoplankton and zooplankton to changes in environmental forcing will depend greatly on the status of the remainder of the food webs. Given co-occurrence, the joint effects of novel ecological interactions and climate change have the potential to affect the structure, biomass, productivity and dynamics of aquatic communities. A recent review of over 600 studies for terrestrial systems found that climate change can influence virtually every type of species interaction. Furthermore, because different species or functional groups will not necessarily respond to climate change in a similar way and because one or a few 'keystone' species may have particular leverage in a community, short and especially long-term dynamics are difficult to predict.
▪ Impacts of climate change on the full range of biodiversity (ecosystem, habitats, community, non-commercial species including interactions) have not been comprehensively examined.

Appendix 3

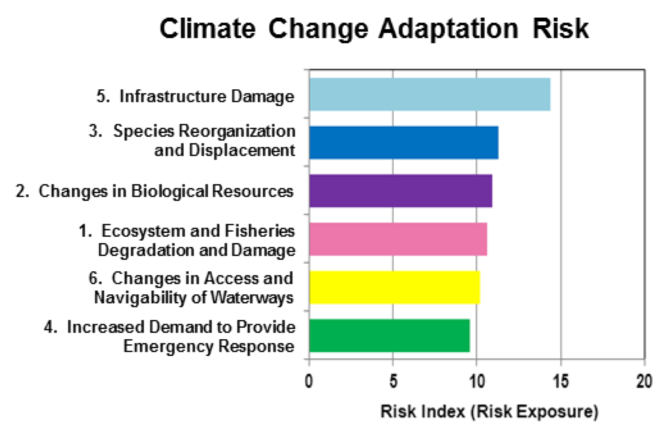
Risk summary sheet for Risk 2: Changes in Biological Resources for the Atlantic LAB. Note that there is a direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Atlantic Large Aquatic Basin (Gulf , Maritimes, Newfoundland, Quebec)
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*)

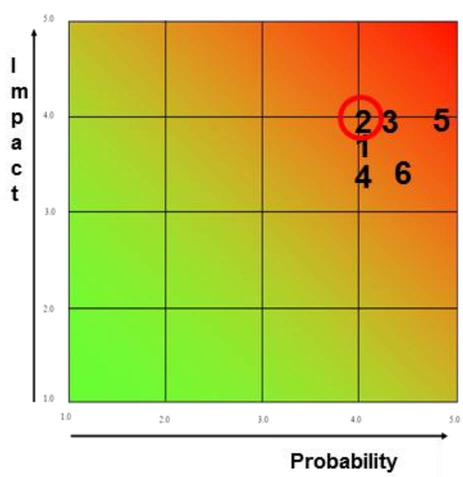
Position on Heat Map (10 year Horizon)



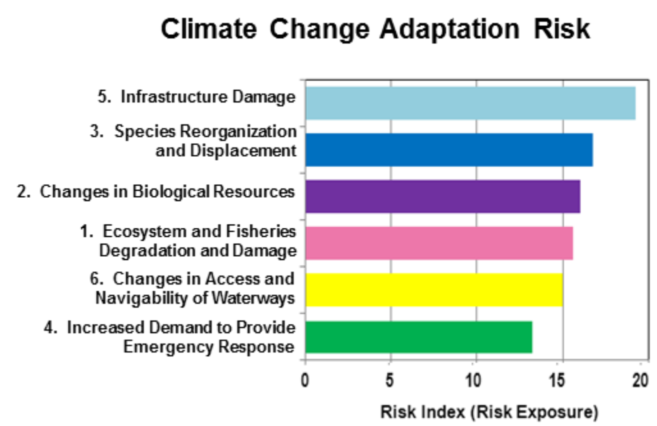
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



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



Main Risk Drivers	Potential Consequences: Threats
A) Combined projected increase in sea surface temperature and lower dissolved oxygen may result in decreased productivity of cultured finfish and shellfish species (AQ)* and especially in shellfish species due to lower pH.	**A)** Projected increase in sea surface temperature and lower dissolved oxygen may also lead to increased disease and parasites, increased fouling, pests, nuisance species and predators through both increased survival of Aquatic disease organisms and decreased resistance at some sites.
B) Higher temperature and reduced nutrient availability may favour an increased occurrence of harmful algal blooms, particularly in **southerly and coastal areas**, and allow range expansion into Newfoundland and Labrador Shelf/Slope.	**B)** Increase in harmful algal blooms leading to shellfish toxicity and increased finfish mortality during peak summer temperatures.
C) Lower dissolved oxygen will negatively affect deepwater species/populations especially if they are depleted (e.g. Deepwater and Acadian redfish) or if a species is close to its tolerance limit in areas that are already severely hypoxic, such as the St. Lawrence Estuary and the head of Esquiman Channel (e.g. Greenland halibut, Northern Shrimp).	**C)** –same as driver
D) Species that use calcium carbonate to build carapaces and shells may be affected negatively by the continued decrease in pH of the ocean (crustaceans, and molluscs).	**D)** –same as driver
E) Projected increase in water temperature and ocean stratification (and its effect on nutrient distribution) will favor smaller phytoplankton cells and smaller-bodied zooplankton communities particularly in southern part of basin.	**E)** A decrease in plankton size is likely to favour a larger microbial loop as well as predation by smaller zooplankton, resulting in an increase in food chain length that decreases the efficiency of energy flow from the primary producers to top predators. The southern part of the basin and coastal areas will be most affected. This effect may be counterbalanced to some extent if phytoplankton production in northern latitudes increases by mid-century as a result of a longer growing season. It may also be counterbalanced if earlier onset of the spring phytoplankton bloom, as well as decreased occurrence of Arctic species, allows Calanus finmarchicus populations to achieve a prolonged production period throughout most of the western Atlantic basin.
F) Projected increases in water temperature may lead to population decline in southern part of their range (e.g. Plaice, Halibut, Capelin, Northern Shrimp and especially Snow crab, Greenland halibut.	**F)** –same as driver
G) Commercial and subsistence harvested marine mammals, particularly ice dependent seals, will decline or move from currently harvested areas.	**G)** Changes in abundance of harvested marine mammals will alter availability to harvesters. These changes will also alter marine mammals' prey community structure (fish) which may then not be as available to harvesters.

H) Further depletion of Atlantic salmon in southern areas (due to warmer summer sea surface temperature and freshwater temperatures linked to summer minimum flow). Parr production may decrease due to warmer winters in the north and drier conditions in the south. Further, salmon will have reduced resistance to infections.	**H)** Recreational fisheries and stock allocation will be affected.
I) Increases in ocean and freshwater temperatures and changes in spring freshwater discharge will impact the timing and/or duration of various salmon life-history stages (i.e. migrations, spawning, hatching, smolting).	**I)** Changes in timing and duration various salmon life-history stages will negatively affect salmon production.
J) Climate changes will exacerbate the effects of other stressors (e.g. Aquatic invasive species, overfishing, pollution, habitat degradation).	**J)** Stressors tend to reduce resilience through a reduction of diversity (e.g. intraspecific diversity including genetic, age structure and subpopulation diversity). As diversity connotes resilience, heavily stressed areas and populations can have compromised ecosystem resilience so that they are more susceptible to climate change.
K) Seasonal biological cycles are closely tied to temperature. The timing of these seasonal events will change due to elevated spring and fall temperatures.	**K)** Because fisheries managers open and close fisheries based on seasons, they may have to adjust dates for some species.

Opportunities

- Cultured finfish/shellfish species: Over the next few decades, warmer sea surface temperature and enhanced primary productivity will lead to increased production of filter-feeders, longer growing seasons, reduced winter natural mortality, enhanced growth and food conversion rates, and expanded geographic range suitable for culture.
- Wild Fisheries: On the basin-scale, colder water areas (Eastern SS, GSL, NL) likely to benefit because the productivity of several species will be enhanced due to longer growing season, temperatures closer to optimal temperature for growth, decreased mortality, and possibly enhanced primary productivity (e.g. Salmon, Haddock, Cod, Herring, Mackerel, adult Halibut, Northern Shrimp, Capelin and shallow-habitat Lobster) .

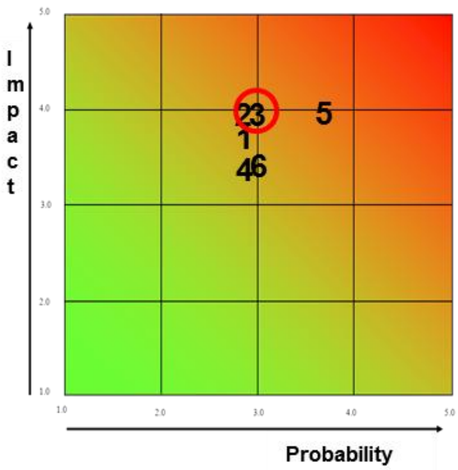
Gaps
▪ SEASONAL EFFECTS: For many species, the rate of change in annual temperature is well within their eco-physiological limits. However, their seasonal cycles will change due to earlier spring and later falls. Because fisheries managers open and close fisheries based on seasons, they may have to adjust dates for some species (PH). There is no comprehensive review on species-specific relationships between the seasonal temperature cycle and seasonal biological cycles (e.g. spawning, moulting, migration). ▪ For wild fisheries, there is almost no literature on the impact of acidification. Lack of knowledge is the reason acidification is not mentioned as a risk factor for wild fisheries, but it is expected to influence at least some shellfish populations. ▪ Potential effects of harmful algal blooms/climate change interaction on non-commercial species have not been reviewed (e.g. marine mammals). ▪ There is a gap in our understanding of adaptive capacity; climate change can result in differential selection on genotypes without a change in distribution and consequences are unknown. ▪ A large gap is the lack of climate change information to assess impacts on bays and estuaries and in general for the near-shore coastal region (<50 m). ▪ The potential effects of climate change on diadromous species have not been reviewed. ▪ The impacts of salinity on aquaculture are not fully understood. ▪ Impacts of climate change on the full range of biodiversity (ecosystem, habitats, community, non-commercial species including interactions) have not been comprehensively examined.

Appendix 4

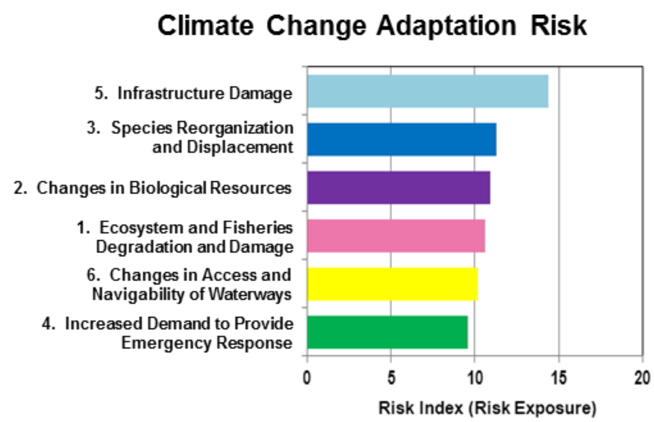
Risk summary sheet for Risk 3: Species Reorganization and Displacement for the Atlantic LAB. Note that there is a direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Atlantic Large Aquatic Basin (Gulf , Maritimes, Newfoundland, Quebec)
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*).

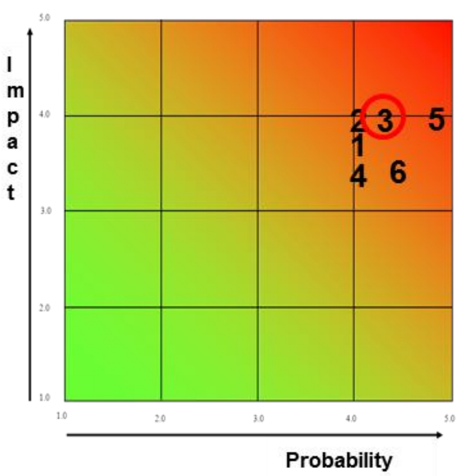
Position on Heat Map (10 year Horizon)



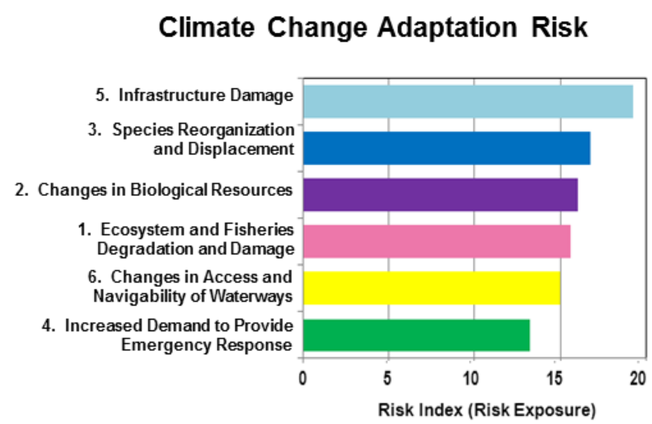
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



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



Main Risk Drivers	Potential Consequences: Threats
A) Projected temperature increases will negatively impact the diadromous endangered species (Atlantic Salmon (inner bay of Fundy population) and Atlantic Whitefish).	**A)** Atlantic Salmon may be extirpated from southern regions.
B) Loss of ice will negatively affect species such as Beluga Whale which is an ice cover dependent species, and has a geographically isolated population in the Gulf of St Lawrence.	**B)** same as driver
C) Depleted or rare species in the most southern part of the Basin may decline due to projected increase in temperature for example: Acadian Redfish, American Plaice, Atlantic Cod, Atlantic Wolffish, Deepwater redfish, Northern Wolffish, Spotted Wolffish, and Thorny Skate.	**C)** Resident species at risk are at greatest risk due to climate change on the Western Scotian Shelf.
D) Climate change may favour invading species which compete with and impact native species.	**D)** An increase in the introduction of non-native species due to the loss of sea ice in arctic and sub-arctic regions that results in higher vessel traffic. Changes in environmental parameters (e.g., temperature, salinity, dissolved oxygen, etc.) tends to introduce physiological stress to communities and acclimated native species - the greater this stress the more susceptible native communities are to the introduction of non-native (potentially invasive) species. Predicted changes in environmental parameters (e.g., temperature increases, salinity decreases) will likely facilitate the range expansion of non-native species and will make population establishment and persistence more viable.
E) Climate changes will exacerbate the effects of other stressors (e.g. overfishing, pollution, habitat degradation).	**E)** Stressors tend to reduce resilience through a reduction of diversity (e.g. intraspecific diversity including genetic, age structure and subpopulation diversity). As diversity connotes resilience, heavily stressed areas and populations can have compromised ecosystem resilience so that they are more susceptible to climate change.
F) The Blue Whale and Right Whale feed on a very limited range of prey. Projected temperature increases will cause a reduction in prey size, a reduction in prey production and a change in prey distribution.	**F)** The Blue Whale and Right Whale may experience an increased energy cost of feeding and/or make it difficult for whales to find sufficient food particularly in southern part of the basin. This may reduce likelihood of recovery.
G) Lower dissolved oxygen will negatively affect deepwater species especially if populations are depleted (e.g. Deepwater and Acadian Redfish, Spotted Wolffish).	**G)** – same as driver

Opportunities
▪ An increase in water temperature will increase the habitat area of 5 pelagic and 6 diadromous depleted (including some species at risk) fish species whose range is limited by their tolerance to cold water. This includes the pelagic Atlantic Bluefin Tuna, Basking Shark, Blue Shark, Porbeagle, and White Shark; and the diadromous Alewife, American Eel, American Shad, Atlantic Salmon, Atlantic Sturgeon, and Striped Bass.

Gaps
▪ Impacts of climate change on freshwater and mollusca species at risk have not been fully reviewed. ▪ Impacts of climate change on the full range of biodiversity (ecosystem, habitats, community, non-commercial species including interactions) have not been comprehensively examined.

Appendix 5

Risk summary sheet for Risk 4: Increased Demand to Provide Emergency Response for the Atlantic LAB. Note that there is a direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

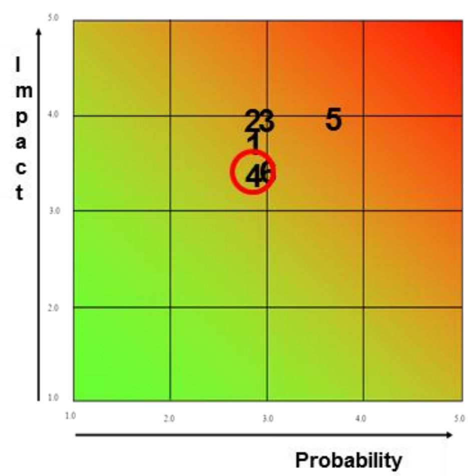
Atlantic Large Aquatic Basin (Gulf , Maritimes, Newfoundland, Quebec)

Risk 4: Increased Demand to Provide Emergency Response

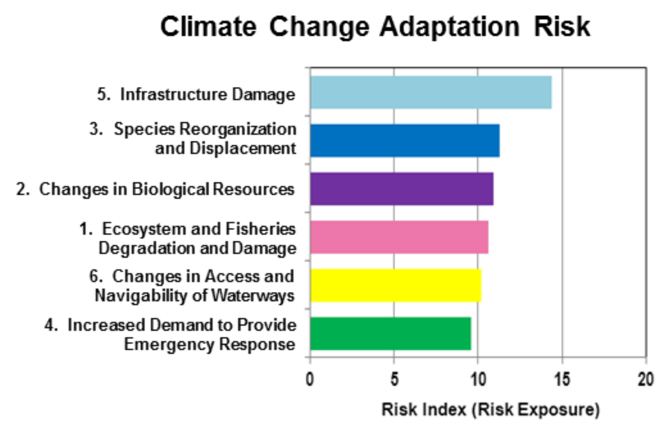
Risk Statement: There is a risk that climate change will affect DFO's ability to provide acceptable levels of environmental response and search and rescue activities

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 DFO's capacity to respond

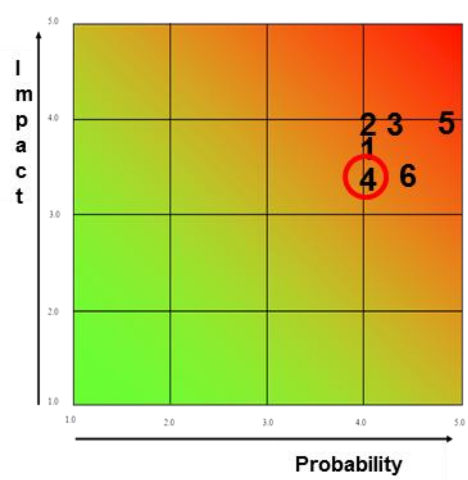
Position on Heat Map (10 year Horizon)



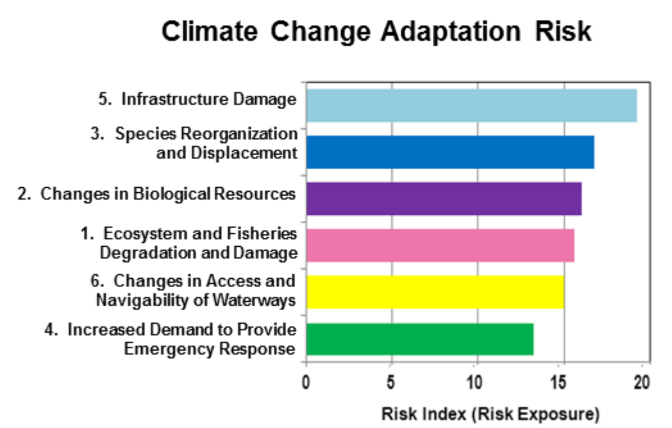
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



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



<table>
<tr><th>Main Risk Drivers</th><th>Potential Consequences: Threats</th></tr>
<tr><td>A) Projected reduction and spatial changes in sea ice, will result in increased geographic scope and volume of marine activity (e.g. shipping, oil and gas, tourism, mining, fishing).
B) Potential changes in winds and storms (storm tracks) moving north may result in increased marine incidents in the north.
C) Projected increase in wave activity in previously ice-covered areas may result in increased marine incidents.</td><td>A) and B).Changes will result in increased demand for coordination of environmental response and search and rescue services. Changes will result in increased geographic scope of DFO’s emergency response, navigational aids and channel maintenance activities, and associated strain on resources and personnel.
A) Environmental damage from marine incidents
A) DFO will not have the capacity to adequately mitigate environmental incidents.
B) Loss of life associated with marine incidents.
B) Inability to keep risk assessment and emergency response models as effective as possible (used to strategically deploy personnel and equipment).</td></tr>
</table>

Opportunities
▪ Heighten / improve upon communications with mariners about the need to travel with extensive supplies of necessities due to potentially longer response times to marine emergencies. ▪ Heighten / improve upon communications with mariners about anticipated changes in the marine environment. ▪ Collaborate with local emergency response personnel in small Northern communities to prepare for a scenario where the community would provide respite housing and other necessities of life for a large number of people in the event of emergency incidents. ▪ To effectively communicate what is currently understood about climate change (or being studied) to other Sectors, Departments and coastal communities. ▪ New opportunities in previously ice-covered areas. ▪ Work/collaborate with other agencies/universities to improve climate change knowledge base.

Gaps
▪ High uncertainty for climate projections in Atlantic LAB. ▪ High uncertainty regarding projected future changes in storms and winds for the Northwest Atlantic. ▪ Limited understanding of how the range and distribution of fish stocks may shift: indicators / scenarios affecting the identification of areas of future increased use and related risk vulnerability, and correlated deployment of both resources and personnel. ▪ Northern waters are largely uncharted, or charted within only widely-spaced spot soundings taken through the ice that give only a minimal indication of the actual water depths, and can be misleading when used without an understanding of their reliability.

Appendix 6

Risk summary sheet for Risk 5: Infrastructure Damage for the Atlantic LAB. Note that there is a direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

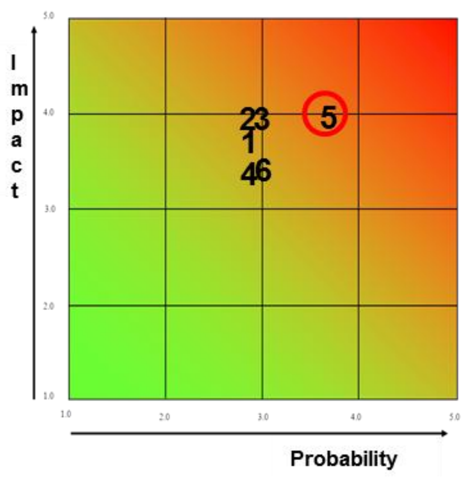
Atlantic Large Aquatic Basin (Gulf , Maritimes, Newfoundland, Quebec)

Risk 5: Infrastructure Damage

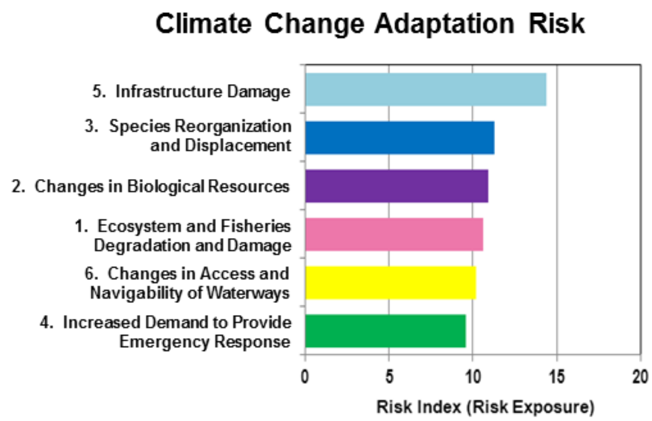
Risk Statement: There is a risk that climate change will result in damage and the need for alterations to DFO vessels, coastal and Small Craft Harbours infrastructure.

Context : DFO maintains considerable infrastructure to support its operational and scientific activities in both the marine and freshwater environments (built infrastructure includes: harbours, wharves, bases, stations, buoys, slipways, buildings, labs, lighthouses, navigation aids, hatcheries and DFO aquaculture activities)

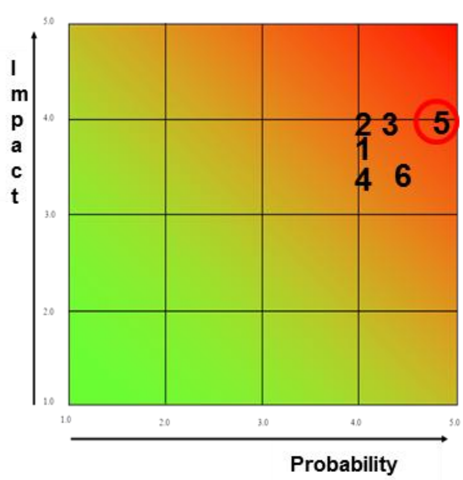
Position on Heat Map (10 year Horizon)



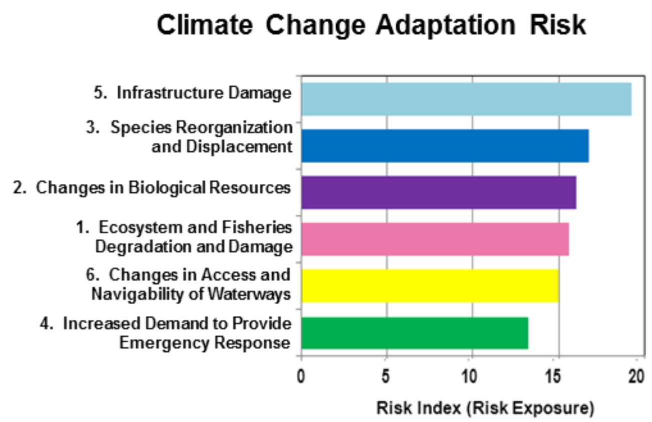
Risk Index (Probability x Impact) (10 year Horizon)



Position on Heat Map (50 year Horizon)



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



Main Risk Drivers	Potential Consequences: Threats
A) Projected increases in mean and extreme sea level, and waves, and potential changes in winds, storms will compromise the design capacity and structural integrity of assets (i.e., coastal infrastructure).	**A)** The need to update coastal infrastructure will only intensify.
B) Projected temperature increases and resultant ecosystem trends may require harbour infrastructure to be adapted for increased/changed use.	**B)** Harbour infrastructure will need to be adapted for changes in use.
C) Projected increase in coastal erosion will compromise coastal infrastructure and access.	**C)** Increased flooding and erosion endangers harbour structures and clients' safety.
D) Projected reduction of sea ice, and potential changes in winds, storms, and waves, will result in increased operational requirements.	**D)** Increasing demands for ship operations (e.g., to survey and re-deploy channel markers) and associated strain on resources.
E) Potential increases in extreme precipitation events and associated river run-off may impact coastal infrastructure.	**E)** Increased flooding and erosion endangers coastal infrastructure.

Opportunities

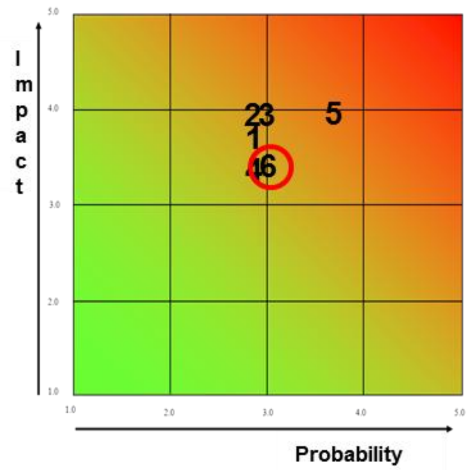
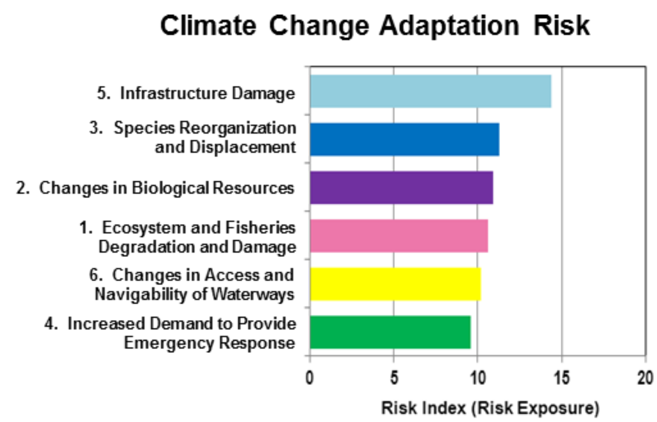
- Provide regional or localized Fact Sheets—designed for public consumption—summarizing trends and projections about sea level rise, storm surge and waves, precipitation and lake and river flows and levels, and ice extent and movement. Provide to SCH for use with mariner and community engagement and collaborative planning.
- Support federal and provincial efforts for publicly available coastal sensitivity indexes.
- Potential for increased collaboration with other agencies/universities.
- To lead or be a major supporter of research and knowledge dissemination regarding alternative climate-wise harbour infrastructure designs such as breakwaters, including productive capacity of artificial structures, and to update / make available associated best practices.
- To effectively communicate what is currently understood about climate change (or being studied) to other Sectors, Departments and coastal communities.

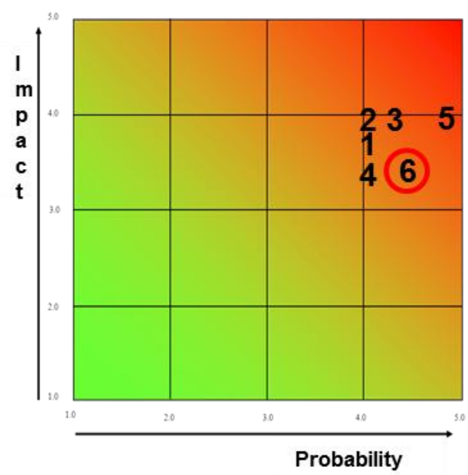
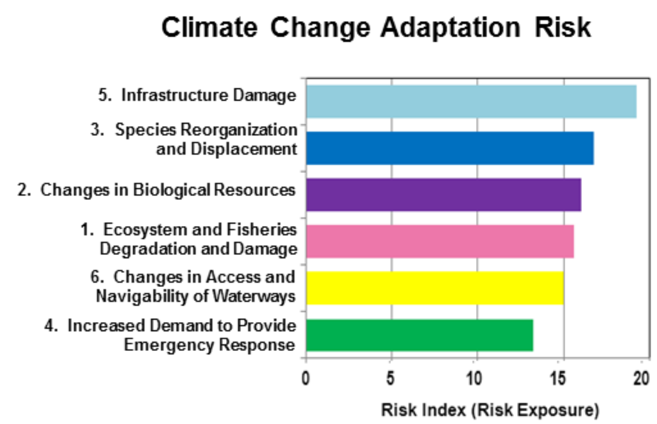
Gaps
▪ High uncertainty for climate projections in Atlantic LAB. ▪ Lack of understanding of the various contributions to both global and regional mean sea level rise. ▪ Lack of knowledge regarding extreme sea level (storm surge, tides) and return periods in areas of the Atlantic LAB where long tide gauge records do not exist. ▪ An understanding of how the range and distribution of fish stocks may shift: indicators / scenarios of what would trigger such shifts and thus perpetuate changes in the use of harbour infrastructure.

Appendix 7

Risk summary sheet for Risk 6: Changes in Access and Navigability of Waterways for the Atlantic LAB. Note that there is a direct link between the main risk drivers (on the left side of the table) and the consequences (on the right)

Atlantic Large Aquatic Basin (Gulf , Maritimes, Newfoundland, Quebec)
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 climate factors such as sedimentation, severe weather, wave energy, icebergs and sea ice.

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
A) Projected changes in sea ice extent and duration will result in a northward shift in need for ice routing and information services.	**All:** Loss of life and injury associated with marine incidents. **All:** Environmental damage from marine incidents.
B) Projected changes in sea ice conditions may result in a re-alignment in ice breaking services due to increased maritime activities in areas where sea ice formerly impeded travel.	**B) –E)**. Increase and reallocation of resources required to cover new and update existing geographical locations.
C) Projected changes in sea ice extent and duration will result in an increased need to create / update CHS charts for waters where sea ice historically impeded travel.	
D) Projected changes in mean sea level and the effects of coastal erosion will result in an increased need to update CHS charts and chart datum.	**D) and E)** Increased need of navigational aids.
E) Projected changes in precipitation and associated river run-off and potential increases in extreme events may result in greater need for dredging caused by increased sedimentation.	**E)** Major economic consequences if sedimentation impedes or endangers shipping.

Opportunities
▪ Support CHS efforts to pursue or partner for the exploration of new uses of existing technology, or development of new technology that allows soundings to be conducted both through ice, and remotely (e.g., via satellites or with LIDAR for bathymetry). ▪ Support Departmental, inter-Departmental and provincial efforts for publicly available coastal sensitivity indexes: describing risk vulnerability to erosion under a range of scenarios. ▪ Increased open-water season may encourage better sea-floor mapping, infrastructure and harbours near communities. ▪ To effectively communicate what is currently understood about climate change (or being studied) to other Sectors, Departments and coastal communities.

Gaps
▪ High uncertainty for climate projections in Atlantic LAB. ▪ Northern waters are largely uncharted, or charted within only widely-spaced spot soundings taken through the ice that give only a minimal indication of the actual water depths, and can be misleading when used without an understanding of their reliability. ▪ Lack of understanding of the various contributions to both global and regional mean sea level rise. ▪ Lack of modeling of sediment transport where the need for dredging is already high and is noticeably intensifying.

Appendix 8

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

Impact ranking (DFO Integrated Risk Management)

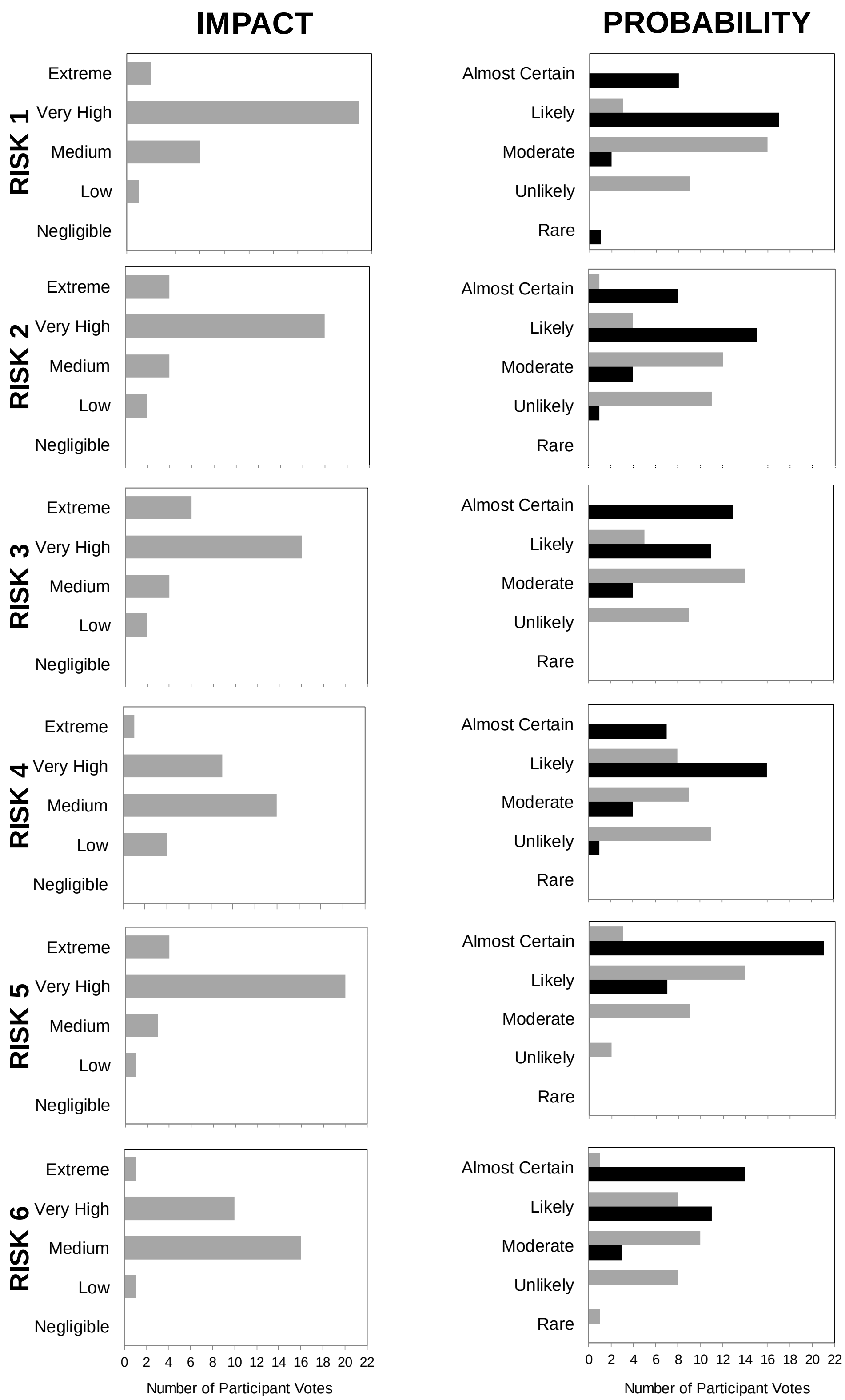
Impact	Definition of Impact
Extreme	A major event that will require DFO to make a large scale, long term realignment of its operations, objectives or finances.
Very High	A critical event that with proper management can be addressed by DFO.
Medium	A significant event that can be managed under normal circumstances 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 ranking

Vote	Probability Level	% Probability
5	**Almost Certain (or Very Likely)**	More than 80%
4	**Likely**	61-80%
3	**Moderate (or Moderately Likely)**	41-60%
2	**Unlikely**	20-40%
1	**Rare**	Less than 20%

Appendix 9

Results of Impact and Probability ranking by participants during the meeting using the criteria from Appendix 8. For 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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